The Hong Kong Polytechnic University

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The Selection of Design-build Operational Variations in the People's Republic of China Using Delphi Method and Fuzzy Set Theory

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CERTIFICATE OF ORGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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ABSTRACT

The design-build (DB) system has been demonstrated as an effective delivery method and has gained its popularity worldwide. Within the overall concept of design-build, a number of operational variations of the DB system have been developed, which are similar to, but different from each other. Every DB operational variation has its own strengths and weaknesses, and owners have to choose the appropriate one to best deliver their projects. However, it is never an easy task and poses changes to most of DB owners. In addition, there are few, if any, systematic research studies focusing on the selection of DB operational variations. The aim of this research study is, therefore, to develop a model using the Delphi survey technique and fuzzy set theory for objectively, reliably and practically choosing the appropriate DB operational variations in the construction industry of China.

Although the importance of selecting an appropriate DB operational variation has been widely accepted, the classification of DB operational variations remains controversial. A comprehensive literature review has been conducted to assess various classification frameworks proposed by different researchers. The rationales for their classifications were explored and summarized as contracting methods, design proportions, and contractor selection methods. These classification rules were then developed to set up a new classification framework. Finally, five fundamental operational variations of DB have been proposed, which include *develop and construct, novation design-build,*

enhanced design-build, traditional design-build and *turnkey*. These five categories serve as the basic alternative options in the selection of DB operational variations.

In order to facilitate the selection process, a set of evaluation criteria for determining the appropriateness of each operational variation is required. A three-round Delphi questionnaire survey was conducted with 20 construction experts in the People's Republic of China (PRC) to obtain such criteria. Seven top selection criteria and their importance weightings were finally identified, which include, namely, (1) availability of competent design-builders, with the weighting of 0.178; (2) owner's experience, with the weighting of 0.156; (3) project complexity, with the weighting of 0.147; (4) owner's control of project, with the weighting of 0.137; (5) early commencement & short duration, with the weighting of 0.132; (6) reduced responsibility or involvement, with the weighting of 0.127; and (7) clear end user's requirements, with the weighting of 0.122. A statistically significant agreement on the top seven selection criteria was also obtained. These identified criteria could furnish stakeholders, in particular the DB owners, with objective and reliable perspectives to compare and evaluate the different operational variations of the DB system.

The selection of DB operational variation is a complex multi-criteria decision making process involving fuzzy characteristics and uncertainties. A fuzzy multi-criteria decision-making (FMCDM) model is regarded as the most suitable technique for this problem. The fuzzy membership function, which is a core concept in fuzzy set theory, can be adopted to measure the performance of each operational variation against the selection

criteria. A modified horizontal approach with the bisector error method was applied to set up the fuzzy membership functions. These fuzzy membership functions provided quantitative calculation method for measuring performance of each DB operational variation. As a result, owners could objectively examine the suitability of each DB operational variation. A fuzzy multi-criteria decision-making model was finally developed using the weighted mean method to aggregate the performance of DB operational variations measured against the selection criteria. The proposed model enables owners to perform quantitative calculations in a fuzzy decision-making environment and provides a useful tool to select the most suitable DB operational variation with respect to a set of situational factors.

This research study is the first attempt to develop a fuzzy multi-criteria selection model for DB operational variations. The selection model will not only offer a better understanding of different design-build options but also can be used as a guideline for the design-build delivery practice. It will in turn, help promote the design-build application in China. In addition, considering that the problem of selecting appropriate DB operational variations also exist in the overseas DB markets, this research study provides useful reference for similar studies in different geographical locations.

LIST OF RESEARCH PUBLICATIONS (2007-2010)

Refereed Journal Papers (Published and Accepted)

1. Xia Bo, Chan A.P.C (2008) Review of the design-build market in the People's Republic of China, *Journal of Construction Procurement*, 14 (2), 108-117.
2. Xia Bo, Chan A.P.C (2008) Classification research on general contract of design-build in China, *Construction Economy (建筑经济, supplement 12)*, 1-4.
3. Xia Bo, Chan A.P.C, Yeung J.F.Y. (2009) Identification of key competences of design-builders in the construction market of the People's Republic of China (PRC), *Construction Management and Economics*, 27 (11), 1141-1152.
4. Xia Bo, Chan A.P.C. (2010) Key competences of design-build clients in China, *Journal of Facilities Management*, 8 (2), 114-129.
5. Zhang X.L., Shen. L.Y., Skitmore M., and Xia Bo (2010) Key competitiveness indicators for new real estate developers, *Journal of Financial Management of Property and construction*, 15 (2), 143-157.
6. Xia Bo, Chan A.P.C. Investigation of barriers to entry into the design-build market in the People's Republic of China (PRC), submitted to *Journal of Construction Engineering and Management*, ASCE, (Accept with minor revision)

Refereed Journal Papers (Under Review)

1. Xia Bo, Chan A.P.C. A classification framework for design-build operational

variations, submitted to *Journal of Construction Engineering and Management*, ASCE, (Under Review)

2. Xia Bo, Chan A.P.C. Identification of selection criteria for operational variations of design-build system—A Delphi study in China, submitted to *Journal of Management in Engineering*, ASCE. (Under Review)
3. Xia Bo, Chan A.P.C. Measuring complexity for building projects—A Delphi study, submitted to *Engineering, Construction and Architectural Management*. (Under Review)
4. Xia Bo, Chan A.P.C. Constructing fuzzy membership functions for DB operational variations, submitted to *Construction Management and Economics*. (Under Review)

Refereed Conference Papers (Published)

1. Xia Bo, Chan A.P.C. (2008) The investigation of design-build variants in the construction market of the People's Republic of China. *First International Conference on Construction in Developing Countries (ICCIDC–I)*, *August 4-5, 2008, Karachi, Pakistan*

2. Xia Bo, Chan A.P.C. (2009) Identification of key competences of DB clients in the construction market of China. *ISEC-5, September 21-27, 2009, Las Vegas, U.S*

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CHAPTER 1 INTRODUCTION

1.1 RESEARCH BACKGROUND

Design-build (DB) is a delivery method in which the design-builder is contractually responsible for both design and construction works (Songer *et al*., 1997). It has been demonstrated to be an effective delivery method and has gained popularity overseas in the recent years (Haque *et al*., 2001). Within the DB system, a number of operational variations have been developed in order to meet varying needs of construction circumstances (CIOB, 1988; Akintoye, 1994; Beard *et al*., 2001). The essential difference among the DB operational variations is the amount of design work undertaken by owners or their design consultants, which is included in DB request for proposals (Janssens, 1991).

After owners decide to employ the DB method, an important step forward is to determine which operational variation is the most appropriate to deliver their DB projects. However, the selection process is never an easy task (Janssens, 1991; Beard *et al*., 2001). This is because selecting different operational variations means different requirements and workloads for owners. It requires owners not to "go too far" with the design that may incur unnecessary fees and deny the contractor's innovation to the design process. At the same time owners should not provide too little information in the briefing stage otherwise it may create misunderstanding to the potential contractors. A typical DB variation will

lie between the two extremes, wherein the design work will be developed adequately as a vehicle for tendering and beginning to procure the project (Harris and Mccaffer, 1995; Cushman and Loulakis, 2001). As a result, the selection of DB operational variations often poses more difficulties than other issues, especially to an inexperienced employer (Janssens, 1991). In the current construction industry of China, most of DB owners remain inexperienced with DB system. Given the importance of the selection of DB operational variations, a systematic selection model is urgently required for DB owners in the PRC construction industry.

1.2 KNOWLEDGE GAP AND RESEARCH QUESTIONS

Design-build has accounted for an increasing proportion of the construction market worldwide. Within the DB system, there have been a number of operational variations, which are similar to, and yet different from each other. After the selection of DB method, owners need to decide which variation is the most appropriate option for their projects (Janssens, 1991; Beard *et al*., 2001). However, there are few, if not none, comprehensive and systematic studies on this research area. Thus the research gap emerges in this field. In order to fill the research gap, this study aims to develop a systematic model, which would enable owners to select an appropriate DB operational variation. It is the first attempt to focus on the selection of DB operational variations, and is believed to be able to make a significant contribution to the knowledge within the DB field in general and in the construction market of China in particular.

In order to establish an objective selection model, the following fundamental questions would have to be addressed:

(1) What are the most important criteria for selecting DB operational variations?

(2) How would the identified criteria enable the establishment of an objective and systematic selection model?

1.3 RESEARCH SCOPE AND OBJECTIVES

This research focuses on studying different categories of DB operational variations in the construction market of China. It deals with the situation where owners have already decided to use design-build system and tries to find out which operational variation is likely to be the most appropriate one to deliver their DB projects.

This research study aims to develop a systematic model to enable owners to select an appropriate DB operational variation in the construction market of China. In order to achieve the aim, the specific objectives are designated as follows:

(1) To review the current design-build market in China;

(2) To put forward a systematic classification framework of DB operational variations;

(3) To identify the most important selection criteria and their importance weightings in determining an appropriate DB operational variation;

(4) To establish the fuzzy membership functions to measure the performance of each DB operational variation against the identified selection criteria.

(5) To develop a fuzzy multi-criterion selection model for the selection of DB operational variations;

(6) To validate the reliability and applicability of the model.

1.4 RESEARCH METHODOLOGY

The overall research approach consists of literature review, face-to-face interviews, content analysis, Delphi questionnaire survey, questionnaire survey, and fuzzy set theory, which are designed specifically for achieving the stated research objectives. Both qualitative and quantitative measures for establishing the selection model will be employed in this study. The specified objectives and the corresponding methodologies will be further discussed in greater details in Chapter 2.

1.5 STUCTURE OF THE THESIS

Chapter 1 gives the introduction of the research study. It covers the background, problems and questions, aims and objectives, scope and significance of the research. The research approach and the structure of the thesis will also be outlined.

Chapter 2 describes the research process and research methodologies for the study.

Chapter 3 describes the current design-build market in China. It investigates the Chinese construction industry, the DB business operated by domestic and foreign contractors, and the barriers to entry into the DB market in China.

Chapter 4 develops a classification framework of DB operational variations. This classification framework forms the basis of DB options for the selection model.

Chapter 5 reports the Delphi survey, which is conducted to objectively develop a series of weighed selection criteria to assess different DB operational variations. A three-round Delphi survey with 20 experts will be reported in this chapter.

Chapter 6 explains how the fuzzy membership functions for DB operational variations are established.

Chapter 7 provides the detailed account on the development of a fuzzy multi-criteria selection model. The verification and validation of the fuzzy multi-criteria decision-making model will also be reported in this chapter.

Chapter 8 is the conclusion for the research where the summary of the research, implications of the study and recommendations for future works will be presented.

The reason for not providing a single chapter of literature review lies on the fact that there are few systematic research studies on the selection of DB operational variations.

However, relevant literature reviews such as the general idea of the design-build, classification of DB operational variations, and fuzzy multi-criteria decision-making model will be provided in subsequent chapters where appropriate.

1.6 SIGNIFICANCE AND VALUE OF THE RESEARCH

Selecting an appropriate DB operational variation is very important to the success of project delivery but it also poses difficulties to owners. Especially in the construction market of China, where most of owners are inexperienced with the DB method, it constitutes great challenges to owners when implementing DB projects. However, there are few, if not none, systematic studies focusing on the selection of DB operational variations. Therefore, it is important to conduct research to fill this knowledge gap.

This research not only proposes a systematical classification framework of DB operational varieties but also provides owners with practical tools to evaluate different operational variations and finally enables them to choose an appropriate DB option that best suits the circumstantial situations. The selection model will offer a better understanding of different design-build options and can be used as a guideline for the design-build delivery practice. It will in turn, help promote the design-build application in the construction market of China.

This research is the first attempt to develop a fuzzy multi-criteria selection model for DB operational variations. It is not only of great essence for owners in China but also offers

useful perspectives for international projects sponsors who want to invest in the construction industry in China.

1.7 CHAPTER SUMMARY

This introductory chapter describes the framework for conducting the research study, including (1) background of research, (2) research problems and questions, (3) research scope and objectives, (5) research methodology, and (6) project significance and value.

CHAPTER 2 RESEARCH METHODOLGOY

2.1 PROBLEM DEFINITION AND THE RESEARCH PROCESS

The research aim at the core of this study is to develop a systematic selection model for DB operational variations. It is hoped that this model will facilitate DB owners selecting the most appropriate DB operational variation to deliver their projects. In order to achieve the research aim, the research objectives and research process were formulated and were delineated in Table 2.1. The rationale for choosing the selected methodologies would be further explained in Section 2.2.

Table 2.1 Research objectives and the corresponding research methodologies

Phases	Objectives	Research Methodologies
Stage 1	Review of the design-build market in China	Literature review and questionnaire survey
Stage 2	Classification of design-build operational variations	Literature review
Stage3	Identify important selection criteria and determine their importance weightings	Literature review, Delphi Method
Stage 4	Determine fuzzy membership functions	Literature review, questionnaire survey, and fuzzy set theory
Stage 5	Develop the fuzzy multi-criteria selection model	Literature review, fuzzy multi-criteria decision-making method
Stage 6	Validate the model	Face-to-face interviews with DB experts in China

The flow of research is summarized in Figure 2.1. The research methods and the research process employed for achieving each of the research objectives are depicted. Throughout the research process, a large amount of data, which were sought through literature review, interviews, and questionnaire survey, were analyzed and consolidated.

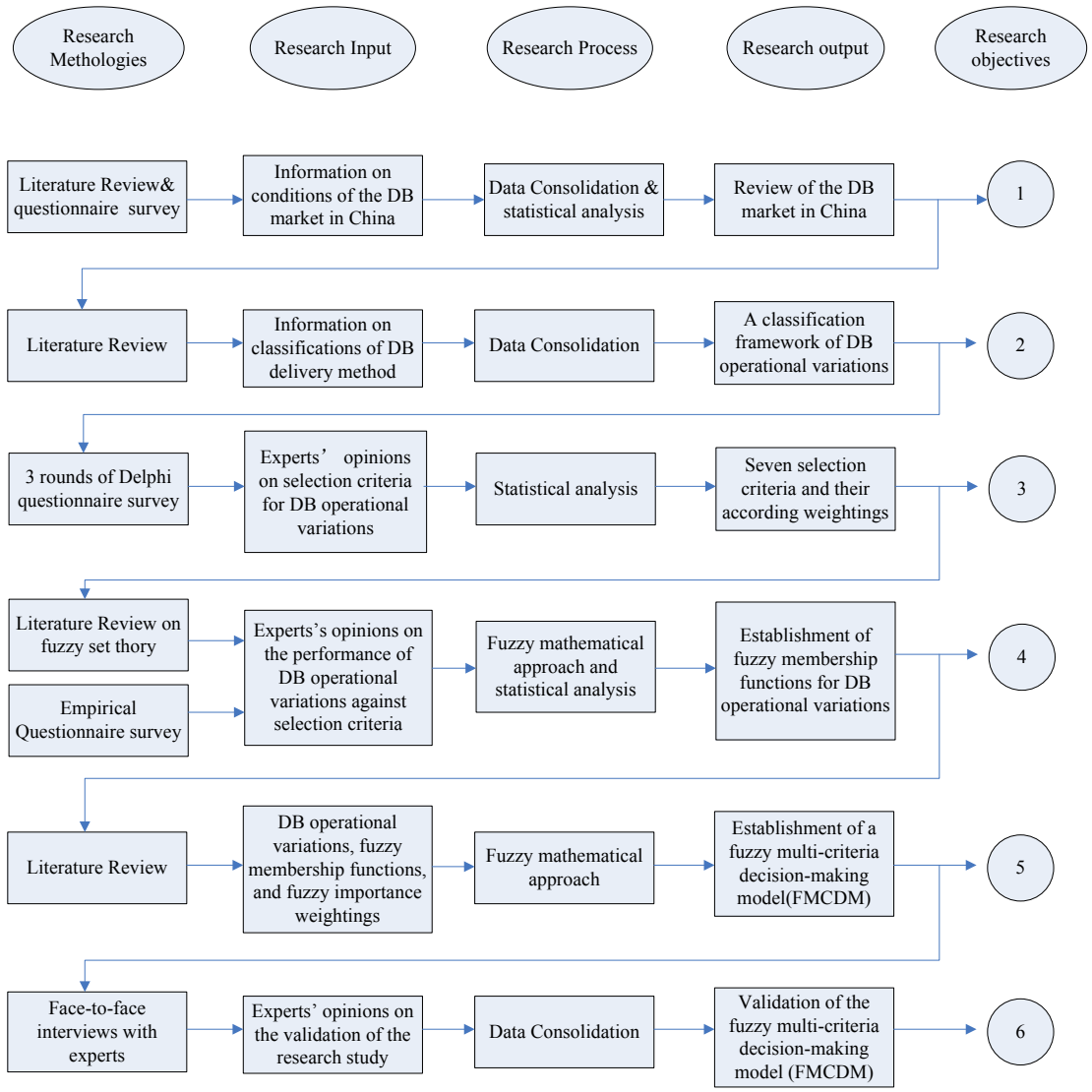

Figure 2.1 The flow chart of the research study

2.2 RESEARCH METHODS IN THIS STUDY

2.2.1 Literature Review

Literature review is the collection of background information of a research study. It aims to consolidate all previous studies related to the research topic and to form understanding of the current practice (Chow, 2005). A suitable literature review could help researchers to identify research problems vividly. Literature review is not just about reading the relevant publications but rather about presenting critiques of existing works in order to identify gaps in knowledge (Yeung, 2007).

Comprehensive literature review and data collection were first conducted in order to obtain a holistic picture of the DB market in China. After a thorough investigation of the current DB market, it was concluded that the development of the DB system in China is still at its infancy stage. In order to explore the potential obstacles attributing to this situation, another literature review on the barriers to entry in industrial economics was conducted. The theory of barriers to entry provides perspectives for both potential and incumbent design-builders to understand and analyze the DB market in China.

After the overview of the DB market in China, a comprehensive literature review was further extended to the classification of DB operational variations over the past decade. In the DB field, although the importance of selecting an appropriate DB operational variation has been widely accepted, the classification of DB operational variations remains controversial. Many researchers have proposed various classifications of DB

operational variations. However, most of the classifications are not widely accepted. Researchers classified DB operational variations with different rules and using different terminology. Moreover, some of the classifications contradict each other. This adds confusion to many owners, especially to the inexperienced ones. Although owners do not work on just labels and they can investigate the uniqueness of each project, a comprehensive classification framework will be of great help to deepen the knowledge of DB system and facilitate the selection of DB operational variations. Through the comprehensive literature review on various classification frameworks proposed by different researchers, the rationales for their classifications were explored and summarized. These classification rules were then consolidated and modified to set up a new classification framework for DB operational variations for the current study.

Having defined a classification framework, literature review on selection methods of DB operational variations was then conducted. It was found that there were limited systematic studies on this field. Therefore, the core research gap emerged after the literature review. In order to find an appropriate method for the selection of DB operational variations, a comprehensive literature review on the fuzzy set theory was further conducted. It is found that fuzzy multi-criteria decision-making theory is an appropriate method to facilitate the selection process. The selection of DB operational variation is a multi-criteria decision making process. In order to select an appropriate DB operational variation, owners should take multiple criteria into consideration, which include project requirements (such as cost, time, and quality), their DB experience, project characteristics, and design-builders' capabilities. At the same time, the selection

process is also characterized by subjectivity and uncertainty. This is because owners have to decide the suitability of each DB operational variation with respect to the evaluation criteria. The "suitability" itself is fuzzy by nature. After the literature review on the fuzzy set theory and a close examination of the selection process of DB operational variations, it is concluded that a fuzzy multi-criteria decision-making model should be established in order to achieve the research objectives.

2.2.2 Empirical Questionnaire Survey

- Reasons for conducting an empirical questionnaire survey

The questionnaire survey technique is frequently used in construction management field. Conducting surveys for construction management studies have a number of merits because surveys (1) require less time and are relatively inexpensive; (2) allow to have a larger sample size; (3) allow respondents to have adequate time to read, understand and answer the questionnaire; (4) provide privacy for responding; (5) allow visual data input rather than auditory input solely; and (6) allow respondents to answer the questionnaire at their convenience (Mangione, 1995). Therefore, questionnaire survey is generally accepted as one of the most preferable methods in the construction management field (Chow, 2005). A questionnaire survey method can be used to obtain information from construction practitioners regarding conditions of the DB market in China. In addition, time and cost constraints make frequent meetings and interviews infeasible for this research study.

However, it should be pointed out that questionnaire surveys must be carefully developed to ensure that the questions do not lead to biased answers or misunderstandings. It is recommended that the questionnaire should be piloted to ensure that questions are developed appropriately.

- Empirical questionnaire surveys in this study

During the overview of the DB market in China, two rounds of empirical questionnaire surveys were conducted through email in order to identify and evaluate the current barriers to entry into the DB market. An open-ended questionnaire survey was first conducted with 15 industrial practitioners in order to identify all the potential factors that constitute barriers to entry into the DB market in China. After the open-ended questionnaire survey, a list of 22 barriers to entry was identified. After that, another questionnaire survey was conducted with another 435 experts in the DB market in order to prioritize and evaluate these barriers to entry. Statistical analyses, such as the analysis of variance (ANOVA), factor analysis were conducted to provide a deeper understanding of the DB market in China. Considering all the respondents were DB experts in China and did not always have sufficient English skills to respond to the questionnaires, a Chinese version of questionnaire was used throughout the survey. Questionnaire in both Chinese and English versions is attached as Appendix 1 to Appendix 2.

The open-ended questionnaire was used to solicit experts' opinions on the barriers to

entry into the DB market of China. In order to ensure the validity of the research findings, all the experts should have sufficient DB knowledge, and extensive hands-on DB experience (at least more than 5 years DB experience). 31 experts who satisfied all the selection criteria were finally identified from the address available from government offices, industry associations, universities, and through personal contacts. The questionnaires were sent to them through email. They were requested to list down barriers to entry into the DB market according to their experience. In particular, they were requested to take into consideration of the unique characteristics of the PRC construction industry. Finally, 15 valid responses were received. Content analysis was employed to identify the barriers after the collection of their responses. After employing the content analysis, the open-ended questionnaire survey resulted in a final list of 22 barriers to entry into the DB market in China.

In order to prioritize and evaluate these barriers to entry, another questionnaire survey was conducted with experts in the DB market. A total of 435 respondents were identified, which are from the groups of academics, government departments, state-owned companies, and private companies in the construction industry. All of the respondents should have more than 5 years working experience in the construction industry. In addition, they should have been involved in DB projects in China. In this questionnaire survey, the respondents were requested to provide opinion on the extent of influence/importance of each barrier to entry into the DB market on a five-point Likert scale, which ranges from 1 (the least important) to 5 (the most important). Finally, a total of 140 responses were received. The response rate was 32%, which was considered to be

high considering the complexity of the research study and the unpopularity of DB system in China. This high response rate is mainly attribute to the careful selection of the respondents who shared similar research interest in the current study. The number of the valid responses is considered large enough to conduct the factor analysis in order to categorize these barriers. According to Gorsuch's (1983) recommendation, five subjects per item with a minimum of 100 subjects were considered appropriate to conduct the factor analysis.

Again, questionnaire survey technique was also used in constructing the fuzzy membership functions for DB operational variations (Questionnaire in both Chinese and English versions is attached as Appendix 6). The fuzzy membership functions were used to measure the suitability of DB operational variations against each selection criterion. It requires the input of the DB professionals in the DB market of China. To do so, an empirical questionnaire survey was conducted to capture experts' opinions on the performance of each DB operational variation. The respondents should have sufficient DB experience and DB knowledge since it was these experts who indirectly generated the fuzzy membership functions. 20 potential experts who satisfied the selection requirements were identified from addresses available from government offices, construction associations, universities, and through personal contact. A questionnaire together with a cover letter stating the objectives of the study was delivered to the 20 design-build experts in China. They were asked to quantify the selection criteria with respect to the five DB operational variations. Of the 20 questionnaire distributed, 17 valid replies were received. Finally, 17 responses were used to establish the fuzzy membership

functions using modified horizontal approach with bisector error method (Ng *et al*., 2002; Yeung, 2007).

2.2.3 Delphi Questionnaire Technique

- Reasons for using the Delphi method to identify the selection criteria

The identification of selection criteria for DB operational variations is of great importance because an appropriate selection model depends largely on prudent identification of selection criteria to reflect owners' and project objectives. However, it should be emphasized that the nature of selecting the most important selection criteria is quite subjective.

In order to deal with the problem of subjectivity in identifying the most important selection criteria, the Delphi survey method was used in this research study because it is a highly formalized method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts (Chan *et al.*, 2001).

The Delphi concept was first developed by the American defense industry in 1953 at RAND Corporation to solve future military issues. It is designed to obtain the most reliable agreements of a group of experts by a series of intensive questionnaires interspersed with controlled opinion feedback, and with results of each round being fed into the next round (Linstone and Turoff, 1975). Even if these collective judgments of

experts are made up of subjective opinions, it is considered to be more reliable than individual statements, thus, more objective in its outcomes (Masini, 1993).

The Delphi method is best suited in fields where there are no adequate historical data for the use of other quantitative methods (Martino, 1973). It is considered as one of the best known agreement-reaching and qualitative methodology (Jones, 1980). According to Linstone and Turoff (1975), the Delphi method is particularly appropriate when the following conditions apply:

(1) The problem does not lend itself to the precise analytical techniques but can benefit from subjective judgment on a collective basis;
(2) Time and cost make frequent meetings infeasible;
(3) More individuals are needed than can effectively interact in face-to-face exchange;
(4) The individuals needed to contribute to the examination of a broad or complex problems have no history of adequate communication and may represent diverse experience or expertise;
(5) Disagreements among individuals are so severe or politically unpalatable that the communication process must be referred and/or anonymity assured.
(6) The heterogeneity of participants must be preserved to assure validity of the results.

It is quite clear that almost all the conditions proposed by Linstone and Turoff (1975) are fully met when exploring the selection criteria for DB operational variations. Particularly, in the contemporary research field there is no adequate historical data of selection criteria for quantitative analysis. In addition, the process of identifying selection criteria is characterized with subjectivity and uncertainty; it needs knowledgeable input from experts. The Delphi technique, therefore serves as an appropriate agreement-reaching method for this study.

- The Delphi survey in this study

In order to identify the most important selection criteria for DB operational variations, a three-round Delphi questionnaire survey was conducted in this research study (Questionnaire in both Chinese and English versions is attached as Appendix 3 to Appendix 5). In round 1, all panel members were asked to list at least five criteria for the selection of DB operational variations. In round 2, panel members were provided with the consolidated results from round 1 and were required to rate all the criteria based on a 5-point Likert scale to evaluate the importance of each criterion. In round 3, the panel members were asked to reconsider their ratings of each criterion in the light of consolidated results of round 2. The consistency of the results of round 2 and round 3 were analyzed and compared using Kendall's Concordance Analysis.

One of the most important considerations when carrying out the Delphi study is the identification and selection of potential members to constitute the panel of experts (Stone

and Busby, 1996; Ludwing, 2001). The selection of members or panelists is important because the validity of the study is directly related to this selection process. In each Delphi study, the knowledge and expertise of each panelist must be relevant to questions posed by researchers (Dawson and Brucker, 2001). In this Delphi survey, the researchers attempted to identify all the panelists who are knowledgeable or have practical engagement in the DB field. The following criteria were devised in order to identify eligible participants for this study:

(1) Having extensive working experience in the DB projects in the PRC,
(2) Having direct involvement in the management of DB projects, and
(3) Having a sound knowledge of the DB operational variations.

The Delphi method typically involves a series of questionnaires given to a group of experts to gain knowledge, opinions or judgments (Moore, 1987; Outhred, 2001; Cabaniss, 2002). Through the Delphi process, individual responses to each survey are shared through the development of each successive survey, but individual responses usually remain anonymous. The desired outcome is that, by using such an interactive forecasting procedure, the experts will achieve unanimity on the studied issues. Even if these collective judgments of experts are made up of subjective opinions, it is considered to be more reliable than individual statements, thus, more objective in its outcomes (Johnson and King 1988; Masini, 1993).

The original Delphi procedures have three features: (1) Anonymous response; (2) Iteration and controlled feedback; and (3) Statistical group responses. The features are designed to minimize biasing affects of dominant individuals, irrelevant communications, and group pressure toward conformity. In general, the number of rounds varies between two and seven (Rowe and Wright, 1999; Adnan and Morledge, 2003). Too many rounds would waste panel members' time, and stopping the study too soon could yield meaningless results (Schmidt, 1997). In order to reach an acceptable and stable degree of consensus/agreement, the majority of the studies have used three rounds. The majority of Delphi studies have used between 15-20 respondents (Ludwig, 2001). Moreover, with a homogeneous group of experts, good results can be obtained even with a panel as small as 10-15 individuals (Ziglio, 1996). Therefore, the opinions solicited from the 17 experts in the third round of the Delphi questionnaire survey in this study are considered adequate to provide reliable results.

2.2.4 Face-to-face Interviews

- Reasons for selecting face-to-face interviews

Face-to-face interviews were adopted because of the synchronous communication in time and place. They offer the possibility of dispelling ambiguity because the interviewer is next to the interviewee as the questions are being answered (Opdenakker, 2006). Another main reason of conducting face-to-face interviews lies in the quality of the data obtained. Since the DB system has not been commonly used in the PRC, the mail survey

response may suffer from the depth of coverage of this topic in response to an open-ended question. The depth and clarification of responses from face-to-face interviews usually provides data better than those obtained from self-completion methods (Ayidiya and McClendon, 1990). Data and valuable information often rely on the minds, attitudes, feelings or reactions of the respondents.

- Face-to-face interviews in this study

Face-to-face interviews were conducted in this study to validate the research findings. Validation is the final stage of research to test whether the fuzzy multi-criteria decision-making model is good or not. It is to determine the adequacy of the system in meeting the needs of users (Gupta, 1991). Face-to-face interviews acquire subjective opinions from industrial practitioners on the performance of the selection model.

Five face-to-face interviews were conducted with experts from construction industry in China to ascertain whether the proposed selection model for DB projects in China is comprehensive, objective, reliable and practical enough. The researcher first introduced the research process and findings of the research project. Then the experts were asked to (1) evaluate whether the seven selected criteria together with their importance weightings are appropriate to measure the performance of different DB operational variations in the DB market of China, and to (2) examine whether the fuzzy multi-criteria decision-making model is practical to help owners select the appropriate DB operational variations. In particular, they are asked to evaluate whether the selection model will help owners to

evaluate performance of each operational variation and to effectively eliminate the subjectivity in the selection process.

2.2.5 Fuzzy Multi-criteria Decision-making Method

Decision-making can be interpreted as choosing an optimal decision against some goals or objectives from the set of all possible alternative decisions (Klir and Yuan, 1995; Triantaphyllou, 2000). In practical decision-making scenarios, the number of goals or objectives under consideration is often more than one. Such situations are normally described as multiple objectives decision-making (MOD). Since objectives are established on the basis of criteria, the multiple objective decision-making scenarios are also described as multiple criteria decision-making (MCDM).

In the selection of DB operational variations, the multi-criteria decision-making model (henceforth the MCDM) may serve as the most appropriate technique. MCDM is a mathematical tool for evaluating and comparing alternatives to assist in selecting the optimal one (Triantaphyllou, 2000). It enables owners to evaluate the performance of each operational variation against the selection criteria. It also allows owners to assign weightings to these criteria that reflect their importance to the decision-making. The MCDM can be successfully applied to the context of DB operational variations selection.

When applying the multi-criteria decision-making technique, however, it is a challenge to measure the performance of each DB operational variation against the identified criteria objectively. The performance presents the overall suitability of an alternative option

against each criterion. It also reflects a decision maker's preference over the available alternative. However, the "suitability" or "preference" is fuzzy by nature. It is usually characterized by subjectivity and uncertainty. Quantifying the performance of each alternative should be based on its characteristics, impacts, and other relevant attributes. It usually requires group agreement, which might be very difficult and time consuming to acquire. As a result, owners will hardly be able to determine the performance of DB operational variations crisply and on a cardinal scale.

Fuzzy set theory can be utilized for dealing with subjectivity and uncertainties during the selection process. Zadeh (1965) first introduced the fuzzy set theory, which was based on the rationality of uncertainty due to imprecision or vagueness. A fuzzy set is a set whose elements have varying degrees of membership (Cross and Sudkamp, 2002; Niskanen, 2004). The fuzzy set theory is capable of presenting vague knowledge, and it has been applied within the field of decision-making (Triantaphyllou and Lin, 1996). The fuzzy decision-making approach can deal with the vagueness or fuzziness inherent in subjective or imprecise determinations of preferences, constraints, and goals (Yager, 1982). In particular, the fuzzy membership function, which is the core concept in fuzzy set theory, can be adopted to quantify and determine the performance/function of the DB alternative options. Therefore, a fuzzy multi-criteria decision making model is suitable for the selection of DB operational variations.

2.3 CHAPTER SUMMARY

In order to achieve significant research outputs, appropriate research methods have to be conducted. A combination of literature review, questionnaire survey, Delphi questionnaire techniques, face-to-face interviews and fuzzy set theory were used to set up a fuzzy multi-criteria decision-making model for the selection of DB operational variations.

CHATPER 3 REVIEW OF THE DESIGN-BUILD MARKET IN THE PEOPLE'S REPUBLIC OF CHINA (PRC)

3.1 INTRODUCTION

Design-build (DB) is a procurement method where one entity or consortium is contractually responsible for both design and construction of a project (Akintoye, 1994; Songer and Molenaar, 1997). It has been demonstrated to be an effective delivery method and has gained popularity overseas in the recent years. According to the Design-Build Institute of America (DBIA, 2005), an association founded in 1993 to promote the application of DB system, about 40 percent of all non-residential construction projects in both public and private sectors in the United States used this approach. It is also estimated that the DB system will be the leading method of project delivery by 2010.

However, it does not receive the same popularity in the construction market of the PRC, which is dominated by the traditional design-bid-build procurement system. Up until 2006, less than 10 percent of the construction projects are delivered in DB method (China Construction Industry Association, "CCIA", 2006).

Despite the sharp contrast between the domestic and international DB markets, general agreement on the advantages of DB system has been reached among owners and

government officials. It is believed that the DB market will have great potential given the prosperous construction industry and strong promotion from the government (Xun, 2003; Xia and Chan, 2008). Design-build provides many advantages and is undoubtedly a popular choice in other parts of the world, but it does not automatically mean that it would bring equal benefits to the construction industry of the PRC. Therefore, an appropriate review of the DB market in the PRC and a close examination of the suitability of this delivery system are urgently required.

Therefore, this chapter reports a comprehensive review of the DB market in the PRC. The review mainly aims to (1) investigate the suitability of DB system in the construction market of the PRC, and (2) explore the possible reasons why DB system is not receiving the same kind of popularity whilst in theory it should be beneficial. This chapter will, hopefully, provide a solid platform to conduct further studies on DB system, and promote its application in the construction market of the PRC. The data in this chapter are primarily collected from the following sources:

--*National Bureau of Statistics of China*

--*Ministry of Construction of the People's Republic of China*

--*Ministry of Commerce of the People's Republic of China*

--*China Federation of Project Engineering Management*

--*China Construction Industry Association*

--*China Exploration & Design Association*

--*China International Contractors Association*

--*Engineering News Record*

3.2 BACKGRROUND OF THE DESIGN-BUILD SYSTEM

Design-build is not a new concept. Its roots originate in the ancient "Master Builder" concept where responsibility for both design and construction resided with one person (Songer and Molenaar, 1997; Palaneeswaran and Kumaraswamy, 2000). In the ancient Greece, great temples, public buildings, and civil works were both designed and built by master builders. During the Renaissance, architecture and construction evolved as distinct professions and the presence of master-builders gradually diminished. During this era, project complexity increased and functional needs for specialization in both design and construction were required; therefore the “traditional” design-bid-build method of project emerged as the primary procurement method (Twomey 1989; Natkin 1994). In the 1970s and 1980s, because of the severe inflation and increased project litigation, owners began to re-evaluate and use design-build method as means to reduce project responsibilities and risk. As a result, current project delivery markets are experiencing the resurgence in the use of design-build method (McManamy 1994; Ndekugri and Turner 1994; Rosenbaum 1995; Yates 1995).

As a procurement method, DB system offers much strength or advantages such as single-point responsibility, time saving, enhanced financial certainty, improved buildability, reduced disputes, and increased productivity (Songer and Molenaar, 1997; Konchar and Sanvido, 1998; Beard *et al*., 2001; Hale et al., 2009). In DB projects, owners can allocate all design responsibilities to DB contractors in a single-point contract, and concentrate on project definition. Owners’ administrative burden will be, in turn, greatly reduced.

Although owners are still required to oversee the design and construction process, this responsibility is less time-consuming. Being the single party responsible for design and construction work, the design-builder can have a better control over the project. Many researchers (Song and Molenaar 1997; Mo and Ng, 1997; Pearson and Skues, 1999; Leung, 1999) have proposed that if DB projects are under control of experienced DB contractors, it will probably lead to the success of DB projects.

Design-build is considered to be the fastest project delivery system. Konchar and Sanvido (1998)'s empirical research indicates that the delivery speed of DB is faster than that of construction management and traditional design-bid-build system in the U.S. This is mainly because, firstly, DB system encourages the overlapping of design and construction process, which reduce the delivery schedule (Gordon, 1994; Tam, 2000; Beard *et al*., 2001; Loulakis, 2003). Secondly, the buildability of the design work will be greatly increased due to the early input of construction knowledge to the design process and the close communication among project participants (Akintoye, 1995; Turner, 1995; Songer and Molenaar, 1997). In addition, the earlier completion of DB projects will also provide owners with earlier use of the facility.

The DB system will secure the certainty of project cost and schedule at an early stage. The DB contract is usually awarded on a lump-sum basis, which will provide owners with early estimation of project cost (Rowlinson, 1997). By allowing only one entity to have the total control over design, scope and budget, DB method offers a higher possibility of completing the project within budget and schedule. Additionally, an

improved communication between design team and design-builder reduces possible design changes, which may lead to construction changes and eventually project delay (Bramble and West, 1999).

In addition to the advantages identified above, there are other benefits derived from the DB system. The shortening of project duration, close relationship between the designer and contractor, and better buildability will lead to cost reduction (Akintoye, 1994; Gordon, 1995; Songer and Molenaar, 1997). The singular responsibility will motivate design-builders to foster creative design and construction solutions, which will, in turn, improve the buildability. The single-point responsibility of design-builders will also reduce claims and litigations. Even if owners may lose the direct control over project quality, there is no apparent reason for the construction quality in DB to be lower than with the traditional design-bid-build approach (Ndekugri and Turner, 1994)

The main disadvantage of this system is that the owner's interests and requirements may not be fully satisfied. In DB system, a designer does not function as an independent agent for the owner to oversee the project and the work of the contractor (Bramble and West, 1999). As many owners do not have design and construction expertise, the owner's interests may not be well protected with the same firm designing and building their projects.

In addition, the DB system usually poses higher challenges to owners. First, owners must have a clear idea of scope and concept at very early stage of DB projects. They should

prepare sufficient specifications and clear project definition for the bidding job. Otherwise, it can be very costly if the information provided by the owner to the contractor is inaccurate at the outset of the DB process (Mogaibel, 1999). Second, although DB owners can leave most of the responsibilities to design-builders, they are required to have sufficient staff devoted to DB projects. If the owners do not have the in-house staff for DB projects, out-source adviser or design consultant should be employed. Otherwise, there may not be an independent party providing the necessary service to protect DB owners.

The DB system may also limit the bidding competitiveness from potential DB contractors. In DB projects, design-builders have to spend a large sum of money and resources for the higher-cost bidding because it requires clear understanding of owner's requirements, early involvement of construction experts in the design development, and close corporations between various professionals (Cheng, 1995; Arditi, *et al.*, 2002; Yang, *et al*., 2003; Zin, *et al*., 2004). Only the bigger companies with diverse skills and resources can set up the estimation/bidding system for the DB contract and afford the high bidding cost. For the unsucessful DB proposers, it is an expensive process. As a result, the high cost will dissuade many potential design-builders. And owners may not acquire the bidding competitiveness as in traditional delivey method.

Moreover, procurement laws in some countires may mandate the use of separate design and construction contracts. Projects in public sectors usually require a competitive process to choose a contractor, and some statutes and regulations even absolutely require

a competitive bidding on the basis of price. As a result, the DB method gives rise to conflicts with competitive bidding laws.

It is advocated that design-build system works best when the following conditions prevail:

- Owners employ best value rather than price-based selection procedures (Molenaar *et al*., 1999; Palaneeswaran and Kumaraswamy, 2000).
- The financial security of DB projects can be guaranteed (Beard *et al*., 2001).
- Owners' requirements and project scope are clearly defined and the potential design-builders will have similar understanding (Songer and Molenaar, 1997; Pearson and Skues, 1999; Gransberg *et al*., 2006; Lam *et al.*, 2008).
- The contract terms make reasonable assignments of risks between owners and design-builders (Bramble and West, 1999).
- The owner's organization has sufficient resource to answer design and construction related problems in a timely manner (Molenaar and Songer, 1998; Lam *et al*., 2004).
- A working environment of trust and mutual respect can be established among owners and design-builders (Bramble and West, 1999; Beard *et al*., 2001).

3.3 DESIGN-BUILD OPERATIONAL VARIATIONS

In order to meet different requirements of DB owners, certain modifications to the basic design-build system have emerged. Within the overall concept of design-build, a number

of terminologies are used to describe different 'operational variations', which include, for example, *develop-and-construction, bridging, novation DB, package deals, direct DB* and *turnkey* method (Janssens, 1991; Akintoye, 1994; Beard et al., 2001; Masterman, 2002; Gransberg et al., 2006). The essential difference between the operational variations is the proportion of design work undertaken by the client (Janssens, 1991; Beard et al., 2001; Gransberg et al., 2006).

Every DB operational variation has its own strengths and weaknesses. For instance, in the develop-and-construction, the client will engage a design consultant to complete a substantial part of design (more than 50% design) before engaging the design-builder. This may preclude the design-builder from any significant creativity or innovation, since basic solutions and concepts have already been determined before his engagement (Quatman and Dhar, 2003), however it can give the client greater control of projects. In the turnkey method, by contrast, the client simply provides requirements for the final product, and then requires the contractor to come up with a complete design and construction plan. Under this contractual arrangement, the client can leave most of the design responsibilities to the design-builder, but he may lose control of the project and may not obtain the project as required (Huse, 2002). When selecting DB operational variations, clients should, therefore, balance trade-offs and take multiple variables into consideration.

A number of studies have been undertaken on the DB system (Molenaar and Songer, 1997; Alhazmi and McCaffer, 2000; Chan, 2001; Cheung *et al*, 2001; Kumaraswamy and Dissanayaka, 2001; Chang and Ive, 2002; Luu *et al*, 2005). However, there are limited

studies focusing on the selection of DB operational variations. Janssens (1991) was one of the first researchers to look into this topic. He categorized the variables, which influence the choice of DB operational variations, into those relating to design, cost, time and other particular circumstances. The variation that suits all circumstantial variables will be selected as the most appropriate method for each proposed project. This method has its shortcoming because in real-life projects, it is rather unlikely that all the prescribed requirements can be met.

Beard *et al* (2001) listed three basic operational variations of design-build (direct design-build, design criteria design-build, and preliminary design-build) and gave detailed explanations of how the choice of these variations may affect a client's project. They asserted that selection of suitable operational variations mainly depends on client's decisions on (1) whether to define his needs by resources within its organization or outside its organization and (2) when the needs or problem-to-be-solved are sufficient to hand over to a contracted entity. Although Beard et al. (2001) gave detailed introduction of each variation; no practical methods or tools were provided for the selection of different operational variations.

The U. S. Federal Highway Administration (2006) advocated that after choosing design-build contracting to deliver a particular project, contracting agencies must decide appropriate level of preliminary design to initiate the design-build contract. This decision is influenced by the nature and complexity of the project, the needs of prospective teams to understand the requirements of the clients, the potential risks of the proposed project,

and the comfort level for design-builder to develop the scope of the project. Although the importance of selecting DB operational variations was emphasized, the Federal Highway Administration (2006) did not provide practical methods to determine the appropriate level of preliminary design in DB request for proposals.

In order to provide a clearer direction for the selection of DB operational variations, more research work is required. This is particularly the case for the construction industry of the People's Republic of China (PRC), where selecting an appropriate DB operational variation poses a lot of challenges to most clients. This is because the DB market in the PRC is still immature and most of owners and DB contractors remain unfamiliar with the delivery process of different DB operational variations. It is believed that the selection of DB operational variations constitutes obstacles to the application of DB system in China (Xia and Chan, 2008).

3.4 OVERVIEW OF THE CONSTRUCTION INDUSTRY IN CHINA

The construction industry in the PRC has developed rapidly in the recent years, and it has become a pillar industry of the national economy. In 2008, the construction industry represents about 5.7% of the GDP. Table 3.1 shows the added value of the construction industry from year 2000 to 2008. Considering the rapid and continuous growth, the construction industry will have great potential and larger market capacity.

Table 3.1 The added value of the construction industry from year 2000 to 2008

Year	Construction added value (Billion USD)	Growth (%)	The percentage in GDP (%)
2000	66.86	6.8	5.6
2001	71.81	7.4	5.4
2002	78.11	9.0	5.4
2003	90.50	15.9	5.5
2004	105.04	16.1	5.4
2005	123.73	16.6	5.5
2006	151.74	16.9	5.6
2007	186.36	18.2	5.6
2008	245.8	21.8	5.7

Note: the Growth (%) is calculated based on the RMB added value of the construction industry, and the figures of the construction added value are in nominal terms.

Source: National Bureau of Statistics of China. Statistical Yearbook 2009

However, the construction industry is still at low concentration rate. According to the *Engineering News Report* and *Construction Times (*2006*),* the domestic turnover of the top ten Chinese contractors is US$40.323 billion, which only makes up 12.02% percent of the total output of the construction industry. According to Bain (1968)'s analysis of concentration ratio (CR), the construction industry has a very competitive market structure. In 2007, there are 62070 construction firms completing in the construction market (National Bureau of Statistics of China, 2008). Most of them are medium to small scales, and only engage in the labor-intensive construction works. The low market concentration and the large number of companies lead to fierce competition and low profitability in the construction industry. In 2007, the total profit of the construction enterprises takes up only 3.0 percent of the product value; the ratio of liability to assets is

as high as 65.5 percent (National Bureau of Statistics of China, 2008). Many of the stronger or larger scale firms, therefore, intend to explore the DB market because DB projects generally offer higher profit margins to DB contractors.

In the PRC construction industry, over-schedule and over-budget have presented the most serious problems, in particular to public sector owners (Xia and Chan, 2008; Wang et al., 2008). This is mainly because many project owners are state-owned organizations that have no responsibility for the overruns of budgets and construction time. With the government transferring its planned economic system into a market-oriented economic system, new procurement methods have been introduced to overcome these problems. The DB system, in particular, has been strongly promoted by the government because of its obvious advantages and popularity overseas.

It is believed that the DB system will bring benefits to the PRC construction industry. It can provide solutions to many problems in the current construction market of the PRC (Xia and Chan, 2008). The DB system is the return of the old "Master Builder" concept, and regains its popularity when the traditional design-bid-build system no longer fit for the inflationary 1970s and the litigious 1980s (Songer and Molenaar, 1997). In particular, it has experienced extraordinary growth internationally in the recent years. Agreement on the effectiveness of DB system has been reached among many owners and government officials. Many key projects have been successfully delivered by this method. It is anticipated that the DB system will be widely used in the construction market of the PRC in the future (CCIA, 2006).

3.5 REVIEW OF THE DESIGN-BUILD MARKET IN THE PRC

3.5.1 Definition and Scope of Design-build System in the PRC

In the PRC, DB system is defined as "one type of the general contracting system under which the contractor performs both design and construction practices and take full responsibilities of project quality, safety, schedule, and cost under one single contract" (Ministry of Construction of the PRC, 2003). Among other general contracting systems are Engineering-Procurement-Construction (EPC), Engineering-Procurement (EP) and Procurement-Construction (PC). In this definition, the DB system is different from the EPC method in which the contractor is responsible for design, procurement, construction, commissioning and operation. However, most of the statistics, published or disseminated in the PRC, lump these different variations into one broad category. More importantly, they share the most essential element that contractors take full responsibilities of design and construction under one single contract. Therefore, the DB system in this chapter basically refers to the general contracting system, which includes DB, EP, PC, and EPC.

3.5.2 The Design-Build Market in the PRC

In the PRC, the DB delivery system was first introduced into the Petroleum and Chemistry industry in the 1980s and then spread to the metallurgical industry, electronic industry, infrastructure construction, and housing industry (Wang and Bai, 2008). There are now over 200 construction enterprises conducting DB business. It is estimated that

there are about 30 percent of the projects are suitable or partially suitable for the DB contract (CCIA, 2006).

DB contractors have made sound progress in the DB market in recent years. According to the statistics of the top 60 Chinese Contractors (*Engineering News Record & Construction Times,* 2003-2008), the DB contract value of the top 60 contractors was USD$23.4 billion in year 2008. In year 2005, there were already 46 Chinese contractors on the list of the top 225 international contractors, and 12 of them were among the top 100. Meanwhile, the DB contract value of the top 100 design consulting companies in year 2008 was USD$32.27 billion according to the statistics conducted by China Exploration & Design Association (2009). Table 3.2 shows the DB contract values of the top 60 contractors and the top 100 design consultants from 2003 to 2008.

Table 3.2 DB contract values of the top 60 contractors & top 100 design consultants 2003-2008

Year	DB contract value of the top100 design consultants （Billion USD）	DB contract value of the top 60 contractors (Billion USD)	The sum of the total value (Billion USD)	The total output of the construction industry (Billion USD)	The ratio （%）
2003	4.55	6.6	11.2	278.9	4.0
2004	6.57	8.5	15.1	350.6	4.3
2005	9.40	10.4	19.8	421.9	4.7
2006	12.55	14.8	27.4	521.2	5.3
2007	20.15	18.1	38.3	673.8	5.7
2008	32.27	23.4	55.7	880.5	6.3

Note: the figures of the contract values are in nominal terms

Source: China Exploration & Design Association and *Engineering News Record & Construction Times (2003-2008)*

Although the DB delivery system developed rapidly in the PRC, only 10 percent of the construction projects are delivered in DB system this far (CCIA, 2006). The total value of the DB contract, undertaken by the top 100 design consultants and the top 60 contractors, takes up less than 10 percent of the total output of the construction industry. The DB system develops unevenly in different industries. It is estimated that there are only 5-10 percent of DB projects in the housing & communication industry, while 15-20 percent in the metallurgical industry, chemical industry, and metallurgical industry. The operational ways of DB system also vary in different industries. In the petrochemical, metallurgical and electronic fields, more than 50 percent of the DB projects are delivered in the EPC/Turnkey method because of the necessity for one entity to take control over design, construction, procurement and commissioning. While in the housing industry, most of the DB projects are delivered in the way of developed-and-construct method in which owners entail design consultants to develop most of the design work before engaging design-builders to complete the remaining detailed-design and construction work.

In addition, the DB contract values of the top 100 design consultants vary greatly in different industries. For example, the metallurgical and the petrochemical industry have much larger DB contract values than those of housing industry, communication industry and municipal construct field. The DB contract values of the top five industries make up more than 75 percent of the total sum of the DB contract values. The description of DB contract values in the top 5 industries is demonstrated in Table 3.3

Table 3.3 The DB contract values in different industries (top 5) (million USD)

INDUSTRY	2002	2003	2004
Metallurgic	544.5	1213.2	1716.7
Petrochemical	1128.1	975.2	1452.8
Electronic	552.6	583.2	879.5
Chemical	329.1	384.2	573.0
Building material	215.2	336.6	348.2
∑sum above	2769.5	3492.4	4970.3
The ratio	75.0 %	76.2 %	75.5 %

Note: the figures of the contract values are in nominal terms

Source: China Exploration & Design Association (2002-2004)

Figure 3.1 specifically illustrates the ratios of the DB contract values in different industries to the total sum in 2004:

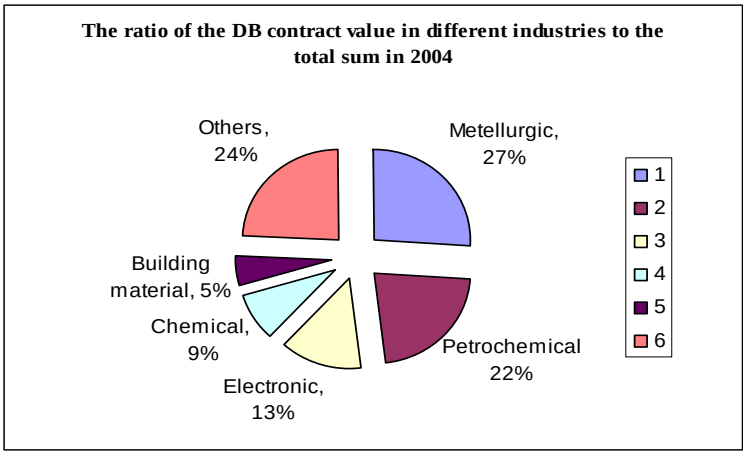

Figure 3.1 The ratio of the DB contract value in different industries in 2004

(Source: China Exploration & Design Association, 2004)

3.5.3 Foreign Contractors in the DB Market of the PRC

With China's open-up policy since 1980s, many foreign contractors have entered into the PRC construction market. Meanwhile, a large number of foreign-invested construction companies have been established in the PRC, especially after China's accession to the WTO in 2001. According to the statistics released by the Ministry of Construction (2006), at the end of year 2000, only 136 foreign enterprises from 15 countries or regions obtained the qualification certificates issued by the Ministry of Construction and local construction administrative departments. At the end of October 2006, five years after China's accession to the WTO, 1189 foreign-invested construction companies and 223 foreign-invested design companies have been registered in the PRC. Among the 1189 foreign-invested construction companies, 570 of them from Hong Kong, 110 of them from Japan, and 100 of them from the U.S. The numbers of foreign-invested construction companies are shown in Figure 3.2. Among the 223 foreign-invested design companies, 133 of them from Hong Kong, 24 of them from U.S.A, and 14 of them from Singapore. The numbers of the foreign-invested design companies are shown in Figure 3.3.

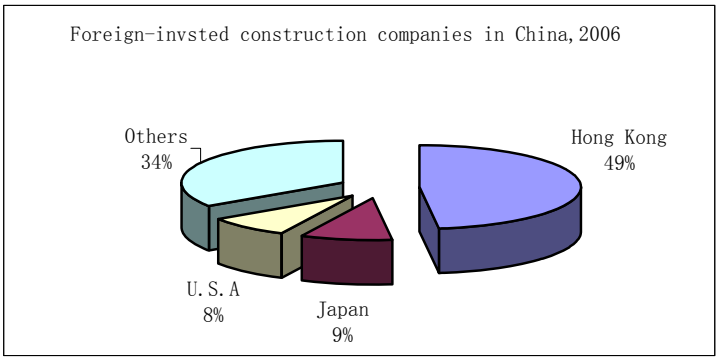

Figure 3.2 The numbers of foreign construction enterprises in China in year 2006
(Source: Ministry of Construction of the People's Republic of China, 2006)

Although Hong Kong has the largest numbers of both construction and design companies registered in the PRC, the contract values of these companies are relatively small. Most of their businesses focus on decorative engineering and equipment installation. While there are fewer American and European contractors, most of them are world-class contractors, and engage mainly in the DB and project management fields. In general, foreign contractors operate higher proportion of DB business than Chinese contractors. According to the statistics collected by the Ministry of Construction of the PRC (2006), the contract value of the American and Singaporean contractors in 2005 is US$1.8 billion and US$1 billion respectively, and more than 50% of the projects are delivered in the DB system.

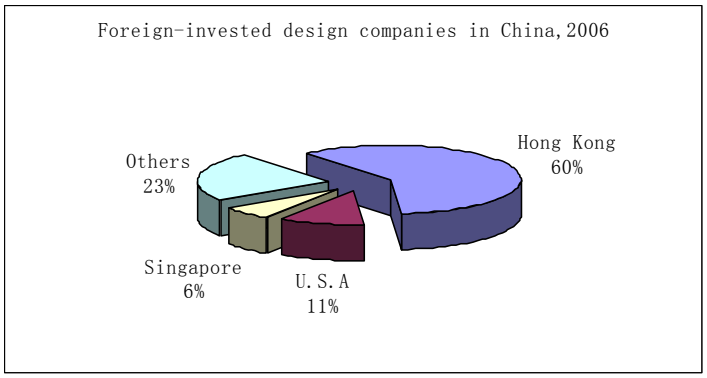

Figure 3.3 The numbers of foreign construction enterprises in China in year 2006

(Source: Ministry of Construction of the People's Republic of China, 2006)

3.6 BARRIERS TO ENTRY INTO THE DB MARKET IN CHINA

After the investigation of the DB market in the PRC, it can be seen that the DB system has not been widely used yet. In exploring potential reasons attributing to this situation,

the theory of barrier to entry provides an insightful perspective to analyze the DB market. Barrier to entry is anything that makes it difficulty for a new entrant to enter into a market. Oster (1990) described barriers to entry as "industry characteristics that reduce the rate of entry of new firms". It is regarded that any kind of entry barrier is a distortion of the competitive process (Yang, 1998). In industrial economics, there are various sources of barriers to entry, which include absolute cost advantages, economies of scale, high capital requirements, product differentiation, the degree of firm concentration, market risk, experience or learning curve, industry regulation, and the size and expected growth of the market (Bain, 1956; Mann, 1966; Porter, 1980; Baldwin, 1995). These barriers keep the number of companies competing in an industry small, and allow the incumbent firms to earn higher-than-normal profits (Avgeropulos, 1998). Therefore, understanding sources of barriers to entry in an industry is of significant importance to both potential entrants and incumbent companies.

3.6.1 Concept of Barriers to Entry

The concept of barriers to entry was first introduced by Bain (1956). It was advocated that the existence of barriers could aid market incumbents in limiting the intensity of competition in their respective industries and therefore enable them to have above-average profitability. Bain (1956) identified economies of scale, product differentiation, and absolute cost advantages of established firms as major determinants of the barriers to entry. Porter (1980) has written extensively on barriers to entry, and proposes six major sources of barriers, which include cost advantages of incumbents, product differentiation of incumbents, capital requirements, customer switching costs, access to distribution

channels, and government policy. Over the past decades, several other sources of barriers have been identified including, for example, advertising (Harrigan 1981; Demsetz 1982), research and development (R&D) (Schmalensee 1983), patents (Mansfield *et al*., 1981), market risk (Baldwin, 1995), and the size and expected growth of the market (Baldwin, 1995).

Although there are diverse sources of barriers to entry, the industrial organization and strategic management theory suggests that (1) economies of scale, (2) capital requirements, and (3) product differentiation are the most important entry barriers (Bain, 1956; Hofer, 1975; Shepherd, 1975; Porter, 1980; Hay and Morris, 1991; Siegfried and Evans, 1994).

Economies of scale

The effect of economies of scale exists when a decline in product cost is accompanied by an increase in product output. It represents efficiencies in production that cannot be easily achieved by new entrants. Many researchers (Bain 1956; Stigler, 1968; Faulkner, 2002) argue that the effects of economies of scale in any industry are strongly associated with large firm size. When the plant scale increases, the unit cost of a product declines because of (a) favorable access to raw materials; (b) government subsidies; and (c) more effective learning or experience curve (Karakaya and Stahl, 1989).

Capital requirements

The capital requirement constitutes barrier to entry when companies need to invest large financial resources in order to compete or enter a market. Generally, such barrier is higher in capital-intensive industries. It is suggested that new entrants will encounter difficulties in raising capital, locating and training a qualified workforce, and developing inventories and distribution channels in order to build an appropriate sized plan (Geroski *et al*., 1990).

Product differentiation

Product differentiation is the ability of a firm to establish brand identification that represents a barrier to new entrants (Dickinson, 2006). The established firms have brand identification and customer loyalties due to advertising, being first in a market, customer service, or product differences. Cave and Porter (1977) asserted that product differentiation reduces the likelihood that customers will switch to competitor's products. Thus, entrants must persuade consumers to compare products with different specifications and then to re-evaluate their purchasing habits.

Extensive economic theories on barriers to entry demonstrate how various elements of industry structure impose disadvantages on entrants. Meanwhile, it should be noticed that the barriers to entry vary from industry to industry. In addition, even for the same industry, the barriers to entry will also vary in different geographical locations and over different economic development stages. Therefore, the identification of contemporary barriers to entry in the DB market of the PRC will be introduced in the next section.

3.6.2 Identification of Barriers to Entry into the DB Market of China

In order to identify the contemporary barriers to entry into the DB market of the PRC, two rounds of questionnaire survey were conducted. An open-ended questionnaire survey was first conducted with industrial professionals through e-mail and phone-call. The open-ended questionnaire was used to solicit experts' opinions on the barriers to entry into the DB market of China. In order to ensure the validity of the research findings, all these experts have sufficient DB knowledge and extensive hands-on DB experience (at least more than 5 years DB experience). 31 experts who satisfied all the selection requirements were finally identified from the address available from government offices, industry associations, universities, and through personal contacts. They were requested to list down all the barriers to entry into the DB market according to their experience. In particular, they were requested to take into consideration of the unique characteristics of the PRC construction industry. The findings from the literature review were also provided for their reference. Finally, 15 valid responses were received. Content analysis was employed to identify the barriers to entry into the DB market after the collection of their responses. After employing the content analysis, the open-ended questionnaire survey resulted in a final list of 22 barriers to entry into the DB market in China.

In order to prioritize and evaluate these barriers to entry, another questionnaire survey was conducted with another group of experts in the DB market. A total of 435 respondents were identified, which are from the groups of academics, government

departments, state-owned companies, and private companies in the construction industry. In order to ensure the validity of the survey results, all the respondents should have more than 5 years working experience in the construction industry. In addition, they should have been involved in DB projects in China. In this questionnaire survey, the respondents were requested to provide opinion on the extent of influence/importance of each barrier to entry into the DB market on a five-point Likert-type scale, which ranges from 1 (the least important) to 5 (the most important). Finally, a total of 140 responses were received. The response rate was 32%, which is very encouraging considering the fact that the DB system has not been widely used in the PRC.

3.6.2.1 Analysis of the First Questionnaire Survey

E-mail questionnaire survey is a widely used survey mode. It has demonstrated superiority over postal surveys in terms of response speed and cost efficiency. E-mail survey provides an easier and more immediate means of response, and a potential decrease in delivery time and cost (Flaherty, *et al*., 1998; Schonlau *et al*., 2002).

Given the unique situation of the DB markets in China, all the experts should satisfy following selection criteria.

(1) The expert should have at least 5 years hands-on DB experience,
(3) The expert should have publications in the DB field to show their extensive DB knowledge.

Questionnaires were sent to 31 experts who met all the selection criteria. Finally, 15 valid responses were received. A list of the final respondents and their affiliations are shown in Table 3.4. The respondents represent a wide spectrum of construction professionals in the PRC and provide a balanced view for the study.

Table 3.4 List of the panel of experts for the open-ended questionnaire study

Type of firm / department	Number
Government department	2
Design consultant company	3
Project management company	3
University	3
Construction company	4
Total	15

Among the final respondents, each of them has at least one publication in the academic journals in the DB field. In addition, all of them have sufficient experience and expertise in DB field. The average DB experience is 10 years. Most of them (53%) have 5-10 years DB experience. One-third of respondents (33%) have 10-20 years of DB experience, and the rest of them (13%) have over 20 years experience in the DB field.

The open-ended questionnaire survey was conducted as the exploration process and was of crucial importance. After the completion of questionnaire survey, content analysis was

used to identify the barriers to entry into the DB market in China. Weber (1990) stated that content analysis could help classify textual material, reducing it to more relevant, manageable bits of data. In conducting the content analysis in this research study, all the key points and main ideas of each survey transcript were first documented. Then, similar main points and ideas were assembled and different main themes were finally consolidated from the analyzed survey transcripts. After the analysis, a total of 22 main themes of the barriers to entry into DB market were identified (shown in Table 3.5). It is obvious that most of the identified themes relate to the barriers listed in the literature review. For example the high contract price and high financial requirements relate to the capital requirements, the regulation and law issues relate to the government policy. Other themes such as the lack of real owners in the public sector and the lack of credit system in the construction market are due to the unique conditions of the PRC construction industry.

Table 3.5 Summary of barriers to entry into the design-build market in China

1. Lack of promotion from local governments
2. Unfamiliarity of DB owners
3. Lack of enough competent design-builders
4. Lack of experience of design-builders
5. Difficulty in determining the DB contract price
6. Lack of interest from public owners
7. Lack of sophisticated design expertise of contactor-led design-builders
8. Lack of project management capability of design-led design-builders
9. Lack of enough design-build professionals in the DB market
10. Owner's lack of ability to successfully define project requirements
11. Lack of credit system in the construction market

12. Lack of competent sub-contractors

13. Lack of suitable organization format for design-builders

14. Difficulty in coordination with sub-contactors

15. Higher contract price of DB projects

The contract price of DB projects is comparatively higher than traditional DBB projects

16. Lack of bidding and evaluation method for DB projects

There are only bidding regulations on exploration, design, construction, and construction supervision

17. Risk management of design-build projects

The risk of DB projects is comparatively higher, and there is a lack of risk management approach.

18. The effectiveness of design-build system

The effectiveness of DB system are not obvious compared with other delivery systems in China

19. Less control of DB projects

Many owners have concern that DB system will result in less control of their projects

20. Lack of regulations on qualification management

There is a lack of licensing regulations on design-builders in China

21. Lack of real owners in public sectors

Many public owners take no responsibility for the performance of projects

22. Conflict with the existing bidding system

Most of public projects require open bidding and many even require absolute lowest-price bidding.

3.6.2.2 The Second Questionnaire Survey

Questionnaire Development

After the open-ended questionnaire survey, the consolidated twenty-two barriers to entry into the DB market were used in the second questionnaire survey. Respondents were

asked to evaluate the importance of the barriers to entry on a 5-point scale, where 1=not important, 2=somewhat important, 3=important, 4=very important, and 5=extremely important or essential. A total of 435 respondents were identified from government departments, contractor associations, and construction-management departments in universities. The questionnaires were sent to them by email. A total of 140 responses were finally received. To ensure that the survey results were credible, any replies from respondents with less than 5 years of experience in construction industry were discarded. However, the results revealed that all the respondents have more than 5 years working experience, and most of them (86%) have been working in the construction industry for more than 10 years. All the respondents have been involved in DB projects, and 80% of them have the DB experience for more than 5 years. The details of the 140 respondents are summarized in Table 3.6 and Table 3.7. In addition, it should be pointed out that although the experts from academia take up more than 50% of the respondents, most of them have close connections to the industry and provide consultancy services to contractor agencies and government departments in DB projects.

Table 3.6 Respondent classifications by years in the construction industry and DB field

Working Years	Working experience in construction industry (%)	Working experience in design-build market (%)
1-5 years	--	20
5-10 years	16	37
10-20years	42	32
More than 20 years	42	11

Table 3.7 Respondent classifications by working organizations and working areas

Working organizations		Working areas	
University	58 %	Residential and Building	62 %
Government	10 %	Heavy construction	19 %
State-owned company	21 %	Industrial	19 %
Private company	11 %		

Data Analysis and Discussion

Two separate statistical analyses were undertaken using the SPSS software. The first analysis ranked the barriers to entry based on mean value of responses, compared the means for different groups of respondents and provided an analysis of variance (ANOVA), which test the null hypothesis that the mean of the individual barrier to entry is equal in different groups. The second analysis was intended to explore and detect the underlying relationship among these barriers to entry into DB market using factor analysis.

Analysis 1: Rankings of barriers to entry into the DB market in China

As part of the analysis, the reliability analysis was first conducted. Reliability analysis is

to test whether the instrument will produce the same result each time it is administered to the same person in the same setting. Coefficient alpha (Cronbach's alpha) is designed as measures of internal consistency. In this study, the Cronbach's coefficient alpha is 0.801, which suggests that the 5-point Likert-type scores provided by the respondents in the study are reasonably reliable.

The analysis of mean values of the barriers to entry into the DB market, shown in Table 3.8, suggests that the most dominant barriers to entry (whose mean scores are 4.0 or above, which means "very important") are, namely, lack of design expertise of contractor-led design-builders, owners' lack of interest toward DB system, lack of suitable organization structure, lack of DB specialists, and lack of credit record system in the construction market. As a DB contractor assumes the total responsibility for a DB project, he/she should possess the ability to combine the design and construction functions successfully. However, the majority of design-builders were developed from general contractors, lacking sophisticated design expertise in China. In addition, because the development of DB system is still in its infancy stage, many DB contractors lack enough DB specialists and suitable organizational structures to deliver the DB projects. In the construction market of China, although many owners have recognized the advantages of the DB system, many of them—especially the owners in public sectors—have no strong incentives to adopt this new alternative. This is mainly because owners have been used to the traditional delivery system and many of them still have concerns about DB system such as losing the control of DB projects. Furthermore, due to the lack of credit record system in the construction market, many owners are unwilling to adopt

DB system because it is not easy to find the reliable DB contractors. Therefore, it is not surprising that these factors were listed on the top of the ranks as barriers to entry into the DB market in China.

With the exception of the (1) lack of interest from owners, (2) lack of competent design-builders, (3) lack of qualification regulations, (4) conflicts with existing bidding law, and (5) coordination with sub-contractors, there is no statistically significant difference in the opinions of respondents toward the factor rankings, at 5% significant level. It suggests that experts in universities, government departments, state-owned companies, and private company generally have similar opinions on those prioritized factors, which constitute barriers to entry into the DB market of China.

For the factors of (1) lack of interest from owners, (2) lack of competent design-builders, (3) lack of qualification regulations, (4) conflicts with existing bidding law, and (5) coordination with sub-contractors, the p values are less than 0.05, which suggests that experts in different groups have different opinions on their importance rankings. In order to explore which groups have different opinions toward these barriers to entry, a multiple comparison of Bonferroni post-hoc test was conducted. The post hoc test is used to determine the significant differences between group means in an analysis of variance setting. The Bonferroni is probably the most commonly used post hoc test, because it is highly flexible, very simple to compute, and can be used with any type of statistical test (Keppel and Wickens, 2004). Pairs of groups, whose mean scores are significantly different from each other, are shown in Table 3.9. It can be seen that the group of state-

owned company have different opinions from private company on the following barriers to entry, which include the lack of qualification regulations, and the coordination with subcontractors. The reason why these barriers were ranked higher in the group of sate-owned company is that many state-owned companies often get involved in large-size DB projects in public sectors; and these large projects usually require the highest grades of enterprise qualifications and sophisticated coordination with a variety of specialty contractors.

The factor of conflicting with existing bidding laws was ranked 22 by the academic group, but it was ranked higher (ranked 14) in the group of government department. Many experts in government believe that the DB method may give rise to conflicts with competitive bidding laws. This is because projects in the public sector usually require a competitive process to appoint a contractor, and some local statutes and regulations are subject to a mandatory requirement to obtain a competitive bidding on the basis of price. However, the price-oriented process of contractor selection may not be suitable for DB projects, and it may prevent the owner to obtain the best value of the DB projects.

The lack of suitable organizational structure was ranked as the most dominant barrier by both state-owned and private companies compared with the rank of 12 by government departments and the rank of 6 by academics. A suitable DB organization format is critical to contractors when conducting DB projects. This is because most of them are not integrated design-builders. They need to collaborate with other companies to possess both

design and construction functions. However, it is very difficult to most of contractors and designers due to the complexity in the allocation of project risk and responsibility.

Table 3.8 Barriers to entry into the DB market of China

Barriers to entry	Overall Mean	Rank	Academic	Rank	Government department	Rank	State-owned company	Rank	Private company	Rank	*p*-value
1. Lack of design expertise	4.03	1	4.12	1	4.00	4	3.83	6	3.93	3	.509
2. Lack of interest from owners	4.03	2	3.98	5	4.29	2	4.30	2	3.53	8	.043
3. Lack of suitable organizational structure	4.01	3	3.93	6	3.57	12	4.40	1	4.13	1	.052
4. Lack of DB specialists	4.01	4	4.02	2	4.07	3	4.00	4	3.87	4	.952
5. Lack of credit record system	4.00	5	3.88	8	4.57	1	4.17	3	3.80	7	.069
6. No real owners in public sectors	3.93	6	4.01	3	4.00	5	3.73	9	3.80	6	.571
7. Lack of construction management ability	3.90	7	3.99	4	3.64	8	3.97	5	3.53	9	.310
8. Lack of DB experience	3.81	8	3.93	7	4.00	6	3.70	11	3.20	14	.080
9. Unfamiliarity of owners	3.75	9	3.75	9	3.64	9	3.73	10	3.87	5	.964
10.Too much control of the owner	3.68	10	3.70	11	3.71	7	3.83	7	3.20	15	.292
11.Lack of support from local governments	3.56	11	3.57	12	3.64	11	3.30	13	4.00	2	.267
12.Lack of competent design-builders	3.51	12	3.73	10	3.21	15	3.43	12	2.73	18	.008
13.Uncertaintiy of DB contract price	3.35	13	3.37	13	3.57	13	3.23	14	3.27	12	.828
14. Higher risk of DB projects	3.31	14	3.32	14	3.64	10	3.10	16	3.40	11	.499
15.Lack of qualification regulations	3.26	15	3.19	16	3.21	16	3.77	8	2.67	20	.018
16.Effectiveness of DB projects	3.12	16	3.25	15	3.14	17	2.93	19	2.80	17	.359
17.Difficulty in writing design-build RFPs	3.12	17	3.14	17	3.00	18	3.20	15	3.00	16	.908
18.Lack of contractor selection methods	3.03	18	3.02	18	2.86	20	3.00	17	3.27	13	.766
19.Higher contract price of DB projects	2.99	19	2.96	19	2.93	19	2.93	18	3.47	10	.224
20.Conflicting with existing bidding laws	2.56	20	2.40	22	3.43	14	2.50	21	2.73	19	.022
21.Coordination with subcontractor	2.48	21	2.49	20	2.07	21	2.87	20	2.00	22	.010
22.Lack of specified sub-contractors	2.37	22	2.44	21	2.00	22	2.37	22	2.33	21	.612

Note: *. The mean difference among groups is significant at the .05 level

Table 3. 9 Multiple comparison of Bonferroni post-hoc test--groups with different opinions

Barriers to entry with different opinions	Pairs of groups with different opinions	*p*-value
Lack of competent design-builders	Academic and private company	.007
Lack of qualification regulations	State-owned company and private company	.016
Conflicts with existing bidding law	Government and academic	.015
Coordination with sub-contractors	State-owned company and private company	.024

Analysis 2: Underlying dimension of barriers to entry—Factor Analysis

Factors analysis is a statistical technique used to examine the underlying patterns or relationships for a large number of variables (Norusis, 1992). In particular, it seeks to discover if the observed variables can be explained largely or entirely in terms of a much smaller number of variables called *factors*. Variables that are highly correlated (either positively or negatively) are likely influenced by the same factors, while those that are relatively uncorrelated are likely influenced by different factors (DeCoster, 1998).

The factor analysis requires two essential stages, factor extraction and factor rotation (Norusis, 1992). The primary objective of the factor extraction is to make an initial decision about the number of factors underlying a set of measured variables. In the factor extraction, the principal component analysis is the most commonly used method because it considers the total variance in the data, and determines the minimum number of factors that will account for the maximum variance in the dataset. The objective of the factor rotation is to make the factors more interpretable and make final decisions about the

number of underlying factors. The varimax rotation is most popular method in the factor rotation analysis because it tries to maximize the variance of each of the factors (Abdi, 2003).

In order to investigate the underlying dimension of barriers to entry, the 22 barriers to entry were subjected to the factor analysis, with principal components analysis for factor extraction and varimax method for factor rotation. The results are shown in Table 3.10. In order to evaluate the appropriateness of the factor extraction, the Kaiser-Mayer-Olkin (KMO) measure of sampling accuracy and Barlett's test of sphericity were conducted. The KMO measure of sampling adequacy tests whether the partial correlations among variables are small. Kaiser (1974) recommended KMO values of greater than the threshold of 0.5 as acceptable. The results show that KMO measure is .686, which is greater than 0.5 for a satisfactory factor analysis to proceed. Bartlett's test of sphericity is used to test the null hypothesis that the variables in the population correlation matrix are uncorrelated. The observed significance level is .000, which rejects the null hypothesis. It was concluded that the strength of the relationship among variables is strong and therefore a factor analysis for analyzing the data can be proceeded.

Table 3.10 Factor profile of barriers to entry into the DB market of China

Details of the factors and barriers to entry	Factor loading	Variance explained
Factor 1: The competence of design-builders		12.764%
Lack of DB experience	.500	
Lack of design expertise	.838	
Lack of construction management ability	.701	

Lack of DB specialists	.636	
Lack of suitable organizational structure	.578	
Factor 2: Difficulty in project procurement		11.854%
Difficulty in writing request for proposals (RFPs)	.563	
Lack of bidding and contractor selection method	.554	
Conflicts with existing bidding law	.533	
Lack of specialty contractors	.788	
Difficulty in coordination with specialty contractors	.681	
Factor 3: Characteristics of DB projects		9.392%
Higher price of DB contracts	.588	
Uncertainty of DB contract price	.600	
Higher project risk of DB projects	.575	
Effectiveness of DB method	.732	
Less control of projects for the owners	.470	
Factor 4: Lack of support from public sectors		8.541%
Lack of promotion from local government	-.515	
Lack of interest from public owners	.752	
Lack of qualification regulations	.624	
Factor 5: The competence of owners		7.606%
Unfamiliarity of owners	.688	
No real owners in public sectors	-.524	
Factor 6: Immature DB market		7.228%
Not enough competent design-builders	.700	
Lack of credit record system in the DB market	.506	

Cumulative variance explained = 57.386%
Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.686
Significance of Bartlett's Test of Sphericity =0.000

The results in Table 3.10 show that there are six dimensions underlying the 22 barriers to entry. On the basis of examining the content of these six factors, they were named as the competence of design-builders, difficulty in project procurement, characteristics of DB projects, the lack of support from public sectors, the competence of owners, and the immature DB market. In total, these six factors accounted for 57.386% of the variable variance.

3.6.2.3 Discussion of Factors Analysis Results

The competence of design-builders

As the key stakeholders in DB projects, design-builders play a vital role in the delivery process because they take full responsibilities of design and construction, and take control of the project management. Many studies reflect that the competences of design-builders are critical to the success of DB projects. Molenaar and Songer's (1998) multi-attribute analysis and retrospective case studies found that DB contractor's experience is crucial for successful DB projects in the public sector. Chan *et al.* (2001a) conducted multiple regression analysis in Hong Kong and found that DB contractor's competences are important to bring successful DB project outcome. Lam *et al.* (2008) conducted

multiple regression analysis and identified that the competence of the design-builders is one of the determinants of the successful DB projects. Puterto *et al.* (2008) asserted that owners are willing to pay more to get highly competent DB contractors. All these research studies advocate that a competent DB contractor could ensure the success of DB projects.

In the construction market of the People's Republic of China, however, the majority of DB contractors lack adequate competences to execute the DB projects successfully. According to China Construction Industry Association (2008), the total value of the DB contract, undertaken by the top 100 design consultants and the top 60 contractors, takes up less than 7 percent of the total output of the construction industry. The lack of sufficient DB competence of design-builders was regarded as one of the major obstacles to the application of DB system in China (Xun, 2003; Zheng and Cheng, 2004). DB contractors should, therefore, exploit their resources and capabilities to build up their competence and establish the competitive advantages in the DB market.

Difficulty in project procurement

The project procurement represents the purchasing procedures that owners or their representative must take to gain the service and commodities as required (Beard *et al*., 2001). In order to procure the satisfactory DB projects, owners or their representatives should be able to define what they want clearly through the requests for proposals (RFPs). However, it is never an easy task. Owners are required to clearly define the project scope and expected outcomes in advance of the procurement selection. Otherwise it can be very

costly if the information provided by the owner to the contractor at the outset of the DB process is not correct (Mogaibel, 1999). At the same time, owners should stop short of describing how to get there for it may preclude the DB team from any significant creativity and innovation (Quatman and Dhar, 2003).

The selection of DB contractors is also a difficult task during the procurement process. Firstly, there are different levels of competition, from open tendering to single negotiation in the contractor selection process. Owners have to decide whether it is suitable for competitive tendering or more co-operative process where non-price criteria play a significant part. Secondly, it is very difficult to evaluate the DB competence of potential contractors because many selection criteria for design-builders are qualitative, subjective and imprecise (Fong and Choi, 2000). As a result, most of owners in China tend to select design-builders on a price-oriented basis, which may not be suitable for DB projects.

The characteristics of DB projects

The execution of the design-build system is quite different from the traditional way. In the DB process, most of the construction work starts before the total completion the shop drawings, thus cause large fluctuation in the labor force and material supply (Ernzen and Schexnayder, 2000). It will, in turn, not only require huge capital scale of DB contractors but also incur higher risk to design-builders because most of them are awarded on a lump-sum basis. As a result, the contract prices of DB projects are usually higher than the similar projects with traditional delivery system in China. In addition, the cost estimation

for a DB project is very difficult because the design documents are often preliminary and may change over the course of the project. Cost estimation should be accurate and reasonably verifiable in order to minimize risk. Only the bigger companies with diverse skills and resources could set up the estimation system for the DB contract competently.

As an alternative delivery method, DB system offers much strength or advantages such as single-point responsibility, time saving, enhanced financial certainty, improved buildability, and reduced disputes (Rowlinson 1997; Leung 1999). Although various empirical studies overseas indicated that DB system is superior to traditional delivery system in regards to time and cost (Konchar and Sanvido, 1998; Hale *et al*., 2009), the effectiveness of DB system in China is yet to be demonstrated. The main reason is that the DB market is still at the infancy stage, and most of stakeholders lack the experience to conduct DB projects successfully. However, given the prosperous construction industry and strong promotion from the government; it is believed that the DB market will have great potential in the future.

Lack of support from public sectors

In the recent years, the central government has been promoting the DB system with great efforts. However, the DB system is not favored by the local governments. It is mainly because most of the local governments lack the experience in administrating this new system due to the lack of tendering procedure, licensing regulations, and standard contract forms for the DB system in the PRC construction market. Furthermore, some

local governments still keep traditional perspectives to DB system. For example, they always require a competitive bidding in DB projects on the basis of price. However, the price-oriented process is not always suitable for DB projects and may prevent the owner to obtain the best value of the DB projects.

In the public sectors, a majority of owners still prefer traditional delivery system. Firstly, they have got used to the design-bid-build system, which has long dominated the construction market. Second, many public owners have the concern that their interests may not be well protected if the projects are under control of design-builders. In addition, due to the traditional investment system in China, many owners in government-invested projects have no responsibility for the overruns of budgets and construction time. As a result, the public owners take less interest in adopting the DB system despite its theatrical advantages and strong promotion from the central government.

The competence of owners

DB system provides owners with a number of advantages. At the some time however, owners are also required to possess certain competences to conduct the DB projects. For example, owners should be able to clearly define the project requirements (Kometa *et al*., 1995; Mo and Ng 1997; Songer and Molnaar 1997; Lam *et al*., 2008), have the ability to manage design changes (Deakin, 1999; Pearson and Skues 1999); to have adequate staffing to coordinate with other participants (Songer and Molenaar, 1997; Ling and Liu, 2004), and to have the similar design-build experience in the past (Mo and Ng, 1997;

Molenaar and Songer, 1998; Ling and Liu, 2004; Lam *et al*. 2008). These new requirements of DB projects pose challenges to most of the owners, and may discourage them to attempt the DB system. It will take time for owners to fully accept this new system in the construction market of China.

Immature design-build market

In the PRC, the DB delivery system was first introduced into the Petroleum and Chemistry industry in the late 1980s and than spread to the metallurgical industry, electronic industry, infrastructure construction, and housing industry. Although it has witnessed rapid growth in the recent years, the development of the DB system is still at its infancy stage. In the construction market of Chin, there have been no specific laws or ordinances on the DB delivery system. The existing laws including the *construction law, tendering law* and *Construction Quality Management Ordinance* only have regulations on exploration, design, construction, and construction supervision. The legal system constitutes one of the major obstacles to the promotion of DB system.

In addition to the lack of specific laws and regulations on DB method, there are not enough competent design-builders in the DB market. Most of the DB projects in China are large and multidisciplinary, and require design-builders to have combined design and construction functions, sophisticated human relationship skills, and adequate staff dedicated to the project. However, many design-builders are not competent enough to conduct the DB project successfully. As a result, the public sector owners take less

interest in adopting the DB system despite its stated advantages and strong promotion from the central government. Furthermore, considering that there is no matured credit record system in the DB market, many owners are reluctant to leave the whole project to design-builders in one single-point contract. They may have the concern that their interests may not be well protected if the projects are under the sole control of design-builders.

3.7 CHPATER SUMMARY

This chapter has conducted a comprehensive overview of the DB market in China. It is concluded that the development of DB method is still at its infancy stage even though the DB system will bring benefits to the PRC construction industry. The barriers of entry into the DB market of China were then investigated. Twenty-two ranked entry barriers have been identified through a comprehensive literature review and questionnaire survey. The underlying dimensions of these factors have also been examined. The findings indicate that the competence of design-builders, difficulty in project procurement, the characteristics of DB projects, lack of support from public sectors, the competence of owners, and the immaturity of DB market constitute the main barriers to entry into the DB market of China. The research findings help DB stakeholders to have a better understanding of the DB market. Based on the finding results, the government, owners, and DB contractors can take corresponding approaches to overcome the barriers and promote the application of DB system in China.

CHAPTER 4 THE CLASSIFICIATON OF DESIGN-BUILD OPERATIONAL VARIATIONS

4.1 INTRODUCTION

Design-build (DB) has been demonstrated as an effective delivery method and gained increasing popularity overseas in recent decades. In order to meet varying sets of construction circumstances, certain modifications to the basic design-build system have been developed (CIOB, 1988). Within the overall concept of design-build, a number of terminologies have emerged to describe what can be called different 'variations' of DB procurement. Current studies on DB variations have focused almost entirely on the structural variations, which are characterized by roles of the parties within the DB entity, including joint venture, designer-led, contractor-led, integrated firm, and developer-led arrangements (Beard *et al.*, 2001).

While structural variations are important, another way to analyze and categorize design-build is to consider the operational variations. Most owners agree that the choice of which DB operational variation to employ in their projects is considerably more important than what structural variation to employ (Beard *et al.*, 2001). This is because selecting different operational variations means different requirements and workloads for owners. At one extreme (such as in the turnkey method), there could simply be a requirement for a final product, which then requires the contractor to complete all the

design and construction. At the other extreme (such as in the develop-and-construct), the owner has to provide detailed design and specification before engaging the design-builder. A typical DB variation contract will lie between the two extremes, wherein the design work will be developed adequately as a vehicle for tendering and beginning to procure the project (Harris and Mccaffer, 1995).

The importance of selecting an appropriate DB operational variation has been widely accepted, however, the classification of DB operational variations remains controversial. In the DB field, many researchers have proposed various classifications of DB operational variations. However, most of the classifications are not widely accepted. Researchers classified the DB operational variations with different rules and using different terminology. Moreover, some of the classifications even contradict each other. For example, Janssens (1991) and Akintoye (1994) took *design-and-mange* as one of the DB operational variations; Masterman (1992), by contrast, referred to design-and-mange as one of management-oriented procurement systems. Quatman (2003) and Gransberg *et al*. (2006) include *bridging* as one of the DB operational variations. In Beard *et al*. (2001)'s classification framework however, *bridging* is not regarded as design-build system, because it is more akin to traditional design-bid-build and the owner is again in the position of warranting the completeness of the design to the bridging contractor. This adds confusion to many owners, especially to the inexperienced ones. Although owners do not work on just labels and they can investigate the uniqueness of each project, a comprehensive classification framework will be of great help to deepen the knowledge of DB system and facilitate the selection of DB operational variations.

Therefore, the objective of this chapter was to set up a systematic classification framework for DB operational variations that can be selected by DB owners. Although each owner may draw on their own past experience and have their preferences in selecting the suitable operational variations, the proposed framework in this study will facilitate their selecting process by closely examining each operational variation of design-build.

4.2 PREVIOUS CLASSIFICATIONS OF DB OPERATIONAL VARIATIONS

Janssens (1991) listed six most commonly accepted DB variations, namely, develop-and-construct, DB 1-stage, DB 2-stage, negotiated DB, design-and-manage, and turnkey. The difference between them is mainly related to the proportion of design undertaken by the owner or its consultant, which is included in the DB enquiry. From develop-and-construct to turnkey, there is a gradual shift of design responsibility from owners to DB contractors.

Masterman (1992) proposed four principal operational variations of design-build, which are *novated design and build, package deals, turnkey method* and *develop and construct*. In novated design and build, the owner novates its design team to the successful bidder to carry out the detailed design as contractor's consultant. The fundamental difference between design-build and package deal system is that the DB method provides a bespoke design solution to suit owner's specific needs whereas the package deal uses a proprietary building system which is unlikely to satisfy all of the owner's needs. In turnkey method,

the contractor is usually responsible for the total project from design through post-construction functions. The main difference between design-build and develop-and-construct is the design proportion that has been developed by the owner before inviting the tenders.

Akintoye (1994) identified six hybrids of design-build from construction procurement literature and practice in UK: *traditional design-build, package deal, design and manage, design-manage-and-construct, novation design-build* and *develop-and-construct*. Traditional DB, develop and construct, and novation DB are widely encountered in practice, while design and manage and design-manage-and-construct are less popular.

Anumba and Evbuomwan (1997) classified design-build into two main types: direct DB, and competitive DB. In direct DB, the owner negotiates with a single DB contractor, while the competitive DB allows for competition between several firms interested in a given project.

Beard *et al.* (2001) classified operational variations of DB into three main categories: *direct DB, design criteria DB,* and *preliminary design DB.* These operational variations differentiate each other according to proportions of project information generated and issued by the owner. Other delivery variations such as *design-design-build, draw-build, detail build* and *bridging* are not regarded as design-build in this framework, because they are more akin to traditional design-bid-build and the owner is again in the position of warranting the completeness of the design to the bridging contractor.

Gransberg *et al.* (2006) followed Beard's classification framework in which the percentage of design in DB enquiry by the owner was the crux basis for classification. However, they also included *design draw-build*, *bridging* and *novation design-build* as operational variations of design-build.

Most studies simply list several operational variations of DB and fail to differentiate them effectively from one another. Nonetheless, these references can be used to outline and assess the rules that can be used as a basis for logical classification of DB operational variations. The summary of previous classification frameworks is shown in Table 4.1.

Table 4.1 Summary of operational variations of design-build

Previous Studies	Design-build operational variations																			
	Develop and construct/ Design develop & construct	Design-build 1-stage and 2-stage	Negotiated design-build	Design and manage	Turnkey	Direct design-build	Design criteria design-build	Preliminary design design-build	Competitive design-build	Design and build/ Design and construct /traditional (pure) DB	Package deal	Design manage and construct	Novation/Novated Design-build	Super-turnkey, design-build-lease/	Bridging, design draw-build	Enhanced D+C/ Enhanced DB	Detail D+C, Design-develop-and-construct, design-document-and-construct, document-and-construct	Managing contractor	BPF	BOT/ BOOT/ BOO/ Build-own-manage
CIOB (1988)	√			√															√	
Janssens (1991)	√	√	√	√	√															
Masterman (1992)	√				√					√	√		√							
Akintoye (1994)	√			√	√					√	√	√	√							
Aumba and Evbuomwan (1997)	√					√			√				√							
Mo and Ng (1997)										√			√			√				
Chappell, Powell-Smith (1999)	√			√	√					√	√									
Rowlinson & Mcdermott (1999)				√	√					√		√								√
Carmichael (2000)				√	√					√							√	√		
Beard et al. (2001)						√	√	√												
Quatman (2001)					√									√	√					
Cook (2003)	√				√					√	√									
Chan (2003)						√			√				√			√				
Walker and Hampson (2003)					√					√			√							
Hughes et al (2006)										√	√		√							
Gransberg et al. (2006)						√	√	√					√		√					

4.3 CLASSIFICATION RULES FOR DB OPERATIONAL VARIATIONS

Although the categories of DB operational variations proposed by researchers are quite different, the rules for their classifications can be interpreted as (1) design proportion provided by owners or project scope undertaken by design-builders, (2) methods of DB contractor selection, and (3) method of contracting. These classification rules are illustrated in Table 4.2.

Table 4.2 Summary of classification rules

Classification rules	Examples	References
Design proportion	Develop and construct	Janssens, 1991; Masterman, 1992; Aumba and Evbuomwan, 1997; Cook, 2003;
	Enhanced design-build	Mo and Ng, 1997; Chan, 2003;
	Preliminary design design-build	Beard *et al.,* 2001;
	Traditional design-build / design and construction	Masterman, 1992; Akintoye, 1994; Rowlinson and Mcdermott, 1999; Hughes *et al*., 2006;
	Turnkey method	Janssens, 1991; Akintoye, 1994; Quatman, 2001; Cook, 2003
Selection method	Direct design-build	Aumba and Evbuomwan, 1997; Chan, 2003;
	Competitive design-build	Aumba and Evbuomwan, 1997; Chan, 2003;
	Negotiated design-build	Janssens, 1991;
	Design-build (two-stage tender)	Janssens, 1991;

Contracting method	Novation design-build	Masterman, 1992; Akintoye, 1994; Chan, 2003; Hughes *et al.,* 2006
	Package deals, super-turnkey, BOT	Masterman, 1992; Akintoye, 1994; Quatman, 2001; Cook, 2003;
	Managing contractor	Carmichael, 2000;
	Design and manage	Janssens, 1991; Akintoye, 1994; Rowlinson and Mcdermott, 1999; Carmichael, 2000.

4.3.1 Design Proportion

The proportion of design completed by owners or contractors is one of the most fundamental rules for DB classification. From owner's perspective, selecting the appropriate design proportion means he/she has to decide when to hand over the project to the contractor. For many owners however, the selection of appropriate design proportion is never an easy task. This is because, on the one hand, the owner should not provide too many design solutions in the enquiry that may incur unnecessary fees and limit the contractor's innovation to the design process. On the other hand, the owner should not provide too little design information, which may impose unnecessary expenses to the potential contractors and the owner may not obtain satisfactory design solutions in the tenders. This presents a major problem for many owners.

Given the importance of deciding appropriate design proportion, some organizations in different regions have put forward suggestions on owner's design proportion in DB

enquiry (shown in Table 4.3). It will help reduce the project risk and guarantee the successful fulfillment of DB projects.

Table 4.3 The proportion of the design work in enquiry in different countries

Countries	Departments	Owner's design proportion in enquiry (%)
Singapore	Housing Development Board	None
	Public Works Department	20
U. K	High Ways Agency	20-30
Japan	Residence Trade Union	30
U. S	Design-build Institute of America	None
	American Council of Engineering Companies	35

Resource: Chen (2004)

4.3.2 Methods of Contractor Selection

The selection of DB contractor is a critical task in DB projects. There are different levels of competition, from open tendering to single negotiation in the contractor selection process. Some owners prefer competitive or open tendering in which the contractor selection is usually price-oriented, while others favor negotiation or more co-operative process where non-price criteria play a significant part.

Molenaar *et al*. (1999) investigated various DB methods used among state and federal

agencies in the U.S., and identified three primary categories of design-builder selection methods in public sectors. These categories include one-step, two-step, and qualifications-based DB. One-step procedures provide for competitive evaluations of technical proposals, with the contract award decision based on price only or qualifications and price. Two-step procedures separate the technical proposals from the fixed price. It is a hybrid approach that seeks to exploit the advantages of negotiation and competition (Hughes *et al*., 2006). Qualifications-based, or source selection, involves the selection of a contractor through competitive negotiations. The award criteria are qualifications only or qualifications and prices.

4.3.3 Methods of Contracting

Gordon (1994) classifies contracting method into four parts—scope, organization, contract and award. This method is used to classify different delivery systems, such as traditional delivery system, integrated DB and construction management. An owner has to decide the portion of project task—design, construction, and finance—to be assigned to the contractor, and chooses the method how to select and pay the contractor.

In pure form of DB contracting, the owner engages a building contractor at the outset who is then responsible for design and construction work. The typical payment method is on a lump sum basis. The novation D&B contracting is closer to the traditional model in so far as the owner's design team is novated to the successful contractor who takes the design responsibility and then constructs the building. The package deals increases the

scope of a contractor's work in terms of allocating risks and responsibilities to the contractor. The contractor will carry out all of the design, construction, and commissioning work. In design and manage contracting, a single organization is appointed to both design the project and manage the construction operations using package contractors to carry out the actual work (Masterman, 1992). Although some researchers list the design and mange among categories of DB operational variations, this contracting method is normally regarded as management contracting or management-oriented system.

4.4 THE PROPOSED CLASSIFICATION FRAMEWORK

It can be seen that many researchers combined different rules to classify the DB system and proposed a confusing array of DB operational variations. Among these rules, the design proportion is considered to be, for the purpose of assisting the selection of the most suitable operational variations of DB, the most appropriate means for DB classification.

An owner who wishes to use DB system for his project must prepare a DB enquiry or other forms of solicitation. As mentioned before, deciding upon the content of DB enquiry is far from simple. An owner should provide neither too much nor too little design information in the DB enquiry. Selecting the appropriate design proportion is more important and challenging than other issues. Furthermore, the level of design, which is completed by the owner, will significantly influence the contractor selection

methods. When minimal design information is provided in the enquiry, the selection of DB contractor will be usually qualification-based. Conversely, one-step and competitive bidding is often adopted when a large percentage of design work has been completed. As to the contracting method, it is most commonly used to differentiate the design-build with other procurement methods such as the design-bid-build, construction management, management contracting, public-private partnership, public-private partnership, etc.

Therefore, the design proportion can be regarded as the most fundamental rule for DB classification. But this rule also has its disadvantages; In particular, the proportion of design is quite vague and hard to define. The design process is nonlinear and highly interactive, embracing a mix of rational and intuitive decision-making (McElhiney and Demkin, 2006). Even with the same design proportion, the design work may vary dramatically in different genre of projects.

The design service stages, by contrast, are comparatively fixed and can be easily identified. It is much easier to fulfill the role effectively if the architect adopts a series of logical routine procedure for every contract. Despite the lack of definitive step-by-step procedures, the design stages in construction projects are essentially the same in many different regions. According to Royal Institute of British Architects (RIBA) Outline Plan of Work (2007), the sequence of design work includes concept design, design development and technical design. In AIA Document B141—the most commonly used form of owner-architect agreement in the United Stated—the American Institute of Architects (AIA) schedules the design procedures into schematic design, design

development, and construction document stages. In the People's Republic of China (PRC), the design procedure consists of following main three steps: conceptual/schematic design, preliminary design/design development, and working drawing/detailed design. Although these stages may vary operationally and sometimes overlap according to the different requirements of owners and different characteristics of projects, the essence of the design service remains the same. The summary of design stages in different places is shown in Table 4.4

Table 4.4 The summary of design stages in different regions

Design stages			Design Proportion (%)
RIBA Work Plan	AIA Document B141	Mainland China	
Concept	Schematic design	Scheme design	10-35
Design development	Design development	Preliminary design	30-50
Technical design	Construction Document	Work drawing	> 50

Moreover, the design stages also closely correlate with the design proportions. Although there is no precise design proportion for every design stage, some consensus has been achieved on proportion ranges for certain design milestones. For example, the conceptual/scheme design is probably at 30 or 35 percent of design completion, and the site work design is at more than 50 percent. The relationships between design stages and design proportions are also shown in Table 4.4.

Above all, although the design procedures may vary in different countries and different genres of projects, the fundamental stages remain the same. Scheme design, design

development and construction document can be regarded as the basic logical stages, and each stage closely correlates with the design proportion. The design stages are therefore adopted alternatively in this research to replace the design proportions as the fundamental rule for the classification of DB operational variations. Meanwhile, it is important to know that these stages are not necessarily sequential and rigidly included (Thompson 1990). Sometimes tasks will be done at different stages or there will be overlapping of stages (Lawson 2006). However, these stages offer an architect the idea that he/she must work in a logical and systematic way, and the stages can be regarded as milestones in the design procedure. Meanwhile, given the condition that the novation DB and turnkey method have been widely accepted as variations of DB system in the construction industry, the contracting method is also adopted as another classification rule in this framework.

Finally, a new classification framework for the DB system was proposed according to (1) different design stages that an owner or contractor undertakes, and (2) different contracting arrangements/methods between the owner and contractor. Although DB owners, practitioners, and researchers can have their own ways of classification, this classification framework is more logical and systematic and provides a more holistic perspective to compare different DB operational variations. The ultimate unification of the DB operational variations is illustrated in Figure 4.1. The definitions of these operational variations are as follows,

(1) Develop and construct

In this variation, owners have or engage their design consultants to do the design work up to the design development stage. The successful DB contractor is responsible for the construction document and construction work.

(2) Novation design-build

The successful contractor is responsible for construction and the construction document or up to design development at most with assignment of a design consultant from the owner. The 'novation contract' is most suitable and recommended in the develop-and-construct.

(3) Enhanced design-build

In this variation, owners have or engage their design consultants to complete the scheme design. The successful DB contractor is responsible for the design development, construction document and construction work.

(4) Traditional design-build

The successful contractor takes full responsibility for all the design and construction. The contractor undertakes the design tasks at least up to the scheme design. The owner may prepare the brief/enquiry himself or leave to the contractor.

(5) Turnkey

The contractor provides everything including the commission and/or handover after the construction. All that remained for the owner to do is simply 'turn the key' to open the door.

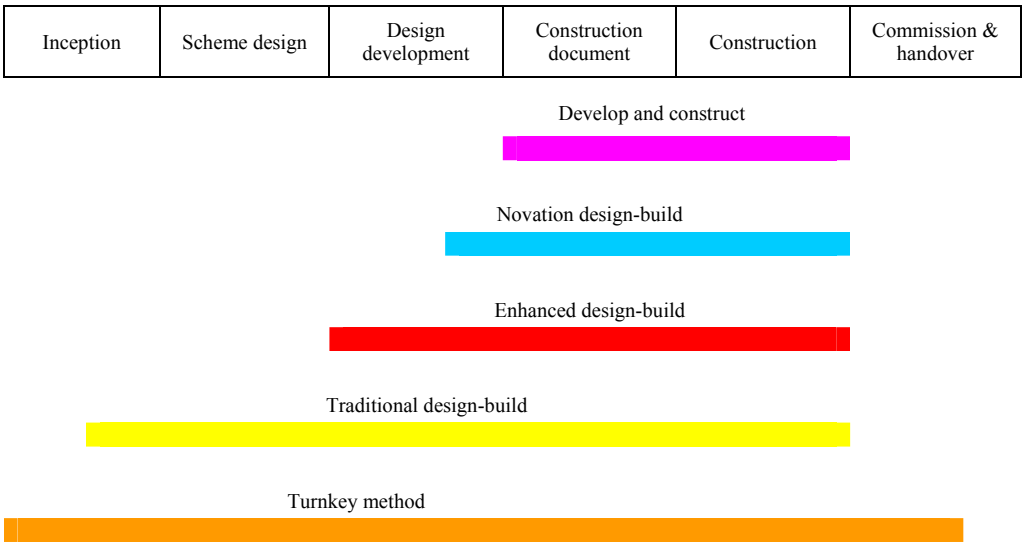

Figure 4.1 The classification of design-build operational variations

4.5 DISSCUSSION

Develop and construct is short-form for 'develop the detail from the employer's design and construct the works' (Janssens 1991). The owner or his consultant will do the design work at least to the design development stage and design the building almost completely. Because the owner involves in too much design work (about 50 percent), Beard *et al.* (2001) excluded it as the design-build system. This method may preclude the DB team from any significant creativity and innovation, since basic solutions and concepts have

been determined before the design-build team begins, and the design-builder selection tends to be price-oriented (Quatman, 2001). Although develop and construct is not favored by DB contractors (Akintoye, 1994), many owners take it a hybrid system to take advantage of DB and traditional delivery method.

Although the term 'enhanced design-build' is not widely used, both Mo and Ng (1997) and Chan (2000) take it as the one of the DB variations wherein the contractor is contractually responsible for design development, working details, and construction work. It is an emerging procurement system, which has attracted a lot of enthusiasm in Hong Kong (Chan 2000). The enhanced DB gives the owner greater control, while preserving the time saving advantages of DB. Furthermore, the advantages in enhance DB, which prevail in Hong Kong may also be applicable to other parts of the world.

The 'traditional design-build' represents the original 'design-build' in which the design-builder takes full responsibility of design and construction. From the aspect of design stages, the DB contractor undertakes the design work at least up to the scheme/concept design. The word 'traditional' is especially designated to this variation to distinguish it with 'design-build', which now embraces the whole DB variation spectrums.

In turkey method, a contractor provides everything and all that the employer has to do is to 'turn the key' to use his/her building. The term 'turnkey' and its concept have been widely accepted in the industry. As one of the basic DB operational variations, the turnkey method is traditionally applied to major industrial projects (Janssens, 1991).

Other similar methods (such as package deals and EPC), although there are minor differences among them, they all share the same type of contracting where the contractor does everything for the owner. Therefore, those similar arrangements are all incorporated in the turnkey spectrum.

The novation agreement is a contract arrangement that the successful contractor is required to engage the employer's consultants to complete the design in the post-contract stage. It is most commonly used in develop and construct wherein the preliminary design work has been completed by consultants. The contractor accepts the novated consultants to keep the consistency of design work. However, it should be pointed out that the novation agreement might not be appropriate for all the DB operational variations (Janssens, 1991). The more design tasks the contractor takes, the more likely he/she will decline such arrangement because it may restrain design-builder's design innovation. In the overseas DB industry, the novation contract arrangement is very popular and has been widely used, so that it is taken as one of the basic DB operational variations.

Some researchers (Janssens, 1991; Akintoye, 1994; Chappell and Powell-Smith, 1999; Carmichael, 2000) listed design and manage among DB variations. However, many of them agreed that it is not strictly the DB system. Chappell and Powell-Smith (1999) described it as 'simply an architect-led version of the contractor-led construction management'. Masterman (2002) referred to design and mange as one of management-oriented procurement systems that also include management contracting and construction management. Cook (2003) described this system combining some of the attributes of

design-build with those of generic management contract. Janssens (1991) pointed out that there are two form of design and manage; one is design-build and the other a form of management contract, and the distinction lies in the nature of the contract into which the parties enter. All these will add confusion to the owners; therefore it is not adopted as the design-build system in this classification framework.

As to the direct design-build, negotiated design-build and competitive design-build, they described the way in which design-build contractors are selected. In other words the 'competitive' or 'negotiated' are the variations of contractor selection method after the decision of DB operational variations. Generally, any contract of DB variations can be negotiated or competitively obtained.

4.6 CHAPTER SUMMARY

Selecting an appropriate DB operational variation is very important to the success of project delivery and also poses challenge to owners (Janssens, 1991; Beard *et al.*, 2001). In order to facilitate the selection process, especially to the inexperienced owners, this chapter aimed to set up a systematic classification framework of DB operational variations. This chapter reviewed a number of previous classification schemes and outlined the rules for their classifications. Design stages and contracting methods are finally adopted as the fundamental rules to classify the DB operational variations. Finally, five basic operational variations of DB were proposed, which are, namely, *develop and*

construct, *novation design-build*, *enhanced design-build*, *traditional design-build,* and *turnkey*. This classification framework adds knowledge to the DB field and hopefully can sets a benchmark for the later research in selecting the appropriate DB operational variations for DB owners.

CHAPTER 5 IDENTIFICATION OF SELECTION CRITERIA FOR DB OPERATIONAL VARIATIONS

5.1 INTRODUCTION

Whenever an owner decides to employ the DB delivery method, an important step forward is to determine which operational variation of DB is most appropriate for meeting the owner and project's needs (Beard *et al.*, 2001). Even though the essence of DB contracting is that the design-builder is responsible for both design and construction works, an owner should prepare the DB enquiry and decide how much design work should be undertaken before engaging a design-builder (Janssens, 1991).

The selection process of DB operational variations is similar to the selection of construction procurement methods. According to Luu *et al*. (2005), the selection process of procurement methods includes two consecutive stages, namely, selection criteria formulation and procurement selection. The formulation of selection criteria is of great importance to the selection process because an appropriate procurement selection model depends largely on prudent identification of selection criteria to reflect owners' and project objectives (Masterman and Gameson, 1994). As a result, a set of selection criteria for construction procurement methods has been identified, which include speed, time certainty, price competition, cost certainty, flexibility, responsibility, complexity, risk

allocation, dispute and arbitration, and quality level (Alhazmi and McCaffer, 2000; Chang and Ive, 2002; Ng *et al*., 2002; Chan, 2003; Luu *et al*, 2005).

Even though these criteria have been most commonly used for the procurement selection, they may not be suitable for the selection of DB operational variations. This is because, firstly, the identified selection criteria only reflect owner's needs for a construction project. The selection of DB operational variations, however, is also affected by other factors pertinent to experiences or capabilities of owners, project characteristics, and external environment. For example, for an inexperienced owner, even though the turnkey method may best satisfy his or her requirements for a project, it may not necessarily be the best choice for the owner because he or she may lose control of the project and does not get the project as expected.

Secondly, these criteria do not address the unique conditions of the DB market in China. The DB system has gained popularity overseas in recent years (Haque *et al*., 2001); however the same does not occur in China. Many owners and DB contractors remain unfamiliar with the delivery of the DB system. In addition, there is a lack of tendering laws, licensing regulations, and standard contract forms for DB system. Many local governments generally lack the experience in administrating this new system. As a result, when selecting the DB operational variations, owners do not simply evaluate the performance of those variations with respect to the selection criteria of speed, cost and quality. They may also consider other variables, such as the availability of competent design-builders and the impact of regulation rules, as the more important factors during

the decision-making.

In order to facilitate the selection of DB operational variations, a specific set of selection criteria is urgently required. This chapter focuses on identifying the most important selection criteria for different categories of DB operational variations in the construction market of China. Three rounds of Delphi questionnaire survey were undertaken with 20 experts in China. The iterations of the Delphi exercise enable the experts to propose and select the most appropriate selection criteria for DB projects in China. A statistically significant agreement on the importance rankings of the selection criteria was also sought from the experts. Finally, a series of weighted selection criteria was developed after the Delphi questionnaire survey.

5.2 SELECTION CRITERIA FOR DB OPERATIONAL VARIATIONS

As introduced in Chapter 2, the Delphi method is regarded as an appropriate tool for this research study. As a highly formalized method of communication, the Delphi method is suitable to deal with the problem of subjectivity in the process of identifying the most important selection criteria for DB operational variations. It is one of the best-known agreement-reaching methods to obtain the reliable consensus of a group of experts. The Delphi technique was first used to identify a series of selection criteria for DB operational variations in the construction market of China.

5.2.1 Selection of Expert Panel

One of the most important considerations when carrying out the Delphi study is the identification and selection of potential members to constitute the panel of experts (Stone and Busby, 1996; Ludwing, 2001). The selection of members or panelists is important because the validity of the study is directly related to this selection process. In each Delphi study, the knowledge and expertise of each panelist must be relevant to questions posed by researchers (Dawson and Brucker, 2001). In this Delphi survey, the researcher attempts to identify all the panelists who are knowledgeable or have the practical engagement in the DB field. A purposive approach was adopted to select this group of experts (Chan *et al*., 2001a; Manoliadis *et al*., 2006). The following criteria were devised in order to identify eligible participants for this study:

(4) Having extensive working experience in the DB projects in the PRC,
(5) Having direct involvement in the management of DB projects, and
(6) Having a sound knowledge of the DB operational variations.

In order to ensure that all the experts have similar understanding of the research study, invitation letters were e-mailed to 31 potential panelists as to explore their availability to participate in this study. The supporting materials including research background, classification of DB operational variations, and pre-designed procedure were also enclosed to familiarize the panelists with the purpose of the study. In addition, considering the DB system is not widely used in China, all the experts were solicited

from the most developed cities or provinces where the DB system has been commonly used. Finally, 20 experts who met all the selection criteria agreed to participate in the Delphi survey after the first contact. They were all from Beijing, Shanghai, Zhejiang province, Jiangsu province, and Guangzhou province, which are the most developed regions in China. Considering that the majority of Delphi studies have used 15-20 respondents (Ludwig, 2001), the number of experts was considered adequate to conduct this Delphi study. A list of the panel members and their occupations are shown in Table 5.1 (experts names and their organizations are not reported to respect their anonymity).

Table 5.1 List of the panel experts for the Delphi study

Type of firm / department	Number
Real estate developer	1
Government department	3
Design consultant company	3
Project management company	3
University	4
Construction company	6
Total	20

The selected experts represent a wide spectrum of construction professionals in the PRC and provide a balanced view for the Delphi study. Most of the experts have sufficient experience and expertise in DB projects. Table 5.2 depicts the frequency of the respondent's number of years working in the construction industry and the DB field.

Table 5.2 Respondent classifications by years in the construction industry and DB field

Years	In construction industry	In DB field
0-5	5%	15%
6-10	30%	50%
11-20	30%	30%
20+	35%	5%
Average (Years)	15	9

All the experts have the management experience of DB projects. Furthermore, most of the experts hold senior positions in their organizations. The respondents' job positions/titles are provided in Table 5.3.

Table 5.3 The job positions of the panel experts

Job position	Number
Chief engineer	1
Deputy chief engineer	2
Deputy general manager	2
Project manager	3
General director	1
Project management director	1
Academic	2
Engineer	2
Project management consultant	2
Director of research institute	2
Deputy division chief in government	2
Total	20

The experts' abundant working experience and sound knowledge of DB project management ensure the validity of this Delphi research.

5.2.2 Development of the Delphi Questionnaire

According to Manoliadis *et al*. (2006), the key issues in preparing a Delphi are: (1) the definition of experts and their selection; (2) the number of rounds; and (3) the questionnaire structure in each study round. In order to reach an acceptable and stable degree of agreement but also avoid wasting panel members' time, this research conducted three rounds of Delphi survey. In round 1, all panel members were asked to list at least five criteria for the selection of DB operational variations. In round 2, panel members were provided with the consolidated results from round 1 and were required to rate all the criteria based on a 5-point Likert scale to evaluate the importance of each criterion. In round 3, the panel members were asked to re-consider their ratings of each criterion in the light of consolidated results of round 2. The consistency of the results of round 2 and 3 were analyzed and compared using Kendall's Concordance Analysis. The questionnaires in each round are as follows:

Questionnaire1: Please list at least five selection criteria for DB operational variations.
Questionnaire2: Please give ratings to the selection criteria according to their importance.
Questionnaire3: Please re-rate the selection criteria in the light of the consolidated results obtained from all experts in round 2.

5.2.3 Three Rounds of Delphi Questionnaire Survey: Results and Analysis

5.2.3.1 Round 1: Listing the selection criterion for DB operational variations

The first round of the Delphi questionnaire survey (please refer to Appendix 3) was conducted as the exploration process and was of crucial importance. After the completion of first round survey, the criteria suggested by the 20 experts were carefully analyzed through content analysis. The content analysis is often used to determine the major facets of a set of data by simply counting the number of times a topic is depicted (Fellows and Liu, 2008). The process in conducting content analysis at this research stage was that all the key points and main ideas of each verbatim transcript were first marked down. Then, those conveying similar meanings were combined, rephrased, and finally crystallized. After employing the content analysis, a total of 15 criteria were formulated and consolidated. Considering the fact that the first round stage served as the exploration process and the research topic was relatively new to the experts, all the 15 criteria obtained in this stage remained for the next round survey. Table 5.4 shows all the criteria provided by experts in the round one survey.

Table 5.4 Criteria provided by the panel of experts in round one Delphi survey

Selection criteria for DB operational variations	**Experts frequency**
1. *Availability of competent design-builders*	90 %

Are there many competent design-builders in the local construction market?	
2. *Owner's design expertise* Does the owner have similar DB experience, particular the sophisticated design expertise?	80 %
3. *Project complexity*. Does the project have very high requirements for construction method, project management, etc?	75 %
4. *Owner's control of project* Does it enable the owner to have more control of the project?	70 %
5. *Reduced responsibility or involvement* Does it reduce the owner's project responsibility and involvement as much as possible?	55 %
6. *Early commencement & short duration* Does it enable the owner to start projects as soon as possible? Is the short duration first priority?	55 %
7. *Early cost-establish* Dose it enable the owner to establish the project cost as soon as possible?	40 %
8. *Bid competition* Does it increase the bidding competition? Is the price-oriented or quality-based method preferred?	35 %
9. *Law & trade's tradition* Is it allowed or preferred by the construction laws and local tradition?	30 %
10. *Reduced or controlled project variation* Does it reduce the project variation? Does it allow the owner have much project variation?	30 %
11. *Reduced risk* Does it reduce owner's risk as much as possible? Is the risk-aversion emphasized by the owner?	15 %
12.*Clear end user's requirements* Does the owner have clear project definition or project requirement?	5 %
13.*Peer relationship with contractor* Does it promote better communication between owner and design-builder?	5 %
14.*The quality requirement of project* Does it improve the project quality as much as possible? Is the quality more emphasized?	5 %
15.*Buildability of the construction* Does it improve the buidablity of project as much as possible?	5 %

5.2.3.2 Round 2: Ratings obtained from experts

The purpose of the second round Delphi survey (please refer to Appendix 4) was to differentiate the relative importance of each selection criterion. A list of 15 criteria with their explanations and experts-frequency was provided to experts for reference. Finally 17 experts returned their completed round 2 questionnaires.

At this stage, a 5-point Likert rating scale was used, which ranges from 1=not important, 2=somewhat important, 3=important, 4=very important, and 5=extremely important or essential. The 1-5 ordinal scale is frequently used in Delphi research. Respondents specify their level of agreement to a statement when responding to a questionnaire item (Dukes, 2005). The mean rating for each criterion was computed to indicate the degree of its importance. In this research, mean score of 3.0 was adopted as a cut-off point. Only the criteria regarded as IMPORTANT will remain for the re-evaluation in round 3. Table 5.5 shows the results of round 2 of the Delphi questionnaire survey.

Table 5.5 The results of round 2 of the Delphi survey

Criteria for DB variations selection	Mean rating	Rank
Contractor's competence	4.44	1
Owner's design experience	3.87	2
Project complexity.	3.81	3
Owner's control of the project	3.41	4
Reduced responsibility or involvement	3.25	5
Early commencement & short duration	3.15	6

Early cost establishment	3.07	7
Clear end user's requirements	3.03	8

Notes:

Number (n) =17.

Kendall's Coefficient of Concordance (W) =0.197. Level of significance=0.000

The Pearson correlation matrix for the data set is given in Table 5.6. Inspection of the correlation matrix reveals that the top eight selection criteria were not highly correlated with each other at 5% significance level (even most of them are insignificantly correlated with each other). This provides an adequate basis for proceeding to the next round of Delphi survey on these selection criteria.

In order to measure the degree of agreement between the panel members on the ordered list by mean rankings, the Kendall's Coefficient of Concordance (W) was calculated with the aid of the SPSS software. The Kendall's Coefficient of Concordance indicates the degree of agreement between the panel members on the ordered list by mean ranks by taking into account the variations between the rankings (Doke and Swanson, 1995). The Kendall's Coefficient of Concordance (W) for the rankings of top eight criteria was 0.197, which was statistically significant at 1%. The null hypothesis that the respondent's ratings within the group are unrelated to each other would have to be rejected. Therefore, it can be concluded that a significant amount of agreement among the respondents of panel experts has been found.

Table 5.6 The Pearson Correlations matrix among the top eight selection criteria

	Contractor competence	Design competence	Project complexity	Project control	Reduced responsibility	Short duration	Early cost establishment	Clear requirements
Contractor competence	1	-.088	.302	-.217	-.174	-.009	.091	-.318
Owner's design competence		1	.372	.426	-.380	.112	.008	-.311
Project scale & complexity			1	.314	-.307	.010	.109	-.546*
Owner's project control				1	-.425	-.294	-.050	-.082
Reduced responsibility					1	.306	.386	.499*
Short duration						1	.172	.241
Early cost establishment							1	.436
Clear end user's requirements								1

Notes: *Correlation is significant at the 0.05 level (2-tailed).

5.2.3.3 Round 3: Reassessing the selection criteria

The round 3 questionnaire survey (please refer to Appendix 5) was concerned with the re-examination of the importance of each criterion in the light of the overall panel response in round 2. Finally, 17 experts returned their completed questionnaire.

Most experts reconsidered their evaluation and made adjustments to their ratings. The results of the statistical summary are provided in Table 5.7. In this final round, seven criteria passed the cut-off point of 3.0.

Table 5.7 The results of round 3 of the Delphi survey

Criteria for DB variations selection	Mean rating	Rank	Weightings (*w*)

Contractor's competence	4.53	1	0.178
Owner's experience	3.97	2	0.156
Project complexity.	3.75	3	0.147
Owner's control of the project	3.50	4	0.137
Early commencement & short duration	3.37	5	0.132
Reduced responsibility or involvement	3.25	6	0.127
Clear end user's requirements	3.12	7	0.122
Early cost establishment	***2.93***	8	

Notes:

Number (n) =17.

Kendall's Coefficient of Concordance (W) = 0.301. Level of significance=0.000

The weightings of these selection criteria are calculated as follows:

$$W_{SCi} = \frac{M_{SCi}}{\sum_{i=1}^{7} M_{SCi}}$$

Where:

W_{SCi} represents the importance weighting of one of the top seven selection criteria.

M_{SCi} represents the mean rating of one of the top seven selection criteria.

$\sum M_{SCi}$ represents the summation of mean ratings of the top seven selection criteria.

Table 5.6 and 5.7 show no change in the order of the top four criteria, which are contractor's competence, owner's design experience, project complexity and owner's control of the project. 'Early commencement & short duration' changed from sixth rank

to the fifth rank; 'Early cost establishment' failed to pass the importance evaluation and it was excluded from the final list of selection criteria. The Kendall's Coefficient of Concordance (W) was also calculated with the aid of the SPSS software to measure the degree of agreement among the panel members. It reveals that the consistency of the experts' rankings for the top seven selection criteria improved by 52.8%, which was also statistically significant at 1% level.

The Pearson correlation matrix as indicated in Table 5.8 manifests that the top seven selection criteria were not highly correlated with each other at 5% significance level (even most of them are insignificantly correlated with each other). It indicates that these competences were independent with each other, and they were not likely to have any multiplier effect between them. Finally, these seven criteria were adopted as the key criteria for the selection of DB operational variations.

Table 5.8 Correlations matrix among the top seven selection criteria

	Contractor competence	Design competence	Project complexity	Project control	Short duration	Reduced responsibility	Clear requirements
Contractor's competence	1	-.142	.316	-.275	-.149	-.026	-.516*
Owner's design competence		1	.384	.468	.143	-.445	-.335
Project scale & complexity			1	.227	-.057	.202	-.505*
Owner's project control				1	-.182	-.428	-.074
Short duration					1	-.027	.093
Reduced responsibility						1	.197
Clear end user's requirements							1

Notes: * Correlation is significant at the 0.05 level (2-tailed).

5.2.4 Discussion on the Selection Criteria of DB Operational Variations

The final outcome of this chapter is the identification of seven selection criteria for DB operational variations in the construction market of the PRC. In order to ensure the success of DB projects, owners and their consultants should closely examine these criteria to select the appropriate operational variation. It should be added that the Delphi method, by its inherent nature, serves as a self-validating mechanism because panel experts are given chances to re-assess their scores with reference to the consolidated mean scores assessed by other experts. By using the Delphi method, the maximum amount of unbiased and objective information can be obtained from the experts.

Availability of competent design-builders

Many researchers (Molenaar and Songer 1998; Mo and Ng, 1997; Pearson and Skues, 1999; Leung, 1999) propose that DB projects should be under the control of experienced design-builders. As a design-builder becomes the single-point entity of a DB project, he or she should possess the ability to combine both design and construction functions and coordinates various building professionals for the project. The DB contractor's competence is important and positively affects the success of the DB projects (Chan *et al.*, 2001a; Ling *et al.*, 2004). In the selection of DB operational variations, if more definition and design work are left to the design-builder such as in the turnkey method, there will be

higher requirements for design-builder's abilities. Therefore, it requires a large number of competent design-builders in the construction market. These design-builders should have sufficient DB experience, corresponding qualification levels, and large company scale to convince more and more owners to utilize the DB system in the PRC.

The experience of DB owners

The DB owner plays an important role in contributing to the success of DB projects. Although he or she may leave most of the design work to a design-builder (such as in the turnkey method), one should still possess the design competence or engage a sophisticated design consultant to review the design solutions proposed by the design-builder. To ensure the success of the DB project, the owner or his consultants should decide on the optimal level of design completion when the budget is fixed and tenders are invited (Ling and Liu, 2004). The owner should also install effective monitoring and approval mechanisms for design changes, and establish tight management of the design development process (Deakin, 1999; Pearson and Skues, 1999). Harris (1999) proposed that, for the DB project, the owner should adopt a more extensive assessment of the design quality as a proactive measure to successfully complete the projects. Therefore, when selecting DB operational variations, the owner should objectively evaluate his or her design competence and decide when to hand over the project definition and design work to the design-builder.

Project characteristics

Project complexity is regarded as the most important project characteristics that affect the selection of DB operational variations. It is generally accepted that the operational variations, in which the design-builder undertakes most of the project definition and design work, are malleable for projects of high to medium complexity. Although the concept of complexity is not entirely clear (Kauffman, 1995; Corning, 1998; Williams, 1999; Bertelsen and Koskela, 2002), the importance of the complexity to the project management process is widely acknowledged (Baccarini, 1996). Many empirical studies in the construction field have found that project complexity affects project outcomes in various ways (Akintoye, 2000; Doly and Hughes, 2000; Tatikonda and Rosenthal, 2000; Austin *et al*., 2002; Wantanakorn, 2002; Chan *et al*., 2004). In large or more complex projects, it is applicable to reach out immediately to a total facility provider to develop a facility program, because such projects usually call for multiple contracts, sub-contractors, suppliers, outside agencies, and complex coordination systems.

Owner's requirements

The following three selection criteria, namely, owner's control of the project, early commencement & short duration, and reduced responsibility, clearly reflect the owner's expectations toward the DB delivery system. As the traditional design-bid-build delivery method is inadequate to meet the demands and challenges of the changing world, more and more owners resort to the DB operational variations due to their evident advantages, such as single-point responsibility, shortening time, pushing contractors to upgrade

technology (Ndekugri and Turner, 1994; Songer and Molenaar, 1997; Konchar and Sanvido, 1998). However, when selecting DB operational variations, it should be kept in mind that every DB operational variation has its own strengths and weaknesses, and the owner has to face trade-offs when choosing the appropriate one. For example, in the turnkey method, the owner can reduce his or her project responsibility or involvement, but will have less control of the project. Therefore the selection of DB operation variations is a comprehensive evaluation process in which various aspects should be considered.

Clear definition of projects

The clear end user's requirement means that the owner should have a clear conception of the building functions at the early stage. Many studies propose that the owner should develop a clear project definition, owner's requirements, and owner's brief in DB projects (Mo and Ng, 1997; Molenaar and Songer, 1998; Leung, 1999; Pearson and Skues 1999; Chan *et al*., 2001a). If the owner is very clear about the project's goals, scope, and expected outcome, then the DB system will work to the owner's benefit; otherwise, it can be very costly if the information provided by the owner to the contractor at the outset of the design build process is incorrect (Mogaibel, 1999).

5.3 CHAPTER SUMMARY

The focal point of this chapter is to develop the selection criteria for DB operational variations in the construction market of the PRC. Although there has been a large amount of research on the DB field, few, if any, systematic studies focus on the selection process of DB operational variations, which poses difficulty to DB owners. A three round of Delphi questionnaire survey was conducted to identify the selection criteria, and the descending order of the top seven selection criteria were found to be: (1) availability of competent design-builders; (2) owner's experience; (3) project complexity; (4) owner's control of the project; (5) early commencement & short duration; (6) reduced responsibility or involvement; and (7) clear end user's requirements. The selection criteria offer perspectives to better understand different operational variations of the DB system. It also deepens the current body of knowledge and serves as an acceleration of the development in this field.

In identifying and developing a practical set of selection criteria for DB operational variations, the Delphi method serves as a self-validating mechanism and provides a valuable framework for tapping experts' knowledge. This is especially true when there are very few studies available in this field. It yielded both insight and structure to assess different DB variations. Given that the selection of DB operational variations is a problem not only in China, further research should be conducted in other geographical locations to seek their similarities and differences by adopting the same research method for international comparisons.

CHAPTER 6 CONSTRUCTING FUZZY MEMBERSHIP FUNCTIONS FOR DESIGN-BUILD OPERATIONAL VARIATIONS

6.1 INTRODUCTION

In the previous chapters, five major DB operational variations and seven selection criteria (and their importance weightings) have been identified. In order to choose an optimal DB operational variation, DB owners have to take all the selection criteria into consideration. Therefore, a multi-criteria decision-making model (henceforth the MCDM) may serve as an appropriate technique. MCDM is a mathematical tool for evaluating and comparing alternatives to assist in selecting the optimal one (Triantaphyllou, 2000). It is designed to answer the question, "What is the best choice?" It enables the owner to evaluate the performance of each operational variation against the selection criteria. It also allows the owner to assign weightings to these criteria that reflect their importance to the decision-making. The MCDM can be successfully applied to the context of DB operational variations selection.

When applying the multi-criteria decision-making technique, the most important but challenging part is to measure the performance of each DB operational variation with respect to the evaluation criteria. The performance presents the overall suitability of an

alternative option against each criterion. It also illustrates a decision maker's preference over the available alternative. However, the "suitability" or "preference" is fuzzy by nature. It is usually characterized by subjectivity and uncertainty. Quantifying the performance of the alternative should be based on its characteristics, impacts, and other relevant attributes. It usually requires group agreement, which might be very difficult and time consuming to acquire. As a result, owners will hardly be able to determine the performance of DB operational variations crisply and on a cardinal scale.

The Fuzzy set theory can be utilized for dealing with subjectivity and uncertainties. In particular, the fuzzy membership function, which is a core concept in fuzzy set theory, can be adopted to quantify and determine the performance/function of the alternative options. A fuzzy set is a set whose elements have varying degrees of membership (Cross and Sudkamp, 2002; Niskanen, 2004). The degrees of membership of an element are expressed by the membership function. In the selection of DB operational variations, the fuzzy membership functions can represent degrees of suitability of each operational variation with regard to the selection criteria. They enable owners to perform quantitative calculations in the fuzzy decision-making. As a result, owners could perform their evaluation process based on the established fuzzy membership functions of DB operational variations, rather than applying their subjective value judgment.

The primary aim of this chapter is, therefore, to establish the fuzzy membership functions of DB operational variations. A modified horizontal approach in the fuzzy set theory will be adopted to establish the fuzzy membership functions. The construction of fuzzy

membership functions helps owners quantify and determine the performance of each operational variation against the identified selection criteria. Furthermore, it paves the way to establish the fuzzy multi-criteria decision making model in the next chapter that facilitates DB owners to select the appropriate operational variations of the DB system.

6.2 FUZZY SET THEORY AND FUZZY MEMERSHIP FUNCTIONS

Fuzzy set theory was initiated by Zadeh in the early 1960's. This theory has begun to be applied in a wide range of scientific areas such as pattern recognition, decision analysis, and control theory (Chan *et al*., 2009). Fuzziness can be defined as the characteristics of classes in which there is no sharp boundary between those objects that belong to the class and those that do not. Therefore a fuzzy set is a set whose elements having varying degrees of membership.

A fuzzy set A on the given universe U is that, for any u $\in$ U, there is a corresponding real number $\mu_A(u) \in [0,1]$ to u, where $\mu_A(u)$ is called the grade of membership of u belonging to A . This means that there is a mapping:

$$\mu_A : U \to [0,1], \qquad u \text{ a } \mu_A(u)$$

This mapping is called the membership function of A.

Therefore, a membership function is a function that maps a universe of objects, *X*, into the unit interval [0, 1] (Bharathi-Devi and Sarma, 1985; Civanlar and Trussel, 1986; Zimmermann, 2001). Baloi and Price (2003) viewed that membership functions in fuzzy set theory play a similar role to that of probability distribution functions in probability theory, that is, membership functions are used to represent uncertainty. It enables one to perform quantitative calculations in fuzzy decision-making.

In the selection of DB operational variations, a scale of 0-1 can be used to represent the suitability of each operational variation with regards to each selection criterion. A degree of zero means the operational variation is totally unsuitable while a degree of one represents the most suitable. The fuzzy sets of DB operational variations can be established as follows:

A_i Represents the fuzzy set of "suitability of Alternative i"

For every condition of selection criterion *x*, there is a corresponding real number $\mu_{A_i}(x) \in [0,1]$ to *u*, where $\mu_{A_i}(x)$ is the suitability of fuzzy alternative A_i referring to the selection criterion *x*. Therefore, the suitability can be expressed as the fuzzy membership functions. They enable the owners to perform quantitative calculations in the fuzzy decision-making.

6.3 CONSTRUCTING FUZZY MEMEBERSHIP FUNCTIONS FOR DB OPERATIONAL VARIATIONS

Constructing proper fuzzy membership functions is not an easy task. In general, the determination of fuzzy membership functions is acquired from human experts using trial-and-error method (Bagis, 2002). There are four main methods for establishing the fuzzy membership functions (Ng *et al.*, 2002; Yeung, 2007), including (1) the horizontal approach; (2) the vertical approach; (3) the pairwise comparison method; and (4) the membership function estimation approach with the aid of probabilistic characteristics. In addition, Ng *et al.* (2002) proposed a 'modified horizontal approach' to develop the fuzzy membership function to address the fuzziness of the procurement selection criteria. In this research study, the modified horizontal approach was adopted for developing the fuzzy membership functions because it has higher accuracy and allows the final outcome to be derived from simple probability functions (Ng *et al*., 2002; Chow and Ng, 2007). In addition, considering that the selection process of DB operational variations is similar to the selection of procurement methods, the modified horizontal approach is considered to be appropriate for constructing the fuzzy membership functions of DB operational variations.

The modified horizontal approach is based on an amalgamation of the horizontal approach and the graphical approach (Ng *et al*., 2002). It consists of four main steps in the fuzzy environment of DB operational variations:

Step1--Qualifying fuzzy selection criteria based on a 10-point likert scale

Through a questionnaire survey, experts were asked to provide a numerical figure (f_0) that fit for every DB operational variation pertinent to each selection criterion. Take the owner's design experience for instance; an expert may think that the develop-and-construct is the most suitable choice when the owner's design experience is at the score of 6, while the turnkey method is the most suitable at the score of 10 (which is the highest requirement for owner's design expertise).

A questionnaire together with a cover letter stating the objectives of the study was delivered to the same 20 design-build experts who joined the previous Delphi questionnaire survey. These experts were considered highly qualified because they not only have sufficient DB experience but also be familiar with our research work. The questionnaire includes two parts. The first part reports the results of the previous research study, including the proposed classification framework and the selection criteria for DB operational variations. The second section asks the respondents to quantify the selection criteria with respect to five DB operational variations. Of the 20 questionnaire distributed, 17 valid replies were received. All the 17 experts were those who completed the three-round Delphi questionnaire survey.

Step2—Identifying the X value of the membership functions

A membership function of a fuzzy set is basically formulated by two values: *X* and *A*. *X*

represents the value in the universe of discourse, while A stands for the value of the membership function of that fuzzy set. X_i values are defined as the means of bands B_i (i =1, 2, …, k), where B_i (i=1,2,…,k) are the bands of values f_0 given by the respondents to each operational variation pertinent to the selection criteria. The X_i values are calculated according to the lowest and highest values of f_0 for each selection criterion and the number of bands k. Ng et al. (2002) adopted Bharathi-Devi and Sarma (1995)'s approach to estimate the number of bands:

$$k = 1.87(N-1)^{2/5},$$

Where N is the total number of valid responses in the questionnaire survey.

Step3—Identifying the A values of the membership functions

The value of membership function A_i was calculated according to the formula:

$$A_i = n(B_i)/n_{\max} \ , \ \ i = 1,2,...,k \ .$$

Here $n(B_i)$ is the number of responses that have the values of f_0 belonging to a certain band B_i, and n_{max} is the maximum value of all the $n\ (B_i)$ with $i = 1,2,...,k$.

Step4—Formulating fuzzy membership functions with bisector error method

The fuzzy membership functions were formulated in this research is first presented in a tabular form as shown in Table 6.1. Based on the *X* and *A* values, a scatter diagram for the membership function is plotted, with the horizontal axis representing the *X* values and the vertical axis representing the *A* values (see Figure 6.1). After the point-wise grades of membership has been determined, the fuzzy membership functions were constructed through constrained best-fit lines with the Bisector Error Method to minimize the residual sum of squares by the average of vertical and horizontal distances (Yeung, 2007).

The reason why Bisector Error Method was adopted is that this method considers the errors created by not only the Vertical Error Method (minimizing the residual sum of squares by vertical distance only), but also with the Horizontal Error Method (minimizing the residual sum of squares by horizontal distance only), and it is taken as superior to the other two methods (Yeung, 2007).

Table 6.1 *X* and *A* values of the novation DB with respect to the project complexity

Complexity of the DB project (X)	3	4	5	6	7	8
Degree of Membership (A)	0.2857	0.1429	0.2857	1	0.5714	0.1429

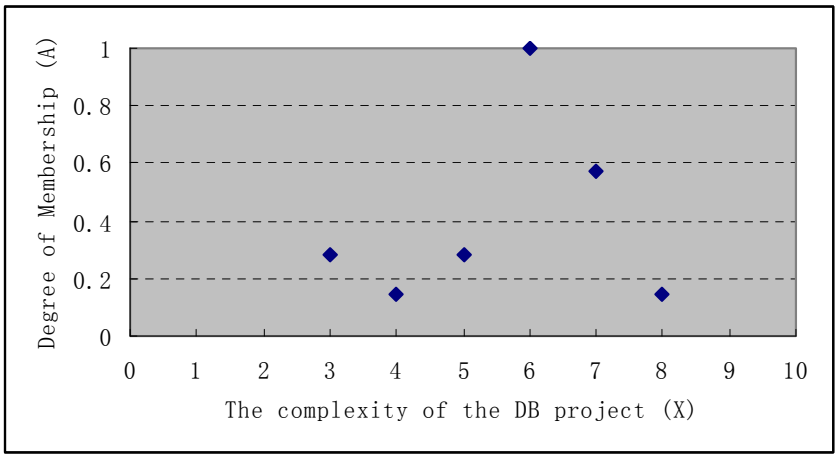

Figure 6.1 Scattered diagrams representing the membership functions of the Novation DB with respect to the project complexity

6.3.1 Fuzzy Membership Functions for DB Operational Variations

Contractor's competences

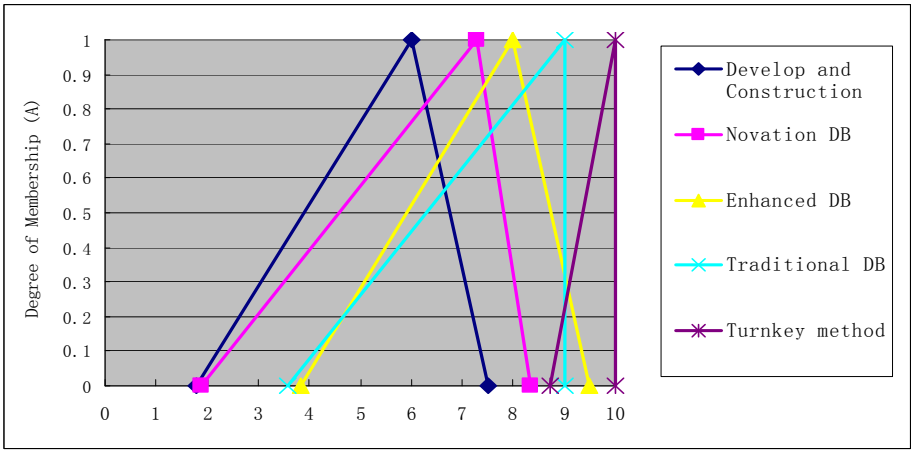

Figure 6.2 Fuzzy membership functions for DB operational variations with respect to contractor's competences in the construction market of the PRC

As shown in Figure 6.2, the membership functions of develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey method are triangular-shaped. The results indicate that the full membership of the five operational variations occur when the scores of the contractor's competences are 6, 7.3, 8, 9, and 10, respectively. It means that if the contractor's competences (in a 10-point likert scale) are at the scores of 6, 7.3, 8, 9, and 10 point respectively, the develop-and-construct, novation DB, enhanced DB, traditional DB and turnkey method will be the most appropriate operational variations for the DB project accordingly. Generally, the requirements for contractor's competence increase when the DB operational variation moves from develop-and-construct to the turnkey method. It implies that owners can leave more proportion of DB projects to the design-builders who are more competent. The degree of membership at whichever level of contractor's competences can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.2373x - 0.4328 \ldots\ldots\ldots\ldots\ldots (1.7859 \le x < 6) \\ -0.6667x + 5 \ldots\ldots\ldots\ldots\ldots\ldots (6 \le x \le 7.4999) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.1844x - 0.3461 \ldots\ldots\ldots\ldots\ldots (1.877 \le x < 7.3) \\ -0.9524x + 7.9525 \ldots\ldots\ldots\ldots\ldots (7.3 \le x \le 8.35) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.2403x - 0.9224 \ldots\ldots\ldots\ldots\ldots (3.8385 \le x < 8) \\ -0.6667x + 6.3333 \ldots\ldots\ldots\ldots\ldots (8 \le x \le 9.4999) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.1847x - 0.6623 \ldots\ldots\ldots\ldots\ldots (3.5858 \le x < 9) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (x = 9) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.7858x - 6.857 \ldots\ldots\ldots\ldots\ldots (8.7272 \le x < 10) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (x = 10) \end{cases}$$

Owner's experiences

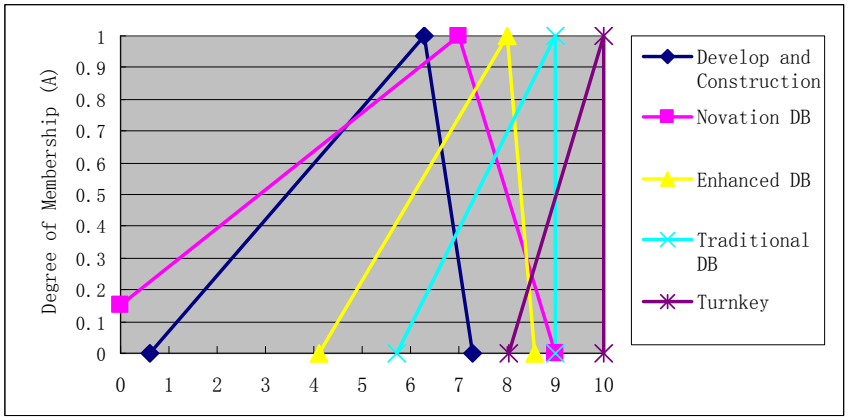

Figure 6.3 Fuzzy membership functions for DB operational variations with respect to owner's experiences in the construction market of the PRC

As shown in Figure 6.3, the membership functions of develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey method are triangular-shaped. The results indicate that the full membership of the five operational variations occur when the scores of the owner's experiences are 6.286, 7, 8, 9, and 10, respectively. According to the fuzzy

membership functions, it is appropriate for inexperienced owners to complete more design work by their internal design staff or external design consultants before leaving projects to design-builders. Otherwise, the owners may lose control of the projects. The degrees of membership at whichever levels of owner's experiences can be calculated according to the formulation of membership functions for every DB operational variation as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.1849x - 0.1625 \ldots\ldots\ldots\ldots\ldots (0.5917 \le x < 6.286) \\ -x + 7.286 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.286 \le x \le 7.286) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.1209x - 0.1537 \ldots\ldots\ldots\ldots\ldots\ldots (0 \le x < 7) \\ -0.5x + 4.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7 \le x \le 9) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.257x - 1.056 \ldots\ldots\ldots\ldots\ldots\ldots (4.1089 \le x < 8) \\ -1.7142x + 14.7136 \ldots\ldots\ldots\ldots (8 \le x \le 8.5834) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.3045x - 1.7407 \ldots\ldots\ldots\ldots\ldots (5.7159 \le x < 9) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (x = 9) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.5067x - 4.067 \ldots\ldots\ldots\ldots\ldots (8.0264 \le x < 10) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (x = 10) \end{cases}$$

Project complexity

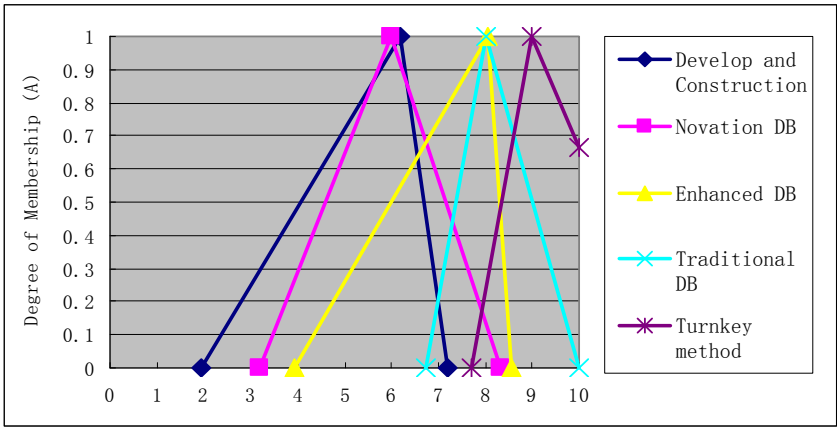

Figure 6.4 Fuzzy membership functions for DB operational variations with respect to project complexity in the construction market of the PRC

As shown in Figure 6.4, the membership functions of develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey method are triangular shaped. The results indicate that the full membership of the five operational variations occur when the scores of the project complexity are 6.2, 6, 8.0714, 8, and 9, respectively. According to the membership functions, the develop-and-construct and novation DB are more suitable for DB projects with low degree of complexity. The enhanced DB, traditional DB, and turnkey method are more appropriate for DB projects with medium to high complexity. The results confirm Berard *et al*. (2001)'s finding that a design-builder should take more control of DB projects that have higher degrees of complexity. The degrees of membership of whichever levels of project complexity can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.2341x - 0.4512 \ldots\ldots\ldots\ldots\ldots (1.9283 \le x < 6.2) \\ -x + 7.2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.2 \le x \le 7.2) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.3552x - 1.1309 \ldots\ldots\ldots\ldots\ldots (3.1847 \le x < 6) \\ -0.4286x + 3.5714 \ldots\ldots\ldots\ldots\ldots (6 \le x \le 8.3332) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.2418x - 0.9518 \ldots\ldots\ldots\ldots\ldots (3.9358 \le x < 8.0714) \\ -2x + 17.1428 \ldots\ldots\ldots\ldots\ldots (8.0714 \le x \le 8.5714) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.8x - 5.4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.75 \le x < 8) \\ -0.5x + 5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.7778x - 6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.7143 \le x < 9) \\ -0.3333x + 4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9 \le x \le 10) \end{cases}$$

The control of the DB projects

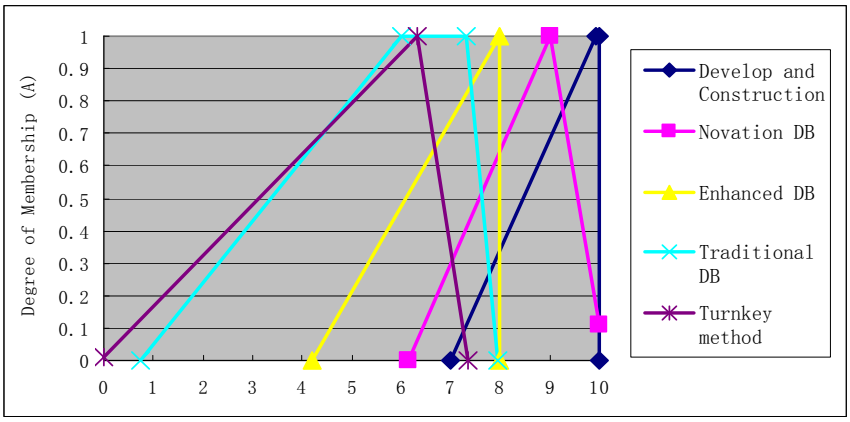

Figure 6.5 Fuzzy membership functions for DB operational variations with respect to project control in the construction market of the PRC

As shown in Figure 6.5, the membership functions of novation DB, enhanced DB, and turnkey are triangular-shaped, whereas the membership functions of develop-and-construct, and traditional DB are trapezoidal-shaped. The results indicate that the full membership of the five operational variations occur when the scores of owner's project control are 9.944-10, 9, 8, 6-7.3, and 6.333 by using a 10-point Likert scale, respectively. According to the fuzzy membership functions, the develop-and-construct and novation DB enable owners to have more control of projects than the enhanced DB, traditional DB and turnkey method. It means that the more design work undertaken by owners, the more control over the projects. However, it will also prevent the innovation input from design-builders, and limit the advantages of the DB method. The degrees of membership at whichever levels of project control can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.3403x - 2.3841 \ldots\ldots\ldots\ldots\ldots (7.0058 \le x < 9.9444) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9.9444 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.3524x - 2.1716 \ldots\ldots\ldots\ldots\ldots (6.1623 \le x < 9) \\ -0.8889x + 9 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.2639x - 1.1112 \ldots\ldots\ldots\ldots\ldots (4.2107 \le x < 8) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (x = 8) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.1903x - 0.1418 \ldots\ldots\ldots\ldots\ldots\ldots (0.7451 \le x < 6) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6 \le x < 7.3) \\ -1.5489x + 12.307 \ldots\ldots\ldots\ldots\ldots (7.3 \le x \le 7.9456) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.1564x + 0.0095 \ldots\ldots\ldots\ldots\ldots\ldots (0 \le x < 6.3333) \\ -x + 7.3333 \ldots\ldots\ldots\ldots\ldots\ldots (6.3333 \le x \le 7.3333) \end{cases}$$

Early commencement and short duration

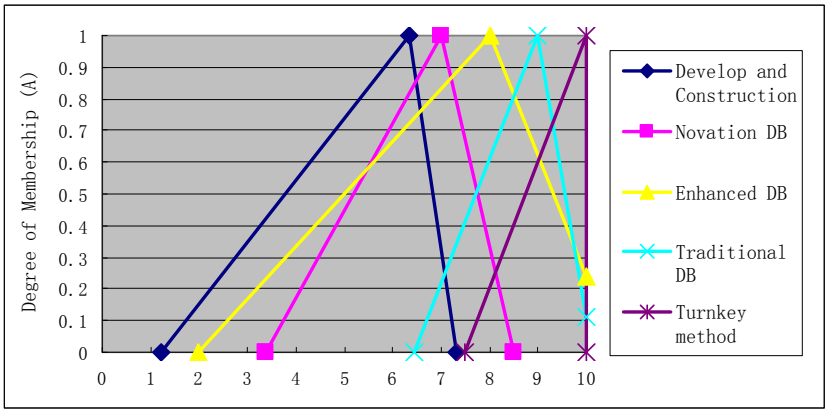

Figure 6.6 Fuzzy membership functions for DB operational variations with respect to early commencement & short duration in the construction market of the PRC

As shown in Figure 6.6, the membership functions of develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey method are all triangular-shaped. The results indicate that the full membership of the five operational variations occur when the scores of the early commencement & short duration are 6.333, 7, 8, 9, and 10, respectively. In order to start the project as soon as possible and greatly reduced project

schedule, owners should reach out to design-builders as soon as possible. When design-builders undertake more proportion of design work, the buildability of the design work will be greatly improved due to the overlapping of design and construction, the early input of construction knowledge to the design process, and the close communication among project participants (Songer and Molenaar, 1997). The degree of membership at whichever level of short duration can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.196x - 0.2414 \ldots\ldots\ldots\ldots\ldots\ldots (1.2313 \le x < 6.3333) \\ -x + 7.3333 \ldots\ldots\ldots\ldots\ldots\ldots (6.3333 \le x \le 7.3333) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.2757x - 0.9301 \ldots\ldots\ldots\ldots\ldots\ldots (3.3729 \le x < 7) \\ -0.6667x + 5.6667 \ldots\ldots\ldots\ldots\ldots\ldots (7 \le x \le 8.5) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.1667x - 0.3336 \ldots\ldots\ldots\ldots\ldots\ldots (2 \le x < 8) \\ -0.381x + 4.048 \ldots\ldots\ldots\ldots\ldots\ldots (8 \le x \le 10) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.3895x - 2.5055 \ldots\ldots\ldots\ldots\ldots\ldots (6.4326 \le x < 9) \\ -0.8889x + 9 \ldots\ldots\ldots\ldots\ldots\ldots (9 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.4x - 3 \ldots\ldots\ldots\ldots\ldots\ldots (7.5 \le x < 10) \\ 1 \ldots\ldots\ldots\ldots\ldots\ldots (x = 10) \end{cases}$$

Reduced responsibility and administrative burden

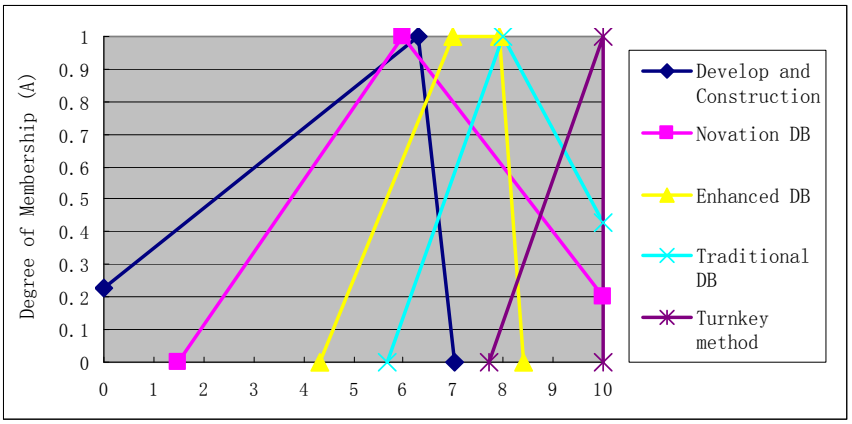

Figure 6.7 Fuzzy membership functions of DB operational variations with respect to reduced responsibilities in the construction market of the PRC

As shown in Figure 6.7, the membership functions of develop-and-construct, novation DB, traditional DB, and turnkey are triangular-shaped, whereas the membership functions of enhanced DB are trapezoidal-shaped. The results indicate that the full membership of the five operational variations occur when the scores of the reduced responsibility are 6.3, 6, 7-7.9167, 8, and 10 by using a 10-point Likert scale, respectively. According to the membership functions, owners will take less responsibility in DB projects when they leave more design spaces to design-builders. If owners prefer to work with the traditional design consultants to complete most of the design work before the DB contract, the potential design-builders will feel reluctant to take all the project responsibilities and may demand higher contract prices to compensate for the risks. The

degree of membership at whichever level of reduced responsibility can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.1224x + 0.2289 \ldots\ldots (0 \le x < 6.3) \\ -1.3677x + \ldots\ldots (6.3 \le x \le 7.0312) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.2215x - 0.329 \ldots\ldots (1.4853 \le x < 6) \\ -0.2x + 2.2 \ldots\ldots (6 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.3746x - 1.6222 \ldots\ldots (4.3305 \le x < 7) \\ 1 \ldots\ldots (7 \le x < 7.9167) \\ -2x + 16.8334 \ldots\ldots (7.9167 \le x \le 8.4167) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.4286x - 2.4288 \ldots\ldots (5.6668 \le x < 8) \\ -0.2857x + 3.2856 \ldots\ldots (8 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.4384x - 3.384 \ldots\ldots (7.719 \le x < 10) \\ 1 \ldots\ldots (x = 10) \end{cases}$$

Clear definition of the DB project

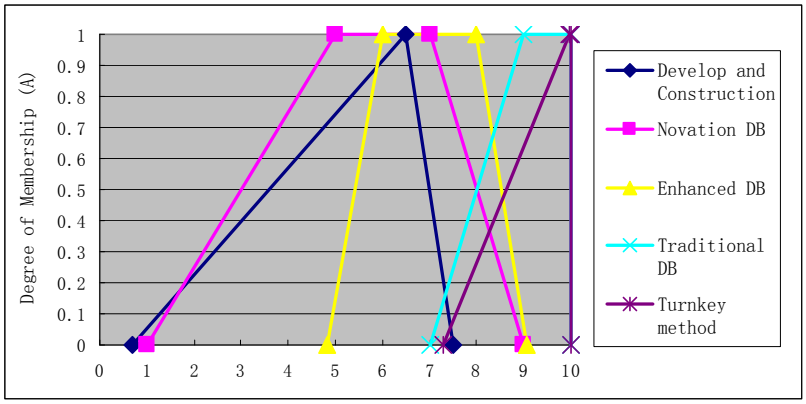

Figure 6.8 Fuzzy membership functions for DB operational variations with respect to clear definition in the construction market of the PRC

As shown in Figure 6.8, the membership functions of develop-and-construct are triangular-shaped, whereas the membership functions for novation DB, enhanced DB, traditional DB, and turnkey are trapezoidal-shaped. The results indicate that the full membership of the five operational variations occur when the scores of the clearness of project definition are 6.5, 5-7, 6-8, 9-10, and 9.96-10 by using a 10-point Likert scale, respectively. In develop-and-construct, novation DB and enhanced DB, because owners undertake some of design work before leaving the projects to the design-builders, the requirements to the clearness of DB projects are comparatively low at the stage of project definition. However, if owners prefer to leave all the projects to design-builders as soon as possible, they should have a clear understanding of the perceived DB projects at the very early stage. The degree of membership at whichever level of the clearness of project definition can be calculated according to the formulation of membership functions for every DB operational variations as follows:

Fuzzy membership functions for Develop and construct:

$$y = \begin{cases} 0.1726x - 0.1219 & (0.7023 \le x < 6.5) \\ -x + 7.5 & (6.5 \le x \le 7.5) \end{cases}$$

Fuzzy membership functions for Novation DB:

$$y = \begin{cases} 0.25x - 0.25 & (1 \le x < 5) \\ 1 & (5 \le x < 7) \\ -0.5x + 4.5 & (7 \le x \le 9) \end{cases}$$

Fuzzy membership functions for Enhanced DB:

$$y = \begin{cases} 0.8571x - 4.1426 & (4.8333 \le x < 6) \\ 1 & (6 \le x < 8) \\ -0.9524x + 8.8162 & (8 \le x \le 9.05) \end{cases}$$

Fuzzy membership functions for traditional DB:

$$y = \begin{cases} 0.5016x - 3.5144 & (7.0064 \le x < 9) \\ 1 & (9 \le x \le 10) \end{cases}$$

Fuzzy membership functions for Turnkey method:

$$y = \begin{cases} 0.3771x - 2.7161 & (7.2798 \le x < 9.96) \\ 1 & (9.96 \le x \le 10) \end{cases}$$

6.3.2 Discussion

In this chapter, the fuzzy membership functions for DB operational variations have been established. These membership functions provide owners with means to quantitatively

evaluate the performances of every DB operational variation with regard to various evaluation attributes. They enable DB owners to examine and compare the different operational variations of DB system before making the final decision. The summary of the fuzzy membership functions is shown in Table 6.2.

Table 6.2 Summary of the fuzzy membership functions

DB operational variations / Selection criteria	Develop-and-construct	Novation DB	Enhanced DB	Traditional DB	Turnkey
Contractor's competence	Low	Low	Medium	Medium to high	High
Owner's experience	Low	Low	Medium	Medium to high	High
Project complexity	Low	Low	Medium to high	Medium to high	High
Project control	High	High	Medium	Medium to Low	Low
Short duration	Low	Low to medium	Medium	Medium to high	High
Reduced responsibility	Low	Low	Medium	Medium to high	High
Clear project definition	Low	Low	Medium	High	High

According to the fuzzy membership functions, develop-and-construct is more malleable for projects of low complexity. It enables owners to have more control of DB projects since basic solutions and concepts have been determined before the design-build team begins. At the same time, this method may preclude the full combination of design and construction, and the DB advantage of reducing project schedule will be diminished. In addition, owners have to take more responsibilities of DB projects including design errors. The delivery of develop-and-construct is similar to the traditional design-bid-build

system, and the design-builder selection tends to be price-oriented (Quatman and Dhar, 2003).

In novation DB, a successful design-builder is required to engage the employer's design team to complete the design work in the post-contract stage. This contract arrangement will give owners great control of the projects. According to the fuzzy membership functions, the novation DB is more suitable for projects of medium to low complexity. However, Love *et al*. (1998) and Chan *et al*. (2001b) indicated that the novation DB, which is characterized by the comparatively higher utility factor, is suitable for projects with medium to high complexity for that the novation DB has been commonly used in highly specialized and technological advanced projects in Hong Kong and Australia. But it is rarely used in complex DB projects in the construction market of China. In novation DB, the requirements for owner's DB experience, design-builder's competence, and the clearness of project definition are comparatively low. However, the contract arrangement in novation DB may restrict design-builder's innovation input and prevent the full combination of design and construction.

In enhanced design-build, the design-builder is contractually responsible for design development, working details and construction work. The fuzzy membership functions imply that design-builders will have more control of DB projects in enhanced DB than in develop-and-construct and novation DB. The enhanced DB is suitable for projects of medium to high complexity. The project duration can also be greatly reduced. These results accord with the research findings of Chan *et al*. (2001b). However, the more

design work design-builders undertake, the higher requirements for their competences. In enhanced DB, owners can reduce their project responsibilities, but have less control of DB projects at the same time.

The traditional design-build represents the original 'design-build' in which the design-builder takes full responsibility of design and construction. According to the fuzzy membership functions, the traditional DB is malleable for projects of medium to high complexity. It gives design-builders great control of a project and enables them to fully combine the design and construction. As a result, the delivery speed is faster than that of construction management and traditional design-bid-build system (Konchar and Sanvido, 1998). Meanwhile, this DB operational variation has much higher requirements for design-builder's competence. Only the competent design-builders can successfully take charge of DB projects and speed up the project process. In traditional DB, owners can greatly reduce their responsibilities and leave nearly all the projects to design-builders. However, they should have sophisticated design experience and have a clear definition of the projects when deciding to adopt this method. Otherwise, DB owners may lose control of their projects.

In the turnkey method, a DB contractor provides everything, and all the owner has to do is to 'turn the key' to use his or her building. The turnkey method is mostly suitable for complicated DB projects, especially for the major industrial projects (Janssens, 1991). It gives design-builders the greatest control of projects and significantly reduces owners' responsibilities. Meanwhile, it has the highest requirements for design-builder's

competence and owner's experience. Although the owners can leave all the projects to the design-builders, they should have very clear concept of the projects at the very early stage. Otherwise, they may not get the final projects as required. For the inexperienced owners, external consultants should be employed to protect their interest throughout the project.

6.4 CHAPTER SUMMARY

Selecting an appropriate DB operational variation is a multi-criteria decision making process. Every DB operational variation has its strength and weakness, and DB owners have to take a variety of selection criteria into consideration. It is never easy for most of owners. In particular, it is very challenging to determine the performance of DB operational variations crisply and objectively.

The fuzzy membership functions are introduced from the fuzzy set theory to deal with the subjectivity and uncertainty during the performance evaluation of DB operational variations. A modified horizontal approached was adopted to set up the fuzzy membership functions of those operational variations. The fuzzy membership functions represent degrees of the suitability of each operational variation against the selection criteria. Therefore, owners can evaluate the performance of operational variations based on the established fuzzy membership functions, rather than applying their subjective value judgment.

The findings of this study provide owners with perspectives and ways to examine and compare different operational variations. When the operational variation moves from develop-and-construct to turnkey method, the level of requirements for design-builder's competence, owner's experience, and clearness of the project definition increase. At the same time, owners will have less control of projects and take less project responsibilities. In addition, when the project complexity increase, it is appropriate to leave more design work to design-builders.

Further research could be conducted to set up the fuzzy multi-criteria decision making model for the selection of the DB operational variations in the light of the findings in this study. In order to set up the selection model, it is required to determine how to aggregate the performance of every DB operational variation with regard to all the selection criteria. It is expected that the final selection model will facilitate the selection process for DB owners.

CHAPTER 7 FUZZY MULTI-CRITERIA DECISION-MAKING MODEL (FMCDM) FOR DESIGN-BUILD OPERATIONAL VARIATIONS

7.1 INTRODUCTION

The selection of DB operational variations is a multi-criteria decision-making problem. Owners have to evaluate the suitability of every DB operational variation referring to various selection criteria. When the fuzzy set theory (fuzzy membership functions) were introduced into the selection process to measure the performance of each DB operational variation, a fuzzy multi-criteria decision-making model (FMCDM) will serve as the most appropriate technique.

In the previous chapters, five major DB operational variations, seven selection criteria and their importance weightings, and fuzzy membership functions (measuring the performance of each operational variation) have been identified. Based on these findings, a fuzzy multi-criteria decision-making model will be established.

In this chapter, the rationale of the FMCDM was firstly introduced. Then the process of establishing the FMCDM for DB operational variations was explicitly explained. Finally, in order to test the validity of the newly established FMCDM model, the verification process was also reported in this chapter.

7.2 FUZZY MULTI-CRITERIA DECISION-MAKING MODEL (FMCDM)

A decision-making problem is choosing an optimal decision against some goals or objectives from the set of all possible alternative decisions (Klir and Yuan, 1995; Triantaphyllou, 2000). In practical decision problems, the number of goals or objectives under consideration is often more than one. Such problems are referred to as multiple objective decision making problems (MOD). Since objectives are established on the basis of criteria, the multiple objective decision-making problems are also referred to as multiple criteria decision-making (MCDM) problems.

Let U be a set of objects for evaluation, let $\pi = \{c_1, c_2, ..., c_m\}$ be the set of basic criteria in the evaluation system (or process), and let $E = \{e_1, e_2, ..., e_n\}$ be a set of alternatives used in the evaluation. For every project *u*, the objective function with respect to a criterion c_i on the alternative e_j can be denoted as r_{ij}. It expresses the degree to which criterion c_i is satisfied by alternative e_j. There are $m \times n$ values of entries, and can be expressed in the matrix form:

$$R = \begin{bmatrix} r_{11} & r_{12} & ... & r_{1n} \\ r_{21} & r_{22} & ... & r_{2n} \\ \text{M} & \text{M} & ... & \text{M} \\ r_{m1} & r_{m2} & ... & r_{mn} \end{bmatrix} \tag{7.1}$$

The most common approach to multiple criteria problems is to convert them to single-criteria decision problems (Klir and Yuan, 1995). This is done by finding a global criterion $d_j = h(r_{1j,} r_{2j,} ... r_{mj,})$, that for each alternative $e_j \in E$, it is an adequate aggregate of values $r_{1j}, r_{2j}, \ldots, r_{mj}$ to which the individual factor/criteria $c_1, c_2, \ldots, c_m$ are satisfied. A frequently employed aggregating operator is the weighted $\sum$, then the d_j has the following form:

$$d_j = \sum_{i=1}^{m} w_i r_{ij} \qquad (j \in ¥_n), \tag{7.2}$$

Where $W = (w_1, w_2, ..., w_m)$ is a constant weights vector that indicates the relative importance of factor $c_1, c_2, \ldots, c_m$. Hence, we have the following presentation:

$$D = W \bullet R \tag{7.3}$$

In the selection of DB operational variations, fuzziness can be introduced into this multi-criteria decision-making model. The fuzzy membership function can be adopted to quantify and determine the performance/function of the alternative options. It can represent degrees of suitability (the fuzzy set) of each DB operational variation against the selection criteria. Therefore, we have the following presentation in this fuzzy situation:

$$\underset{\cdot}{D} = \underset{\cdot}{W} \bullet \underset{\cdot}{R} \tag{7.4}$$

In this formulation, the entries of matrix **R** are fuzzy members $\tilde{r}_{ij}$ that are determined by the fuzzy membership functions.

7.3 CONSTRUCTING THE FUZZY MULTI-CRITERIA DECISION-MAKING MODEL FOR THE SELECTION OF DB OPERATIONAL VARIATIONS

When utilizing multi-criteria decision-making technique, decision makers have to (1) determine the relevant criteria and alternatives, (2) measure the relative importance of the criteria and the impacts/performance of the alternatives on these criteria, and finally (3) determine a ranking of each alternative (Triantaphyllou, 2000). In the selection of DB operational variations, the sequent steps to establish the fuzzy multi-criteria decision model would be introduced in this section.

7.3.1 Identification of Alternatives—DB Operational Variations

The major alternative operational variations of the DB system have been proposed in Chapter 4, which include develop-and-construct, novation DB, enhanced DB, traditional DB and Turnkey. Each DB operational variation has its strengths and weaknesses, and DB owners would have to face trade-offs when choosing the appropriate one. The essential difference between them is the proportion of design work undertaken by the owners.

Develop-and-construct

In this operational variation, owners complete most of the design work (usually more than 50% design). The successful DB contractor is responsible for the remaining detailed design and construction work.

Novation DB

In this variation, the successful contractor is responsible for construction work and detailed design (sometimes may extend to design development) with the assignment of a design consultant from the DB owner.

Enhanced DB

In this variation, owners or their design consultants undertake the design work from project definition to schematic design. The DB contractor is responsible for design development, detailed design and construction work.

Traditional DB

The design-builder takes full responsibility of all the design and construction work. The owner may prepare the brief himself/herself or leave it to the design-builder.

Turnkey

The design-builder provides everything including the commission and/or handover after the construction. All that remains for owners to do is simply ‘turn the key’ in the lock to

open the door. This operational variation is traditionally applied in major industry projects.

Therefore, the set of alternatives has been obtained:

E= {*develop-and-construct, novation DB, enhanced DB, traditional DB, turnkey*}

7.3.2 Identification of Selection Criteria and Importance Weightings

The selection criteria for DB operational variations in the construction market of the PRC has been developed in Chapter 5 through a three-round Delphi survey conducted with 20 construction experts. The top seven selection criteria and their importance weightings are shown in Table 7.1. The Kendall's Coefficient of Concordance (W) was also calculated to measure the degree of agreement among the panel members. The Kendall's Coefficient of Concordance (W) for the rankings of top seven criteria was 0.301, which was statistically significant at 1%. Therefore, it can be concluded that a significant amount of agreement among the respondents of panel experts has been found.

Table 7.1 The results of round 3 of the Delphi survey

Criteria for DB variations selection	Weightings (*w*)
1. *Contractor's DB competence* Are there many competent design-builders in the local construction market?	0.178
2. *Owner's experience* Does the owner have similar DB experience, particular the sophisticated design expertise?	0.156

3. Project complexity. Does the project have high requirements for construction method, project management, etc?	0.147
4. *Owner's control of project* Does it enable the owner to have more control of the project?	0.137
5. *Early commencement and short duration* Does it enable owners to start projects as soon as possible? Is the short duration first priority?	0.132
6. *Reduced responsibility or involvement for owners* Does it reduce the owner's project responsibility or involvement as much as possible?	0.127
7. *Clear end user's requirements* Does the owner have clear project definition or project requirement?	0.122

Therefore, the set of selection criteria has been obtained:

π ={*Contractor's competence, owner's experience, project complexity, owner's control, short duration, reduced responsibility, clear requirements*}

After the three rounds of Delphi questionnaire survey, the relative importance of each criterion has also been obtained in Chapter 5. The importance weighting of each criterion was computed by using the mean rating of each criterion that is divided by the summation of mean ratings of all the seven criteria. Not all selection criteria are equally important. The weight of each criterion can be obtained by either direct assignment or indirectly using pair-wise comparisons (Hsu and Chen, 1994). In this research project, ratings for each selection criterion (from 1=not important to 5=extremely important in a 5-point Likert scale) in the third round Delphi questionnaire survey were used to obtain their relative importance. This is because, firstly, the likert scale system has been proved

to be effective in measuring the attitudes of respondents (Albaum, 1997). Secondly, after three rounds of Delphi questionnaire survey, experts have already reached an agreement on the relative importance of these selection criteria. The ratings in the Round 3 Delphi questionnaire survey clearly indicate degrees of importance for every selection criteria. Therefore, the fuzzy importance-weighting vector is obtained as:

$$W = (0.178, 0.156, 0.147, 0.137, 0.132, 0.127, 0.122)$$

7.3.3 Establishing Fuzzy Membership Functions

The fuzzy membership functions for DB operational variations have been established in Chapter 6. They were used to represent the performance of every DB operational variation with regard to selection criteria. The fuzzy membership functions enable DB owners to perform quantitative calculations in the fuzzy decision-making environment rather than applying their subjective value judgment.

In order to construct the fuzzy membership functions, the modified horizontal approach, which is proposed by Ng et al (2002), was adopted because it has higher accuracy and allows the final outcome to be derived from simple probability functions (Chow and Ng, 2007; Yeung, 2007; Ng *et al*., 2002;). For every specific DB project, DB owners can calculate the performance of every DB operational variation with regard to the selection criteria according to the established formulation of fuzzy membership functions. Owners

are only required to produce a qualitative assessment on the selection criteria based on a 10-point Likert scale.

7.3.4 Final Fuzzy Multi-criteria Decision-making Model and Selection Rules

After the establishment of the fuzzy membership functions for each selection criterion, the performance matrix $\underset{\sim}{R}$ for every project can be obtained. Therefore, the final evaluation results can be calculated as follows,

$$\underset{\sim}{D} = \underset{\sim}{W} \bullet \underset{\sim}{R} = \left(d_1, d_2, ..., d_n\right) = (w_1, w_2, ..., w_m) \bullet \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}$$

$$d_j = \sum_{i=1}^{m} w_i \otimes r_{ij}$$

Where d_j is the degree of membership of alternative e_j with respect to the corresponding selection criteria. This model is called the weighted mean method. The reason why the weighted mean method is used is because it considers the impact of every selection criterion (Chan, 2007).

In the final fuzzy multi-criteria decision-making model, r_{ij} represents the suitability or performance of alterative e_j against selection criterion f_i. Therefore, d_j represents the

overall suitability/performance of the alterative e_j against the entire selection criterion. As a result, the DB operational variation with the biggest value of d could be regarded as the most appropriate one for the DB project.

7.4 NUMERICAL EXAMPLE

In this section, a hypothetical problem for the selection DB operational variation is designed to demonstrate the computational process of this fuzzy multi-criteria decision-making model.

Step 1. Assume that a DB owner has chosen the DB method to deliver his/her project, and now he/she has to decide the appropriate DB operational variation for this project. The DB project is having medium complexity, and there are not many competent design-build candidates in the current construction market. Similar to most of the DB owners in China, the owner does not have much DB experience; however, he/she wants to have firm control of the project. At the same time, the owner also wants to reduce the project responsibility and administrative burden as much as possible. In addition, the owner expects the DB project to be completed as soon as possible. Furthermore, the owner does not have clear project scope/objectives for the time being.

According to the project characteristics, the conditions of the selection criteria can be rated based on a 10-point Likert scale as shown in Table 7.2

Table 7.2 Conditions of the selection criteria

Criteria for DB variations selection	Ratings
1. Contractor's DB competence	6
2. Owner's experience	5
3. Project complexity	8
4. Owner's control of project	9
5. Early commencement and short duration	9
6. Reduced responsibility or involvement for owners	8
7. Clear end user's requirements	6

Step 2. After defining the ratings of all the selection criteria, the fuzzy memberships for five DB operational variations against all selection criteria can be obtained according to the fuzzy membership functions established in Chapter 6.

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the contractor's DB competence are expressed as:

$r_{1j} = [0.333, 0.9447, 0.7597, 0.6306, 0]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the owner's DB experience are expressed as:

$r_{2j} = [0.762, 0.4508, 0.229, 0, 0]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the project complexity are expressed as:

$r_{3j} = [0, 0.1526, 0.9826, 1, 0.2224]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the owner's control are expressed as:

$r_{4j} = [0.6786, 1, 0, 0, 0]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the early commencement and short duration are expressed as:

$r_{5j} = [0, 0, 0.619, 1, 0.6]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the reduced responsibility and project involvement are expressed as:

$r_{6j} = [0, 0.6, 0.8334, 1, 0.1232]$

The fuzzy memberships of the develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey against the clearness of project requirements are expressed as:

$r_{6j} = [0.9137, 1, 1, 0, 0]$

Therefore, the fuzzy matrix $\underset{\sim}{R}$ can be expresses as follows:

$$\underset{\sim}{R} = \begin{bmatrix} 0.333 & 0.9447 & 0.7597 & 0.6306 & 0 \\ 0.762 & 0.4508 & 0.229 & 0 & 0 \\ 0 & 0.1526 & 0.9826 & 1 & 0.2224 \\ 0.6786 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0.619 & 1 & 0.6 \\ 0 & 0.6 & 0.8334 & 1 & 0.1232 \\ 0.9137 & 1 & 1 & 0 & 0 \end{bmatrix}$$

The fuzzy importance-weighting vector has been obtained after the round 3 Delphi questionnaire survey as:

$$\underset{\sim}{W} = [0.178, 0.156, 0.147, 0.137, 0.132, 0.127, 0.122]$$

Step 3. After the obtaining the fuzzy membership matrix and the weighting vector, the performance for DB operational variations can be calculated according to formula (7.4):

$$\underset{\sim}{D} = (d_1, d_2, ..., d_n) = \underset{\sim}{W} \bullet \underset{\sim}{R}$$

$$= [0.178, 0.156, 0.147, 0.137, 0.132, 0.127, 0.122] \bullet \begin{bmatrix} 0.333 & 0.9447 & 0.7597 & 0.6306 & 0 \\ 0.762 & 0.4508 & 0.229 & 0 & 0 \\ 0 & 0.1526 & 0.9826 & 1 & 0.2224 \\ 0.6786 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0.619 & 1 & 0.6 \\ 0 & 0.6 & 0.8334 & 1 & 0.1232 \\ 0.9137 & 1 & 1 & 0 & 0 \end{bmatrix}$$

$$= [0.3826, 0.5965, \underline{0.6249}, 0.5182, 0.1275]$$

According to the selection rule, the enhanced DB with the highest performance score (**0.6249**) is regarded as the most appropriate DB operational variation for this project.

The final choice is considered quite reasonable. The hypothetical project is characterized by high level of complexity and medium to low level of scope clarity, and it is required to be completed as soon as possible. Meanwhile, the owner does not have sufficient DB experience, but wants to have a firm control of the project and less project responsibility. The enhanced DB is suitable for projects with medium to high level of complexity (Love *et al.*, 1998; Chan *et al*., 2001b). It provides the time saving advantage of DB system. At the same time, it offers full conformance to the basic design developed by the original design team, which in turn, enables owners to have greater control of design quality (Chan, 2000). Even though there may be a limited number of design-builder with a proven record of both design and construction, the enhanced DB is still regarded acceptable because owners will complete the schematic design before leaving the project to the winning design-builder.

7.5 VALIDATING THE RESEARCH FINDINGS

Validation is the final stage of the research study to test whether the quality of a developed system and model has achieved an acceptable standard. In other words, validation is to determine the adequacy of the system in meeting the needs of users (Gupta, 1991). Validation could be conducted in qualitative or quantitative manner. Quantitative validation uses statistical techniques to evaluate the expert system against some preset criteria while qualitative validation acquires subjective opinions on the

performance of expert system (O'Keefe et al, 1987).

In this research study, the qualitative validation was adopted to measure reliability of the model. This is because, firstly, there are not enough historical data to conduct the statistical analysis. Secondly, it is very difficulty to find appropriate on-going DB projects to apply the selection model considering the time and resource limit. It is more practicable to conduct the qualitative validation to solicit opinions of industrial experts on the adequacy of the selection model. Therefore, face-to-face interviews were conducted with DB practitioners in the construction industry of China to collect their responses about the level of agreement with the research findings.

According to Botten *et al*. (1989), validation measures the accuracy, adequacy, usability, precision, etc of the system. In this research study, the validation aims to validate:

1. Whether the classification of DB operational variations is comprehensive and suitable in the construction market of China.
2. Whether the list of selection criteria is comprehensive and appropriate to measure the performance of DB operational variations.
3. Whether the fuzzy membership functions can effectively eliminate the subjectivity when measuring the performance of DB operational variations, and whether the fuzzy multi-criteria decision-making model is practical enough to facilitate DB owners to select the DB operational variations.

Five structured interviews were conducted with five DB project participants who had hands-on experience in running DB projects in the construction industry of China to collect their views on the newly developed model. All interviewees are at Directorate grade and each has more than 15 years of experience in the construction industry. Each of them also has experience in running three or more DB projects in China; the profiles of the interviewees are provided in Table 7.3.

Table 7.3 Interviewees' details for validating FMCDM for DB operational variations

No.	Position	Organization	Role	Working years in construction	Working years in DB field
1	Senior project manager	Construction group company	Consultant	35	22
2	General manager	Construction engineering company	Main contractor	16	9
3	General director	Project management company	Owner consultant	24	17
4	Construction division chief	University	Owner	22	15
5	Project manager	Real estate developer	Owner	15	7

7.5.1 Validation of the Classification Framework

In the DB field, many researchers have proposed various classifications of DB operational variations. However, most of the classifications are not widely accepted, and some of the classifications even contradict each other. In order to facilitate the selection process, this research study proposed a new classification framework, which include

develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey. In order to evaluate the suitability of this classification, the interviewees were asked for the comments on this framework, including:

- Are the classification rules adopted in the classification framework appropriate?
- Is the classification framework useful for DB owners to differentiate and compare DB operational variations?
- Have the proposed DB operational variations practiced in the construction market of China?
- Are there any other DB operational variations, which should be included in the spectrum?

All the experts agreed that the classification framework is comprehensive, and adequate to include the existing DB operational variations in the construction market. While expert 1 stressed that it may not be easy to just label them with these five categories. The ways or rules to classify DB system are more important than the classification results. Expert 2 and expert 5 pointed out that in their DB experience, they have not been involved in novation DB projects. However, both of them agreed that the classification framework provided useful perspectives to understand the operational ways of DB system. Expert 3 emphasized that the turnkey method was mostly applied in industrial sectors, such as the chemical industry, electric industry and metallurgic industry, and there are very few turnkey projects in the building industry.

In general, the experts agreed that the classification framework is applicable in the construction market of China. It is very useful for owners, especially the inexperienced one, to better understand the operational process of DB projects. In addition, all of them acknowledged that the selection of DB operational variation is a challenging but vital issue when delivering DB projects.

7.5.2 Validation of the Selection Criteria and Their Weightings

The identification of selection criteria is of great importance to the selection process because an appropriate selection model depends largely on prudent identification of selection criteria to reflect owners' and project objectives and to address specific project attributes. In order to ensure that the final fuzzy multi-criteria decision-making model for DB operational variations in the construction market of China is comprehensive, objective, reliable and practical enough, the seven identified selection criteria together with their individual weightings should be validated to ascertain that they are appropriate to measure the performance of every DB operational variation.

The seven criteria were presented to the interviewees. The processes of the three round Delphi questionnaire survey were also explained. The interviewees were requested to examine the appropriateness of the seven identified selection criteria together with their individual weightings. In addition, they were encouraged to propose other variables that should be taken into consideration when making the similar decisions.

In general, although minor variation exists on the ranking of selection criteria, most of the interviewees agreed that the seven selection criteria and their individual weightings developed are appropriate to measure the performance of DB operational variations in China. While expert 3 proposed that the factor of relationship between owners and DB contractors should also be considered. This is because, when there is a lack of mutual trust between owners and DB contractors; owners tend to undertake more pre-construction work themselves before leaving the projects to design-builders. This factor was once identified in the first round of the Delphi survey. However, it did not pass the importance evaluation in the second round (with the mean score lower than 3.0).

7.5.3 Validation of the Fuzzy Membership Functions and the Final Selection Model

In order to quantitatively measure the performance of every DB operational variations, the fuzzy membership functions were established for each selection criterion. Finally, a fuzzy multi-criteria decision-making model was constructed. The fundamental issue of validation is to examine whether the fuzzy membership functions and the FMCDM model could reduce the subjectivity of evaluation and facilitate the selection of DB operational variations.

The researcher first briefly explained the reasons and procedure for developing fuzzy membership functions for the performance evaluation. After that, the establishment of the fuzzy multi-criteria decision-making model was further explained. Then the interviewees were asked to examine whether the fuzzy membership could effectively eliminate the

subjectivity of performance evaluation, and whether the final selection model was practical and useful enough to facilitate the selection of DB operational variations.

All the interviewees agreed that objectively measuring the performance of every DB operational variation was the most challenging and essential part in the selection process. The establishment of fuzzy membership functions is an innovative and appropriate method for this purpose because it makes use of the group agreement of DB experts in the questionnaire survey. As a result, owners could perform their evaluation process based on the established fuzzy membership functions of DB operational variations. In addition, most of the interviewees agreed that the fuzzy membership functions for the selection criteria generally confirm to their DB experience. For example, when the clarity of the project requirements increases, owners could leave more project work to design-builders as in turnkey or traditional DB method.

As for the final selection model, most of them opined that it is practical to use this model to select the appropriate DB operational variations. However, some of them had reservation on the practicality of fuzzy MCDM framework. Expert 1 pointed out that although the final model can help owners objectively compare and select the DB operational variation; owners might still resort to their own experience to make the final decision. This is mainly because the DB system has not been popular in the construction market, and most owners believe that DB contractors are not competent enough to conduct the DB projects. Expert 3 mentioned that in many public construction projects, the turnkey or traditional DB systems were not allowed because of the restraints from

laws and regulations. Therefore, the practicality of this model will be reduced. However, all of them agreed that the final selection model takes full advantage of the experts' knowledge, experiences, and makes a decision maker feel comfortable to give quantitative evaluation on different DB operational variations.

7.6 CHAPTER SUMMARY

The selection of DB operational variation is a complex multi-criteria decision making problem involving fuzzy characteristics and uncertainties. This chapter develops a fuzzy multi-criteria decision-making framework to solve this problem. The framework includes identification of selection criteria, assessment of importance weightings, evaluation of alternative performance, and determination of ranking orders for every DB operational variation. It is an efficient and feasible framework for practitioners, especially for DB owners.

When developing the FMCDM model, a three-round Delphi questionnaire survey was conducted to identify the selection criteria and their relative importance. It provides a valuable framework for tapping experts' knowledge and yields both insight and structure to assess different DB variations. A modified horizontal approach with the bisector error method was further applied to set up the fuzzy membership functions, which enables owners to perform quantitative calculations on the performance of every DB operational variation. The fuzzy multi-criteria decision-making model was finally developed using the weighted mean method to aggregate the performance of DB operational variations against the identified selection criteria. The proposed model enables owners to perform

quantitative calculations in a fuzzy decision-making environment and provides a useful tool to cope with different project attributes.

The fuzzy multi-criteria decision-making framework provides owners with perspectives and quantitative ways to examine and compare the different operational variations. It is expected that the selection model will deepen the understanding of DB operational variations in general, and promote the application of the DB system in the construction market of the PRC in particular.

CHPATER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

Various researchers and organizations have already undertaken a great deal of research on various aspects of DB field such as the selection of DB system (Molenaar and Songer 1998; Molenaar and Gransberg, 2001), frameworks of DB success criteria (Chan *et al.*, 2001a, 2002), and design-builder selection procedures (Kumaraswamy 2000;Molenaar and Gransberg 2001; Singn and Tiong, 2005). However, there are few, if any, systematic studies focusing on the selection of DB operational variations. For most of DB owners, especially the inexperienced ones, selecting an appropriate DB operational variation poses challenges when delivering DB projects.

The aim of this research study was to develop a comprehensive, objective, reliable and practical selection model for DB operational variations in the construction market of China. To develop this model, six research objectives were identified, which included (1) comprehensively reviewing the current design-build market in China; (2) proposing a systematic classification framework of DB operational variations; (3) identifying important selection criteria and their corresponding weightings; (4) establishing the fuzzy membership functions to measure the performance of every DB operational variations

with regard to the selection criteria; (5) developing a fuzzy multi-criterion selection model for the selection of DB operational variations and, (6) validating the reliability and applicability of the model.

8.2 REVIEW OF RESEARCH OBJECTIVES

8.2.1 Review of the Design-build Market of the PRC

Design-build (DB) system has been demonstrated as an effective delivery method and been widely used overseas. Even though there are ample evidences that the DB system will theoretically bring benefits to the PRC construction industry, it does not receive the same degree of popularity in the PRC. After a thorough investigation of the current DB market, it can be concluded that the development of the DB system is still at its infancy stage. The barriers to entry into DB market are many-folded, which mainly relate to the legal restraints, negative owner attitude, high requirement of DB projects, and the lack of adequate competences of DB contractors. However, with rapid growth in the construction industry, new requirements in modern construction projects, and strong promotion from governments, it is believed that the DB market in China will have great potential in the near future.

8.2.2 Classification of DB Operational Variations

Within the DB system, there are a number of operational variations, which are similar to, and yet different from each other; and owners need to decide which variation is the most suitable for their projects. Although the importance of selecting an appropriate DB operational variation has been widely accepted, the classification of DB operational variations remains controversial. A comprehensive literature review has been conducted to assess various classification frameworks proposed by different researchers. The rationales for their classifications were explored and summarized as contracting methods, design proportions, and contractor selection methods. These classification rules were then developed to set up a new classification framework. Finally, five operational variations of DB have been identified, which include *develop and construct, novation design-build, enhanced design-build, traditional design-build* and *turnkey*.

8.2.3 Identification of Selection Criteria for DB Operational Variations

In order to select the appropriate DB operational variations, a set of evaluation criteria for determining the appropriateness of each operational variation are required. A three-round of Delphi questionnaire survey has been conducted with 20 construction experts in the PRC to obtain such criteria. Seven top selection criteria and their importance weightings were finally identified, which include, namely, (1) availability of competent design-builders, with the weighting of 0.178; (2) owner's DB experience, with the weighting of 0.156; (3) project complexity, with the weighting of 0.147; (4) owner's control of project, with the weighting of 0.137; (5) early commencement & short duration, with the weighting of 0.132; (6) reduced responsibility or involvement, with the weighting of

0.127; and (7) clear end user's requirements, with the weighting of 0.122. A statistically significant agreement on the top seven selection criteria was also obtained. These findings could furnish stakeholders, in particular DB owners, with perspectives to understand and compare the different operational variations of the DB system.

8.2.3 Construction of Fuzzy Membership Functions

The selection of DB operational variation is a multi-criteria decision-making process. It requires owners to objectively evaluate the performance of every operational variation against each selection criterion. However, the performance evaluation is very difficult and characterized by subjectivity and uncertainty. The fuzzy membership function, which is a core concept in fuzzy set theory, can be adopted to represent the performance of each operational variation against the identified selection criteria. A modified horizontal approach with the bisector error method was applied to set up the fuzzy membership functions. The fuzzy membership functions provide quantitative calculation method for measuring performance of every DB operational. With the construction of fuzzy membership functions, owners can objectively examine the suitability of every DB operational variation against each selection criterion in a fuzzy decision-making environment.

8.2.4 Establishment of the Fuzzy Multi-criteria Decision-making Model

The selection of DB operational variation is a complex multi-criteria decision making problem involving fuzzy characteristics and uncertainties. A fuzzy multi-criteria decision-making (FMCDM) model is regarded as the most suitable technique for this problem. After identifying the categories of DB operational variations, the selection criteria & their importance weightings, and the fuzzy membership functions, the fuzzy multi-criteria decision-making model was finally developed using the weighted mean method to aggregating the performance of each DB operational variation against the identified selection criteria. The proposed model enables owners to perform quantitative calculations in a fuzzy decision-making environment and provides a useful tool to cope with different project attributes.

8.3 VALUES AND SIGNIFICANCE OF THE RESEARCH

This research study has made three significant contributions to the research area of design-build. The first one was to conduct a comprehensive review of the DB market in China. After the investigation of the construction industry, the current DB market, and the involvement of overseas contractors in the domestic DB market, a holistic picture of the DB market in China was obtained. It could be concluded that the development of the DB system is still at its infancy stage. However, there are ample evidences that the DB system would bring benefits to the PRC construction industry, and the DB market would have great potential in the future. At the same time, the possible barriers to entry into the DB market of China were also obtained. All these findings would provide a solid platform to conduct further studies of DB system, and promote its application in the

construction market of the PRC.

The second major contribution was to develop a classification framework for DB operational variations. In the DB field, although many researchers have proposed various classifications of DB operational variations, most of the classifications are not widely accepted, and some of the classifications even contradict each other. The research work proposed a comprehensive framework of DB operational variations, which provides owners with perspectives to understand various DB categories. Although every researcher and practitioner can have their own ways of classification, the investigation of the rules in their classification frameworks helps to provide DB stakeholders with guidelines to examine various operational ways of DB method and deepen the understanding of DB system. It would add knowledge to design-build and serve as a significant acceleration of developments in this filed.

The third major contribution was to develop a comprehensive, objective, reliable and practical fuzzy multi-criteria decision-making model by using Delphi survey and Fuzzy Set Theory. The selection of DB operational variation is a multi-criteria decision making process, which requires owners to objectively evaluate the performance of each operational variation against the selection criteria. However, it is very difficult and is characterized by subjectivity and uncertainty. The research study established a fuzzy multi-criteria decision-making (FMCDM) model for selecting the most suitable DB operational variation. A three-round Delphi questionnaire survey was conducted to identify the selection criteria and their relative importance. A modified horizontal

approach with the bisector error method was further applied to set up the fuzzy membership functions. The fuzzy multi-criteria decision-making model was developed using the weighted mean method to aggregate the performance of DB operational variations against the identified selection criteria. The proposed model enables owners to perform quantitative calculations in a fuzzy decision-making environment and provides a useful tool to cope with different project attributes.

8.4 LIMITATION OF THE STUDY

In the final fuzzy multi-criteria decision-making model, owners are only required to objectively evaluate the conditions of the seven project attributes/selection criteria on a 10-point Likert scale. Then the model would provide the overall performance of each DB operational variation. However, it should be pointed out that it is not easy to give ratings to the project attributes precisely. This is because some of the selection criteria (such as the owner's experience, project complexity) are still perceptive and vague in nature. Different assessors may have their own semantic interpretation on each selection criterion.

In addition, as with any other opinion-based study, this research study suffers from subjectivity, bias, imprecise definition, and human inability to process complex information. In the research study, face-to-face interviews, Delphi survey technique, and questionnaire survey were conducted to solicit the opinions from industrial experts. The reliability of selection criteria, fuzzy membership functions mostly rely on the experience and knowledge of these experts. The subjectivity of the evaluation could not be

eliminated entirely. Therefore, it cannot be fully guaranteed that the model will always provide the optimal variation of design-build, and hence the practicality of the selection model may reduce. However, the effects of these limitations could be further reduced by taking a study with larger sample size when the DB market matures in China.

8.5 RECOMMENDATIONS FOR FUTURE RESEARCH

In order to score to the selection criteria precisely, further study could be conducted to identify suitable quantitative interpretations or indicators for each selection criterion. In addition, it is necessary to provide objective evaluation or rating rules based on quantitative evidences. Finally, computer-based software could be developed to sever as a practical and automated tool to facilitate the selection of DB operational variations. The users could obtain overall performance rankings for the five DB operational variations.

Furthermore, although the model was developed in the construction market of China, the problem of selecting appropriate DB operational variations exists in other counties such as the U.S, U.K, and Australia. Therefore, further research could be conducted in these countries to compare and contrast their similarities and differences by replicating the same research methodology.

8.6 CHAPTER SUMMARY

The research study met the objectives set out in Chapter 1, and the main conclusions and the value of the research were summarized. More research work in the field of DB operational variation could be conducted to yield more reliable results, and future research directions have been suggested. It is believed that the current research study provides insights in the knowledge of design-build, and provides practical benefits to design-build practitioners in general and to DB owners in particular.

Appendix 1

First questionnaire survey on the barriers to entry into the DB market in China

APPENDIX 1: First Questionnaire Survey on the Barriers to Entry into the DB Market in China (English Version)

Dear Mr./Ms.

My name is Paul, and I am currently a PhD student at the Hong Kong Polytechnic University under the supervision of Professor Albert Chan. I am inviting you to participate in a research study on design-build field. The purpose of this study is to identify the barriers to entry into the current design-build market in China.

Design-build (DB) is a procurement method where one entity or consortium is contractually responsible for both design and construction of a project. In the recent years, this integrated delivery system has been demonstrated to be an effective delivery method and has gained popularity worldwide. However, it does not receive the same popularity in the construction industry of China, which is dominated by the traditional design-bid-build procurement system. By now, only less than 10 percent of the construction projects are delivered in DB method (China Construction Industry Association, "CCIA", 2006).

In this questionnaire survey, you are required to list the dominant barriers to entry in the current DB market of China according to your experience and knowledge. This questionnaire survey will take no more than 15 minutes to complete.

Your expertise and knowledge shared through your participation in this study will benefit the design-build community. In appreciating for contributing to my research, I will send you an advanced copy of the research results.

If you have any question about the questionnaire survey, please do not hesitate to contact me by email: boby_xia@ , or by phone: 852-2766-5882.

Thank you for your time, expertise and help.

Paul

PhD candidate

The Hong Kong Polytechnic University

	Barriers to entry into the design-build market in China
1	
2	
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…	

For example: the regulation laws, DB project requirements, and competence of DB contractors.

First Questionnaire Survey on the Barriers to Entry into the DB Market in China

(Chinese version)

工程总承包市场进入障碍咨询

尊敬的专家：

您好！我叫夏波，是香港理工大学的博士生，指导老师是陈炳泉教授。此次写邮件给您是希望您能参加关于我国工程总承包市场进入障碍的研究。

工程总承包模式在理论和实践上都被证明是一种非常有效工程建造模式，并且在国外获得了广泛的应用。虽然建设部门近年来也一直在提倡和推广工程总承包模式，然而工程总承包模式在我国的应用比例还是比较低；尤其在房屋建筑领域，传统的设计-招标-建造模式占据绝对的主导。据根中国建筑业协会的 2006 年不完全统计，目前为止只有少于 10%的项目采用工程总承包。因此，工程总承包目前在我国的应用还存在一定的问题。

本次调查，想请教一下您对目前我国开展工程总承包模式所面临的问题或者总承包市场进入障碍的看法和意见。您可以根据自身经验和理解提出任何您认为对开展工程总承包构成障碍的因素。通过此次专家咨询，本人将汇总各位专家提出的各个因素，然后将结果返回给各个专家确认。然后在国内进行一轮问卷调查，以获得各指标的重要性并进行一定的统计分析。

如果您有任何关于本研究的问题和看法，请及时与本人联系。本人的联系方式为：（电话）852-2766-4816 或者 Email ： boby_xia@ 或 0690

此致

敬礼！

夏 波

建筑与房地产系
香港理工大学

	我国开展工程总承包存在的问题/市场进入障碍
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注：如政策法规，业主，承包商（总承包商，分包商，设计单位，施工单位），总包工程特性等方面

Appendix 2

The second questionnaire survey on the barriers to entry into the DB market in China

APPENDIX 2: The Second Questionnaire Survey on the Barriers to Entry into the DB Market in China (English Version)

Dear Sir or Madam:

My name is Paul, and I am currently a PhD research study at the Hong Kong Polytechnic University under the supervision of Professor Albert Chan. I am inviting you to participate in a research study on the barriers to entry into the DB market in China.

Design-build (DB) is a procurement method where one entity or consortium is contractually responsible for both design and construction of a project. It has been demonstrated to be an effective delivery method and has gained popularity worldwide. However, it does not receive the same popularity in the construction industry of China, which is dominated by the traditional design-bid-build procurement system. By now, only less than 10 percent of the construction projects are delivered in DB method (China Construction Industry Association, "CCIA", 2006).

Within the last two months, 22 initial barriers to entry have been identified through input from 12 professionals from a variety of design-build roles. In order to prioritize these factors, we are inviting you to participate in this questionnaire survey. You will be asked to rate the factors with regard to the importance of each. **The questionnaire survey should take no more than 15 minute to complete.**

Your expertise and knowledge shared through your participation in this study will benefit the design-build community. In appreciation for contributing to our research, we will send you an advanced copy of the research results. If you have any question about the questionnaire survey, please do not hesitate to contact me by email: boby_xia@ , or by phone: 852-2766-5882.

Thank you for your time, expertise, and help.

Paul
PhD candidate
The Hong Kong Polytechnic University

Directions: Please read each barrier to entry, and rate each according to their importance on the scale provided. Your response is vital for this study and we appreciate your input. Thank you for your time and your thoughts.

1= Not Important
2= Somewhat Important
3= Important
4= Very Important
5= Extremely Important or Essential

Barriers into the DB market in China

No.	Barriers to entry into design-build market	←Not important				Extremely important→
		1	2	3	4	5
1	Lack of promotion from the local governments	☐	☐	☐	☐	☐
2	Unfamiliarity of DB owners	☐	☐	☐	☐	☐
3	Lack of enough competent design-builders	☐	☐	☐	☐	☐
4	Lack of experience of design-builders	☐	☐	☐	☐	☐
5	Difficulty in determining the DB contract price	☐	☐	☐	☐	☐
6	Lack of interest from public owners	☐	☐	☐	☐	☐
7	Lack of sophisticated design expertise of contactor-led design-builders	☐	☐	☐	☐	☐
8	Lack of project management capability of design-led design-builders	☐	☐	☐	☐	☐
9	Lack of enough design-build professionals in the DB market	☐	☐	☐	☐	☐
10	Owner's lack of ability to successfully define project requirements	☐	☐	☐	☐	☐
11	Lack of credit system in the construction market	☐	☐	☐	☐	☐
12	Lack of competent sub-contractors	☐	☐	☐	☐	☐
13	Lack of suitable organization format for design-builders	☐	☐	☐	☐	☐

14	Difficulty in coordination with sub-contactors	☐	☐	☐	☐	☐
15	Higher contract price of DB project	☐	☐	☐	☐	☐
16	Lack of bidding and evaluation method for DB projects	☐	☐	☐	☐	☐
17	Risk management of design-build projects	☐	☐	☐	☐	☐
18	The effectiveness of design-build system	☐	☐	☐	☐	☐
19	Less control of DB projects	☐	☐	☐	☐	☐
20	Lack of regulations on qualification management	☐	☐	☐	☐	☐
21	Lack of real owners in public sectors	☐	☐	☐	☐	☐
22	Conflict with existing bidding system	☐	☐	☐	☐	☐

Your background information：

1. Your working experience years in construction field：

   ☐ 1-5 years ☐6-10 years ☐11-15 years ☐ 16-20 years ☐ over 20 years

2. Your working experience years in design-build field：

   ☐ 1-5 years ☐6-10 years ☐11-15 years ☐ 16-20 years ☐ over 20 years

3. Your organizations:

   ☐ Research institution ☐ Government ☐ State-owned company ☐ Private company ☐ Others

4. Types of DB project you got involved:

   ☐ Building project ☐ Civil project ☐ Chemical project
   ☐ Metallurgic project ☐ Electronic project ☐ Petrochemical projects
   ☐ Building Material project ☐ Environmental engineering project ☐ Others

The Second Questionnaire Survey on the Barriers to Entry into the DB Market in China (Chinese Version)

尊敬的专家：

您好！感谢您在百忙之中抽出时间做此调查问卷。此次问卷调查想咨询您对目前我国开展工程总承包所面临问题的一些看法。它占用您 15 分钟左右的时间，但在问卷调查之后您将会获得本研究的调查结果。

工程总承包模式在理论和实践上都被证明是一种非常有效工程建造模式，并且在国外获得了广泛的应用。2005 年，美国的工程总承包比例在非住宅领域占到了 40%。虽然我国建设部门近年来也一直在提倡和推广工程总承包模式，然而在我国的应用比例还是比较低；尤其在房屋建筑领域，传统的设计-招标-建造模式占据绝对的主导。据根中国建筑业协会的 2006 年不完全统计，目前为止只有少于 10%的项目采用工程总承包。工程总承包目前在我国的应用还存在一定的问题。

通过前阶段的专家访问和调查，本研究已经初步获得了我国开展工程总承包所面临的一些问题或者总承包市场进入障碍。而此次问卷调查的目的是希望能获得您对这些因素重要性的看法。您可以通过对指标进行 1 到 5 （分）的打分来判定指标的重要性。在问卷调查结束之后，本人会将调查的统计结果回馈给您，以供参考。

希望您能将完成的调查问卷在 5 月 10 号之前回复至 boby_xia@ ，或者 0690 . 同时我们向您保证此次问卷调查只用于学术研究，绝不会透露您个人信息。

祝身体健康，工作顺利！

此致

敬礼!

夏 波
香港理工大学建筑与房地产系

我国工程总承包市场进入障碍分析

序号	我国工程总承包市场进入障碍因素	←非常不重要				非常重要→
		1	2	3	4	5
1	地方政府推广力度不够	☐	☐	☐	☐	☐
2	业主对工程总承包模式不熟悉，缺乏了解	☐	☐	☐	☐	☐
3	缺乏足够的有能力的承包商	☐	☐	☐	☐	☐
4	总承包企业缺乏设计施工总承包经验	☐	☐	☐	☐	☐
5	设计施工总承包工程的合同价格（在现行造价管理条件下）难以确定	☐	☐	☐	☐	☐
6	业主习惯倾向于采用熟悉的传统模式	☐	☐	☐	☐	☐
7	施工单位为主导的总承包商缺乏设计和规划能力	☐	☐	☐	☐	☐
8	设计单位为主导的总承包商缺乏施工管理能力	☐	☐	☐	☐	☐
9	具有总承包能力的复合型人才较少	☐	☐	☐	☐	☐
10	业主方不能提出合适的招标文件（功能描述书）	☐	☐	☐	☐	☐
11	建筑行业缺乏信用体系	☐	☐	☐	☐	☐
12	缺乏有能力的分包商	☐	☐	☐	☐	☐
13	缺乏适合总承包商的组织架构	☐	☐	☐	☐	☐
14	与分包商的协调存在难度	☐	☐	☐	☐	☐
15	工程总承包合同价格偏高	☐	☐	☐	☐	☐
16	缺乏针对总承包的招标评标方法	☐	☐	☐	☐	☐
17	工程总承包风险偏高	☐	☐	☐	☐	☐
18	工程总承包的绩效不明显	☐	☐	☐	☐	☐
19	业主对总承包项目的控制问题	☐	☐	☐	☐	☐
20	缺乏对工程总承包商的资质管理法规	☐	☐	☐	☐	☐
21	公共建设部门缺乏真正的业主	☐	☐	☐	☐	☐
22	与现行的招投标体系存在一定冲突	☐	☐	☐	☐	☐

您的背景资料：

2. 您在建设及相关领域工作的时间：

☐ 1-5 年 ☐6-10 年 ☐11-15 年 ☐ 16-20 年 ☐20 年以上

2. 你在工程总承包领域工作的时间：

☐ 1-5 年 ☐6-10 年 ☐11-15 年 ☐ 16-20 年 ☐20 年以上

5. 您所在的工作单位的性质

☐ 科研机构 ☐政府机构 ☐ 国有企业 ☐ 民营企业 ☐其他

6. 您曾经参与的工程总承包项目的类别:

☐房屋建筑 ☐道路 ☐ 桥梁 ☐化工 ☐冶金

☐电力 ☐石化 ☐建筑材料 ☐环境 ☐其他

Appendix 3

Round 1 of the Delphi questionnaire survey

APPENDIX 3: Round 1 of the Delphi Questionnaire Survey (English Version)

A survey of developing selection criteria for design-build operational variations (Round one Delphi survey)

Guidance on completion

Thank you very much for participating in this research survey by making the best use of your expertise in providing valuable opinion on identifying the selection criteria for design-build operational variations. In this open-ended round, you are required to list at least five evaluation criteria, which you think are the most important in the selection of design-build operational variations for owners in the construction market of China. Before completing this questionnaire, the following note on design-build operational variations may act as a useful reference.

Notes:

Design-build operational variations

Design-build (DB) is a procurement method where one entity or consortium is contractually responsible for both design and construction of a project. To meet a varying set of circumstances, certain modification to the basic design-build system has been developed. Considering there are diverse DB operational variations and the classification of DB operational variations is not unified yet, this study proposed five basic design-build operational variations based on the different design stages undertaken by owners/contractors. The evaluation criteria will be obtained to help the owner evaluate these five design-build variations and select the most appropriate one. The five DB operational variations are listed as follows:

(1) *Develop and construct.* In this variation, owners have or engage their design consultants to do the design work up to design development stage. The design-

build contractor is responsible for completing construction document and construction.

(2) *Enhanced design-build.* In this variation, owners have or engage their design consultants to do the design work up to the scheme design. The design-build contractor is responsible for completing the design development, construction document and construction.

(3) *Traditional design-build.* The contractor takes full responsibility for all the design and construction. The contractor's design tasks at least up to the scheme design. The owner may prepare the brief/enquiry himself or leave to contractors.

(4) *Turnkey.* The contractor provides everything including the commission and/or handover after the construction. All that remains for the owner to do is simply 'turn the key' in the lock to open the door.

(5) *Novation design-build.* The successful contractor is responsible for construction and construction document or up to design development at most with assignment of design consultants from owners. The 'novation contract' is most suitable and recommended in develop-and-construct.

Round one of the Delphi questionnaire survey

Please list at least five selection criteria for DB operational variations

NO.	SELECTION CRITRIA
1	
2	
3	
4	
5	
Others	

The following are some of the criteria found in previous research studies and literature for your reference:

- Complexity of the project
- The design experience of the owner
- The competitiveness of the proposals
- Early cost establishment
- The owner's control over the project
- Time saving and quick start on site work
- The competence of the contractor
- Less change in the project
- Less responsibility of the owner

Round 1 of the Delphi Questionnaire Survey (Chinese Version)

第一轮调查问卷

XX 先生：

感谢您同意参加本研究的问卷调查。

这一轮的问卷调查要求你列举中出 5 ***条以上能够用来选择不同 DB 变异模式的指标***。这轮调查可能花费您 1 个小时左右的时间，同时要求你在收到调查问卷一周之内将其通过 E-mail 的形式寄回给本人。如果在一周之内没有收到您的回复，本人将会发电子邮件通知您，并且给您额外的 24 小时完成并寄回调查问卷。

同时，这次的德尔菲法调查研究是完全自愿的，如果您中途不方便可以退出或停止参与。但是如果您真的打算退出，希望能事先发 e-mail 和我联系。当然本人热切希望你能完成整个调研，并且能在以后保持良好的合作关系。

如果您有任何关于本研究的问题和看法，请及时与本人联系。本人的联系方式为：（电话）852-2766-4816 或者 Email： boby_xia@ 或 0690

此致

敬礼！

夏 波

香港理工大学

德尔菲法第一轮调查问卷

这是第一轮问卷调查，您可以根据以往的工程经验和知识积累并结合本课题的研究背景，列举出 5 条以上用来选择不同 DB 变异模式的指标，作为业主确定最合适 DB 模式的依据。

此轮问卷完全是开放式的，您可以写下任何您认为重要的指标。这里的 DB 变异模式是指：*develop and construction, novation design-build, enhanced design-build, traditional design-build* 以及 *turnkey* 模式。

在您填完之后，请将此调查问卷寄回 boby_xia@ 或 0690 ，感谢您的合作。

问题：请你列举出 5 个或者 5 个以上您认为重要的指标，使得业主能够根据这些指标来选择合适的 DB 变异模式。

序号	指　标
1	
2	
3	
4	
5	
其他	

注:

以下一些指标是以前研究文献的总结，可以作为参考 .

- 工程的复杂程度
- 业主在设计方面的经验/人力等
- 为了获得投标的竞争性/竞争性的投标价格/ 竞争性设计方案
- 业主希望获得固定的投标价格
- 业主对工程的控制

- 尽快开工的要求/缩短工期的要求
- 承包商的经验和数量等
- 减少工程变更的可能性
- 工程责任的分摊

DB 变异类型的划分:

（1）develop and construct

在这种类型中，业主或者雇用设计顾问一直完成到初步设计阶段。而DB承包商负责项目的施工图设计以及工程的施工建造。

（2）Novation design-build

DB承包商负责施工建造以及施工图的设计（也可以到初步设计阶段，但以施工图设计阶段最合宜），而该模式最重要的特征是DB承包商在中标之后必须聘用业主的设计人员（前阶段为业主设计）以保证设计的连贯性，此后设计人员对DB承包商负责。

（3）Enhanced design-build

在该模式中，业主或其设计顾问完成项目的方案设计。而DB承包商负责项目的初步设计，施工图设计以及工程的施工建设。

(4) Traditional design-build

在此模式中，DB 承包商负责所有的设计和建造工作。承包商的设计职能至少到方案设计阶段。业主可以自己准备招标文件或者直接将工程发包给 DB 承包商。

(5) Turnkey

在该模式中，DB 承包商提供所有的工程服务，包括完工后的试运行和移交。因此该模式主要用于工业项目中。对于业主来说，所要做的就是“转动钥匙”，把门打开即可。

Appendix 4

Round 2 of the Delphi questionnaire survey

APPENDIX 4: Round 2 of the Delphi Questionnaire Survey (English Version)

A survey of developing selection criteria for design-build operational variations (Round Two Delphi survey)

Guidance on completion

The results of Round 1 Delphi questionnaire survey are list as below. The average percentage of all experts is given in column (2). You are required in this round to give ratings on all the selection criteria based on the 5-point Likert scale to evaluate the importance of the five DB operational variations.

Round two of the Delphi questionnaire survey

Please giving ratings for each criteria from ***1=least important, 5=most important***

Selection criteria from Round 1	Experts Frequency	Your ratings
1. Availability of competent design-builders	90 %	
2. Owner's DB experience	80 %	
3. Project scale and complexity.	75 %	
4. Owner's control of project	70 %	
5. Reduced Responsibility or involvement	55 %	
6. Early commencement & shorten duration	55 %	
7. Early cost-establish	40 %	
8. Bid competition	35 %	
9. Law & trade's tradition	30 %	
10. Reduced or controlled project variation	30 %	
11. Reduced risk	15 %	
12. Clear end user's requirement	5 %	

13. Peer relationship with contractor	5 %
14. The quality requirement of project	5 %
15. Buildability of the construction	5 %
16. Familiarity with the DB variations	5 %

Round 2 of the Delphi Questionnaire Survey (Chinese Version)

第二轮德尔菲问卷调查

XX 先生：

感谢您能继续参加本研究的第二轮问卷调查。

在上一轮的问卷调查中，你列举了用来**选择不同 DB 变异模式的指标**。在汇总了您和其他专家的意见之后，希望您能根据自己的理解并参考第一轮专家调查的综合结果，**对指标重要性程度进行打分**。

这轮调查可能花费您 1 个小时左右的时间，同时要求你在收到调查问卷一周之内将其通过 E-mail 的形式寄回给本人。如果在一周之内没有收到您的回复，本人将会发电子邮件通知您，并且给您额外的 24 小时完成并寄回调查问卷。如果您有任何关于本研究的问题和看法，请及时与本人联系。本人的联系方式为：（电话）852-2766-4816 或者 Email： boby_xia@ 或 0690

此致

敬礼！

夏 波
香港理工大学

填表指南：在您仔细阅读了第二轮问卷调查信之后，请您根据上一轮问卷调查结果对选择 DB 变异模式的不同指标进行重要性评价。本轮的指标重要性评价采用 1 至 5 的打分形式，其中 **1 分表示该指标最不重要，5 分表示该指标最重要**。您可以在对应的分值栏中打勾（✓）或者填写对应的分值。在您填完之后，请在一周内将此调查问卷寄回 boby_xia@ 或 0690 ，感谢您的合作。

选择 DB 变异模式的指标	专家认同比例	您的本轮打分
1、承包商的能力与资源 市场上的总承包商是否具备相应 DB 变异模式的承包经验、能力和资源？或者是否有足够能力的承包商	90 %	
2、业主的工程总承包经验和能力 业主是否具备在工程总承包方面的经验和能力，尤其在设计方面？	80 %	
3、工程复杂程度 该工程项目在工艺、施工、技术、管理等方面特别复杂，要求特别高？	75 %	
4、业主对工程的控制 业主能够严格控制项目的设计、进度、质量等，还是主要由总承包商实行项目的控制？	70 %	
5、业主能减少工程责任 该模式能否使业主减少或明确工程责任，减少对项目协调工作？	55 %	
6、尽快开工和缩短工期 该模式能否让项目尽快开工，且缩短工期，或缩短工期是否为业主最关心的因素？	55 %	
7、尽早确定工程造价 能否使业主尽早确定项目的工程造价或签订总承包总价合同？	40 %	
8、投标方案、价格的竞争性 能否使项目的招投标过程获得竞争性的投标方案和投标价格？	35 %	
9、政策法规，行业惯例 当地是否允许相应 DB 变异模式，当地的市场环境，行业管理如何？	30 %	
10、减少或控制工程变更 采用该变异模式能否减少项目的变更，或者业主能够控制工程的变更？	30 %	

11、减少合同风险 该模式是否能够降低工程的合同风险？	15 %	
12、业主对项目的使用功能是否明确 业主能能否编制出适合的功能描述书？	5 %	
13、业主与承包商合作情况 业主和承包商的沟通、信赖程度。	5 %	
14、工程的质量要求 该模式能否确保或提高工程质量，或项目的质量要求是否为业主主要考虑因素？	5 %	
15、充分发挥设计和施工结合的优势 采用该模式更能发挥设计和施工结合的优势？	5 %	
16、业主对该模式的熟悉程度 业主对该模式是否熟悉？	5 %	

专家认同比例是：在第一轮问卷调查中，同时列举该指标的专家人数占所有专家的比例。

Appendix 5

Round 3 of the Delphi questionnaire survey

APPENDIX 5: Round 3 of the Delphi Questionnaire Survey (English Version)

A survey of developing selection criteria for design-build operational variations (Round three Delphi questionnaire survey)

Guidance on completion

Below are the results of Round 2 Delphi questionnaire survey. The selection criteria whose mean score is over 3.0 point will be re-rated in this round. The average ratings of all experts are given column (2). Your Round 2 ratings are given in column (3). You are required in this round to reconsider your ratings to the following criteria provided with the statistical summary of the last round survey. The ratings will still base on the 5-point Likert scale to evaluate these five DB operational variations.

Round Three Delphi Questionnaire Survey

Please giving ratings for each criteria from ***1=least important, 5=most important***

Criteria for DB variations selection (Mean score >= 3.0)	Mean ratings	Your ratings in Round 2	Your ratings in Round 3
Contractor's competence	4.44		
Owner's experience	3.87		
Project complexity	3.81		
Owner's control of project	3.41		
Reduced responsibility	3.25		
Early commencement & short duration	3.15		
Early cost establishment	3.07		
Clear end user's requirements	3.03		

Round 3 of the Delphi Questionnaire Survey (Chinese Version)

第三轮（最后一轮）德尔菲问卷调查

XX 专家：

感谢您协助完成本研究的最后一轮问卷调查!

在上一轮的问卷调查中，您对不同**指标的重要性程度进行了打分**。经过对所有专家的意见汇总和分析，本轮选取了**平均分 3.0 以上**的八项指标进行再一次重要性评价。因此在本轮问卷调查中，您可以**参考所有专家总体意见和您上轮打分的情况，对上一轮的八项指标进行重新打分**。本轮的调查结果将最终确定选择 DB 变异模式的指标并且确定所选择指标的重要性程度。

这轮调查可能花费您 1 个小时左右的时间，同时要求你在收到调查问卷一周之内将其通过 E-mail 的形式寄回给本人。如果在一周之内没有收到您的回复，本人将会发电子邮件通知您，并且给您额外的 24 小时完成并寄回调查问卷。如果您有任何关于本研究的问题和看法，请及时与本人联系。本人的联系方式为：（电话）852-2766-4816 或者 Email ： boby_xia@ 或 0690

此致

敬礼！

夏 波
香港理工大学

填表指南：在此轮问卷调查中，您可以根据上一轮专家总体意见和您自己的打分情况，对上轮平均值大于 6 分的选择指标进行重新评价。本轮的指标评价同样采用 1 至 5 的打分形式，其中 **1 分表示该指标最不重要，5 分表示该指标最重要**。您可以在对应的分值栏中打勾（✓）或者填写对应的分值。感谢您的合作。

选择 DB 变异模式的指标排名	上轮专家 打分平均值	您的上轮打分	您本轮重新打分
1、承包商的能力与资源 市场上的承包商是否具备相应 DB 变异模式的承包经验、能力和资源？	4.44		
2、业主的工程总承包经验和能力 业主是否具备在工程总承包方面的经验和能力，尤其在设计方面？	3.87		
3、工程复杂程度 该工程项目在工艺、施工技术、管理等方面特别复杂，要求特别高？	3.81		
4、业主对工程的控制 业主能严格控制项目的设计、进度、质量等，还是主要由总承包商实行项目的控制？	3.41		
5、业主能减少工程责任 该模式能否使业主减少或明确工程责任，减少对项目协调工作？	3.25		
6、尽快开工和缩短工期 该模式能否让项目尽快开工，且缩短工期，或缩短工期是否为业主最关心的因素？	3.15		
7、尽早确定工程造价 能否使业主尽早确定项目的工程造价或签订总承包总价合同？	3.07		
8、业主对项目的使用功能是否明确 业主能能否编制出适合的功能描述书？	3.03		

Appendix 6

Questionnaire survey for developing fuzzy membership functions for DB operational variations

APPENDIX 6: Questionnaire Survey for Developing Fuzzy Membership Functions for DB Operational Variations (English Version)

Dear Sir or Madam:

My name is Paul, and I am currently a PhD research study at the Hong Kong Polytechnic University under the supervision of Professor Albert Chan. I am inviting you to participate in a research study on the design-build field.

Design-build (DB) is a procurement method where one entity or consortium is contractually responsible for both design and construction of a project. Within the DB system, a number of operational variations of the DB system have been developed, which include *develop-and-construct, novation DB, enhanced DB, traditional DB, and turnkey method*. Every DB operational variation has its own strengths and weakness, and owners have to choose the appropriate one to best deliver their projects. However, it is never an easy task and poses changes to most of DB owners.

In order to facilitate the selection process, 7 selection criteria have been identified through a three-round Delphi questionnaire survey with 20 experts in the DB market. The top seven selection criteria include (1) availability of competent design-builders; (2) owner's design experience; (3) project complexity; (4) owner's control of project; (5) early commencement & short duration; (6) reduced responsibility or involvement; and (7) clear end user's requirements. For every DB operational variation, it is will be considered as the most suitable option when specific conditions of selection criteria are satisfied. We are inviting you to participate in this questionnaire survey to provide numerical figures (from 1 to 10) for every selection criterion that is considered as the most appropriate condition for each DB operational variation. **The questionnaire survey should take no more than 30 minute to complete.**

Your expertise and knowledge shared through your participation in this study will benefit the design-build community. In appreciation for contributing to our research, we will

send you an advanced copy of the research results. If you have any question about the questionnaire survey, please do not hesitate to contact me by email: boby_xia@ , or by phone: 852-2766-5882.

Thank you for your time, expertise, and help.

Paul
PhD candidate
The Hong Kong Polytechnic University

Note: Considering there are diverse DB operational variations and the classification of DB operational variations is not unified yet, this study proposed five basic design-build operational variations based on the different design stages undertaken owners/contractors. The definitions of the DB operational variations are listed as follows:

Develop and construct

In this variation, owners have or engage their design consultants to do the design work up to design development. The design-build contractor is responsible for completing construction document and construction.

Enhanced design-build

In this variation, owners have or engage their design consultants to do the design work up to the scheme design. The design-build contractor is responsible for completing the design development, construction document and construction.

Traditional design-build

The contractor takes full responsibility for all the design and construction. The contractor's design tasks at least up to the scheme design. The owner may prepare the brief/enquiry himself or leave to contractor.

Turnkey

The contractor provides everything including the commission and/or handover after the construction. All that remains for the owner to do is simply 'turn the key' in the lock to open the door.

Novation design-build. The successful contractor is responsible for construction and construction document or up to design development at most with assignment of design consultants from owners. The 'novation contract' is most suitable and recommended in develop-and-construct.

Directions: Please give a numerical number from 1-10 to present the optimal condition of the selection criteria when each DB operational variation is regarded as the most suitable choice

Selection criteria	DB operational variations	Suitable conditions for DB operational variations	
		1 to 10	Notes
1. The competence of design-builders	Develop-and-construct		**10 point**—when design-builders are extremely competent **1 point**—when design-builders are not competent
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
2. The experience of DB owners	Develop-and-construct		**10**—When DB owners have sufficient DB experience **1**—When DB owners are inexperienced with DB project
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
3. Project complexity	Develop-and-construct		**10**—When DB projects are extremely complex **1**—When DB projects are not complicated
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
4. Owners' control of projects	Develop-and-construct		**10**—Owners can have the most control of DB projects **1**—Owners can have the least control of DB projects
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
5. Early commencement and short duration	Develop-and-construct		**10**—It can greatly shorten the project duration **1**—It can not greatly shorten the project duration
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
6. Reduced project responsibility	Develop-and-construct		**10**—Owners have the least project responsibility **1**—Owners have the most project responsibility
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
7. Clear project requirements	Develop-and-construct		**10**—When owners have very clear project requirements **1**—When owners' requirements are not clear
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		

Questionnaire Survey for Developing Fuzzy Membership Functions for DB Operational Variations (Chinese Version)

DB 变异模式对各选择指标的隶属度问卷调查

各位专家：

您好！我叫夏波，是香港理工大学的博士生，指导老师是陈炳泉教授。此次写邮件给您是希望您能参加我的博士课题研究。

DB 总承包是指由单一实体或联合体负责项目的设计与建造的工程建造模式。它与传统的工程建造模式（Design-Bid-Build）和建造管理模式（Construction Management）构成最主要的工程建造模式。由于 DB 模式的制度特性和良好的工程绩效，已经成为工程建设的主流模式，并且根据不同的工程情况发展出许多的变异模式。然而目前存在的 DB 变异模式种类繁多，所用术语不统一，很多学者对 DB 模式的分类都是不一致甚至相互矛盾。通过对不同的 DB 模式分类进行了系统的回顾和整理，并且在系统考察了英国、美国和中国的工程设计过程之后，本研究小组将不同设计阶段作为划分 DB 变异模式的主要标准，最终根据业主/承包商所承担的不同设计任务将 DB 模式划分为下列 5 种类型：Develop and Construction, Novation design-build, Enhanced design-build, traditional design-build 以及 Turnkey 模式。该 5 种不同变异类型的图示和定义见下面的表 1。

为了选择不同的 DB 模式，本课题组通过三轮德尔菲法获得到了用来选择 DB 变异模式的 7 个指标。

1、 承包商的能力与资源

2、 业主的经验和能力

3、 工程复杂程度

4、 业主对工程的控制

5、 充分发挥设计和施工结合优势

6、 业主能减少工程责任

7、 业主对项目使用功能是否明确

而每个 DB 变异模式对各选择指标的匹配程度是不同的。例如 Turnkey 模式对承包商的能力与资源要求比较高，而 Develop & Construct 相对比较低。此次问卷调查希望您对每个 DB 变异模式与选择指标之间匹配度进行打分，以确定各个模式最合适的指标分值。

表 1 不同 DB 变异模式的定义和主要特征

DB 变异模式	定义（主要特征）
1、Develop and Construct	业主或者雇用设计顾问一直完成到初步设计阶段。而DB承包商负责项目的施工图设计以及工程的施工建造。
2、Novation Design-Build	DB 承包商负责施工建造以及施工图设计（也可以到初步设计阶段，但以施工图设计阶段最合宜），而该模式最重要的特征是 DB 承包商在中标之后必须聘用业主的设计人员以保证设计的连贯性，此后设计人员对 DB 承包商负责。
3、Enhanced Design-Build	在该模式中，业主或其设计顾问完成项目的方案设计。而DB承包商负责项目的初步设计，施工图设计以及工程的施工建设。
4、 Traditional Design-Build	在此模式中，DB 承包商负责所有的设计和建造工作。承包商的设计职能至少到方案设计阶段。业主可以自己准备招标文件或者直接将工程发包给 DB 承包商。
5、Turnkey	在该模式中，DB 承包商提供所有的工程服务，包括完工后的试运行和移交。因此该模式主要用于工业项目中。对于业主来说，所要做的就是“转动钥匙”，把门打开即可。

总体而言，业主（或其聘请的设计顾问）承担越多设计任务，该 DB 变异模式越接近传统的工程建造模式，业主对工程各方面的具体控制越强，同时所承担的责任也越多（如设计失误等），设计和施工结合的优势越少，对承包商的总承包能力要求也较低；而对于主要由 DB 承包商负责工程设计（和建造）的 DB 变异模式，业主的工程责任越少，越能发挥设计与施工结合的优势，但业主对工程的具体控制将减弱，同时要求业主能在项目初期提供明确的功能描述，对业主的总承包经验提出更高的要求（业主本身可以缺乏总承包经验，但必须聘请相应的设计顾问或咨询机构与总承包商协调）。

本次问卷调查将花费您半个小时左右的时间。您的答复对本人的研究非常重要，希望能够收到您的回复。同时为了感谢您的答复，我们会把最终的研究结果和您分享。如果您有任何关于本研究的问题和看法，请及时与本人联系。本人的联系方式为：（电话）852-2766-4816 或者 Email： boby_xia@ 或 0690

此致

敬礼！

夏 波
香港理工大学

填表指南：请您输入 各 DB 变异模式对应于不同选择指标的最合适分值（1-10 分）

选择 DB 变异模式的指标	不同 DB 变异模式	各 DB 变异模式与该指标最匹配的分值	
		1--10 打分	分值说明
1、总承包商的能力与资源 市场上的总承包商是否具备相应 DB 变异模式的承包经验、能力和资源？	Develop & Construct		**10 分**—表示该变异模式对承包商的能力与资源要求非常高 **1 分**—表示该变异模式对承包商的能力与资源要求较低
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
2、业主的总承包经验和能力 业主（或其咨询顾问）是否具备在总承包方面的经验和能力？	Develop & Construct		**10 分**—表示该变异模式对业主总承包能力的要求非常高 **1 分**—表示该变异模式对业主总承包能力的要求较低
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
3、工程复杂程度 该工程项目在工艺、施工技术、管理等方面特别复杂，要求特别高？	Develop & Construct		**10 分**—表示该变异模式适合特别复杂的工程项目 **1 分**—表示该变异模式适合比较简单的项目
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
4、业主对工程的控制 业主严格控制项目的设计、进度、质量等，还是主要由总承包商实行项目的控制？	Develop & Construct		**10 分**—表示该变异模式能够使业主严格控制工程项目 **1 分**—表示该变异模式使得主要由承包商实行项目控制
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		

5、尽快开工和缩短工期 该模式能否让项目尽快开工，且缩短工期，或缩短工期是否为业主最关心的因素？	Develop & Construct		**10 分**—表示该变异模式最能够发挥设计与施工结合的优势 **1 分**—表示该变异模式最不易发挥设计施工结合的优势
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
6、业主能减少工程责任 该模式能否使业主减少或明确工程责任，减少对项目协调工作？	Develop & Construct		**10 分**—表示该变异模式能够最大限度减少业主的工程责任 **1 分**—表示该变异模式要求业主承担较多的工程责任
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		
7、业主对项目使用功能是否明确 业主能否编制出适合的功能描述书（尤其在项目初期）？	Develop & Construct		**10 分**—表示该模式要求业主在早期对项目使用功能非常明确 **1 分**—表示该模式对业主早期明确项目功能的要求不高
	Novation DB		
	Enhanced DB		
	Traditional DB		
	Turnkey		

Appendix 7

Face-to-face interview dialogues for validation

APPENDIX 7: Face-to-face Interview Dialogues for Validation

1. Is the classification framework practical, comprehensive?

All the experts agreed that the classification framework is comprehensive, and adequate to include the existing DB operational variations in the construction market. While expert 1 stressed that it may not easy to just label them with these five categories. The ways or rules to classify DB system are more important than the classification results. Expert 2 and expert 5 pointed out that in their DB experience, they did not involve in the novation DB projects. However, both of them agreed that the classification framework provided useful perspectives to understand the operational ways of DB system. Expert 3 emphasized that the turnkey method was mostly applied in the industrial sectors, such as the chemical industry, electric industry and metallurgic industry, and there are very few turnkey projects in the building industry.

In general, the experts agreed that the classification framework is applicable in the construction market of China. It is very useful for owners, especially the inexperienced one, to better understand the operational process of DB projects. In addition, all of them acknowledged that the selection of the appropriate DB operational variations is a challenging but vital issue when delivering DB projects.

2. Is the list of selection criteria comprehensive? Are the importance rankings of these selection criteria appropriate?

The seven criteria were presented to the interviewees. The processes of the three round Delphi questionnaire survey were also introduced. The interviewees were requested to examine the appropriateness of the seven identified selection criteria together with their individual weightings. In addition, they were encouraged to propose other variables that were taken into consideration when making the similar decisions.

In general, although minor variation exists on the rankings of selection criteria, most of the interviewees agreed that the seven selection criteria and their individual weightings developed are appropriate to measure the performance of DB operational variations in China. While expert 3 proposed that the factor of relationship between owners and DB contractors should be considered when evaluating different DB operational variations. This is because, when there is a lack of mutual trust between owners and DB contractors, owners tend to undertake more pre-construction work themselves before leaving the projects to design-builders. This factor was also identified in the first round of the Delphi questionnaire survey, however it was not regarded as the one of the most important factors by the panel experts and was remained for evaluation in the second round.

3. Can the fuzzy membership functions effectively reduce the subjectivity of measuring the performance of DB operational variations with regard to the selection criteria? Is the fuzzy multi-criteria decision-making model applicable to facilitate owners to select the appropriate DB operational variations?

The researcher first briefly explained the reasons and procedure for developing fuzzy

membership functions for the performance evaluation. After that, the establishment of the fuzzy multi-criteria decision-making model was well explained. Then the interviewees were asked to examine whether the fuzzy membership could effectively eliminate the subjectivity of performance evaluation, and whether the final selection model was practical and useful enough to facilitate the selection of DB operational variations.

All the interviewees agreed that objectively measuring the performance of every DB operational variation was the most challenging and essential part in the selection process. The establishment of fuzzy membership functions is an innovative and appropriate method for this purpose because it takes use of the group consensus of DB experts in the questionnaire survey. As a result, owners could perform their evaluation process based on the established fuzzy membership functions of DB operational variations, rather than applying their subjective value judgment. In addition, most of the interviewees agreed the fuzzy membership functions for the selection criteria generally confirm to their DB experience. For example, when the clarity of the project requirement increases, owners could leave more project work to design-builders as in turnkey or traditional DB method.

As for the final selection model, most of them opined that it is practical to use this model to select the appropriate DB operational variations. However, some of them had reservation on the practicality of fuzzy MCDM framework. Expert 1 pointed out that although the final model can help owners objectively compare and select the DB operational variation; owners might still resort to their own experience to make the final decision. This is mainly because the DB system has not been popular in the construction market, and most owners believe that DB contractors are not competent enough to

conduct the DB projects. Expert 3 mentioned that in many public construction projects, the turnkey or traditional DB systems were not allowed because of the restraints from regulation laws. Therefore, the practicality of this model will be reduced. However, all of them agreed that the final selection model takes full advantage of the experts' knowledge, experiences, and makes the decision maker feel comfortable to give quantitative evaluation on different DB operational variations.

REFERENCES

Abdi, H. (2003) Factor Rotations in Factor Analyses. In: Lewis-Beck, M., Bryman, A., Futing, T. (eds.), Encyclopedia for Research Methods for the Social Sciences, Thousand Oaks, CA.

Adnan, H. and Morledge, R. (2003) Application of Delphi method on critical success factors in joint venture projects in the Malaysian construction industry, *Paper presented at CITC-II Conference*, Hong Kong, 10-12 December.

Akintoye, A. (1994) Design and build: a survey of construction contractors' views. *Construction Management and Economics* (1994), 12, 155-163.

Akintoye, A. (2000) Analysis of factors influencing project cost estimating practice. *Construction Management and Economics*, 18, 77-89.

Albaum, G. (1997) The likert scale revisited: an alternative version. *Journal of the Market Research Society*, 39(2), 331-342.

Alhazmi, T. and McCaffer, R. (2000) Project procurement system selection model. *Journal of Construction Engineering and Management*, 126(3), 176–84

Arditi, D., Elhassan, A., and Toklu, Y.C. (2002) Constructability analysis in the design firm. *Journal of Construction Engineering and Management*, 128 (2), 117-26.

Aumba C.J., Evbuomwan N.F.O. (1997) Concurrent engineering in design-build project, *Construction Management and Economics* (1997), 15(3), 271-281.

Austin, S., Newton, A., Steele, J. and Waskett, P. (2002) Modeling and managing project complexity. *International Journal of Project Management*, 20(3), 191-198.

Avgeropoulos, S. (1998) *Barriers to entry and exit, Encycolopedia of Management*. Blackwell, Melden, MA

Ayidiya S.A. and McClendon M.J. (1990) Response effects on mail surveys. *Public Opinion Quarterly*, 54, 229-247.

Baldwin, W.L. (1995) *The Dynamics of Industrial Competition*, Cambridge University Press, London.

Baccarini, D. (1996) The concept of project complexity-a review. *International Journal of Project Management*, 14(4), 201-204

Bagis A. (2002) Determining fuzzy membership functions with tabu search—an application to control. *Fuzzy sets and systems*, 139, 209-225.

Bain J. S. (1968) *Industrial organization*, John Wiely, New York.

Bain, J.S. (1956) *Barriers to New Competition*, Cambridge & Harvard University Press, London & New York.

Baldwin, W.L. (1995) *The Dynamics of Industrial Competition*, Cambridge University Press, London.

Baloi, D., and Price, A.D.F. (2003) Modelling global risk factors affecting construction cost performance. *International Journal of Project Management,* 21, 261-269.

Beard, J.L., Loulakis SR. M. C., and Wundram E.C. (2001) *Design-Build—Planning through Development*, McGraw-Hill, NY

Bertelsen, S. and Koskela, L. (2002) *Managing the three aspects of production in construction*. IGLC-10

Bharathi-Devi B. and Sarma V.V.S. (1985) Estimation of fuzzy memberships from histograms. *Information Sciences*, 35, 43-59.

Botten, N., Nusiak, A., and Raz, T. (1989) Knowledge bases: integration, verification and partitioning. *European Journal of Operational Research*, 42,111-128

Bramble B.B and West J.D. (1999) *Design-build contracting claims*, Aspen Law & Business, N.Y

Cabaniss, K. (2002) Computer-related technology use by counselors in the new millennium: A Delphi study. *Journal of Technology in Counseling*, 2(2), 3-34. Available at http://jtc.colstate.edu/vol2_2/cabaniss/cabaniss.htm (accessed April, 2007)

Carmichael, D.G. (2000) *Contract and International Project Management*, A.A.Balkema Publisher, Rotterdam.

Caves, R.E. and Porter, M.E. (1977) From entry barriers to mobility barriers: Conjectural decisions and contrived deterrence to new competition. *Quarterly Journal of Economics*, 91, 241-262.

Chan, A.P.C (2000) Evaluation of enhanced design and build system-a case study of hospital project. *Construction Management and Economics*, 18, 863-871.

Chan A.P.C (2003), *Procurement Selection Model for Hong Kong*, Research Monograph, The Hong Kong Polytechnic University, Hong Kong.

Chan, A.P.C., Chan, D.W.M., Yeung J.F.Y. (2009) Fuzzy techniques in construction management research. *ASCE Journal of Construction Engineering and Management*, 135 (11), 1241-1252.

Chan, A.P.C, Ho, D. C.K., and Tam, C. M. (2001a) Design and build project success factors: Multivariate analysis. *Journal of construction engineering and management,* 127(2), 93-100

Chan, A.P.C. and Scott, D. and Chan, A.P.L. (2004) Factors Affecting the Success of a Construction Project. *Journal of Construction Engineering and Management*, 130(1), 153-155

Chan, A.P.C., Scott, D., Lam, E.W.M. (2002) Framework of success criteria for design/build projects. *Journal of Management in Engineering*, 18(3), 120-128.

Chan, A.P.C., Yung, E.H.K., Lam, P.T.I., Tam, C.M. and Cheung, S.O. (2001b) Application of Delphi method in selection of procurement systems for construction projects. *Construction Management and Economics,* 19(7), 699-718.

Chan, C.T.W. (2007) Fuzzy procurement selection model for construction projects. *Construction Management and Economics*, 25, 611-618.

Chang, C.Y. and Ive, G. (2002) Rethinking the multi-attribute utility approach based procurement route selection technique. *Construction Management and Economics*, 20, 275–84.

Chappell, D. and Powell-Smith, V. (1999) *The JCT design and build contract*, Blackwell Science, Oxford.

Chen C.H. (2004) *Effect of Completion Level of Owner's Basic Design in Design-Build Projects*, Master degree thesis, department of construction engineering, National Kaohsiung First University of Science and Technology, Taiwan.

Cheng, R.T.L. (1995) Design and build-contractor's role. In *Design and Build Projects-International Experiences, International Congress on Construction*, *5-6 October, Singapore,* 232-241.

China Construction Industry Association (CCIA) (2006) Web page available from World Wide Web: <http://www.zgjzy.org > visited April 2007.

China Exploration and Design Association (2002-2008) Web page available from World Wide Web: <http://www.chinaeda.org> also available in <http://www.china-epc.com> visited April 2008

Chow, L.K. (2005) *Incorporating fuzzy membership functions and gap analysis concept into performance evaluation of engineering consultants – Hong Kong study*, Unpublished PhD thesis, Department of Civil Engineering, The University of Hong Kong, HKSAR

Chow, L.K. and Ng, S.T. (2007) A fuzzy gap analysis model for evaluating the performance of engineering consultants, *Automation in Construction,* 16, 425-435.

CIOB (1988) *Code of Estimating Practice, Supplement No.2: Design and Build*. The Gresham Press, London.

Civanlar, M.R., and Trussel, H.J. (1986) Constructing membership functions using statistical data. *Fuzzy Sets and Systems*, 18(1), 1-13

Cook, M. (2003) *The Design Quality Manual-improving building performance*, Blackwell, Oxford

Construction Times (2003-2008) Web page available from World Wide Web: < http://www.jzsbs.com/htm_60/phb-001.htm > visited April 2008

Corning, P.A. (1998) Complexity is just a word. *Journal of Technological Forecasting and Social Change*, 58

Cross, V.V., and Sudkamp, T.A. (2002) *Similarity and compatibility in fuzzy set theory: assessment and application*, Heidelbey, New York.

Cushman, R.F., and Loulakis, M.C. (2001) *Design-build Contracting Handbook*, Aspen Law and Business, New York.

Dawson, M.T., Brucker, P. S. (2001) The utility of Delphi method in MFT research. *The American Journal of Family Therapy*, 29, 125-140

Deakin, P. (1999) Client's local experience on design and build projects. *Seminar Proceedings on Design and Build Procurement System*, Construction Industry Training Authority, 14 January, 1999, Hong Kong, 11-15

DeCoster, J. (1998) *Overview of Factor Analysis.* Web page available from World Wide Web: < http://www.stat-help.com/notes.html> visited April 2009

Demsetz, H. (1982) Barriers to entry. *American Economic Review*, 72, 139-152.

Design-Build Institute of America (DBIA) Web page available from World Wide Web: <http://www.dbia.org> visited April 2007

Dickinson, V. (2006) *Future profitability and growth, and the roles of firm life cycle and barrier to entry*. University of Wisconsin-Madison, U.S.

Doke, E.R. and Swanson, N.E. (1995) Decision variables for selecting prototyping in information systems development: A Delphi study of MIS managers. *Information and Management*, 29, 173-182.

Doyle, A. and Hughes, W. (2000) The influence of project complexity on estimating accuracy. *Association of Researcher in Construction Management, 16th Annual Conference 2000 September 6-8*, Glasgow Caledonian University, 623-634

Dukes, K.A. (2005), *Likert Scale-Standard Article*, Stoneham, MA, USA.

Engineering News Record (2003-2008) Web page available from World Wide Web: < http://enr.construction.com/Default.asp> visited May 2008.

Ernzen, J. J. and Schexnayder, C. (2000) One company's experience with design-build: labor cost risk and profit potential. *Journal of Construction Engineering and Management*, 126 (1), 10-14.

Faulkner D. (2002) *Strategy: critical perspectives on business and management, volume 3*. Routledge, London.

Federal Highway Administration of the U.S. Department of Transportation (2006) *Design-build Effectiveness Study*. Available at website <http://www.fhwa.dot.gov/reports/designbuild/designbuild0.htm> visited by May 2008.

Flaherty, T. B., Honeycutt, E. D., Jr., and Powers, D. (1998) Exploring text-based electronic mail surveys as means of primary data collection. *The 1998 Academy of Marketing Science National Conference Proceedings,* 260-64.

Fong, P.S.G., and Choi, S.K.Y. (2000) Final contractor selection using the analytical hierarchy process. *Construction Management and Economics*, 18, 547-557.

Geroski, P., Gilbert, R.J., and Jacquemin, A. (1990) *Barriers to entry and strategic competition,* Harwood academic publishers, Switzerland.

Gorden C.M. (1994) Choosing appropriate construction contracting method. *Journal of Construction Engineering*, 120 (1), 196-210.

Gorsuch, R. L. (1983) *Factor Analysis* (2nd. Ed), Hillsdale, NJ: Erlbaum.

Gransberg, D.D., Koch, J.E., and Molenaar, K.R (2006) *Preparing for design-build projects*. ASCE PRESS, USA.

Gupta, U. (1991) *Validating and verifying knowledge-based systems*, IEEE, Computer Science Press, NY.

Hale, D.R., Shrestha P.P, Gibson, G.E., and Migliaccio, G.C. (2009) Empirical comparison of design/build and design/bid/build project delivery methods. *Journal of Construction Engineering and Management*, 135(7), 579-587

Haque, M. E., Alkaabi, N., and Arosha, D.S. (2001) Selection of a right project delivery system: a tabular knowledge base approach. *Proceedings of the Third International Conference on Construction Project Management*, 29-30 March 2001, Singapore, 471-480.

Harrigan, K.R. (1981) Barriers to entry and competitive strategies. *Strategic Management Journal*, 2(4), 395-412.

Harris, F., Mccaffer, R. (1995) *Modern Construction Management*, BSP Professional Books, Oxford.

Harris, G.S. (1999) The significance and promotion of good design in design and construction civil engineering projects. *Seminar Proceedings on Design and Build Procurement System*, Construction Industry Training Authority, 14 January 1999, Hong Kong, 11-15.

Hay, D.A., and Morris, D.K. (1991) *Industrial Economics and Organization: Theory and Evidence*, Oxford University Press, New York.

Hofer, C.W. (1975) Toward a contingency theory of business strategy. *Academy of Management Journal*, 18, 784–810.

Hsu, H. M., and Chen, C. T. (1994) Fuzzy hierarchical weight analysis model for multi-criteria decision problem. *J. Chinese Inst. Indust. Engs.*., 11(3) 129–136.

Hughes, W. Hillbrandt, P., and Kwawu, W. (2006) *Procurement in the construction industry*. Taylor & Francis, London and New York.

Huse J. A. (2002) Understanding and Negotiating Turnkey and EPC contracts, 2nd Edition, Sweet & Maxwell Ltd., London

Janssens D.E.L (1991) *Design-Build Explained*, Macmillan Education Ltd, London.

Johnson, D. and King, M. (1988) *Basic Forecasting Techniques*, Butterworths, London.

Jones T. (1980) *Options for the future: A Comparative Analysis of Policy Oriented Forecast,* Praeger Publisher, New York

Kaiser, H. F. (1974) An index of factorial simplicity. *Psychometrika*, 39, 31–36.

Karakaya, F. and Stahl, M.J. (1989) Barriers to entry and market entry decisions in consumer and industrial goods markets. *Journal of Marketing*, 53, 80-91.

Kauffman, S. A. (1995) *At Home in the Universe The Search for the Laws of Self-organization and Complexity*. Oxford University Press, London.

Keppel, G. and Wickens, T.D. (2004) *Design and analysis: A researchers handbook* (4rd Edition), Upper Saddle River, New Jersey.

Klir, G.J. and Yuan, B. (1995) *Fuzzy set and fuzzy logic*, Prentice Hall PTR, New Jersey.

Kometa, S., Olomolaiye, P.O. and Harris, F.C. (1995). An evaluation of clients' needs and responsibilities in the construction process. *Engineering, Construction and Architectural Management*, 2(1), 57-76.

Konchar, M. and Sanvido, V. (1998) Comparison of U.S project delivery systems. *Journal of Construction Engineering and Management* ASCE, 124(6), 435-444

Lam, E.W.M., Chan, A.P.C, and Chan, D.W.M. (2008) Determinants of successful design-build projects. *Journal of Construction Engineering and Management*, 134(5), 334-341.

Lawson, B. (2006) *How Designers Think--The design process demystified*, Architectural Press, Oxford.

Leung, K.S. (1999) Characteristics of design and build projects. *Seminar Proceedings on Design and Build Procurement System*, Construction Industry Training Authority, 14 January, 1999, Hong Kong, 1-10.

Ling, F.Y.Y., and Liu, M. (2004) Using neural network to predict performance of design-build projects in Singapore. *Building and Environment*, 39 (2004), 1263-1274.

Ling, F.Y.Y., Chan, S.L., Chong, E., and Ee, L.P. (2004) Predicting Performance of Design-Build and Design-Bid-Build Projects. *Journal of Construction Engineering and Management, ASCE,* 130 (1), 75-83.

Linstone, H.A., Turoff, M (1975) The Delphi method: Techniques and applications. Reading, MA: Addison-Wesley.

Loulakis, M.C. (2003) *Design-build for the public sector*, ASPEN publishers, N.Y.

Love, P.E.D., Skitmore, M., and Earl, G. (1998) Selecting a suitable procurement method for a building project. Construction Management and Economics, 16, 221-233.

Ludwig, B. (2001). Predicting the future: Have you considered using Delphi methodology? *Journal of Extension*, 35(5).

Luu, D.T., Ng, S.T. and Chen, S.E. (2005) Formulating procurement selection criteria through case-based reasoning approach. *Journal of Computing in Civil Engineering*, 19(3), 269–76.

Mangione, T.W. (1995) *Mailed survey: Improving the quality*, Sage Publications Ltd., California, U.S.

Mann, H.M. (1966) Seller concentration, barriers to entry and rates of return in thirty industries 1950-1960. *Review of Economics and Statistics*, 48(3), 296-307

Manoliadis, O., Tsolas, I. and Nakou, A. (2006), Sustainable construction and drivers of change in Greece: a Delphi study. *Construction Management and Economics*, 24(2), 113-120

Mansfield, E., Schwartz M., and Wagner, S. (1981) Imitation Costs and Patents: An Empirical Study. *Economic Journal*, 91 (December), 907–918.

Martino, J. (1973) *Method of Technological Forecasting, Assessing the Future and Policy Planning*, Gordon and Breach Science Publisher, New York.

Masini, E. (1993) *Why Future Studies?* Grey Seal, London.

Masterman, J.W.E. (1992) *An introduction to Building Procurement Systems 1st Edition,* E&FN Spon, London.

Masterman, J.W.E. (2002) *Introduction to Building procurement systems 2nd Edition*, SPON PRESS, London and New York.

Masterman, J.W.E and Gameson, A.R. (1994) The selection of building procurement systems by client organizations. In *Proceedings of the 10th Annual ARCOM Conference*, Loughborough University of Technology, 650–659

McElhiney R., Demkin J.A. (2006) *The Architect's Handbook of Professional Practice (13th Edition)-building design,* American Institute of Architecture (AIA), U.S.

McManamy, R. (1994) Design-Build Goes Back to the Future. *Engineering News Record*, 233(1), 26-28.

Ministry of Construction of the People's Republic of China (2000, 2003, 2006) Web page available from World Wide Web: <http://www.cin.gov.cn > visited April 2007

Mo, J.K.W. and Ng, L.Y. (1997) Design and build procurement method in Hong Kong-An overview. In CIB W92 preceding *Procurement-A Key to Innovation, Canada, 20-23 May 1997, The University of Montreal, 453-462.*

Mogaibel, H. (1999) Project delivey systems of mining projects, *CEM 600Master of Engineering Report*, King Fahd University of Petroleum and Minerals, Saudi Arabia

Molenaar, K.R., Songer, A.D. (1998) Model for public sector design-build project selection. *Journal of Construction Engineering and Management* ASCE, 124(6), 467-479.

Molenaar, K.R., Songer, A.D., and Barash, M. (1999) Public sector design/build evolution and performance. *Journal of Management in Engineering*, 15 (2), 54-62.

Molenaar, K.R., and Gransberg, D.D. (2001) Design-builder selection for small highway project. *Journal of Management in Engineering,* 17(4), 214-223.

Moore, C.M. (1987) *Group technique for idea building*, SAGA Publications, California

National Bureau of Statistics of China (2007,2008) Web page available from World Wide Web: <http://www.stats.gov.cn> visited September 2009

Natkin, K. H. (1994). Legal aspects of design/build. *Architecture: The AIA Journal*, 83(9), 125-127.

Ndekugri, I. and Turner, A. (1994) Building procurement by design and build approach. *Journal of Construction Engineering and Management*, 120(2)

Ng, S.T., Luu, D.T., Chen, S.E., and Lam, K.C. (2002) Fuzzy membership functions of procurement selection criteria. *Construction Management and Economics,* 20, 285-296.

Niskanen, V.S. (2004) *Soft computing methods in human science*s, Springer, New York.

Norusis, M.J. (1992) *SPSS for Windows*, Professional Statistics, Release 5, SPSS Inc., Chicago.

O'Keefe, R.M., Balci, O., and Smith, E.P. (1987) Validating expert system performance. *IEEE Expert*, winter, 81-89.

Opdenakker, R. (2006) Advantages and Disadvantages of Four Interview Techniques in Qualitative Research. *Forum: Qualitative Social Research*, 7 (4).

Oster, S. (1990) *Modern Competitive Analysis*, Oxford University Press, New York.

Outhred, G.P. (2001) The Delphi method: a demonstration of its use for specific research types, In *Kelly, John and Hunter (Ed.), COBRA 2001: Proceedings of the RICS Foundation, Construction & Building, 3rd-5th September 2001,* Glasgow Caledonian University, Glasgow, U.K.

Palaneeswaran, E., and Kumaraswamy, M.M. (2000) Contractor selection for design/build projects. *Journal of Construction Engineering and Mangement* ASCE, 126(5), 331-339.

Pearson, M., and Skues, D. (1999) Control of projects implemented through design and build contracts. *Seminar Proceedings on Design and Build Procurement System*, Construction Industry Training Authority, 14 January, 1999, Hong Kong, 49-60.

Porter, M. E. (1980) *Competitive Strategy: Techniques for analyzing industries and competitors*, Free Press, New York.

Puerto, C.L.D, Gransberg, D.D, and Shane, J. S. (2008) Comparative analysis of owner goals for design/build projects. *Journal of Management in Engineering*, 24(1), 32-39

Quatman, G.W. (2001) *Design-Build for the Design Professional,* Aspen Law & Business, Geithersburg

Quatman, G.W. and Dhar, R. (2003) *The Architect's Guide to Design-Build Services*, John Willey and sons, Inc. Hoboken, New Jersey

Rosenbaum, D. B. (1995) Can't we all just get along? *Engineering News Record*, 235(16), 13.

Rowe, G., Wright, G. (1999) The Delphi Technique as a Forecasting Tool: Issues and Analysis. *International of forecasting*, 15(4): 353-375.

Rowlinson, S. (1997) Procurement systems: the view from Hong Kong. In *Proceeding of CIB W92 Procurement—A key to innovation*, 20-23 September, University de Montreal, Montreal, 665–672.

Rowlinson, S. and Mcdermott, P. (1999) *Procurement systems*, Taylor & Francis, London.

Schmalensee, R. (1983) Advertising and entry deterrence: An exploratory model. *Journal of Political Economics,* 90, 636-653.

Schmidt, R.C. (1997), Managing Delphi survey Using Nonparametric Statistical Techniques. *Decision Science*, 28(3): 763-774.

Schonlau, M., Fricker R.D., and Elliott M. N. (2002) *Conducting Research Surveys via E-mail and the Web*, RAND corporation: CA

Shepherd, W.G (1975) *The Treatment of Market Power: Antitrust, Regulation, and Public Enterprise*, Columbia University Press: New York.

Siegfried, J.J., and Evans, L.B. (1994) Empirical studies of entry and exit: a survey of the evidence. *Review of Industrial Organization,* **2**, 121–155.

Singn, D., and Tiong R.L.K. (2005) A Fuzzy Decision Framework for Contractor Selection. *Journal of Construction Engineering and Management*, 131(1), 62-70.

Songer, A.D., and Molenaar, K.R. (1997) Project Characteristic for Successful Public-Sector Design-Build. *Journal of Construction Engineering and Management,* ASCE, 123(1)

Songer, A.D., Molenaar, K.R. and Robinson, G.D. (1997) Selection factors and success criteria for the design-build in U.S and U.K. Web page available from World Wide Web: < http://www.colorado.edu/engineering/civil/db/papers/usuk/ > visit July 2009.

Stigler, G.J. (1968) *The Organization of Industry*, Richard D. Irwin, Homewood, IL.

Stone, F.L., and Busby D.M. (1996) *The Delphi Method, Research Methods in family therapy*. Guildford, New York.

Tam, C.M. (2000) Design and build on a complicated redevelop project in Hong Kong: the Happy Valley Racecourse redevelopment. *International Journal of Project Management*, 18, 125-129

Tatikonda, M. and Rosenthal, S. (2000) Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on engineering management*, 47 (1), 74-87.

Thompson, A. (1990) *Architectural Design Procedures*, Edward Arnold, Great Britain

Twomey, T. R. (1989) *Understanding the legal aspects of design-build*, R. S. Means Co., Kingston, MA.

Triantaphyllou, E (2000) *Multi-criteria decision making methods: A comparative study*. Kluwer Academic Publisher, MA, USA.

Triantaphyllou, E., and Lin, C.T. (1996) Development and evaluation of five fuzzy multi-attribute decision-making methods. *International Journal of Approximate Reasoning*, 14, 281–310.

Turner, DF (1995). *Design and build contract practice, 2nd ed*., Longman, London

Walker D. and Hampson K. (2003) *Procurement strategies: a relationship-based approach*, Blackwell Science, Oxford, 2003

Wang, J., and Bai, S.J. (2008) Risk investigation based on EPC project contract model. *Machinery*, 46 (9), 96-100.

Wang Y.S., Chen H.Y, Shen L.Y., and Zhang Y. (2008) Analysis on the Critical Factors of Over-time and Over-pay Problems for Government Engineering Project Construction, Construction Economy, 2008(7), 76-79.

Wantanakorn, D. (2002) *Project network complexity*, Construction Management Group, Thammasat University, Thammasat, Thailand

Weber, R.P. (1990) *Basic content analysis* (2nd edition). Sage Publication, CA, U.S.

Williams, T.M. (1999) The need for new paradigms for complex projects. *International Journal of Project Management*, 17(5), 269-273.

Xia, B., and Chan A.P.C. (2008) The investigation of design-build variants in the construction market of the People's Republic of China. *First International Conference on Construction In Developing Countries (ICCIDC–I), August 4-5, 2008, Karachi, Pakistan*

Xia, B., Chan, A.P.C (2008) Review of the design-build market in the People's Republic of China, *Journal of Construction Procurement*, 14 (2), 108-117.

Xun, Z. Y. (2003) Thought and suggestion on the development of design-build system. *Construction Economy,* 248 (6), 16-19.

Yager, R.R.(1982) *Fuzzy Sets and Possibility Theory*, Pergamon Press, Oxford.

Yang, G.B. (1998) Barriers to entry and Industrial performance in China. *International*

Review of Applied Economics, 12(1), 39-51.

Yang, Y.Q., Wang, S.Q., Dulaimi, M., Low, S.P. (2003) A fuzzy quality function deployment system for buildable design decision-makings. *Automation in Construction*, 12(4), 381-93.

Yates, J.K. (1995) Use of Design/Build in the E/C industry. *Journal of Management in Engineering,* 11 (6), 33-39

Yeung, J.F.Y. (2007) *Developing a partnering performance index for construction projects—A fuzzy set theory approach*, PhD thesis in the Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong.

Zadeh, L. (1965) Fuzzy sets, *Information Control*, 8, 338-353.

Zheng, L. and Cheng, H. (2004) Difficulties for design-build contractors. *Construction Economy*, 8, 13-16.

Ziglio E. (1996). *The Delphi method and its contribution to decision making, Gazing into the oracle: The Delphi method and its application to social policy and public health,* Jessica Kingsley Publisher, London.

Zimmermann, H.J. (2001) *Fuzzy Set Theory and Its Application*, Kluwer Academic Publishers, London.

Zin, R.M., Nesan, L.J., Mohammed, A.H. (2004) Constructability assessment framework. *Journal of Building and Construction Management*, 9(1), 44-58.