The Hong Kong Polytechnic University

Department of Building and Real Estate

Developing a Partnering Performance Index (PPI) for Construction Projects – A Fuzzy Set Theory Approach

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A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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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

Research into performance measures for partnering projects in construction becomes vital because an increasing trend of client organisations has been observed to adopt partnering approach to their building and construction projects worldwide over the last decade. However, few, if any, comprehensive and systematic research studies focus on developing a comprehensive, objective, reliable and practical performance evaluation model for partnering projects. The aim of this research study is to develop a model using the ***Delphi Survey Technique*** and the ***Fuzzy Set Theory*** for objectively, reliably and practically measuring the partnering performance of construction projects in Hong Kong. Based on a consolidated conceptual framework encompassing 25 performance measures for partnering projects developed from literature review, a Partnering Performance Index (PPI), which is composed of seven weighted Key Performance Indicators (KPIs), has been generated by conducting 4 rounds of Delphi questionnaire survey with 31 construction experts in Hong Kong. The seven most important weighted KPIs were: (1) Time Performance, with the weighting of 0.167; (2) Cost Performance, with the weighting of 0.160; (3) Top Management Commitment, with the weighting of 0.150; (4) Quality Performance, with the weighting of 0.143; (5) Trust and Respect Performance, with the weighting of 0.143; (6) Effective Communications Performance, with the weighting of 0.131; and (7) Innovation and Improvement, with the weighting of 0.106. The weighting for each of the seven selected KPIs is calculated by the mean ratings of a particular KPI divided by the summation of the mean ratings of all the selected KPIs. The PPI can assist in

developing a benchmark for measuring the partnering performance of construction projects in Hong Kong.

However, it is likely that different assessors may have their own semantic interpretation on each KPI. In order to avoid any discrepancies in interpreting the meaning of each KPI and provide objective evaluation result based on quantitative evidences, a set of Quantitative Indicators (QIs) has been established by firstly conducting 5 structured face-to-face interviews with leading industrial practitioners in Hong Kong and subsequently 2 rounds of Delphi questionnaire survey with the same group of panel experts in Hong Kong. The QIs identified with the highest mean ratings for each of the seven most important weighted KPIs were respectively found to be: (1) 'Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time'; (2) 'Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost'; (3) 'Percentage of Top Management Attendance in Partnering Meetings'; (4) 'Average Number of Non-conformance Reports Generated Per Month'; (5) 'Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect Performance by Using a 10-point Likert Scale'; (6) 'Perceived Key Stakeholders' Satisfaction Scores on Effective Communications Performance by Using a 10-point Likert Scale'; and (7) 'Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost'. By incorporating the QIs into the evaluation process, different assessors could perform their evaluation process based on quantitative evidences.

However, the establishment of a set of QIs cannot fully tackle the subjectivity of performance evaluation. For the sake of rectifying this deficiency, this research study has further applied a ***Fuzzy Set Theory approach*** through conducting an empirical questionnaire survey with the same group of panel experts in Hong Kong to establish a well-defined range of Quantitative Requirements (QRs) for each QI measured at five different performance levels, namely, 'poor', 'average', 'good', 'very good', and 'excellent'. By using the ***Modified Horizontal Approach***, Fuzzy Membership Functions (FMFs) have been constructed through ***Constrained Regression Line*** with the ***Bisector Error Method***. The proposed performance evaluation model is not only novel in nature but it can also improve the objectivity, reliability and practicality of performance evaluation for partnering projects.

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5. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. Establishing quantitative indicators for measuring the partnering performance of construction projects in Hong Kong, *Construction Management and Economics. (IN PRESS)*

Refereed Journal Papers (Under Review)

1. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. Comparing the quantitative indicators for measuring construction partnering/alliancing success in Hong Kong and Australia, submitted to *Journal of Construction Engineering and Management, ASCE. (UNDER REVIEW)*

2. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. Developing a Performance Index (PI) for relationship-based construction projects in Australia: A Delphi study, submitted to *Journal of Management in Engineering, ASCE. (UNDER REVIEW)*

3. Yeung, J.F.Y., Chan, A.P.C., Chan, D.W.M. and Li, L.K. A Fuzzy Set Theory Approach for measuring the partnering performance of construction projects in Hong Kong, submitted to *Journal of Construction Engineering and Management, ASCE. (UNDER REVIEW)*

Refereed Journal Papers (Pending Submission)

1. Chan, A.P.C., Chan, D.W.M., Lam, P.T.I., Fan, L.C.N., Sidwell, T.A.C. and Yeung, J.F.Y. Evaluating national culture from the eastern and western perspectives, to be submitted to *Engineering, Construction and Architectural Management.*

2. Chan, A.P.C., Chan, D.W.M., Lam, P.T.I., Fan, L.C.N., Sidwell, T.A.C. and Yeung, J.F.Y. A critical review: organisational culture, to be submitted to *International Journal of Project Management.*

3. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. Partnering and alliancing: are they synonyms or antonyms? Analysing these terminologies by a Wittgenstein's family-resemblance concept, submitted to *International Journal of Project Managemen.t*

4. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. An overview of the application of "Fuzzy" theories in construction management research, submitted to *Journal of Management in Engineering, ASCE. (UNDER REVIEW)*

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1. Chan, A.P.C., Chan, D.W.M., Fan, L.C.N., Lam, P.T.I. and Yeung, J.F.Y. (2005). Project partnering in Hong Kong - A case study of a prestigious office development

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11. Yeung, J.F.Y., Chan, A.P.C. and Chan, D.W.M. (2007). Developing a conceptual framework for identifying Key Performance Indicators (KPIs) for partnering projects in construction, *Proceedings of The 32nd Australasian Universities Building Educators Association (AUBEA) Conference 2007*, Melbourne, Australia, 3-6 July 2007.

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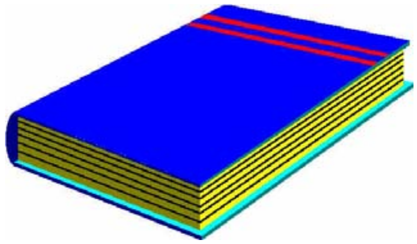

CHAPTER 1 INTRODUCTION

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1.1 BACKGROUND OF THE RESEARCH

A number of research studies on investigating the benefits of adopting partnering (Construction Industry Institute, 1991 and 1996; Cowan et al, 1992; Abudayyeh, 1994; Harback et al, 1994; Lazar, 1997; Thompson and Sanders, 1998; Bayliss, 2000 and 2002; Black et al, 2000; Li et al, 2001; Chan et al, 2003a and 2006), critical success factors for achieving good partnering performance (Construction Industry Institute, 1991; Moore et al, 1992; Mohr and Spekman, 1994; Construction Industry Board, 1997; Bresnen and Marshall, 2000a; Lazar, 2000; Cheng et al, 2000; Black et al, 2000; Chan et al, 2002a, 2004a, 2006 and in press; Wong and Cheung, 2005), difficulties in partnering implementation (Cook and Hancher, 1990; Construction Industry Institute, 1991 and 1996; Sanders and Moore, 1992, Albanese, 1994; Larson, 1995; Larson and Drexler, 1997; Love, 1997; Bresnen and Marshall, 2000b; Chan et al, 2003b), process, conceptual and theoretical models of construction partnering (Latham, 1994; Abudayyeh, 1994; Crowley and Karim, 1995; Crane et al, 1997; Cheng and Li, 2001 and 2004b) have been ubiquitous in the construction management discipline over the past decade. In fact, an increasing number of client organizations have been observed to introduce partnering approach to their building and construction works both locally and worldwide during the last decade (Chan et al, 2002a). With the merits that partnering approach derives, research into performance measures for partnering projects in construction becomes essential because it can assist in developing a benchmark for measuring the partnering performance of construction projects. However, although some related studies and papers have been documented on this research area (Crane et al, 1999; Chan et al, 2001, 2004a and 2006; Cheung et al, 2003; Bayliss et al, 2004; Lo et al, 2006), few, if not none, comprehensive and systematic studies focus on formulating a comprehensive, objective, reliable and practical performance evaluation model for partnering projects. Construction senior executives and project managers may find it difficult to objectively evaluate the partnering performance of their construction projects.

1.2 RESEARCH PROBLEMS AND QUESTIONS

Having conducted a comprehensive literature review on construction partnering and alliancing, a research problem was identified as ‘there is a need to establish a comprehensive, objective, reliable and practical performance evaluation model for partnering projects’. By establishing such a model, construction industry professionals could collectively set benchmarks for delivering partnering projects within an organisation and the constructon industry so that this can help improve the partnering performance of construction projects through proper project monitoring and control. Ultimately it can help improve the efficiency of the construction process not only in Hong Kong but also worldwide. This means that although the PPI was developed locally in Hong Kong, the research method could be replicated in other parts of the world to produce similar indices for international comparisons. Such an extension would aid the understanding of managing partnering projects across different geographic locations. In order to establish an objective and comprehensive performance evaluation model, the following questions of "WHAT" and "HOW" are to be addressed so that the objectives of establishing an evaluation model for measuring the partnering performance of construction projects can be achieved:

(1) What are the most important KPIs for measuring construction partnering projects?

(2) How to measure the KPIs of partnering projects objectively, reliably and practically?

1.3 RESEARCH AIM AND OBJECTIVES

This PhD research study aims to set up a comprehensive, reliable, objective and practical performance evaluation model to evaluate the performance of partnering projects through ***Delphi survery technique*** and ***Fuzzy Set Theory***. The specific objectives are to:

(1) define and compare the definitions of construction partnering and alliancing;

(2) review 'Fuzzy' research in construction management;

(3) develop a conceptual framework for identifying Key Performance Indicators (KPIs) for measuring the performance of partnering projects;

(4) compile a Partnering Performance Index (PPI) for construction projects in Hong Kong;

(5) establish appropriate Quantitative Indicators (QIs) for measuring the performance of partnering projects in Hong Kong; and

(6) determine the Fuzzy Quantitative Requirements (FQRs) for each Quantitative Indicator (QI).

1.4 SCOPE OF THE STUDY

This research focuses on studying partnering projects undertaken in Hong Kong. Partnering is taken as a generic term here referring to both project partnering and strategic partnering, with both structured and unstructured approach. 'Structured' approach means that there are a number of partnering workshops when implementing partnering approach while 'unstructured' approach means that there is just partnering spirit, but no partnering workshops when partnering is adopted in a project. A significant difference between project partnering (relationship established for a single project) and strategic partnering (a long-term commitment beyond a discrete project) is that the former is for a single project (Construction Industry Institute, 1991; Li et al, 2000; McGeorge and Palmer, 2002; Walker et al, 2002) but the latter involves at least two projects (Construction Industry Institute, 1991; Bennett and Jayes, 1998; Li et al, 2000; Cheng and Li, 2004a). In fact, partnering is one kind of relationship contractings, which also include alliancing and joint venture. The reason behind focusing on partnering in this study is mainly because partnering is still dominant in the Hong Kong construction industry when compared with other types of relationship contractings.

1.5 RESEARCH PROCESS

The research process of this study consisted of the following stages: (1) literature review; (2) face-to-face structured interviews; (3) Delphi questionnaire surveys; (4) empirical questionnaire survey; (5) data collection; (6) data analysis, especially on applying Fuzzy Set Theory to establish the Fuzzy Membership Functions and the Fuzzy Quantitative Requirements (FQRs); and (7) verification and validation of the proposed model. The two questionnaire surveys are different in nature in which the Delphi method was used for collecting the data and analyzing the Delphi questionnaire survey while the application of Fuzzy Set Theory was adopted for analyzing the empirical questionnaire survey. However, both of them were undertaken with the same panel of experts. The research process is diagrammatically presented in Figure 2.1. Both qualitative and quantitative measures for establishing the performance evaluation model have been adopted in this study.

1.6 STRUCTURE OF THE THESIS

The structure of the PhD thesis is as follows:

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

Chapter 2 describes the methodologies for the research. Methods of data collection by literature search, face-to-face structured interviews, Delphi questionnaire surveys, and empirical questionnaire survey are explained. Statistical techniques for the research are also introduced.

Chapter 3 makes a significant contribution to define and distinguish between the vague and multifaceted concepts of construction partnering and alliancing by using a Sunflower Model based on the German philosopher Ludwig Wittgenstein's family-resemblance philosophy.

Chapter 4 comprehensively reviews 'Fuzzy' research as applied in the construction management discipline over the past decade. The comprehensive review provided in this chapter polishes the signposts and offers new direction for 'Fuzzy' research and its application in construction.

Chapter 5 develops a conceptual framework of KPIs to evaluate the performance of construction partnering projects based on a comprehensive literature review on performance measures for partnering projects. A consolidated conceptual framework encompassing 25 various measures has been developed, and they are classified into 4 major categories.

Chapter 6 applies the Delphi technique to objectively compile a series of the most important weighted KPIs to assess the performance of partnering projects in Hong Kong based on a previously developed KPIs' consolidated conceptual framework for partnering projects. A formula for calculating the Partnering Performance Index (PPI) for partnering projects in Hong Kong was derived after conducting 4 rounds of Delphi questionnaire survey.

Chapter 7 establishes Quantitative Indicator(s) (QIs) for each of the seven selected weighted KPIs to measure the partnering performance of construction projects. The QIs were identified first by face-to-face structured interviews and subsequently conducting 2 rounds of Delphi questionnaire survey. By doing so, a list of QIs pertinent to the seven selected weighted KPIs for partnering projects has been compiled.

Chapter 8 describes the list of QIs compiled in Chapter 7 and conducts an empirical questionnaire survey to seek experts' expectations on each QI against different performance levels. The Quantitative Requirements (QRs) of each QI pertinent to different performance levels are established by using the Fuzzy Set Theory. The developed performance evaluation model is then verified and validated by face-to-face interviews with construction experts in partnering in Hong Kong.

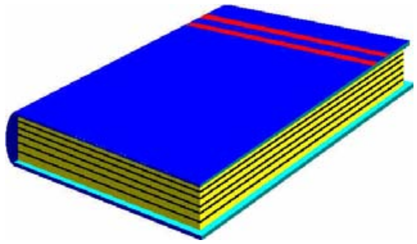
Chapter 9 is the conclusion for the research where the summary of the research, implications of the study and recommendations for future work will be presented.

1.7 SIGNIFICANE AND VALUE OF THE RESEARCH

During the past decade, there has exhibited an increasing trend of client organisations to adopt partnering approach to undertake their building and construction projects. As a matter of fact, research into benefits, critical success factors, difficulties, process, conceptual and theoretical models of construction partnering has become a hot research topic within the construction management discipline in the USA, UK, Australia and Hong Kong. However, few, if not none, comprehensive and systematic research in the area of KPIs for partnering projects has been conducted. Therefore, it is important to conduct research into this gap area. The aim of this research is to develop a comprehensive, objective, reliable and practical performance evaluation model for partnering projects in the Hong Kong construction industry based on a consolidated conceptual framework of KPIs. With the development of a KPIs' performance evaluation model for partnering projects, a benchmark for measuring the performance of partnering projects can be established. As a result, construction senior executives and project managers can apply it to measure, monitor and improve the performance of their partnering projects. It also provides valuable insights into developing a general and comprehensive base for further research.

1.8 CHAPTER SUMMARY

This introductory chapter outlines the framework for conducting this research study, including (1) background of research; (2) research problems and questions; (3) research aim and objectives; (4) scope of study; (5) research process; and (6) significance and value of the research.



CHAPTER 2 RESEARCH METHODOLOGY

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2.1 INTRODUCTION

This chapter first provides an overview of different types of scientific research methodology available for construction management discipline, followed by depicting the approaches and methods adopted in this research study. A comprehensive investigation of relevant research philosophy and methodology is also conducted to find out the most appropriate research method and justify its validity. A number of systematic research methodologies and strategies are utilised and described in this chapter, including: (1) literature review; (2) content analysis; (3) face-to-face interviews with field experts; (4) Delphi surveys; (5) empirical questionnaire survey; and (6) Fuzzy Set Theory.

2.2 OVERVIEW OF RESEARCH METHODOLOGY

Fellows and Liu (1997) stated that research methodology refers to the principles and procedures of logical thought which are applied to a scientific investigation while research method concerns the techniques which are available and those which are actually employed in a research project. They also stated that research is a completed-closed system while Sekaran (1999) viewed that a scientific research should include the features of purpose, rigour, testability and repeatability which indicate a true state of affairs, precision and confidence, objectivity, and ability to generalise. Many researchers have shown interest on the study of different kinds of research methodology, knowledge acquisition processes and international trends in the field of construction management (Grogono and Nelson, 1982; Leedy, 1993; Edum-Fotwe et al, 1996; Fellows and Liu, 1997; Walker, 1997; Kumaraswamy et al, 1997; Loosemore, 1999; Chan et al, 2004).

Eight key characteristics of research were identified by Leedy (1993), who stated that a research: (1) begins in a researcher's mind who has a curious, observant and inquisitive attitude to examine an existing problem; (2) demands the researcher to articulate a research problem for the examining process; (3) demands a specific research method; (4) generally recognises that a big problem can be divided into several problems that are easier to be handled; (5) is generally guided by a number of hypotheses; (6) accepts certain critical assumptions that are generally understood and essential for the research process to proceed; (7) countenances only specific and measurable data as admissible in tackling the problem; and (8) is a helical process.

Clearly, the selection of a suitable research methodology is crucial to the success of a research project. It is generally understood that a research should follow a reasonable and logical procedure. Sekeran (1992) suggested a general model depicting the stepwise research process for basic and applied research. The steps include: (1) observation to identify areas of research interest; (2) preliminary data collection through literature review and interviews; (3) definition of a research problem; (4) theoretical framework; (5) formulation of research hypothesis; (6) scientific research design of methods for data collection and analysis; (7) data collection, analysis, and interpretation of results; and (8) deduction to examine whether the hypothesis is substantiated or the research question is answered.

2.3 RESEARCH METHODS FOR CONSTRUCTION MANAGEMENT IN GENERAL

The research of construction management is commonly carried out with four standard methods, including: (1) literature review; (2) case study; (3) interview; and (4) questionnaire survey (Chow, 2005). Fellows and Liu (1997) stated that the selection of an appropriate research method should rely on the scope and depth of a research.

2.3.1 Literature Review

Basically, literature review is the collection of background information of a research study. It aims to consolidate all previous studies related to the research by other researchers and understanding of the current practice (Chow, 2005). A suitable literature review could help the researcher to dig out the research problems. 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.

2.3.2 Case Study

Case study approach facilitates in-depth investigation of particular instances within the research scope. Data could be collected in rawest form and yield deep but narrow results. However, it is of interest to note that resources constraints may limit the number of studies that could be conducted (Fellows and Liu, 1997). A case study should be drawn up explicitly at the beginning of the research and the research design could be tailored within the research period for any changing conditions that the fieldwork throws up. In fact, case studies should strive for a balance between flexibility and selectivity. Flexibility allows issues to be explored when they develop in the data collection phase while selectivity decides on which features would be covered at the research design stage.

2.3.3 Interview

There are three kinds of research interviews, including: (1) structured interviews; (2) semi-structured interviews; and (3) unstructured interviews. A structured interview is conducted with reference to either a questionnaire or pre-designed set of questions. It is worth noting that the issue of personal interaction between the researcher and interviewee during the interviews should be carefully managed. Simister (1995) pointed out that the interview should be conducted with dexterity and care to avoid the collection of useless data. In addition, the interview questions should be designed with thorough thought to avoid any misunderstandings. Appropriate interview techniques should also be adopted so as to achieve the result effectively and efficiently.

2.3.4 Survey

Survey may be generally accepted as the most preferable method in construction management studies because data with standardised form could be collected from samples of a population (Chow, 2005). Therefore, researchers can reach statistical inferences after data analysis. In fact, the statistical inference can move from particular observations of a sample to the wider generalisations of whole population (Oppenheim, 1992).

Conducting surveys for construction management studies have a number of merits because surveys (1) are relatively inexpensive; (2) allow a large number of respondents to be evaluated in a relatively short period of time; (3) allow respondents to have adequate time to answer the questionnaire and look up information if necessary; (4) provide privacy for responding; (5) allow visual data input rather than auditory input solely; (6) allow respondents to answer the questionnaire at their convenience; (7) allow respondents to read and understand the context of a series of questions; and (8) insulate respondents from the expectations of interviewer (Mangione, 1995).

Questionnaire is an effective tool in conducting a survey research for observing and recording data beyond the physical reach of the observer, and for sampling the opinion of individuals in spatially diverse locations. This is because questionnaire is usually designed to get standardized data from the respondents by giving a set of choices for each question for them to select. The questionnaire designed should be unambiguous and easy to answer, and no extensive data collection by the respondents is required before answering. Fellows and Liu (1997) stated that each question should only concern one issue and the answer should be requested in an unthreatening manner.

Although there are numerous merits of conducting questionnaire survey, there are still some limitations for applying this research tool. In fact, only standardised data could be collected which makes the data not readily be connected to other kinds of information. Nevertheless, data and valuable experience often rely on the minds, attitudes, feelings or reactions of the respondents. To address these limitations in this research, structured face-to-face interviews with field experts were employed in order to get the potential QIs as many as possible and these formed a strong basis for developing QIs and fuzzy QRs.

In addition, a possible adverse consequence of using questionnaire survey is the low response rate. It is normally expected to get 25% - 35% of valid response rate for postal questionnaire. Nevertheless, even the expected response rate is difficult to attain. Chan (1998) pointed out that the following aspects should be paid more attention so as to obtain prompt feedback and higher response rate, including (1) clarity and courtesy; (2) questionnaire design should be focused on the specific research objectives; (3) simple expression and ease of understanding; (4) brevity; (5) consistency; (6) a self-addressed return envelope with stamp; and (7) an offer of the result summary of the survey to respondents. In this research study, however, a high response rate of more than 75% was achieved for the four rounds of first Delphi survey, 65% for the two rounds of second Delphi survey and 60% for the empirical questionnaire survey.

2.4 RESEARCH PROCESS FOR THIS STUDY

2.4.1 Research Initiation and Finalisation of Research Topic

Six steps for research initiation were described by Palaneeswaran (2000), including: (1) problem identification and definition; (2) assessment of needs; (3) evaluation of alternatives; (4) development of abstract approach/theoretical framework; (5) verification of the conceptualized abstract approach; and (5) consideration of the value and relevancy of the research.

During the research initiation stage of the study, preliminary study of the construction partnering and alliancing concepts, and the evaluation methods for the performance of partnering/alliancing projects in Hong Kong and Australia were carried out. Useful data was gathered through literature review and initial discussions with research supervisors. A research problem was finally identified as ‘There is a need to establish a comprehensive, reliable, objective and practical performance evaluation model for partnering projects.’ Thus, the aim of this research was finalized ‘to develop a comprehensive, reliable, objective and practical performance evaluation model for partnering projects in Hong Kong’.

2.4.2 Determination of Research Objectives and Strategies

The purpose of this research study is to make a contribution to the knowledge of performance evaluation for partnering projects in order to obtain a more objective, reliable and practical evaluation result. Six research objectives were established accordingly, including:

- defining and comparing the definitions of construction partnering and alliancing (objective 1) through literature review and content analysis;
- comprehensively reviewing the application of Fuzzy Theories in construction management (objective 2) through literature review and content analysis;
- establishment of a conceptual framework of the performance measures for partnering projects (objective 3) through literature review, content analysis and verification;
- development of a series of weighted KPIs (objective 4) through 4 rounds of Delphi questionnaires;
- identification of appropriate Quantitative Indicator(s) (QIs) for each of the most vital weighted KPIs (objective 5) through face-to-face interviews, 2 rounds of Delphi questionnaires and data analysis; and
- development of fuzzy quantitative requirements (FQRs) for each QI (objective 6) through questionnaire survey and data analysis.

2.4.3 Establishment of Scope of Study

As mentioned in Chapter 1, the study aims at developing a comprehensive, reliable, objective and practical performance evaluation model for partnering projects in Hong Kong through ***Delphi Technique*** and ***Fuzzy Set Theory***.

2.4.4 Data and Information Collection

Loosemore (1999) stated that research activities in construction management are often confined to national and/or cultural boundaries. When compared with research exercises in other fields, the level of cross-country research activities in construction management is relatively low due to different reasons, such as lack of information, resources constraints, and confidentiality of sensitive data. In order to achieve sufficient research results, an extensive information mining process has been carried out to explore different kinds of data collection sources. Useful data will be sought through literature review, interviews with field experts from private, public and infrastructure sector organisations, and questionnaire surveys. Conventional means such as postal/fax correspondence, face-to-face interviews, email, and internet-based resources were employed to enhance the efficiency and coverage of the data collection process.

2.4.5 Data Analysis and Consolidation

The large amount of data acquired should be processed through analysing, distilling, consolidating, and benchmarking (Chow, 2005). This can make new contributions to the current performance evaluation methods by (1) consolidating and adding value to the current practice; (2) changing the present method more meaningful and applicable; and (3) developing new theories/framework/guidelines to guide future practice.

2.4.6 Verification and Validation

Chow (2005) stated that verification and validation is an evaluation procedure to examine whether the research procedures are suitable and free of errors, and the new theories/framework/guidelines established from the research could meet the aim and objectives of the research. Basically, this is a justification for its usefulness, practicality and appropriateness of the research.

2.4.7 Dissemination of Research Findings through Publications

Research findings can be disseminated through refereed research publications (i.e. journal articles and conference papers) and the thesis. Essentially, the process encompasses the preparation and correction of drafts, preparation of final drafts and presentations in the thesis and papers. In addition, recommendations and comments by the reviewers of conference and journal papers provide further insights and directions for the research (Chow, 2005).

2.4.8 Flow of Research

The flow of research is summarised in Figure 2.1. The research strategies, research input, and research process employed for the achievement of each of the research objectives are depicted. In Figure 2.1, four research strategies are illustrated, including (1) literature review; (2) face-to-face interviews with field experts; (3) Delphi survey; and (4) empirical questionnaire survey. Data consolidation and statistical analysis are the major mechanisms to process all the input information.

2.5 RESEARCH METHODS EMPLOYED IN THIS STUDY

Before depicting the research methods employed in this study, it should be emphasized that the nature of the research problem is quite subjective and similar research topics were conducted by Crane et al (1999), Cheung et al (2003) and Lo et al (2006).

Crane et al (1999) conducted detailed interviews with 21 successful partnering relationships and then classified partnering measures into three types: result, process and relationship measures. However, no further performance index was developed and appropriate QIs were not identified for assessing the partnering performance of construction projects, thus making benchmarking difficult.

Cheung et al (2003) adopted eight partnering measures suggested by the New South Wales Public Works Department of Australia and developed a Partnering Temperature Index and an IT system was used to measure the performance of partnering projects. However, the weightings by default were treated as equal for each measure.

Lo et al (2006) used a Balanced Scorecard (BSC) approach to measure the partnering project performance in a holistic manner through an extensive literature review and data analysis (principal components factor analysis) through a questionnaire survey. Although it was comprehensive for this approach to assess partnering performance of construction projects in Hong Kong, different industrial practitioners might interpret the same strategic objectives differently. In addition, corresponding weightings were not derived for different strategic objectives, thus making benchmarking difficult as well.

It should be pointed out that these researchers encountered the problem of subjectivity in selecting the most vital KPIs for partnering projects without good resolution methods. In order to deal with the problem of subjectivity in selecting the most important KPIs, developing their appropriate weightings, and selecting the most suitable QIs, the Delphi survey method was used in this research study because it is a highly formalised method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts (Chan et al, 2001b). In fact, other research methods, including literature review, content analysis, and structured face-to-face interviews were also adopted to develop the evaluation performance model for partnering projects in Hong Kong.

Literature review was used because it could consolidate all previous studies related to the research study done by other researchers and understanding of the current practice (e.g. the definitions of construction partnering and alliancing; the application of fuzzy theories in construction management and performance measures for partnering projects). After conducting extensive literature review, both qualitative and quantitative content analyses were used to achieve Objectives 1, 2 and 3. Fellows and Liu (1997) asserted that content analysis is often used to determine the main facets of a set of data, by simply counting the number of times an activity occurs, or a topic is mentioned. The initial step in content analysis is to identify the materials to be analysed. The next step is to determine the form of content analysis to be employed, including qualitative, quantitative or structural; the choice is dependent on the nature of the research project. The choice of categories will also depend upon the issues to be addressed in the research if they are known. In qualitative content analysis, emphasis is on determining the meaning of the data (grouping data into categories) while quantitative content analysis extends the approach of the qualitative form to yield numerical values of the categorized data (frequencies, ratings, ranking, etc) which may be subjected to statistical analyses. Comparisons can be made and hierarchies of categories can be examined.

To achieve Objective 4, four rounds of the first Delphi questionnaire survey were conducted because this method was to solve the problem of subjectivity in selecting the most vital KPIs and developing their appropriate weightings. To achieve Objective 5, five structured face-to-face interviews were conducted to identify the potential QIs as many as possible. Then, two rounds of the second Delphi questionnaire were conducted to select the QIs with the highest mean ratings in terms of importance, measurability and obtainability for each KPI. After that, the performance evaluation model for partnering projects in Hong Kong was established. Each research method is described in details as follows.

2.5.1 Literature Review and Content Analysis

An extensive literature review on partnering and alliancing over the past two decades was first conducted. The specific objective was to investigate how frequent different elements were discussed in construction partnering and alliancing. The German philosopher Ludwig Wittgenstein's family-resemblance approach was applied to cross-reference the result of this quantitative study. The literature was selected from the website of Google Scholar at http://www.scholar.google.com, and the keywords for ‘scanning’ were partnering, project partnering, strategic partnering, alliancing, project alliancing, and strategic alliancing. These terms were well-known and were common in papers on construction partnering and alliancing. Nevertheless, it was felt that too many papers use these terms and some of them may not be directly relevant to the current study. In order to maintain the efficiency and effectiveness of the literature searching process (i.e. searching the largest number of papers with the highest quality but with the least time spent on the searching process), these terms were finally searched with a restricted symbol (“ ”). In details, the searching process is as follows:

- Initially, more than a thousand papers were searched. To narrow down the scale, the restricted symbol (“ ”) was used in order to search for more relevant papers.
- The titles of the articles were scanned with the keywords. In total more than 800 articles were scanned. However, not too many articles that contained one of the keywords in their titles are either ‘genuine’ construction partnering or alliancing papers or closely related papers.
- Important but missed articles were identified from cross referencing of cited studies. Less related articles were excluded. For instance, some papers just included a small section with little significance on partnering and alliancing. These could not be judged to be relevant papers.

Although it would be better to review partnering in other fields, such as manufacturing, retailing, aviation and services, they were not finally reviewed because of their low relevance to construction and time constraints. Finally, a total of 28 relevant and important research reports, books, and articles from scientific journals and conference proceedings on partnering and alliancing in construction were identified. They constituted the empirical base of the study. Both qualitative and quantitative content analyses were used to identify the 14 essential elements of partnering and alliancing because it could help to classify textual material, reducing it to more relevant, manageable bits of data (Weber, 1990). The process in conducting the content analyses in this research was that all the relevant papers were first selected by 'restricted' literature search, followed by marking all the key points/main ideas of each paper manually. Then, similar points/ideas were grouped together and 14 elements in total were finally crystallized from the analysed materials. A combination of literature review, questionnaire survey and factor analysis could have been used to achieve this but this was not pursued because content analysis was believed to be a more comprehensive approach in developing a conceptual framework.

After distinguishing the concepts of partnering and alliancing, a comprehensive literature review was further extended to the applicaton of fuzzy theories in construction management over the past decade. The selection of literature was mainly based on the top quality journals in construction management, which include (1) *Journal of Construction Engineering and Management, ASCE; (2) Construction Management and Economics; (3) Engineering, Construction and Architectural Management; (4) Journal of Management in Engineering, ASCE; and (5) International Journal of Project Management. In addition, three other top journals in construction, including (1) Benchmarking: An International Journal; (2) Building and Environment; and (3)*

Building Research and Information. It is acknowledged that a more extensive review to journals outside the construction management field should have been made if time allows. However, the review is limited to the abovementioned journals because of the time constraint. Keywords for ‘searching’ were ‘Fuzzy Set Theory’, ‘Fuzzy Logic’, ‘Fuzzy Control’, and other ‘Fuzzy’ Concepts. Fifty nine articles containing one of the keywords were identified. Seven of them were subsequently taken out as they were found to be irrelevant.

After conducting the extensive literature review, it has been found that “Fuzzy” research in construction management during the last decade could be divided into three broad fields, including (1) Fuzzy Set Theory; (2) Fuzzy Logic Theory; and (3) Other Fuzzy techniques, with the applications in five main categories, encompassing (1) Performance; (2) Evaluation/Assessment; (3) Modelling; (4) Decision-making; and (5) Others.

A comprehensive and critical review of the literature on perforamnce measures for partnering projects over the last decade was also conducted. The specific objective was to assess how frequent different measures were applied in evaluating partnering in the construction industry. The search included detailed study of 17 Demonstration Projects using partnering approach (24 Demonstration Projects in total) derived from the Hong Kong Demonstration Projects Committee, which was set up by Hong Kong’s leading construction industry professionals in 2003 (Hong Kong Construction Industry: the webstie is http://www.hkci.org).

A total of ten publications (five journal articles, 2 research monographs, 1 consultancy report, and 2 conference papers) on performance measures for construction partnering were identified. They constituted the empirical base of the study.

2.5.2 The Delphi Survey Method

After conducting the comprehensive literature review on performance measures for partnering projects in construction, a conceptual framework to evaluate the performance of partnering projects was developed. Four (4) rounds of Delphi questionnaire survey were then conducted to develop a series of weighted KPIs for measuring the performance of partnering projects. The Delphi approach was chosen because it has been increasingly adopted in many complex areas in which a consensus is needed to be reached (Chan et al, 2001b), for examples: (1) the development of residential areas (Anatharajan and Anataraman, 1982); (2) theory and design application (Corotis et al, 1981); (3) bridge condition rating and effects of improvements (Saito and Sinha, 1991); (4) procurement selection (Chan et al, 2001b); and (5) sustainable development (Manoliadis et al, 2006). The Delphi method is a highly formalised method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts (Chan et al, 2001b). Therefore, it is appropriate to adopt the Delphi method in this study to obtain a series of weighted KPIs to evaluate the performance of partnering projects in construction because it could assist in tackling the problem of subjectivity in selecting the most important KPIs. By doing so, different partnering projects can be assessed and compared objectively based on a composite Partnering Performance Index (PPI) to measure their project performance. Face-to-face interviews were subsequently conducted with leading industrial practitioners to verify the validity of the identified KPIs.

2.5.2.1 Background of Delphi Technique

In fact, the Delphi concept was developed from the American defence industry (Chan et al, 2001b). A study entitled "Project Delphi" was conducted by the Rand Corporation for the US Air Force in the early 1950s related to the use of expert opinion (Helmer 1967a, 1967b; Robinson, 1991). The Delphi method involves the selection of procedures for suitable experts, development of appropriate questions to be put to them, and analysis of their responses (Cabanis, 2001; Outhred, 2001). The process is typically carried out by remote correspondence, such as mailed questionnaires and email, rather than involving face-to-face group discussions. This enables all Delphi survey participants to respond individually and reduces the impact of group dynamics on the resulting consensus (Manoliadis et al, 2006). The method is based on the judgement of the selected experts, and does not rely on previous historical data being available. In addition, the method is typically intended to provide a judgement or opinion on the specific subject area, rather than producing a quantifiable measure or result. Because of this, the method can easily work well in new areas that are frequently subject to unpredictable forces, which are not easily quantifiable in most of the cases (Manoliadis et al, 2006).

Chan et al (2001b) considered that the Delphi method can be characterised as a method for structuring a group communication process so that the process is effective in allowing a group of individuals as a whole to deal with complicated problems. Delphi is primarily a communication device that is applied when the consensus of experts on an uncertain issue, often intangible, is desired (Linstone and Turoff, 1975). It is generally conducted by several rounds interspersed with group opinion and information feedback in the form of relevant statistical data. The three key features of the Delphi method, as mentioned by Dickey and Watts (1978) and Adnan and Morledge (2003), are (1) anonymity, (2) iteration with controlled feedback, and (3) statistical response. Generally, the number of rounds ranges from 2 to 7 and the number of participants varies between three and fifteen (Rowe and Wright, 1999; Adnan and Morledge, 2003). The desired outcome is that, by using an iterative forecasting procedure, on reaching the final round, the experts will have achieved unanimity on the issues put before them (Manoliadis et al, 2006). The Delphi approach also offers a fringe advantage in situations where it is vital to define areas of uncertainty or disagreement among experts (Chan et al, 2001b). In these examples, Delphi can highlight topics of concern and assess uncertainty in a quantitative manner. The major difficulties of Delphi, however, lie in maintaining high level of response and in reaching and implementing a consensus (Robinson, 1991; Chan et al, 2001b).

2.5.2.2 Format of Delphi Rounds

Manoliadis et al (2006) stated that the key issues in preparing a Delphi study were: (1) the definition of experts and their selection; (2) the number of rounds; and (3) the questionnaire structure (i.e. number of questions) in each study round. The Delphi method used in this first Delphi survey comprised 4 rounds. In the first round of the first Delphi questionnaire, the respondents were asked to select a minimum of 5 to a maximum of 10 KPIs from a consolidated conceptual framework of measuring partnering success. In Round 2 of the first Delphi survey, respondents were provided with the consolidated results from round 1 and were invited to reconsider their options to see if they would like to adjust their original choice. In the third round of questionnaire, respondents were requested to provide ratings on the seven selected KPIs (the seven KPIs have been selected for further study based on a criterion that each of them were selected by at least 50% of experts) based on a 5-point Likert scale to evaluate the performance of partnering projects. In Round 4 of the first Delphi questionnaire, respondents were provided with the consolidated results from Round 3. They were asked to reconsider the ratings of each of the seven selected KPIs to see if they would like to adjust their original ratings in light of the consolidated result.

2.5.2.3 Selection of Expert Panel

The success of Delphi method depends principally on the careful selection of the panel members (Chan et al, 2001b). A group of experts was selected to determine the KPIs of partnering projects in Hong Kong. As the information solicited requires in-depth knowledge and sound experience about KPIs for partnering projects, a purposive approach was adopted to select this group of experts (Bryman, 1996; Morgan, 1998; Edmunds, 1999; Chan et al, 2001b; Manoliadis et al, 2006). The following 3 criteria were devised in order to identify eligible participants for this study:

Criterion 1: Having extensive working experience in partnering projects in Hong Kong.

Criterion 2: Having current/recent and direct involvement in the management of partnering projects in Hong Kong.

Criterion 3: Having a sound knowledge and understanding of partnering concepts.

In order to obtain the most valuable opinions, only practitioners and academics who met all the selection criteria were considered. A total of 39 practitioners and academics were identified and invited to participate in this study. However, 8 of them did not participate because of their heavy workload so ultimately 31 experts were involved in the survey. The selected experts represented a wide spectrum of construction professionals in Hong Kong, with 18 from the private sector, 8 from the public sector, 6 from the infrastructure sector, and 7 from the academic sector. In terms of organisations which the experts represented, 20 experts worked for client organisations, 8 for contractor organisations, 2 for consultant organisations, 7 for univerisities, and 2 for other organisations.

2.5.3 Structured Face-to-face Interviews

After selecting the most important KPIs and developing their appropriate weightings, a total of five structured face-to-face interviews with leading industrial practitioners in Hong Kong were conducted. The interviewees all had extensive hands-on experience in procuring partnering projects. They were invited via a set of structured open-ended questions to propose two most important QIs to evaluate the previously developed seven selected weighted KPIs for the Hong Kong construction industry. The face-to-face interviews were conducted either in the interviewees' offices or in a coffee shop near their offices. Each interview lasted for about 1 to 1.5 hour. A total of 39 QIs for construction partnering projects were proposed by the five interviewees. The meanings of some QIs were similar in nature so they were combined and rephrased into one statement. And the QIs with the highest frequencies identified by the interviewees were selected for further study. Finally, 21 QIs (3 QIs per each KPI) were formulated and consolidated for further analysis. Afterwards, 2 rounds of the second Delphi questionnaire survey were undertaken with the same 31 construction experts who participated in the first Delphi survey to assess the appropriateness of the selected QIs by rating them against their level of importance, measurability, and obtainability based on 5-point Likert scales. Ultimately, the QIs with the highest mean rating for each of the seven selected weighted KPIs were selected to measure the performance of partnering projects in the Hong Kong construction industry.

2.5.4 Empirical Questionnaire Survey and Fuzzy Set Theory

After identifying a set of QIs for measuring the partnering performance of construction projects in Hong Kong, it is important to define quantitative ranges for each QI in order to make the performance evaluation model more objective. To do so, an empirical questionnaire survey was conducted to capture professionals' expectation of different performance levels for each QI. A questionnaire together with a covering letter stating the objectives of the study was delivered to the same 31 construction experts in Hong Kong. The questionnaire is divided into two parts. The first part reports the results of the Delphi survey and the second section asks the respondents to indicate their expectation of each QI with respect to five different performance levels namely 'poor', 'average', 'good', 'very good' and 'excellent'. Of the 31 questionnaires distributed, 22 valid replies were received, which represents a response rate of 70.97%.

A simple method to define reasonable quantitative ranges for each QI was to take the average of the mean expectation between two consecutive grades. However, this method is over simplified and is therefore disposed. Instead, a Fuzzy Set Theory (FST) approach, which is known to be good at solving ill-defined problems (Baloi and Price, 2003), was adopted in this study to define reasonable quantitative ranges.

2.6 CHAPTER SUMMARY

To achieve significant research outputs, an appropriate research method has to be adopted. A seven-step methodology is basically used for this research, encompassing (1) research initiation and finalisation of research topic; (2) determination of research objectives; (3) establishment of scope of study; (4) data and information collection; (5) data analysis and consolidation; (6) verification and validation; and (7) interpretation and presentation of research.

Preliminary data collection was carried out through literature review. The information was consolidated and the aim of research 'To set up a comprehensive, reliable, objective and practical performance evaluation model for partnering projects in Hong Kong' has been finalised. Six research objectives were developed as follows: (1) defining and comparing the definitions of construction partnering and alliancing; (2) comprehensively reviewing 'Fuzzy' research in construction management; (3) establishing a conceptual framework of Key Performance Indicators (KPIs) to evaluate the performance of partnering projects; (4) developing a series of the most important weighted KPIs to assess the performance of partnering projects in Hong Kong; (5) establishing appropriate Quantitative Indicators (QIs) for measuring each of the weighted KPIs; and (6) establishing the fuzzy Quantitative Requirements (QRs) for each QI. A combination of literature reviews, qualitative and quantitative content analyses, face-to-face interviews with field experts, Delphi surveys, empirical questionnaire survey and Fuzzy Set Theory have been adopted to achieve the research aim and objectives.

The research outputs are harvested throughout the study period, including preparation, presentation, and publication of different research reports, journal articles, conference papers, and this PhD thesis.

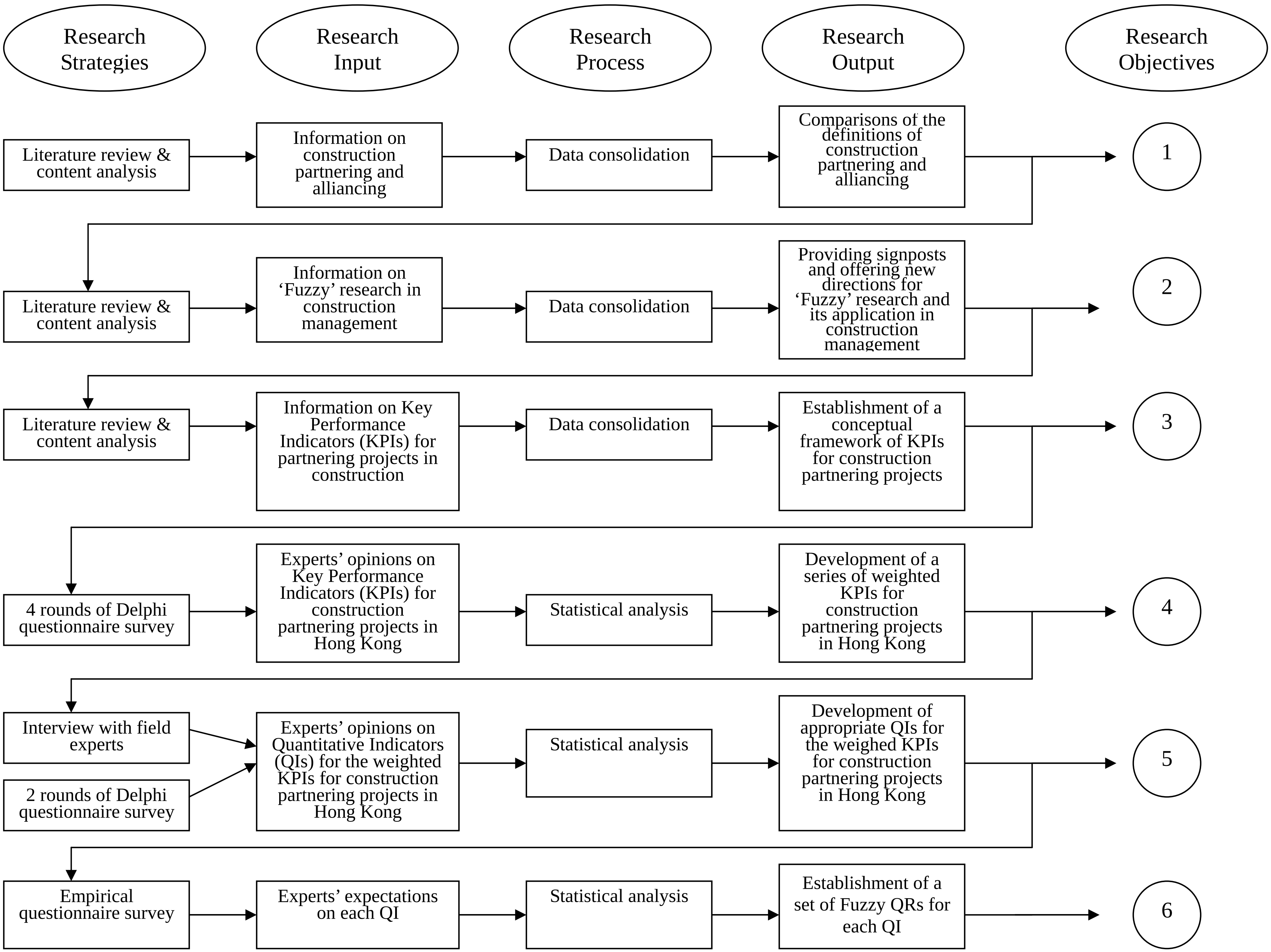
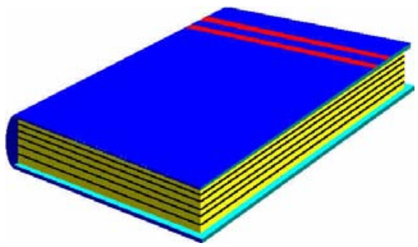


Figure 2.1 Overall Flow of Research



CHAPTER 3 COMPARISONS OF THE DEFINITIONS OF CONSTRUCTON PARTNERING AND ALLIANCING

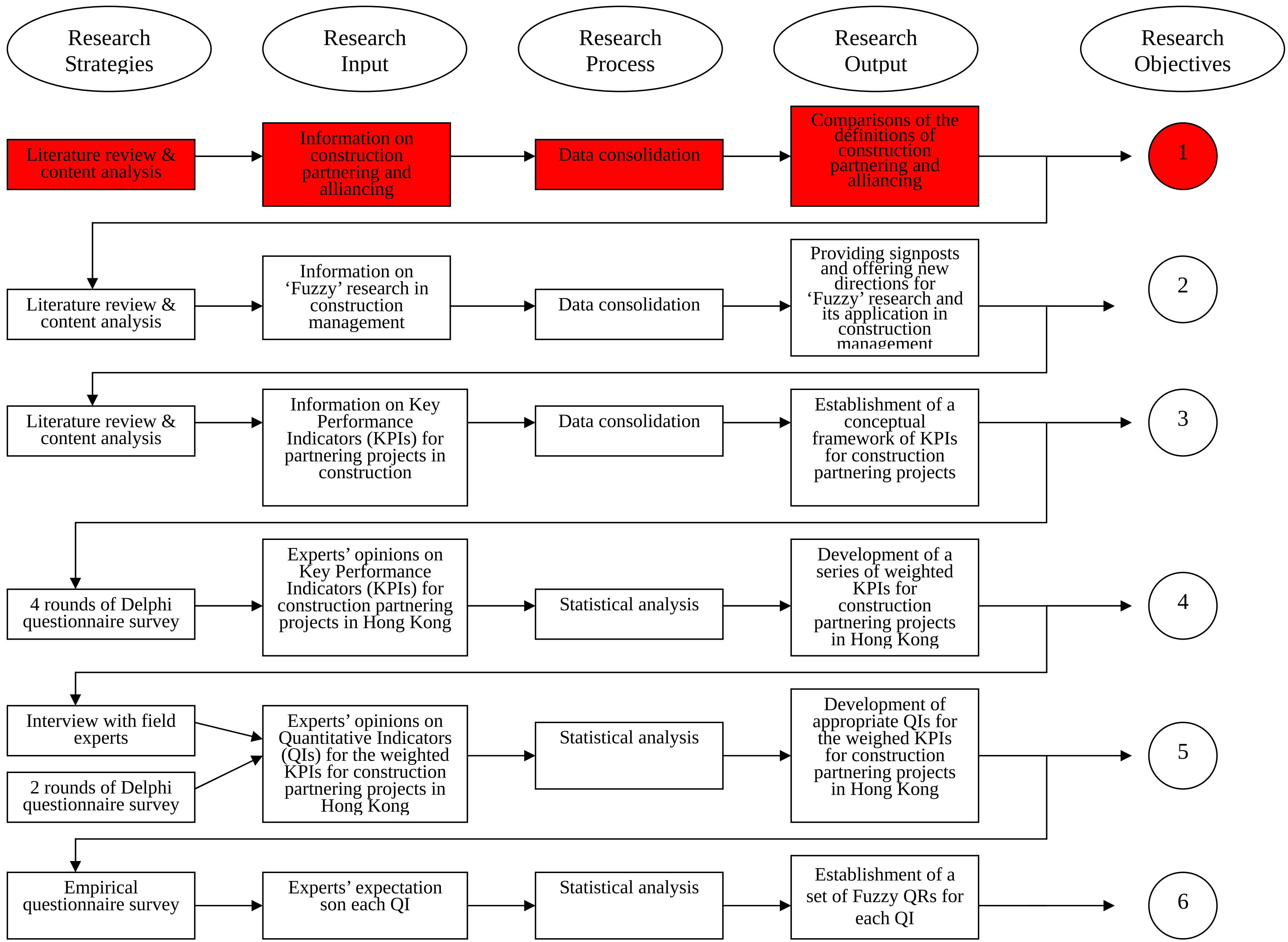


Figure 2.1 Overall Flow of Research

CHAPTER 3 COMPARISONS OF THE DEFINITIONS OF CONSTRUCTION PARTNERING AND ALLIANCING

3.1 INTRODUCTION

Partnering and alliancing, two similar but different innovative and non-adversarial management methods, have provoked a spate of attention from industrial practitioners and academics in the construction industry since 1990s. Partnering was first developed by the US Army Corps of Engineers as a project delivery strategy (Cowan, 1991). Afterwards, it has become an established approach to contracting in the USA, UK and Australia since the 1990s (Bresnen and Marshall, 2000a; 2000b). Like partnering, alliancing has also drawn much attention from industrial practitioners and academics following the development of Australian National Museum project, a well-known alliancing project in Australia completed in the late 1990s (Walker et al, 2000a). In spite of the fact that the characteristics of construction partnering and alliancing have been extensively mentioned and discussed, there is still no consensus on the precise and comprehensive meaning of these two similar but different concepts (Nyström, 2005; Yeung et al, 2007), thus resulting in some confusion to these concepts. As a result, different researchers interpret partnering and alliancing in different ways, hence leading to inconsistent basis for analysis.

In fact, both partnering and alliancing can be characterised as complicated concepts where a standard definition for each has been difficult to reach. An explanation for the increasing number of partnering and alliancing definitions is that the concepts themselves are yet to mature (Li et al, 2000; Yeung et al, 2007). If this is true, comprehensive and conclusive definitions of construction partnering and alliancing, which state the necessary and sufficient conditions, should arise as a result of common practice. However, the reality is just the opposite. It appears that the first step to clearly understand the conceptions of partnering and alliancing is probably to realise that such definitions do not exist for these two similar but different multifaceted concepts.

The need for a common conception of construction partnering and alliancing is obvious because discussions and comparisons will be ineffective if there is no mutual starting point. The following two scenarios illustrate this situation. Firstly, when evaluating different partnering and alliancing projects, what criteria do the evaluators consider and are the criteria the same for both concepts? Secondly, when two industrial practitioners have different opinions about partnering and alliancing, are they really talking about the same thing? Do they include the same elements for both concepts?

The purpose of this chapter is to present an innovative and useful method to define and distinguish partnering and alliancing in the construction context. Earlier studies (Nyström, 2005; Yeung et al, 2007) defined partnering and alliancing in the construction industry firstly by making distinctions between *general prerequisites*, *components*/*elements*, and *goals* of partnering and alliancing projects. The distinctions made it clear that when the essence of the concept is searched, focus ought to be on the *components/elements* of the terms. Earlier works reinforced that the general prerequisites and the goals between partnering and alliancing are equal while the components/elements are similar (Nyström, 2005; Yeung et al, 2007). Similar to the approaches of Nyström (2005) and Yeung et al (2007), this chapter applies the German philosopher Ludwig Wittgenstein's idea of family-resemblance to define partnering and alliancing, thus making the comparisons between these two vague and multifaceted concepts clearer and more effective. This innovative approach generates a useful method to define and compare different variants of partnering and alliancing within the same structure. By doing so, industrial practitioners may find the Sunflower Model useful in the procurement of a construction project. The Sunflower Model can be used as a description of the concept and as a common starting point for discussions between a client and a contractor on how to procure a partnering or alliancing project, thus reducing any misunderstanding of what a partnering or alliancing project is. However, this chapter does not set out to evaluate the strength or weakness of partnering and alliancing. It just discusses how partnering and alliancing can be defined precisely and comprehensively in a systematic way. It should be pointed out that the approach presented here is applicable to all kinds of partnering and alliancing, including project partnering, strategic partnering, project alliancing, and strategic alliancing, because the literature reviewed includes all of them.

3.2 DEFINITIONS OF PARTNERING AND ALLIANCING

3.2.1 Partnering

Numerous definitions of partnering have been derived from past studies (Chan et al., 2001a). Indeed, partnering is a process of establishing a moral contract or charter among the project team members, which will bind each party to act in the best interest of the project and the project team members. Crowley and Karim (1995) defined partnering conceptually as an organisation, one that is formed by resolving conflicts, expediting decision-making and increasing organisational competence in achieving project goals (Figure 3.1). In the light of their model, it could be viewed that contract formality and real gain-pain share are just minor differences and more of semantic differentiation between partnering and alliancing. However, our Partnering Sunflower Model developed later does not support this and advocates that contract formality and real gain-pain share represent some fundamental differences between construction partnering and alliancing. But it should be noted that there are no contradictions between the two models because they just analysed the concepts at different angles.

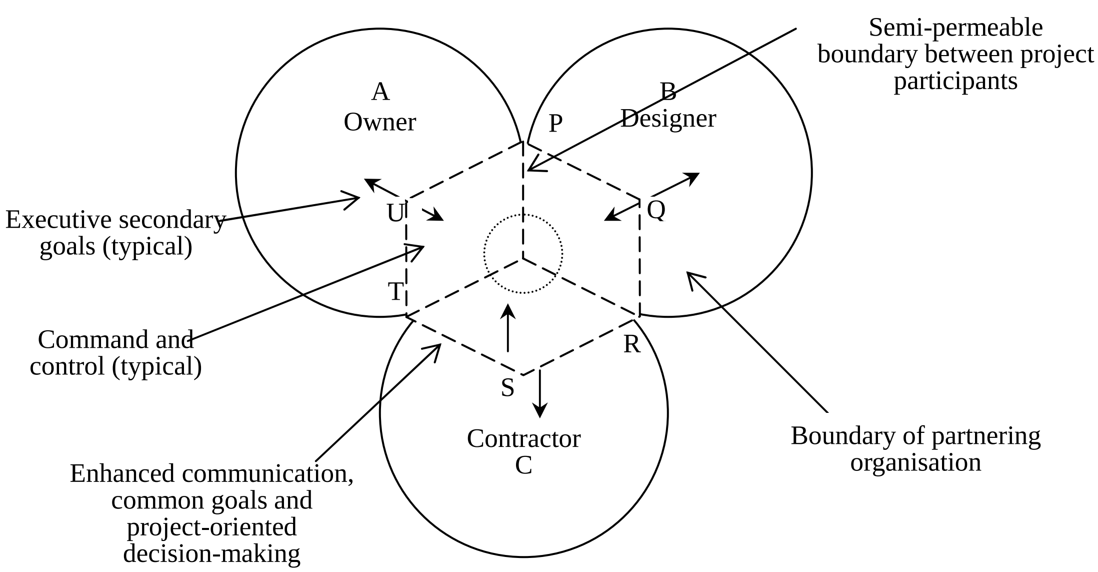


Figure 3.1 Conceptual model of partnering (Crowley and Karim, 1995)

However, partnering was often defined in one of two ways: (1) by its attributes such as trust, shared vision, and long-term commitment; or (2) by the process where partnering goes on to be seen as a verb, such as developing a mission statement and agreeing on goals. The Construction Industry Institute (Constructon Industry Institute, 1991) in the USA and the Construction Industry Board (Construction Industry Board, 1997) in the UK have conducted some well-known research studies into partnering and developed definitions specific to the research.

The Construction Industry Institute (USA) (1991) defined partnering as:

'A long-term commitment between two or more organisations for the purposes of achieving specific business objectives by maximising the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organisational boundaries. The relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values.' (Construction Industry Institute, 1991)

The Construction Industry Board (UK) (1997) defined partnering to be:

'A structured management approach to facilitate team working across contractual boundaries… it should not be confused with other good project management practices, or with long-standing relationships, negotiated contracts, or preferred supplier arrangements, all of which lack the structure and objective measures that must support a partnering relationship.' (Construction Industry Board, 1997)

Latham (1994) further added that project partnering provided a means of introducing participants to partnering without the need for a long-term commitment. It might benefit to future projects or in possible situation of a longer commitment (Wilson et al, 1995). Latham (1994) also introduced the project partnering process, which mainly included the decision to use partnering, the first partnering workshop and the follow-up workshops (Figure 3.2).

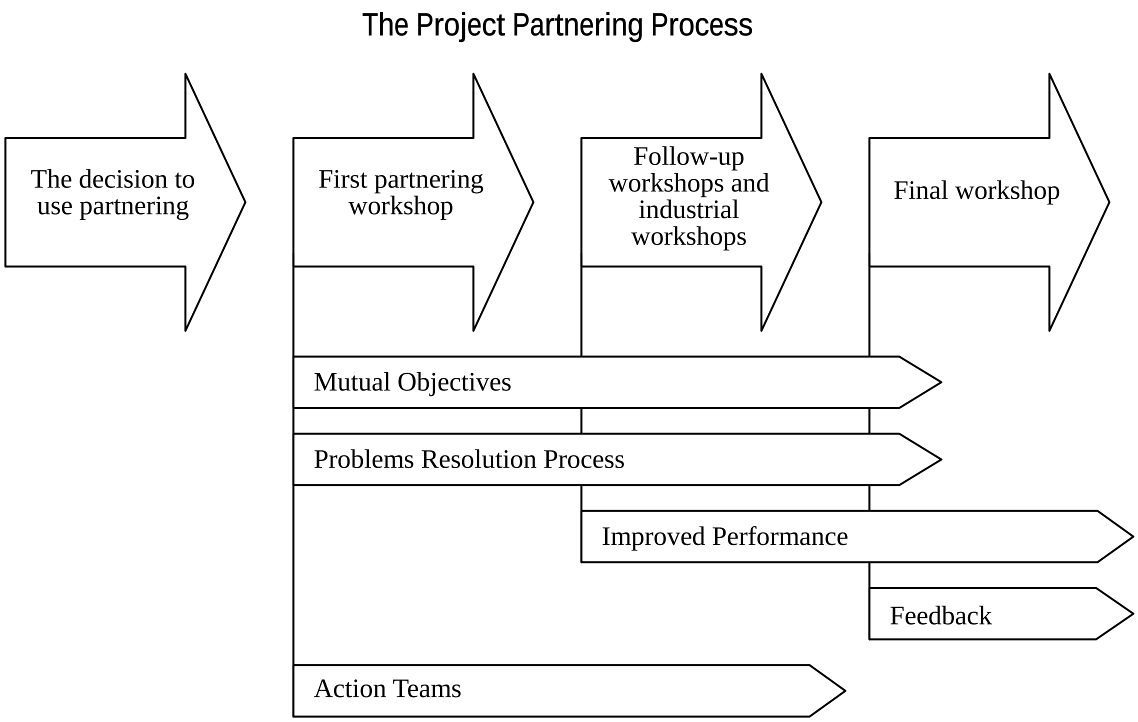


Figure 3.2 The project partnering process (Latham, 1994)

The essential stages of project partnering explained by Latham were similar to Abudayyeh's (1994). According to Abudayyeh (1994), the partnering process should be implemented at the very beginning of the project. The process of partnering included the expression of interest, partnering workshop, follow up workshop and final workshop (Figure 3.3).

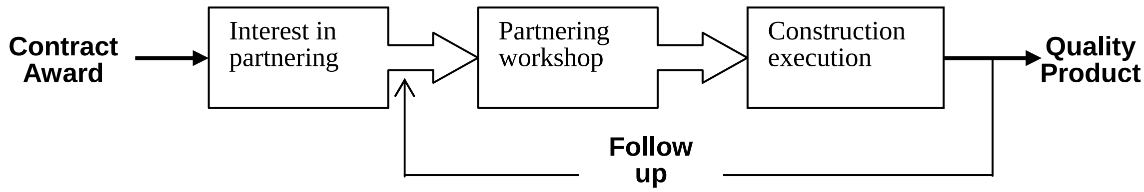


Figure 3.3 The partnering process (Abudayyeh, 1994)

3.2.2 Alliancing

There are also a plenty of definitions of alliancing and the scope of alliances is reflected in the range of definitions which are in common currency (McGeorge and Palmer, 2002; Yeung et al, 2007). These definitions can be very broad, such as ‘A relationship between two entities, large or small, domestic or foreign, with shared goals and economic interests’ (United States Trade Center, 1998), or ‘organisations with capabilities and needs come together to do business and add value to the other partner, at the same time working to provide a product which enhances society and the capability of the ultimate client’ (Nicholson, 1996). Other authors are more specific, for instance, Kwok and Hampson (1996) defined project alliancing as ‘a cooperative arrangement between two or more organisations that forms part of their overall strategy, and contributions to achieving their major goals and objectives for a particular project’. Gerybadze (1995), however, defined project alliancing as ‘the client and associated firms will join forces for a specific project, but will remain legally independent organisations. Ownership and management of the cooperating firms will not be fully integrated although the risk of the project is shared by all participants.’ A common definition of strategic alliancing proposed by Love and Gunasekaran (1999) is to establish inter-organisational relations and to engage in collaborative behaviour for a specific purpose. A strategic alliancing is also seen as an inter-organisational arrangement which usually exists between two companies that extends beyond a specific project and the parties would expect ongoing, mutually beneficial business (Peters et al, 2001).

3.3 USING LUDWIG WITTGENSTEIN'S FAMILY-RESEMBLANCE CONCEPT TO DEFINE CONSRUCTION PARTNERING AND ALLIANCING

A number of definitions of partnering and alliancing described above show how difficult it is to give concise and comprehensive explanations of these two concepts. It seems that there is no consensus on which specific elements should be included and thus the concepts appear vague and difficult to be compared. In fact, the German philosopher Ludwig Wittgenstein argued that complex concepts are unable to be defined in the traditional way by stating necessary and sufficient conditions due to a major reason that there may not be a single or a very small number of characteristics that are common for all variants of a concept (Nyström, 2005; Yeung et al, 2007). Instead he regarded that complicated networks overlap similarities among the things that fall under a complex concept (Kenny, 1975). Murphy (1991) stated that a Ludwig Wittgenstein's classical example is the term 'game', which is illustrated in such a way that a large number of activities are featured as games. However, he argued that there is no a single and common characteristic for all of them. He further elaborated that ball games such as tennis, football and basketball have rules to be followed. But there are no rules stated clearly when a person just throws a ball in the air. Some elements of the ball games, encompassing rules, competitiveness, and reward and penalty, remain but some do not. Such ball games are characteristic of only hard physical work and the ball, when the thought goes to board games. Ludwig Wittgenstein suggests that there is just a complex network of overlapping characteristics without any common features covering all kinds of games. Such an approach to understand a versatile concept is called 'family-resemblance' because it resembles the type of similarity that is able to be found within a family. He further used the following example to illustrate the family-resemblance concept. A daughter in a family could have the 'same' nose as her father while the father and his son have the 'same' ears, but there is no feature common to all members of the family. Nevertheless, there is still a bond between them (Kenny, 1975). Clearly, the Ludwig Wittgenstein's family-resemblance method to define a multifaceted concept is more flexible and structured because it does not restrict the meaning of a concept to a small number of simple characteristics. Therefore, it is suitable to use this innovative method to define the concepts of partnering and alliancing.

3.4 ESSENTIAL ELEMENTS OF PARTNERING AND ALLIANCING

Fourteen key elements of partnering and alliancing were identified from the literature as shown in Table 3.1. A 'tick' in Table 3.1 shows that this element is a vital element underlying the partnering/alliancing concept. Based on the reviewed literature, the top-3 key elements for partnering as mentioned by experts in this field are 'long-term commitment', 'trust', and 'agreed problem resolution methods'. For alliancing, the top-3 key elements are 'trust', 'cooperation and communication', and 'long-term commitment'. Two of their top-3 key elements, including 'trust' and 'long-term commitment', overlap and they can be regarded as their common core soft (relationship-based) elements. Table 3.2 indicates that a major difference between partnering and alliancing is that partnering relies on a 'partnering charter' which has no legal and contractual binding while alliancing involves the constitution of a 'formal contract', with a 'real gain-share and pain-share arrangement' principle attained by a 'joint' rather than 'shared' commitment in which parties agree their contribution and required profit levels beforehand and then place these levels at risk. More precisely, if one party in the alliance under-performs, then all other alliance partners are at risk of losing their rewards (profit and incentives) and could even share losses according to the agreed project pain-sharing/gain-sharing model, and the vice versa (Walker et al, 2000a; 2002).

The following sections briefly present the elements that constitute the whole 'partnering and alliancing family' as they were described in the literature. After that, the application of family-resemblance approach to the partnering and alliancing concept is illustrated.

3.4.1 Major Similarities between Partnering and Alliancing

3.4.1.1 Trust

Many researchers (Construction Industry Institute Australia, 1996; Green, 1999; Li et al, 2000; Lazar, 2000; Manley and Hampson, 2000) viewed trust as one of the top-3 key elements for partnering and alliancing. When this element is developed, other sub-elements are likely to be achieved and the benefits to all parties are easier to be maximised (Construction Industry Institute, 1991; Bennett and Jayes, 1998). Wong et al (2005) opined that establishing trust amongst partners is considered as the most important success factor that underpins partnering success. Similarly, Cheung et al (2005) believed that trust is a pivotal attitudinal factor and trust building is an indispensable exercise of partnering arrangement. Walker et al (2000b; 2002) stated that partnering and alliancing are based upon a need for mutual trust to generate commitment and constructive dialogue, and trust is part of an outcome from negotiation. In fact, trust is bound up with past experience both directly with the persons concerned and indirectly, through projected or anticipated experiences, thus trust is an intensely emotional and human phenomenon. Figure 3.4 illustrates a model of the range of influences that can affect the perception of trust. Walker et al (2002) pointed out that the partnering and alliance team's formation of a management group as a true joint management group with democratic membership ensures that trust and commitment is truly encouraged and manipulation discouraged by the system of alliancing was a vital feature. Hampson and Kwok (1997) proposed trust as an important element of successful strategic alliances as well as successful business relationships. Howarth et al (1995) believed that no successful strategic alliances can be developed without trust. Trust in a strategic alliance also includes the concept of reciprocity, which implies a long-term focus, the acceptance that obligations are mutual, and room for adjustment if one partner is suddenly placed in a compromising position.

Table 3.1 Comparisons of Key Elements Amongst Project Partnering, Strategic Partnering, Project Alliancing and Strategic Alliancing

Papers/Elements	1 Partnering charter	2 Formal contract	3 Real gain-share/pain-share	4 Trust	5 Long-term commitment	6 Common goals and objectives	7 Win-win philosophy	8 Equity	9 Agreed problem resolution methods	10 Continuous improvements	11 Cooperation and communication	12 Facilitated workshops	13 For a single project only	14 For at least two projects
Project partnering														
Bennett and Jayes (1995)	√			√	√	√			√	√		√	√	
Crowley and Karim (1995)				√	√	√	√	√	√			√		
Cnstruction Industry Institute (1996)	√			√	√	√	√	√	√		√			
Hellard (1996)	√				√						√	√		
Green (1999)				√	√							√		
Lazar (2000)				√			√	√						
Li et al (2000)				√	√	√							√	
Bresnen and Marshall (2000a,b,c)				√	√						√	√		
Walker et al (2000b)	√			√	√	√			√	√	√			
Manley and Hampson (2000)				√	√				√					
McGeorge and Palmer (2002)	√				√							√	√	
Walker et al (2002)				√	√			√	√				√	
Rowlinson and Cheung (2004)						√			√	√				
Sub-total	**5**	**-**	**-**	**10**	**11**	**6**	**3**	**4**	**7**	**3**	**4**	**6**	**4**	**-**
Strategic partnering														
Bennett and Jayes (1995)	√				√	√			√	√	√	√		√
Bennett and Jayes (1998)	√			√	√	√		√	√	√		√		√
Walker et al (2000b)	√			√	√	√			√	√	√			
Li et al (2000)				√	√			√						√
Cheng and Li (2004a)										√				√
Sub-total	**3**	**-**	**-**	**3**	**4**	**3**	**0**	**2**	**3**	**4**	**2**	**2**	**-**	**4**
Grand-total	**8**	**-**	**-**	**12**	**14**	**9**	**3**	**6**	**10**	**7**	**5**	**7**	**4**	**4**
Project alliancing														
Kwok and Hampson (1996)						√					√		√	
Hampson and Kwok (1997)			√	√	√				√		√		√	
Abrahams and Cullen (1998)			√	√			√				√			
Walker et al (2000b)		√	√	√	√	√			√	√	√	√		
Manley and Hampson (2000)		√			√			√			√		√	
McGeorge and Palmer (2002)		√	√											
Walker et al (2002)		√	√	√	√	√	√			√	√	√	√	
Rowlinson and Cheung (2004)		√											√	
Hauck et al (2004)		√	√	√		√		√			√		√	
Alchimie and Phillips (2003)			√	√	√						√			
Thorpe and Dugdale (2004)				√	√	√				√				
Sub-total	**-**	**6**	**7**	**7**	**6**	**5**	**2**	**2**	**2**	**3**	**8**	**2**	**6**	**-**
Strategic alliancing														
Howarth et al (1995)				√										
Hampson and Kwok (1997)			√	√	√				√		√			√
Lendrum (2000)					√	√	√							
Walker et al (2000a)		√		√					√	√	√			√
Peters et al (2001)														√
Rowlinson and Cheung (2004)														√
Hauck et al (2004)						√								√
Sub-total	**-**	**1**	**1**	**3**	**2**	**2**	**1**	**0**	**2**	**1**	**2**	**0**	**-**	**5**
Grand-total	**-**	**7**	**8**	**10**	**8**	**7**	**3**	**2**	**4**	**4**	**10**	**2**	**6**	**5**

Table 3.2 Major Similarities and Differences Between Partnering and Alliancing (from various sources as stated below)

<table>
<tr><th></th><th>Partnering</th><th>Alliancing</th></tr>
<tr><td>Major Similarities</td><td colspan="2">• They both derive results through relationship.
• Both of them emphasize on relationship and people.
• Both of them intend to develop a high level of collaboration between parties.
• Both of them are one form of relationship contractings.
• Their objective is similar, that is, to partner with a good team. (Walker et al, 2000a; 2000b; 2002)</td></tr>
<tr><td>Major Differences</td><td>• It runs alongside a traditional standard contract and is just a partnering charter, having no contractual and legal force itself (Construction Industry Institute, 1991; Construction Industry Institute Australia, 1996)

• No real gain-share/ pain-share arrangement (Construction Industry Institute, 1991; Construction Industry Institute Australia, 1996)</td><td>• It is a formal alliance contract that is legally and contractually binding (Walker et al, 2000a and 2000b; McGeorge and Palmer, 2002; Rowlinson and Cheung, 2004; Hauck et al, 2004).

• With real gain-share/pain-share mechanism: if one party in the alliance under-performs, then all other alliance partners are at risk of losing their rewards (profit and incentives) and could even share losses, and vice versa according to the agreed project gain-sharing /pain-sharing model (Walker et al, 2000b; 2002)</td></tr>
</table>

Hauck et al (2004) agreed that trust and integrity are essential for true collaboration while Alchimie and Phillips (2003) viewed project alliancing as an integrated high performance team selected on a best person for the job basis; sharing all project risks with incentives to achieve game-breaking performance in pre-aligned project objectives; within a framework of no fault, no blame and no dispute; characterised by uncompromising commitments to trust, collaboration, innovation and mutual support; all in order to achieve outstanding results.

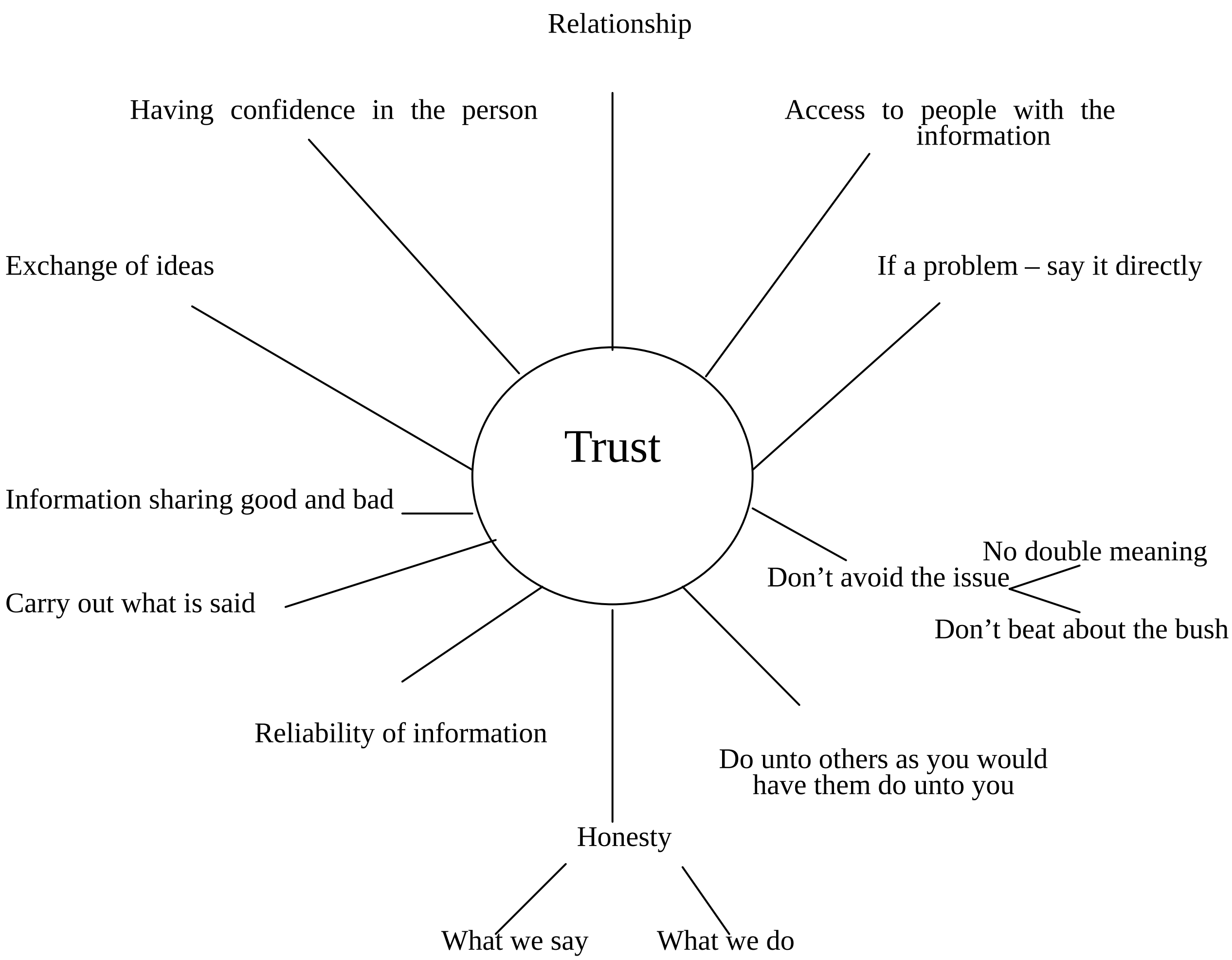


Figure 3.4. Elements of Trust (Source: Whiteley et al, 1998)

3.4.1.2 Long-term Commitment

Long-term commitment is another one of the top-3 key elements for partnering and alliancing as cited by many researchers (Bennett and Jayes, 1995; Construction Industry Institute Australia, 1996; Hampson and Kwok, 1997; Li et al, 2000; Walker et al, 2002). Manley and Hampson (2000) stated that partnering is typically defined in the literature as a commitment between a client and a contractor(s) to actively cooperate in order to meet separate but complementary objectives. Li et al (2000) viewed that strategic partnering requires a long-term commitment and trust by the parties involved to extend their relationships beyond the successful completion of a single project to the formation of an alliance. McGeorge and Palmer (2002) pointed out that in addition to a need for high level of commitment, there is a need for 'internal partnering' while Peters et al (2001) suggested partnering relies solely on the commitment of individuals due to the fact that the partnering charter is not legally binding. The Construction Industry Institute Australia (1996) stressed that there is no partnering contract and an agreed partnering charter forms the basis of a working agreement that is intended to shape a non-adversarial culture to promote win-win working relationships between partners. This is achieved through the aim to foster cooperative and mutually beneficial relationships among project stakeholders and develop an explicit strategy of commitment and communication. These goals are documented in a charter that stands alongside legally binding contractual arrangements (Hellard, 1996). Li et al (2000) analysed that the practice of 'forcing' or premature 'requiring' partnering behaviour of trust and commitment exemplified by entering arrangements where dispute resolution through the legal system that is essentially banned has been criticised. Bennett and Jayes (1998) opined that the strategies need to be supported by all the organisations involved in the partnering arrangement, and this commitment gradually builds up through the experience of working together successfully. Walker et al (2000b) emphasised that trust and commitment underpins the three essential elements of partnering and alliancing (mutual objectives, problem resolution, and continuous improvement), and they added that commitment is the physical and mental manifestation of the concept of trust. It means that another party would take this trust on board and live up to the spirit of the bargain by probably committing more personal pride and obligation to do the right thing than would otherwise be the case. Walker et al (2002) supplemented that the delivery management plan of the National Museum of Australia Project was established on the basis of an alliance concept. The core principle of alliancing was to achieve a positive outcome for all alliance members including the client (also an alliance member) through shared commitment to a common goal of project realisation delivering best value to the client and acceptable reward outcomes to alliance members. The assumption made is that all parties can achieve a win-win situation provided that they work together to help each other to gain not only a realistic reward for their input but to gain a competitive edge in the market as a result of their experience on this milestone project. Thorpe and Dugdale (2004) also agreed that successful alliance contracting requires commitment by both parties to achieving common goals. Alchimie and Phillips (2003) referred that project alliances are characterised by uncompromising commitments to trust, collaboration, innovation and mutual support in order to achieve outstanding results. Lendrum (2000) regarded that for the purpose of making alliances successful, all parties have to agree on the objectives and share the principles' process and general information to gain a partner's initial and ongoing support and commitment.

3.4.1.3 Common Goals and Objectives

Although common goals and objectives are not cited as frequent, they are also important key elements for partnering and alliancing. Construction Industry Institute (1991) viewed shared vision (common goals and objectives) as a vital partnering element in which each of the partnering organisations must understand the need for a shared vision and common mission for the partnering relationship. Bennett and Jayes (1998) proposed that a key element of partnering is to agree common goals to take into account the interests of all the firms involved. Partnering is about people within partnered organisations making commitment and building trust to work together towards their common project goals and objectives (Walker et al, 2000b; 2002). Rowlinson and Cheung (2004) pointed out that partnering is defined as a structured management approach to facilitate team working across contractual boundaries. Its fundamental elements include (1) mutual objectives; (2) agreed problem resolution methods; and (3) an active search for continuous measurable improvements. Thorpe and Dugdale (2004) viewed that alliance contracts are best suited to contracts that require innovation and commitment to achieving common goals. Hauck et al (2004) also agreed that common goals and objectives are key elements for successful alliance contracts.

3.4.1.4 Win-win Philosophy

Similar to common goals and objectives, win-win philosophy is a key element for partnering and alliancing though they are not mentioned frequently in the literature. The possible explanation for this is that it is the foundation for mutual trust, long-term commitment, and common goals and objectives and may have been implied by most researchers. Crowley and Karim (1995) viewed that win-win philosophy is an important element for partnering, and they defined it as ‘neither party wins due to the other losses’. Lazar (2000) mentioned that partnering is able to guide people on and off the project site into the types of interactions and relationship, and produces win-win outcome. Lendrum (2000) mentioned that in order for alliances to be successful, all parties have to agree on the objectives and share the principles, processes and general information to gain their partner's initial and ongoing support and commitment. The contractor must be involved to ensure a win-win long-term relationship. Walker et al (2002) defined an element of alliances was that joint budget and cost and time committed targets established through an alliance board represented by key senior project champions from each alliance member and the client. This implies a win-win philosophy behind. The definition suggested by Abrahams and Cullen (1998) that 'an agreement between entities which undertake to work cooperatively, on the basis of a sharing of project risk and reward, for the purpose of achieving agreed outcomes……' also implies a win-win philosophy.

3.4.1.5 Equity

Equity is another foundation for successful partnering and alliancing implementation. All the interests of stakeholders should be considered in creating mutual goals and there should be commitment to satisfying each stakeholder's requirement based on equity (Crowley and Karim, 1995; Li et al, 2000; Lazar, 2000; Walker et al, 2002). It reflects a sense of proportionality and balance transcending simple fairness (Construction Industry Institute Australia, 1996). Bennett and Jayes (1998) opined equity as one of the seven pillars for the second generation partnering. Equity is defined as everyone is rewarded for their work on the basis of fair prices and fair profits. Manley and Hampson (2000) studied that one of the alliancing features is an equitable risk-reward balance that aligns the commercial interests of the parties. Hauck et al (2004) agreed that the foundation of the collaborative process for project alliancing is equity between parties.

3.4.1.6 Agreed Problem Resolution Methods

Although agreed problem resolution method is cited much more frequently for partnering than alliancing, it is considered as an important element for both management techniques. As suggested by Bennett and Jayes (1998), a key element of partnering is to make decisions openly and to resolve problems in a way that was jointly agreed at the start of a project. Walker et al (2002) stated that agreed problem resolution is essential when establishing trust and commitment between parties. The CII task force considered that a successful partnering relationship element included conflict resolution through agreed problem solving (Crowley and Karim, 1995). Rowlinson and Cheung (2004) agreed that a fundamental element for partnering is agreed problem resolution methods. Walker et al (2000b) stressed that the three essential elements of partnering and alliancing, including (1) mutual objectives; (2) agreed problem resolution; and (3) continuous improvement; are underpinned by trust and commitment. Problem and dispute resolution procedures adopted in alliancing provide for the types of problem to be defined and reasonable timeframes for resolution stipulated. The reason for escalating a dispute may be hardening of diverse positions or may simply be a result of the party not being authorised to commit required resources to resolve the dispute. In cases where a dispute is escalated unnecessarily, the person escalating the dispute may not be appreciated by his peer groups. This provides a self-regulating mechanism for ensuring that problems are indeed resolved at the lowest possible level. Hampson and Kwok (1997) also proposed that joint problem solving method is a key element of the successful alliances. A standard problem resolution flow chart is shown in Figure 3.5.

3.4.1.7 Continuous Improvements

A key element for partnering and alliancing (Construction Industry Institute, 1991; Bennett and Jayes, 1998; Walker et al, 2000b) is continuous improvement, meaning that long-term targets are set and achieved by all the stakeholders. Rowlinson and Cheung (2004) agreed that a fundamental element for successful partnering encompassed an active search for continuous measurable improvements. Cheng and Li (2004a) also consented that continuous improvement is a vital element for successful strategic partnering to create a good learning culture. They illustrated that continuous improvement involves continuous learning (Garvin, 1993) devoted to gradual process improvement (TQM), radical process improvement (BPR), and learning process improvement (a learning organisation) (Kilmann, 1995). Walker et al (2000b; 2002) observed that an essential element of partnering and alliancing was continuous improvement in that performance is measured and analysed to provide knowledge about how improvement can be achieved continuously. There must be a commitment to learn from experience and to apply this knowledge to improve performance. Thorpe and Dugdale (2004) addressed that a vital element of alliance was continuous improvement to achieve results on time and to full specification requirements, while innovation will always be required to improve the current process.

3.4.1.8 Cooperation and Communication

Although cooperation and communication is cited much more frequently for alliancing than partnering, it remains as an important element for both management techniques. Hellard (1996) stated that win-win working relationships between partners are achieved by fostering cooperative and mutually beneficial relationships amongst project stakeholders and developing an explicit strategy of commitment and communication. Walker et al (2000b) stated that partnering and alliancing are founded upon team spirit and the honesty associated with notions of trust, commitment, and the application of power and influence. Excellent and effective communication is essential for successful relationship building. Construction Industry Institute (1991) also viewed effective communication and cooperation as a vital partnering element.

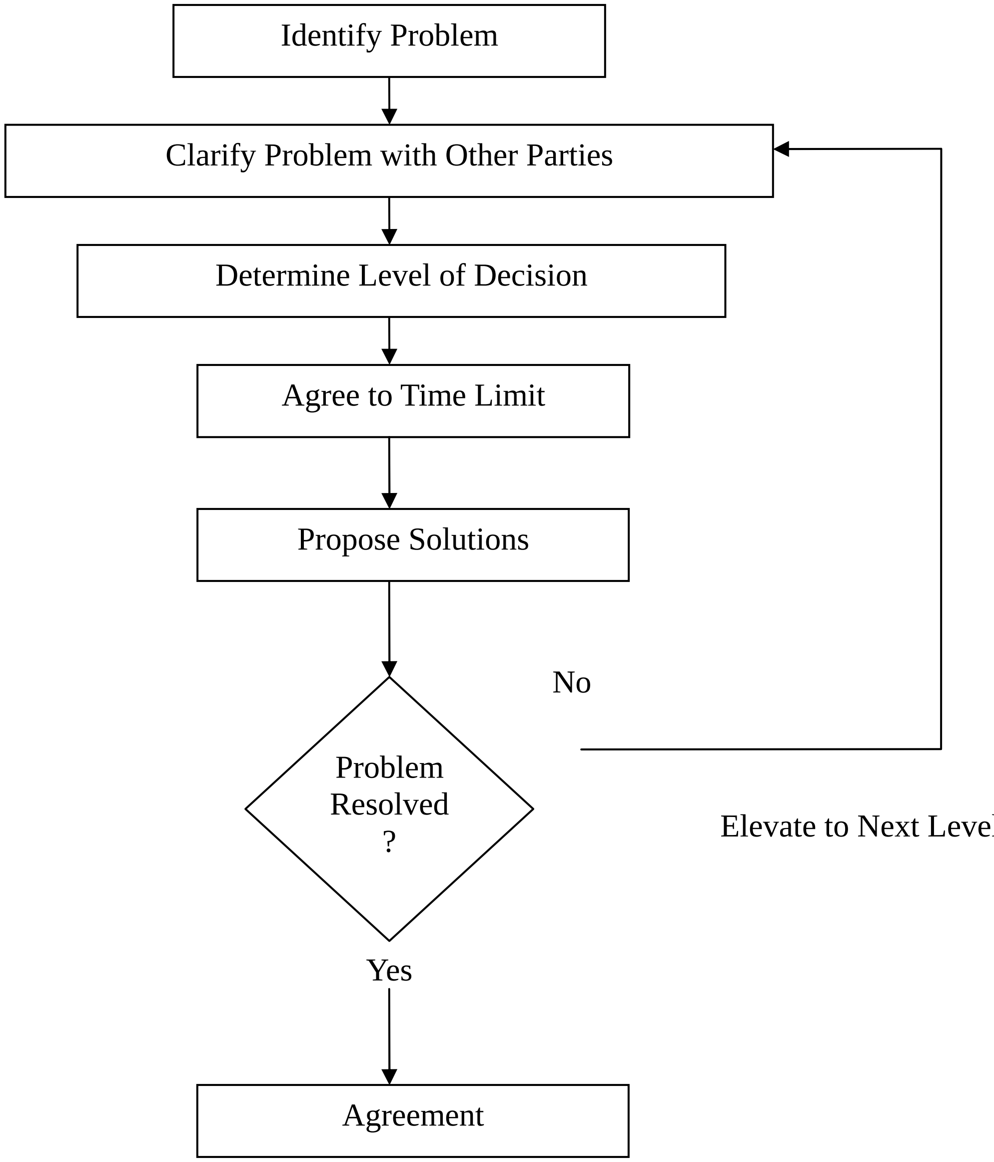


Figure 3.5 Problem Resolution Flow Chart (Source: Bennett and Jayes, 1995)

Abrahams and Cullen (1998) opined that working cooperatively between entities is an important element for alliancing parties to succeed. Both Hauck et al (2004) and Walker et al (2002) pointed out that the intense integration of alliance partners through the whole collaborative process requires excellence in communication at a personal level, at a business level, and at operational level. This generally requires a quantum leap in the use of shared information technology (IT) systems and information processing integration. Alchimie and Phillips (2003) also agreed that cooperation and collaboration are vital elements for successful alliances.

3.4.1.9 Facilitated Workshops

Facilitated workshops are also key elements for partnering and alliancing but with relatively less importance. Green (1999) considered that partnering workshops need to be continuous and not one-off at the project start. Walker et al (2000b; 2002) pointed out that the interviewing process to derive a shortlist of potential alliance members requires sophistication and judgement of a client as does the facilitated workshops. This means that alliancing workshops are useful tool to help select capable construction alliance partners.

3.4.2 Major Differences between Partnering and Alliancing

3.4.2.1 Partnering Charter vs Formal Contract

Manley and Hampson (2000) stated that the major difference between partnering and alliancing is that the former runs alongside standard contracts and is just a partnering charter (Construction Industry Institute, 1991; Construction Industry Institute Australia, 1996; Walker et al, 2000b; McGeorge and Palmer, 2002), having no contractual force itself, whereas alliancing arrangements are expressed in contractual form. In addition, while alliancing is both a relationship management system and a delivery system, partnering is not a delivery system. Hence, one can have an alliance contract, but there is no partnering contract, only a partnering charter. McGeorge and Palmer (2002) viewed that alliancing is somewhat akin to the slogan of the three musketeers 'All for one and one for all' in that alliancing could be described as partnering underpinned with economic rationalism given that alliance partners coalesce into a virtual corporation in which agreed profit and loss outcomes are contractually binding on all parties (Walker et al, 2000a; 2000b). Rowlinson and Cheung (2004) pointed out that a project alliancing agreement is legally enforceable while Hauck et al (2004) also stated that the project alliancing 'agreement' is a legally binding contract and, therefore, legally enforceable.

3.4.2.2 Non-real Gain-share/Pain-share vs Real Gain-share/Pain-share

Another significant difference between alliancing and partnering is that the former induces real gain-pain share but the latter does not because there is formal contractual binding for alliancing but the partnering charter has no contractual force itself. Walker et al (2000b; 2002) analysed that with alliancing, there is a 'joint' rather than 'shared' commitment and parties would share gains and losses according to the agreed project pain-sharing/gain-sharing model. Abrahams and Cullen (1998) defined project alliances as an agreement between entities which undertake to work cooperatively, on the basis of a sharing of project risk and reward, for the purpose of achieving agreed outcomes based on principles of good faith and trust and an open-book accounting approach towards costs. Hauck et al (2004) mentioned that as an alliance of talented professionals pooling resources to achieve the project goal, they develop the project price target through design development with agreed risk and reward sharing arrangements like guaranteed maximum price (GMP) and target cost contracting (TCC) strategies. Agreement on a risk and reward formula where an open-book accounting approach is undertaken to determine cost reimbursement together with agreed and verified site management costs to establish a base target cost. The firm's corporate profit (usually determined from audited figures over an agreed period) is placed as an 'at risk' element to ensure that the agreed project costs are met. A bonus reward mechanism to be shared by all parties is jointly established to encourage further innovation and excellence. Therefore, the agreed project cost can only be determined when the alliance partners have been selected. McGeorge and Palmer (2002) emphasised that alliancing differs radically from partnering in respect to risk and reward sharing. In partnering the client still ultimately purchases a product (usually a building) which is produced, albeit in a spirit of mutual co-operation, with the design and construction team. In alliancing, the virtual corporation produces the product with each member of the corporation sharing risks and rewards. A classical alliancing gain-share/pain-share scheme is shown in Figure 3.6.

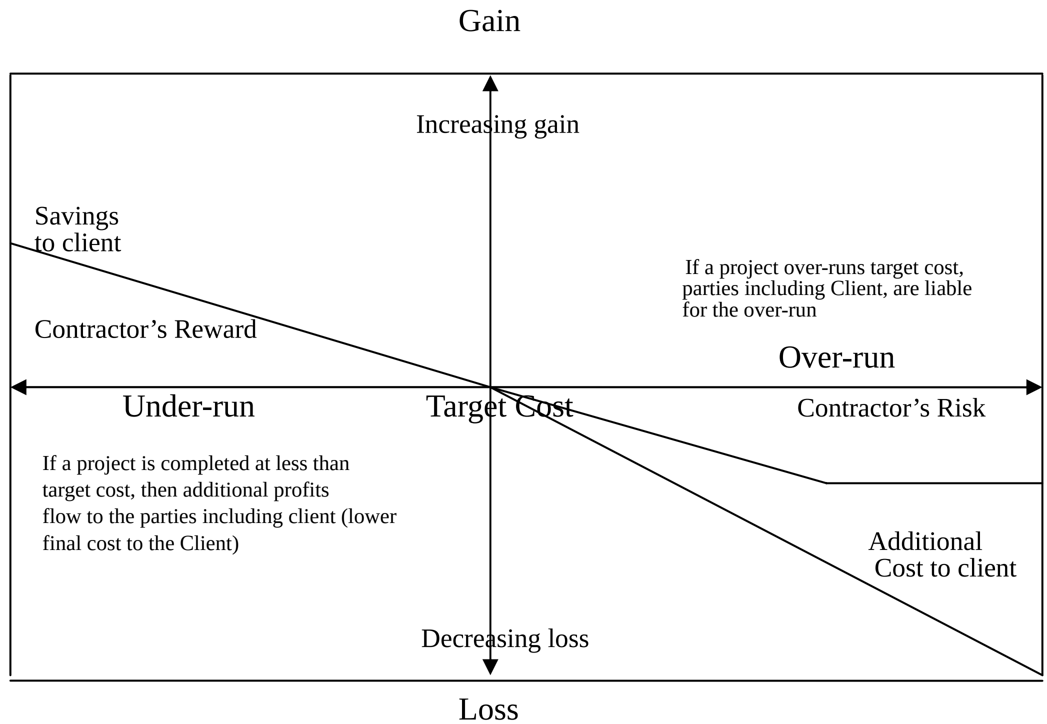


Figure 3.6 Typical Model of Gain-share/Pain-share Philosophy
(Source: Australian Construction Association, 1999)

3.4.2.3 Major Difference between Project Partnering and Strategic Partnering

The major difference between project partnering (relationships established for a single project) and strategic partnering (a long-term commitment beyond a discrete project) is that the former is for a single project (Construction Industry Institute, 1991; Li et al, 2000; McGeorge and Palmer, 2002; Walker et al, 2002) but the latter involves at least two projects (Construction Industry Institute, 1991; Bennett and Jayes, 1998; Li, et al, 2000; Cheng and Li, 2004a).

3.4.2.4 Major Difference between Project Alliancing and Strategic Alliancing

The major difference between project alliancing and strategic alliancing is that project alliancing has a defined end, which is most commonly the practical completion date of a project. The parties are brought together for a specific project or outcome (Kwok and Hampson, 1996; Manley and Hampson, 2000; Peters et al, 2001; Walker et al, 2002; Rowlinson and Cheung, 2004; Hauck et al, 2004). However, a strategic alliance usually exists between two companies that extends beyond a specific project (Hampson and Kwok, 1997; Walker, et al, 2000b; Peters et al, 2001; Rowlinson and Cheung, 2004; Hauck et al, 2004) and the parties would expect ongoing, mutually beneficial business (Peters et al, 2001).

3.5. ANALYSING CONSTRUCTION PARTNERING AND ALLIANCING BY A LUDWIG WITTGENSTEIN'S FAMILY-RESEMBLANCE CONCEPT

3.5.1 The Partnering Sunflower Model and Alliancing Sunflower Model

The results presented in Table 3.1 show that there are altogether fourteen elements of partnering/alliancing summarised from the published literature. 'Trust' and 'Long-term Commitment' appear to be the most vital (soft) elements for construction partnering and alliancing because they are two of the top-3 elements cited by the researchers when defining the partnering and alliancing concepts. In addition to this, these concepts are always implied indirectly by other researchers. Therefore, they could be interpreted as core elements for construction partnering and alliancing. In fact, a slight change or widening has to be made of the family-resemblance theory for the sake of using it as an innovative and useful method to define partnering and alliancing in construction. Instead of simply having a network of overlapping similarities, there are two common characteristics and besides that an overlapping network of similarities.

The resulting analysis of the partnering and alliancing concepts can be described as a 'sunflower' because there must be a centre containing two common core elements to all partnering and alliancing designs, 'trust' and 'long-term commitment,' and with two distinguishing core elements between them, that is, 'partnering charter' and 'non-real gain-share/pain share' for partnering and 'formal contract' and 'real gain-share/pain-share' for alliancing. The rest of the elements described in the literature can be seen as petals. Something is then to be defined as partnering if it contains both the four core elements, including (1) partnering charter; (2) non-real gain-share/pain-share; (3) trust; and (4) long-term commitment; and some of the petals, but there is no specific petal or set of petals that they must contain. Therefore, adding different sets lead to different variants of partnering. Similarly, something is to be defined as alliancing if it contains both the four core elements, encompassing (1) formal contract; (2) real gain-share/pain-share; (3) trust; and (4) long-term commitment; and some of the petals, but there is no specific petal or set of petals that they have to contain. The sunflower as an entity can be seen as the base for portraying the whole 'family' of all partnering and alliancing variants (Figure 3.7 and Figure 3.8). Furthermore, 'formal contract', 'partnering charter', 'real gain-share and pain-share', and 'non-real gain-share/pain-share' can be defined as hard elements because they involve contractual arrangements in nature while 'trust' and 'long-term commitment' can be defined as soft elements because they are related to relationship.

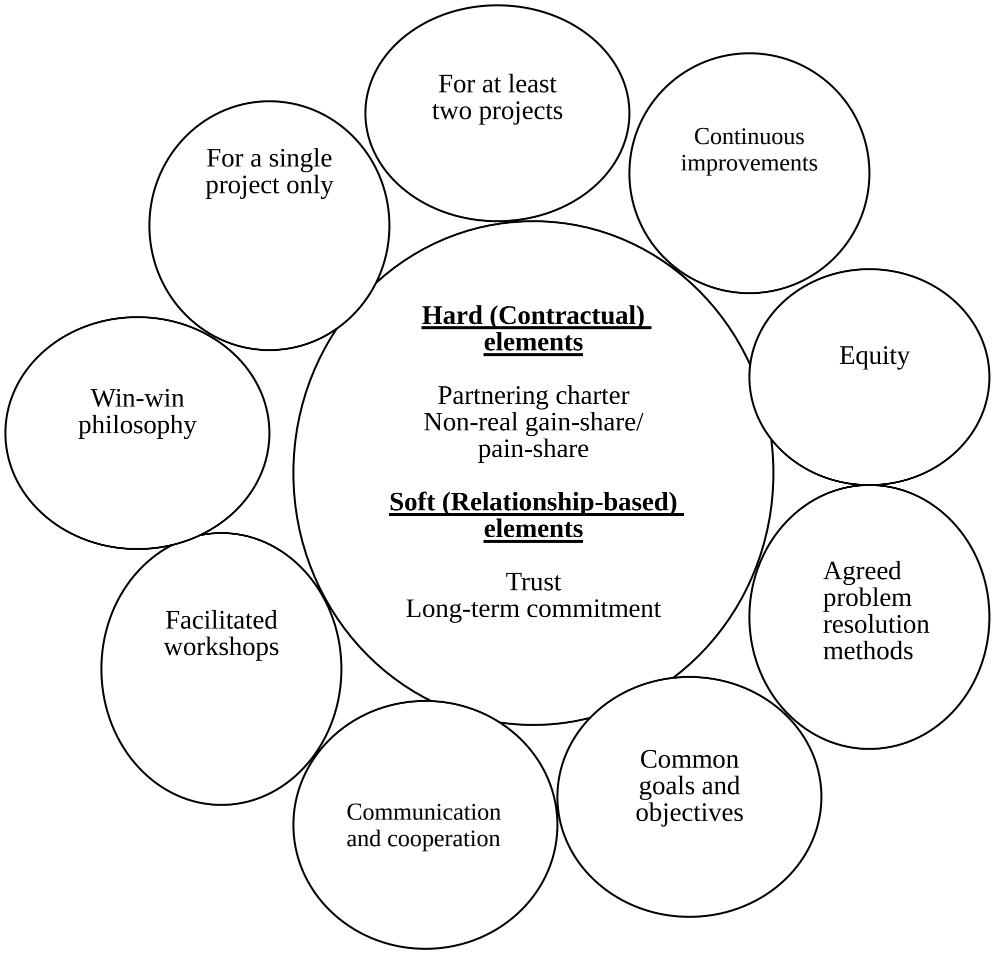


Figure 3.7 Partnering Sunflower Model Containing all the Key Elements of Partnering (Adapted from Nyström, 2005)

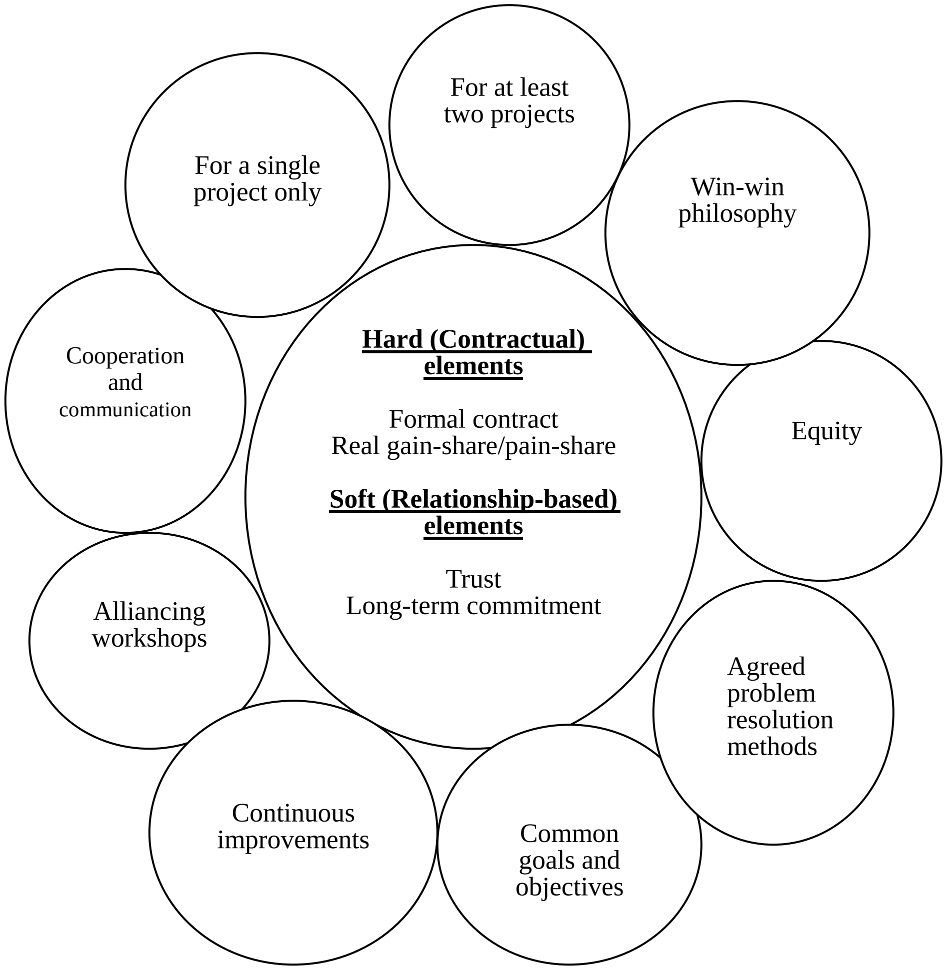


Figure 3.8 Alliancing Sunflower Model Containing all the Key Elements of Alliancing (Yeung et al, 2007)

3.6 APPLICATION OF THE LUDWIG WITTGENSTEIN'S FAMILY-RESEMBLANCE CONCEPT TO PARTNERING /ALLIANCING CONTRACTS

The above-mentioned structure facilitates a practical application of the somewhat vague and multi-faceted concept of family-resemblance. Various designs of partnering and alliancing projects can be captured within the same structure, which is indicated by the following four instances:

Case 1: Chater House, Hong Kong

The first instance is taken from Chan et al (2004a; 2004b; 2004c; 2006), where they described the Chater House, a prestigious office development project in Hong Kong. The client was Hong Kong Land Limited and the main contractor was Gammon Skanska Limited. In addition to the four core elements, including 'partnering charter'; 'non-real gain-share/pain-share'; 'trust'; and 'long-term commitment', this partnering project included: (1) agreed problem resolution methods; (2) cooperation and communication; (3) common goals and objectives; (4) for a single project only; and (5) facilitated workshops. The variant of partnering is shown by the set of elements within the solid line boundary in Figure 3.9.

Case 2: Hang Hau Station and Tunnels, Hong Kong

The second example is also extracted from Chan et al (2004a; 2004b; 2004c; 2006) illustrating the Mass Transit Railway Corporation Limited (MTRCL)'s Tseung Kwan O Railway Extension (TKE) Contract 601 – Hang Hau Station and Tunnels in Hong Kong. The client was the Mass Transit Railway Corporation Limited (MTRCL) and the main contractor was Dragages et Travaux Publics (HK) Limited (DTP). Again, besides the four core elements, this partnering project encompassed (1) win-win philosophy; (2) agreed problem resolution methods; (3) cooperation and communication; (4) continuous improvements; (5) common goals and objectives; (6) for a single project only; and (7) facilitated workshops. This variant of partnering is illustrated by the set of elements within the dotted line boundary in Figure 3.9. The figure shows that even if both projects ‘apparently’ are partnering projects, they are put together by different sets of ‘partnering petals’.

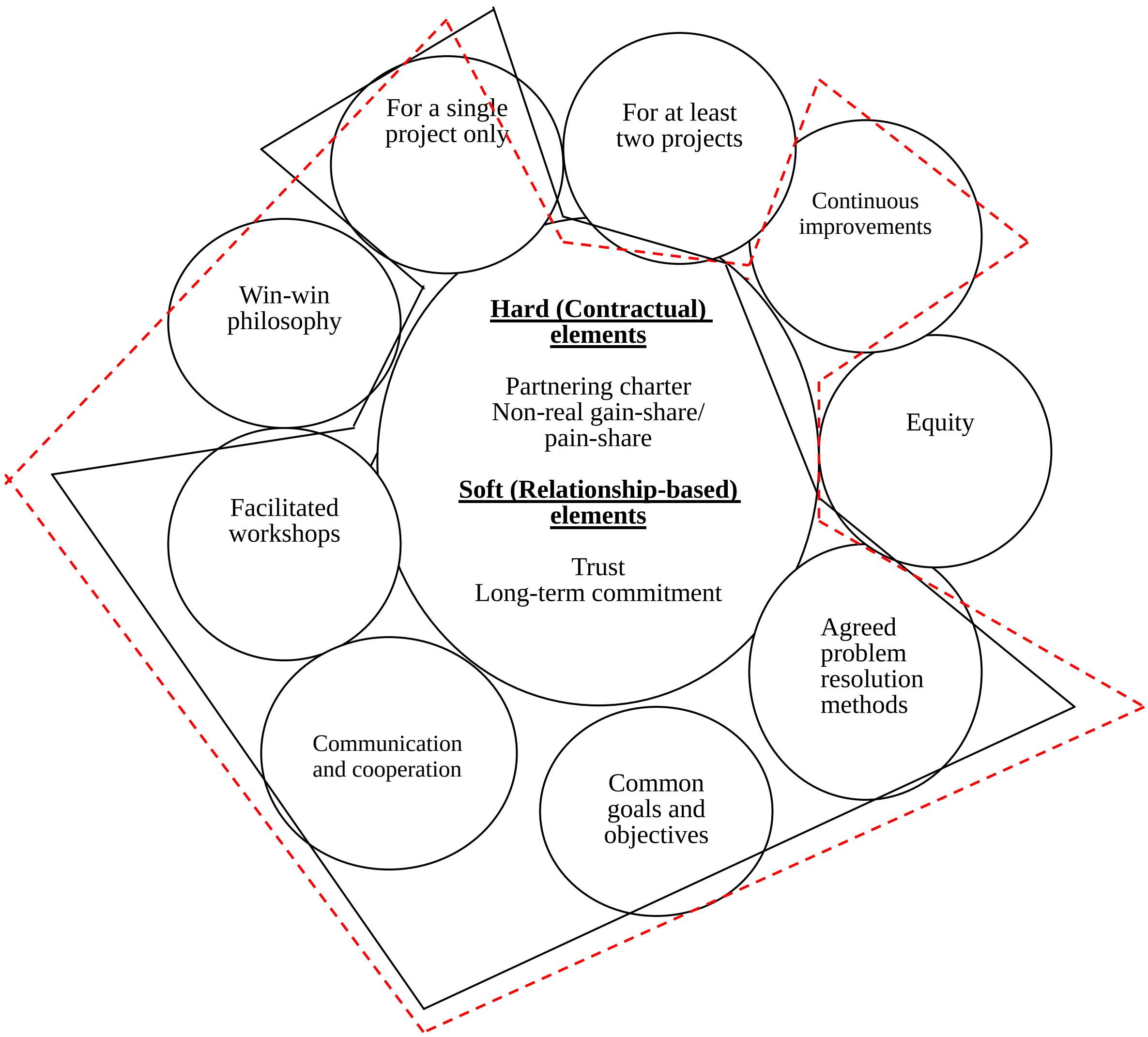


Figure 3.9 The Applied Partnering Sunflower Model

Legend:

Solid lines for Chater House Project

Dotted lines for Hang Hau Station and Tunnels Project

Case 3: Australian National Museum, Australia

The third instance is found from Walker et al (2000b; 2002) where the Australian National Museum Project was described. Apart from the four core elements, including: (1) 'formal contract'; (2) 'real gain-share/pain-share'; (3) 'trust'; and (4) 'long-term commitment', this alliancing project also included: (1) win-win philosophy; (2) continuous improvements; (3) common goals and objectives; (4) facilitated workshops; and (5) for a single project only. The variant of alliancing is perceived by the set of elements within the solid line boundary in Figure 3.10.

Case 4: Wandoo B Offshore Oil Platform, Australia

The fourth example is also drawn from Walker et al (2000b) illustrating the case of Wandoo B Offshore Oil Platform in Australia. Again, on top of the four core elements, this alliancing project comprised: (1) win-win philosophy; and (2) a single project only. This variant of alliancing is explained by the set of elements within the dotted line boundary in Figure 3.10. The figure reflects that although both projects 'observably' are alliancing projects, they are assembled by various sets of 'alliancing petals'.

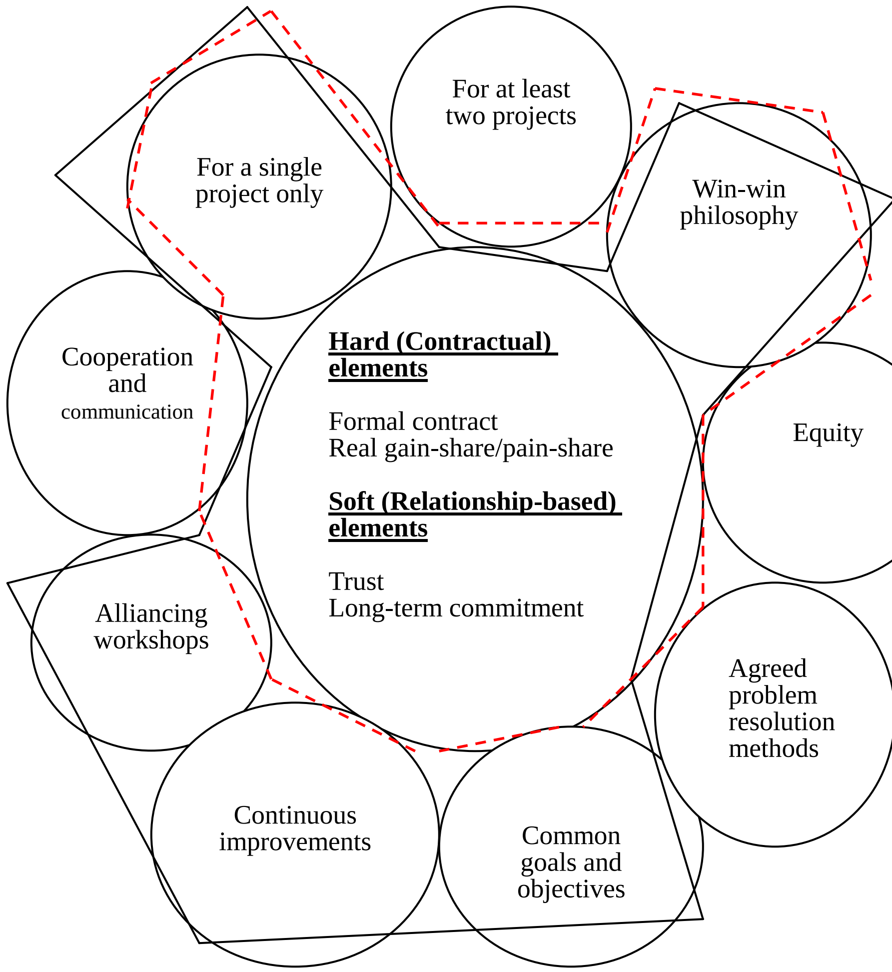


Figure 3.10 **The Applied Alliancing Sunflower Model**

Legend:

Solid lines for Australian National Museum

Dotted lines for Wandoo B Offshore Oil Platform Project

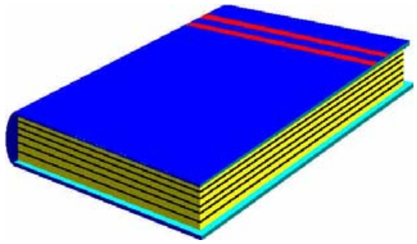
3.7 SIGNIFICANCE AND VALUE OF PARTNERING SUNFLOWER MODEL AND ALLIANCING SUNFLOWER MODEL

More client organisations have adopted partnering and alliancing to manage their building and construction works over the past decade (Walker et al, 2000a; Chan et al, 2002a). With the time going by, the development of construction partnering and alliancing becomes complicated, and it is quite difficult to define what a construction partnering project is. A similar situation is applied to a construction alliancing project as well. In fact, industrial pracitioners and academics are always confused about the concepts and definitions of alliancing and partnering. By adopting the German philosopher Ludwig Wittgenstein's idea of family-resemblance, both a Partnering Sunflower Model and an Alliancing Sunflower Model have been proposed. The two models provide an innovative and useful framework to define the vague and versatile concept of partnering and alliancing in construction in a more flexible and structured way. Industrial practitioners may find both the partnering and alliancing sunflower models useful in the procurement phase of a construction project, particularly if needed, both as a description of the concept and as a common starting point for discussions between the client and the contractor on how to procure a partnering or alliancing project. With a better understanding of this complicated concept, it could help identify critical success factors for partnering and alliancing projects and develop a best practice framework for managing future partnering and alliancing projects to strive for construction excellence.

3.8 CHAPTER SUMMARY

This chapter has made two significant contributions in that the first one is to clearly define construction partnering and alliancing based on an in-depth analysis of reported literature. The second one is to distinguish these two vague and multifaceted concepts in a flexible and structured way by using an innovative and useful approach developed from the German philosopher Ludwig Wittgenstein. Wittgenstein's ideas are that complicated concepts can be understood as a network of overlapping similarities. This is dissimilar to the traditional definition whereby a concept is given necessary and sufficient conditions. Both partnering and alliancing literature was examined according to the Wittgenstein's philosophy and it has been found that four core elements were always included in descriptions, 'partnering charter'; 'non-real gain-share/pain-share'; 'trust'; and 'long-term commitment' for partnering while 'formal contract'; 'real gain-share/pain-share'; 'trust'; and 'long-term commitment' for alliancing. Besides these core elements, there was an overlapping network of the other elements.

The two contributions can be of paramount importance to both the research community and the construction industry. Both the Partnering and Alliancing Sunflower Models, as illustrated by four different case examples, facilitate further research in evaluating partnering and alliancing as more precise hypotheses can be formulated, for example, which effects are related to specific variants of partnering and alliancing and not to partnering and alliancing in general. Various combinations of the partnering and alliancing 'petals' can be tested and assessed based on real-life case studies to develop a set of best practices for successful implementation. Further research can also look closer at how each specific elements can be designed and at the relationship between the petals on a more theoretical model.



CHAPTER 4 REVIEW OF ‘FUZZY’ RESEARCH IN CONSRUCTION MANAGEMENT

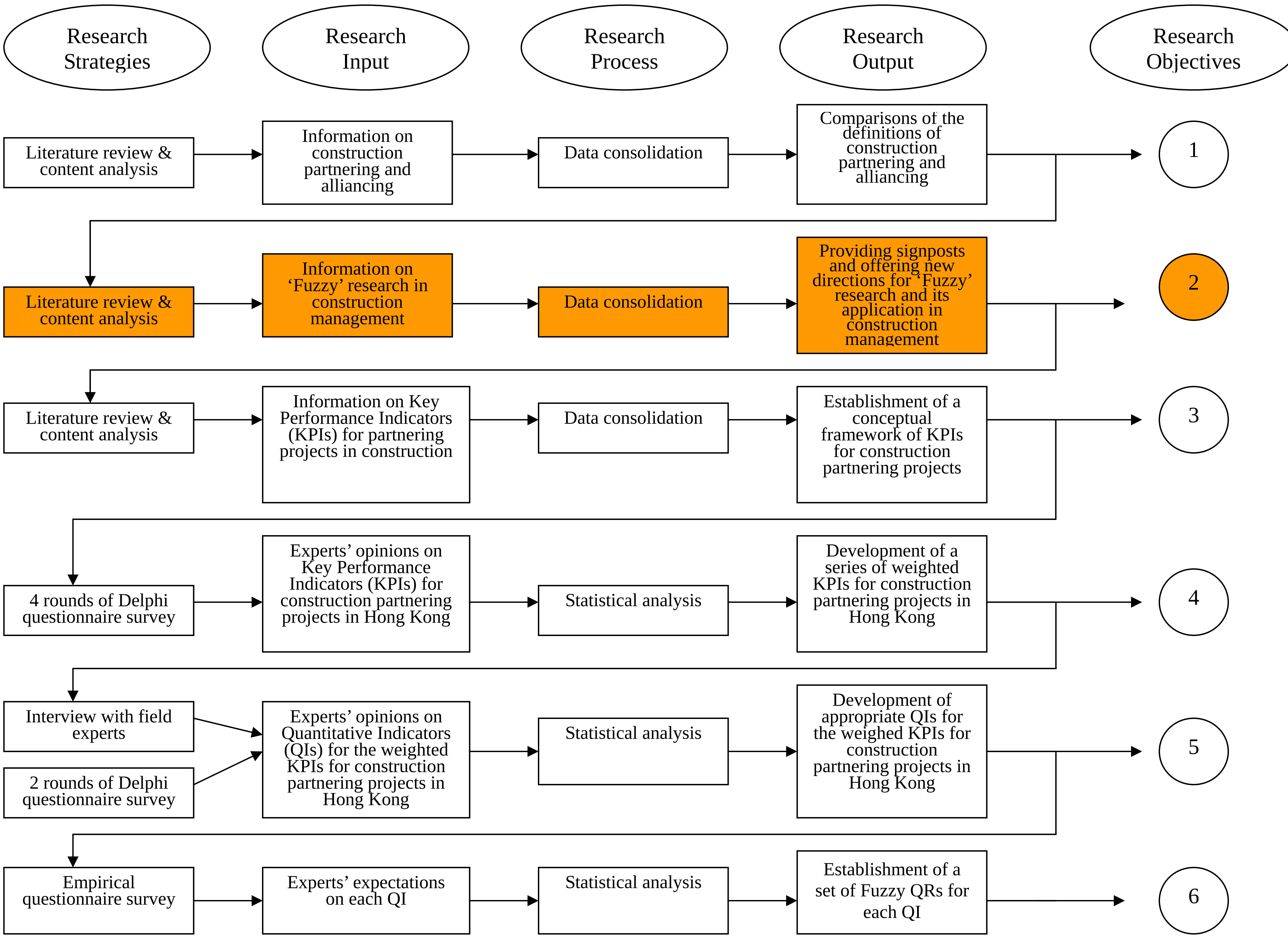


Figure 2.1 Overall Flow of Research

CHAPTER 4 REVIEW OF ‘FUZZY’ RESEARCH IN CONSTRUCTION MANAGEMENT

4.1 INTRODUCTION

The application of ‘Fuzzy Theories’ has been gaining popularity to the research area of construction management over the past decade. To date, nevertheless, no one has attempted to summarise and present a critique of the existing ‘Fuzzy’ literature. The aim of this chapter is to provide an overview of the application of ‘Fuzzy’ Theories in construction management research that has been published in eight first-tier construction journals (Chau, 1997), including: (1) *Journal of Construction Engineering and Management, ASCE; (2) Construction Management and Economics; (3) Engineering, Construction and Architectural Management; (4) Journal of Management in Engineering, ASCE; (5) International Journal of Project Management; (6) Benchmarking: An International Journal; (7) Building and Environment; and (8) Building Research and Information*. In fact, ‘Fuzzy’ is widely accepted as a branch of modern mathematics when compared with traditional mathematics although its history has just over 40 years (Zimmermann, 2001). Its origin can be tracked back when Zadeh wrote a seminal paper in 1965 when he introduced fuzzy sets (sets with unsharp boundaries) to provide a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables. These sets are in general in better agreement with the human mind because they work with shades of grey but not just black or white. Fuzzy sets are typically able to represent linguistic terms, for instance, warm, hot, high and low. Nearly ten years later, Mamdani (1975) succeeded to apply fuzzy logic for control in practice. Table 4.1 records the most important events of the historical development of 'Fuzzy Theories' from 1965 to 1994. After 1994, 'Fuzzy Theories' has been continuously increasing to be applied to the research area of construction management.

Table 4.1 The Historical Development and Application of Fuzzy Theories from 1965 to 2007 (Source: Translated and Expanded from Lam and Pang, 1994)

Year	The Main Event
1965	Prof. L.A. Zadeh of U.C. Berkeley first published a paper on Fuzzy Sets in the Information and Control Journal. He was the first academic who addressed the fuzzy concepts concretely and mathematically.
1972	1. Prof. L.A. Zadeh proposed Fuzzy Control Theory and Approximation Reasoning. 2. Prof. Chi Yeah Shou Long and Prof. Kwun Yeah Tao Fu of Yi Tung Kone University set up 'Fuzzy System Association' in Japan.
1974	1. Prof. E.H. Mamdani of London University succeeded in applying Fuzzy Control Theory in steamed machine. He had successfully completed the first remote controller by using IF-THEN Rule Base and Fuzzy Theory, which was much better than the traditional PID remote controller. 2. The Fuzzy Set and Its Applications Conference was jointly organized by Japan's and the USA's academics. This was the first time to introduce the Fuzzy Theories to academics.
1977	Fuzzy Theory was introduced in mainland China.
1980	The F.L. Smith Co. in Holland applied Fuzzy Theory to the automatic operation of cement making. This was the first commercialized product applying Fuzzy Theory.
1981	1. China established 'China Fuzzy Mathematics and System Association'. The members were mainly mathematicians who were specialized in conducting research in the Fuzzy Mathematics Theories. By doing so, Fuzzy Theory was strengthened in the scope of mathematics. 2. China published 'Journal of Fuzzy Mathematics', the second journal on Fuzzy Theory. In 1987, it was renamed to "Fuzzy System and Mathematics". Since then, China took a leading role in Fuzzy Mathematics Theories.
1982	Prof. C.L. Tang of Wah Chong Polytechnic proposed Grey Theory and Grey Hazy Sets. He proved that Fuzzy Set was a special instance of Grey Hazy Sets. Since then, Grey Theory became vital and it was successfully applied to weather prediction, system modelling,

	decision making, and so on. **Con’t**
1984	The International Fuzzy Systems Association was set up and Prof. H.J. Zimmermann of Technical University of Berlin was elected to be the chairman. At the same time, four branches were set up in North America, Japan, Europe, and China respectively.
1985	The first Fuzzy IFSA World Congress was held in Spain. There were a total of 290 researchers from 29 countries attending the congress. It is of interest to note that the conference papers were mainly related to theoretical foundations, but not practical applications.
1986	1. Japan set up ‘ Japan Society of Fuzzy Theory and System (SOFT)’. 2. Fuji electrical engineering, Fuji Facom and Tokyo Industry University had applied Fuzzy Control Theory to manage the import of clear water system and they had got a very good result.
1987	1. The second Fuzzy IFSA World Congress was held in Tokyo. There were a total of 380 researchers from 25 countries attending the congress. There were a total of 250 conference papers and many of them were related to practical applications. 2. Japan first applied Fuzzy Control to successfully accomplish automatic driving systems.
1988	The first Neural Networks and Fuzzy Logic Applied Technical Conference were held in NASA.
1989	1. The third Fuzzy IFSA World Congress was held in Seattle, and there were numerous conference papers on practical applications. 2. The Laboratory for International Fuzzy Engineering Research was set up, which was mainly composed of industrial practitioners, government officials, and academics. 3. The ‘China’s Governmental Natural Science Funding Committee’ funded 1,350 thousand RMB dollars to set up 35 tertiary institutions and research organisations so as to investigate a research project entitled ‘Fuzzy Message Management and Mechanical Intelligence’, which was led by Professor P.Z. Wang. 4. The China Productivity Centre set up an Interest Group to introduce Fuzzy techniques and highly advocate the Fuzzy theories.
1991	The fourth Fuzzy IFSA World Congress was held in Belgium.
1993	1. An academic journal, ‘IEEE Transaction on Fuzzy Systems’, was first published. 2. The fifth Fuzzy IFSA World Congress was held in South Korea. The themes of conference papers included control system, image processing, machine video, medical diagnosis, share prediction, synthetic assessment, management technology, and system research. 3. The First Asia Fuzzy Symposium was held in Singapore and the first Fuzzy Theory and its Applications Conference was jointly organised by Tsing Wah University and Jiao Tong University.
1994	1. The Republic of China Fuzzy Association was set up. 2. The second Fuzzy Theory and its Applications Conference was held in Taiwan, which was jointly organized by the Taiwan University and Taiwan Industrial Technical University.

	3. The sixth Fuzzy IFSA World Congress was held in the USA. 4. 'Fuzzy theories' were further developed prosperously.
1994-2007	'Fuzzy Theories' has been continuously increasing to be applied to the research area of construction management, construction IT and engineering.

The new Millennium 2000 starts with over 30,000 publications in the area of 'computational intelligence' or 'soft computing' (Zimmermann, 2001). These are terms which have been coined during the first half of the 1990s, when Fuzzy Set Theory, Neural Networks and evolutionary computing joined forces because many researchers felt that there were strong synergies between these areas (Lam et al, 2001a; Boussabaine, 2001a; Liu and Ling, 2003 and 2005). Zimmermann (2001) further stated that it is certainly true that evolutionary computing has its strength in optimization while neural networks are particularly strong in pattern recognition and automatic learning. On the other hand, Fuzzy Set Theory has its strength in modelling, interfacing humans with computers and modelling certain uncertainties. It is worth noting that the USA, Japan and Mainland China are the most important nations to develop Fuzzy Theories and Fuzzy Technology.

Lam and Pang (1994) stated that although Fuzzy Theories were originated in the USA, their developments and applications are both less intensive and extensive than in Japan. In Japan, Fuzzy Control is widely recognized and applied. In many consumer products like washing machines and cameras, fuzzy controllers are used in order to obtain higher machine intelligence quotient and user-friendly products. Its use is also extended to other fields, including control of subway systems, image stabilization of video cameras, and autonomous control of helicopters. However, unlike Japan and the USA, Fuzzy

Theories are further developed by mathematicians in Mainland China. The major achievements include the developments of (1) Molecule Lattice Theory; (2) Fuzzy Normed Linear Space; (3) Fuzzy Topolopy; (4) Fuzzy Measure and Fuzzy Integral; (5) Fuzzy Sets and Fallowing Shadow of Random Sets Theory; (6) Factor Space Theory, and Truth-Valued-Flows Inference (Lam and Pang, 1994).

4.2 ‘FUZZY’ DEFINITIONS

‘Fuzzy’ means blurred, indistinct in shape or outline, frayed or fluffy (Oxford Dictionary, 1993). In modern mathematical society, ‘Fuzzy’ is defined as a branch of modern mathematics that was formulated by Zadeh (1965) to model vagueness intrinsic in human cognitive process and to solve ill-defined and complicated problems because of ambiguous, incomplete, vague and imprecise information that characterize the real-world system. It is appropriate for uncertain or approximate reasoning that involves human intuitive thinking (Zimmermann, 2001) because much of our natural language is fuzzy in nature, for example, it was ‘very hot’ yesterday; 100 is ‘much larger’ than 10; I ‘like’ watching TV; you drive ‘too fast’, please keep it ‘slower’; and he is not too ‘old’.

Fuzzy Theories are generally classified into four main types, including (1) Fuzzy Set; (2) Fuzzy Relation; (3) Fuzzy Logic; and (4) Fuzzy Control. Fuzzy Set Theory uses linguistic variables and membership functions with varying grades to model uncertainty inherent in natural language (Zimmermann, 2001). Fuzzy Relation can be defined as more or less vague relationships between some fixed numbers of objects, and it can formally be treated like fuzzy sets (Bandemer and Gottwald, 1995). Fuzzy Logic is a superset of Boolean conventional logic that has been expanded to handle the concept of partial truth and true-values between ‘completely true’ and ‘completely false’ (Zimmerermann, 2001). Fuzzy Control can be defined as the application of Fuzzy Logic (Lam and Pang, 1994). In general, the design and setting of fuzzy controllers consist of defining three parameters, including (1) defining the domain for the input and output of linguistic variables for each fuzzy controller; (2) defining the set and the type of membership function for each linguistic value – input of every fuzzy controller. The relations between inputs and outputs of linguistic values have to be provided in the form of fuzzy rules, which represent logical inference; and (3) defining the fuzzy logic operators for each IF-THEN sentence, as a base for final inference (Lah et al, 2005).

4.3 ‘FUZZY THEORIES’ APPLICATIONS IN CONSTRUCTION MANAGEMENT

Two ‘Fuzzy Theories’, including Fuzzy Set Theory and Fuzzy Logic Theory, are extensively applied in the construction management discipline. Table 4.4 shows that Fuzzy Set Theory was applied to the area of:

- contractor selection
- site preparation
- competitive bidding strategy
- project management decisions
- dynamic resource allocation

- procurement selection criteria
- productivity
- project scheduling
- risk management
- whole-life costing
- subcontractor selection
- multi-skilled labour allocation
- planning and design tenders selection
- construction time-cost trade off
- contractor prequalification
- assessment of working capital requirement
- value management.

Table 4.5 indicates that Fuzzy Logic Theory was applied to the area of:

- construction labour productivity
- contractor’s markup estimation
- activity delay analysis
- cost control
- productivity
- construction technology
- construction project risk management
- intelligent risk assessment system

- construction site layout planning
- bid/no-bid decision-making
- quality function deployment
- distributor benchmarking.

Since these two theories are increasingly applied to the construction management discipline, they are described in the following sub-section in greater details.

4.4 FUZZY SET THEORY (FST)

Fuzzy Set Theory (FST) is a branch of modern mathematics that was formulated by Zadeh (1965) to model vagueness intrinsic in human cognitive process. Since then, it has been used to tackle ill-defined and complex problems due to incomplete and imprecise information that characterize the real-world systems (Baloi and Price, 2003). In fact, Zadeh stated that when the complexity of a system increases, the ability for human beings to make precise but significant statements about their behaviour diminishes. This will continue to happen until a threshold is reached beyond which precision and significance becomes mutually exclusive – the Principle of Incompatibility. Therefore, it follows that modelling complex or ill-defined systems cannot be made precisely. However, FST was not intended to replace Probability Theory but rather to provide alterative solutions to problems that lack mathematical rigour inherent to Probability Theory (Baloi and Price, 2003). It should be highlighted that FST is an extension of the classical Boolean or binary logic. In fact, the main problem with binary approach is that it fails to convey information effectively, that is, the states between full and non-membership are ignored but they are very vital. Meanwhile, most real-world systems are extremely complicated and ill-defined.

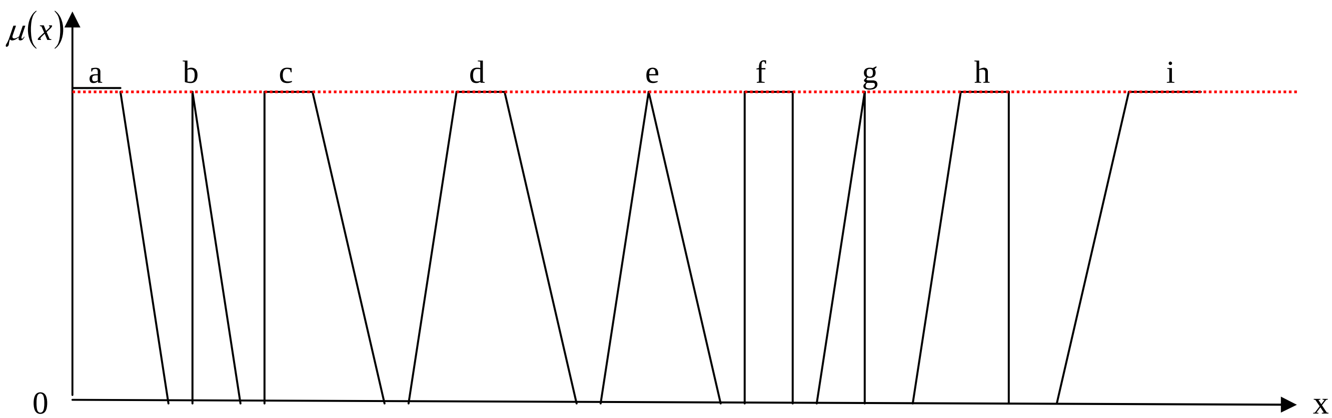
In contrast to binary or dual logic, the essence of fuzziness is that the transition from a membership to non-membership state of an element of a set is gradual rather than abrupt (Baloi and Price, 2003). Thus, FST allows a generalization of the classical set concept to model complex and ill-defined systems. The main concepts associated with FST, as applied to decision systems, are (1) membership functions; (2) linguistic variable; (3) natural language computation; (4) linguistic approximation; (5) fuzzy set arithmetic operations; (6) set operations; and (7) fuzzy weighted average (Bandemer and Gottwald, 1995; Jamshidi, 1997; Grima, 2000; Piegat, 2001; Zimmermann, 2001; Ng et al, 2002; Baloi and Price, 2003; Seo et al, 2004; Zheng and Ng, 2005) In fact, linguistic variable and membership functions are much more widely applied in the construction management discipline.

4.4.1 Linguistic Variable

Baloi and Price (2003) stated that the concept of linguistic variables lies at the core of FST because the basic of FST is the manipulation of linguistic expressions but not numbers. The values assumed by linguistic variables are words. It is clear that a linguistic variable is different from a numerical variable in that its values are not numbers but words or sentences in a natural or artificial language. Since words are generally less precise than numbers, the concept of linguistic variables serves the purpose of providing a means of approximate characterisation of phenomena that are too complicated or too ill-defined to be amendable to description in conventional quantitative terms (Cross and Sudkamp, 2002; Niskanen, 2004). The linguistic variables often assumes different values, such as ‘very high’, ‘high’, ‘moderate’, ‘low’, and ‘very low’, which are fuzzy sets (membership functions) and they represent the perception of a decision-maker or an assessor.

4.4.2 Membership Functions

A fuzzy set is a set whose elements having varying degrees of membership (Bharathi and Sarma, 1985; Civanlar and Trussell, 1986; Ng et al, 2002; Cross and Sudkamp, 2002; Niskanen, 2004). A membership function enables one to perform quantitative calculations in fuzzy decision making. The degrees of membership of an element are expressed by a membership function. Baloi and Price (2003) viewed that membership functions in FST play a similar role to that of probability distribution functions in Probability Theory, that is, membership functions are used to represent uncertainty. A membership function is a function that maps a universal set of objects, X, into the unit interval [0, 1] (Godal and Goodman, 1980; Dubois and Prade, 1983; Bharathi and Sarma, 1985; Civanlar and Trussell, 1986; Zimmermann, 2001). The universal set of objects represents all the elements of the set and the interval corresponds to the set of grades. The grades of membership in fuzzy sets may fall anywhere in the interval [0, 1]. A degree of 0 (zero) means that an element is not a member of the set at all while a degree of 1 (one) represents full membership. Unlike “crisp” sets that have only one membership function, fuzzy sets have a large number of membership functions. Membership functions consisting of straight segments are very often used in practice for their simplicity (Piegat, 2001). The forms of the most often applied functions of the type of polygon are shown in Figure 4.1. Piegat (2001) stated that there are four major advantages of polygonal membership functions. Firstly, a small amount of data is needed to define the membership function. Secondly, it is easy to modify parameters (modal values) of membership functions on the basis of measured values of the input and output of a system. In addition, it is possible to obtain input and output mapping of a model which is a hyper-surface consisting of linear segments. Finally, polygonal membership functions mean that the condition of a partition of unity (it means that the sum of membership grades for each value *X* amounts to one) is easily satisfied. However, it should be noted that polygonal membership functions are not continuously differentiable.



a – the left outside membership function
b,g – triangular asymmetrical membership function
c – trapezoidal asymmetrical membership function
d – trapezoidal symmetrical membership function
e – triangular symmetrical membership function
f – rectangular membership function
h – trapezoidal asymmetrical membership function
i – the right outside membership function.

Figure 4.1 Shapes of the most often applied segmentally-linear membership functions (Source: Piegat, 2001)

In the case of the trapezoidal membership function (Figure 4.2), the following logical variables are introduced (Piegat, 2001):

$$W_1 = \begin{cases} 1 & for \quad a \le x < b, \\ 0 & otherwise \quad , \end{cases}$$

$$W_2 = \begin{cases} 1 & for \quad b \le x < c, \\ 0 & otherwise \quad , \end{cases}$$

$$W_3 = \begin{cases} 1 & for \quad c \le x \le d, \\ 0 & otherwise \quad , \end{cases}$$

The membership function of the type of asymmetrical trapezoid (Figure 4.2) can be represented in the form:

$$\mu(x) = W_1\left(\frac{x-a}{b-a}\right) + W_2 + W_3\left(\frac{d-x}{d-c}\right)$$

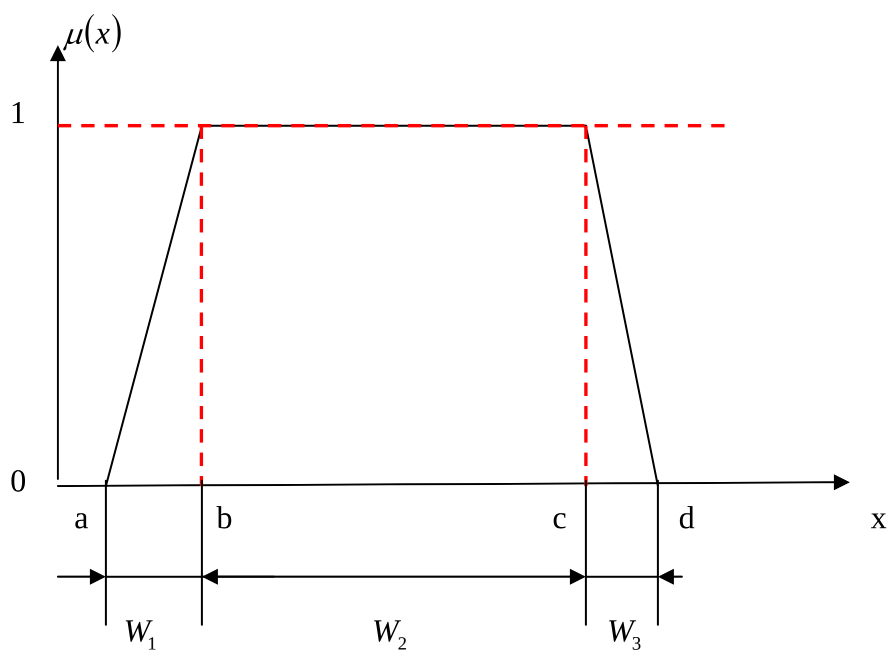


Figure 4.2 Trapezoidal symmetrical and asymmetrical membership functions (Source: Piegat, 2001)

In the case of the symmetrical triangular function (Figure 4.3), only one logical variable W must be introduced.

$$W_1 = \begin{cases} 1 & \text{for} \quad (e - a) \leq x < (e + a) \\ 0 & \text{otherwise} \end{cases} ,$$

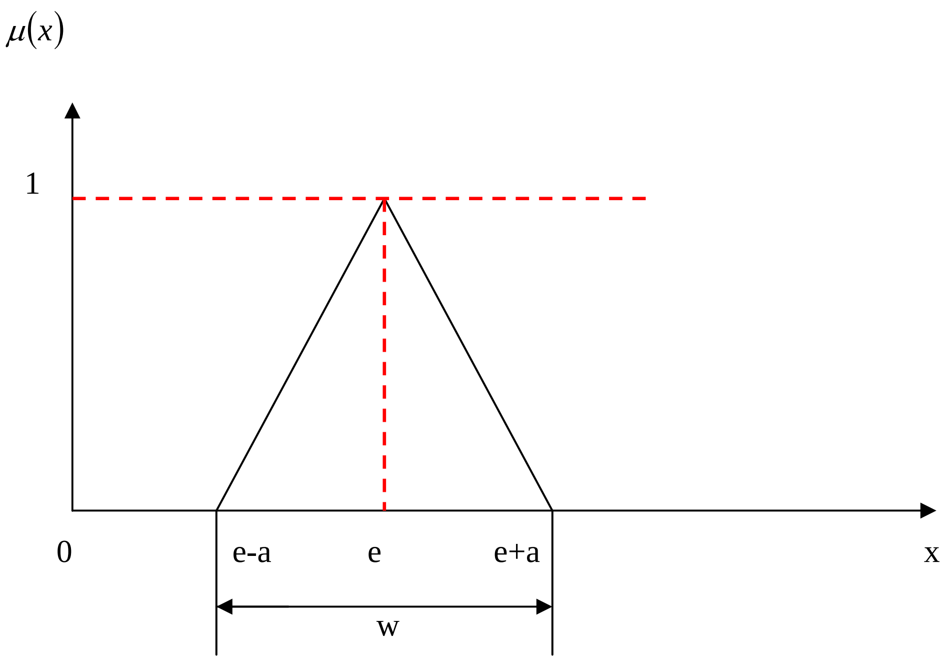


Figure 4.3 Triangular symmetrical membership functions (Source: Piegat, 2001)

Other common membership functions include S-shaped membership function, Z-shaped membership function, bell-shaped membership function, and index-shaped membership function (Lam and Pang, 1994).

The S-shaped membership function (Figure 4.4) can be represented in the form: S-shaped membership function can express the fuzzy concept that ‘*x* is large’.

$$S(x; l, m, n) = \begin{cases} 0, & \\ 2\left(\dfrac{x - l}{n - l}\right)^2 & \\ 1 - 2\left(\dfrac{x - n}{n - l}\right)^2 & \\ 1, & \end{cases} \quad \text{if} \quad \begin{array}{c} x \leq l \\ l \leq x \leq m \\ m \leq x \leq n \\ x \geq n \end{array}$$

The Z-shaped membership function (Figure 4.4) can be represented in the form:

$$Z(x;l,m,n) = 1 - S(x;l,m,n)$$

Z-shaped membership function can express the fuzzy concept that ‘*x* is small’.

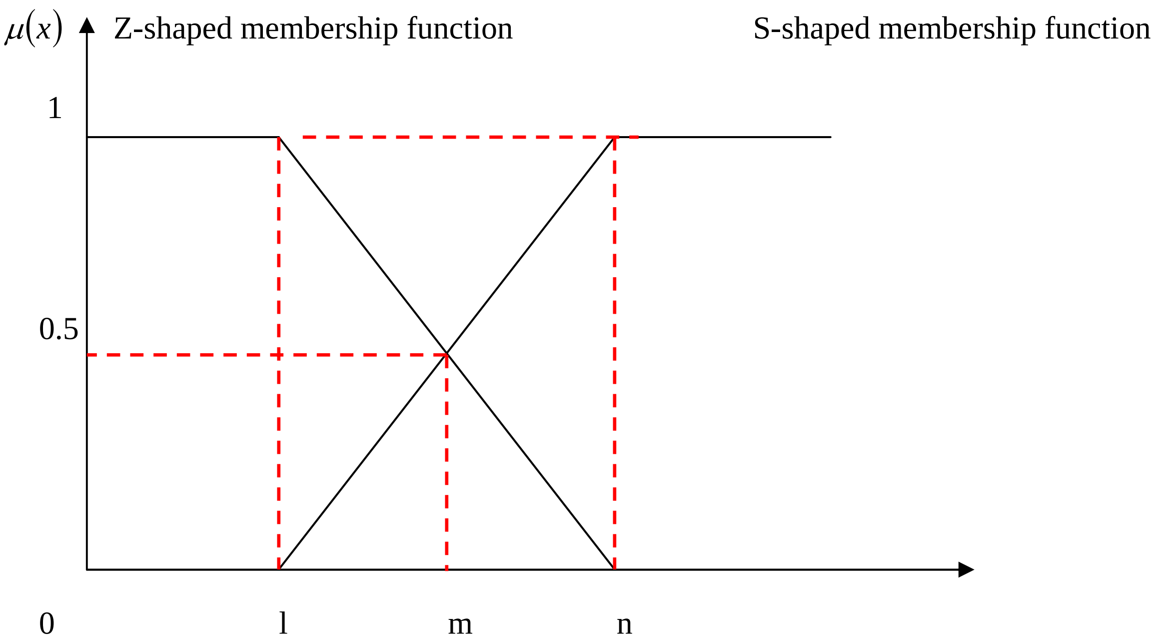


Figure 4.4 S-shaped and Z-shaped membership functions (Source: Lam and Pang, 1994)

The bell-shaped membership function (Figure 4.5) can be represented in the form:

$$\pi(x;b,c) = \begin{cases} S\left(x;c-b,c-\dfrac{b}{2},c\right) & x \le c \\ Z\left(x;c,c+\dfrac{b}{2},c+b\right) & x \ge c \end{cases}$$

where *b* is called bandwidth and *c* is called centre.

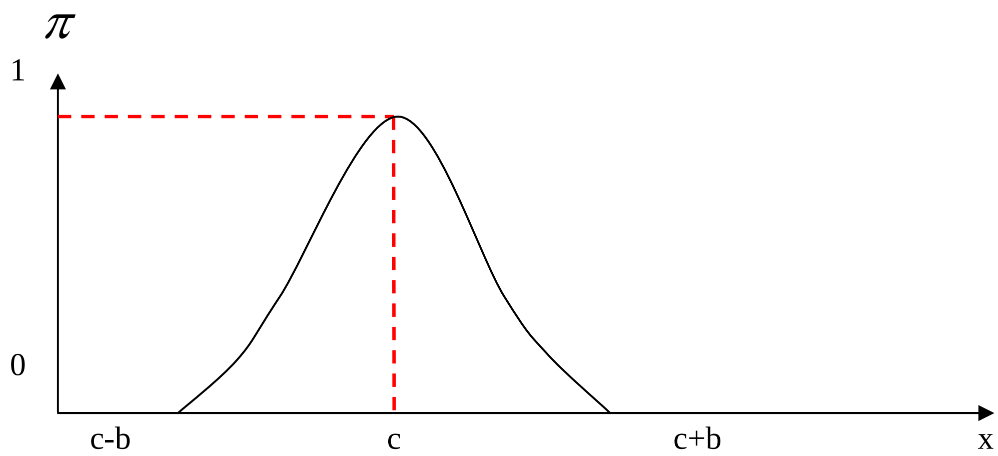


Figure 4.5 Bell-shaped membership function (Source: Lam and Pang, 1994)

The index-shaped membership function can be represented in the form:

$$N(x;m,\sigma) = \exp\left[\frac{-(x-m)^2}{\sigma^2}\right]$$

where m is the centre and σ is the spread. It is of interest to note that index-shaped membership function is often used in Adaptive Fuzzy Control System (Lam and Pang, 1994.

4.5 FUZZY LOGIC THEORY

Fuzzy Logic is a superset of Boolean – conventional logic that has been extended to handle the concept of partial truth and truth-values between 'completely true' and 'completed false' (Mamdani, 1975; Lam and Pang, 1994; Lah et al, 2005). Fuzzy Theory should be seen as a data analysis methodology to generalize any specific theory from 'crisp' to 'continuous'. Fuzzy modelling opens the possibility for straightforward translation of the statements in natural language – verbal formulation of the observed problem - into a fuzzy system. Its functioning is based on mathematical tools. The basic elements are fuzzy subsets – μ_x, μ_y or membership functions for each linguistic variable. In the defined numerical domain, the linguistic variable is arranged with a proper set of membership functions. In fuzzy logic, the arbitrary linguistic variable is represented by fuzzy set *A*, which is composed of a collection of fuzzy subsets – μ_x, μ_y, μ_z $< A$ or membership functions. Each numerical value X_i is defined as a fuzzy element when it is expressed as a pair: numerical value $X_i < X$ and the membership degree to some appropriate membership functions or subsets $\mu_{xi} < X$. Fuzzy set *A* (linguistic variable) is defined as a variable definition area by the arrangement of membership functions $\mu_{(x)}$, $\mu_{(y)}$, $\mu_{(z)}$. Therefore, to each numerical value $X_i < \mu_z$, it belongs to a suitable membership degree of some subset $\mu_{x,y,z}$. The linguistic rules are the basis of the fuzzy system and they are presented in the following form:

$$R_i : \text{IF } X_1 \text{ is } A_i \text{ and (or) } X_2 \text{ is } B_i \text{ THEN Y} = (X_1, X_2),$$

where X_1, X_2 are the input numerical values and Y is output value. A_i, B_i are fuzzy sets characterized by their membership functions (Lah et al, 2005). IF-parts of the rules describe the fuzzy regions of the input variables and THEN-parts are functions of the inputs. In the IF-THEN rules of the fuzzy system, the fuzzy subsets and set are combined with logical fuzzy operations. The basic operations of the set theory are intersection, union, and complement extended for the purpose of fuzzy logic. The standard logic operators are realized in fuzzy logic with extended set operations on membership functions as shown in Table 4.2.

Table 4.2 Standard definitions in fuzzy logic – basic operations of set theory introduced in the framework of the set theory (Source: Lah et al, 2005)

Set definition	Fuzzy logic	Basic operation
Complement 1 – A (x)	Not (A)	1.0 – Ua (x)
Interaction A(x) & B(x)	A and B	Min (Ua(x), Ub(y))
Union A(x) or B(x)	A or B	Max (Ua(x), Ub(y))

4.6 'FUZZY' RESEARCH IN THE PAST

Table 4.3 shows that 'Fuzzy' research in construction management during the past decade can be divided into three broad fields, encompassing (1) Fuzzy Set Theory (FST); (2) Fuzzy Logic Theory (FLT); and (3) Other Fuzzy Techniques (Fuzzy Reasoning, Fuzzy Expert Systems, Fuzzy Neural Network, Fuzzy Analysis, Fuzzy Clustering, Neuro-Fuzzy, and Fuzzy Control), with the applications in five main categories, including (1) Performance; (2) Evaluation/Assessment; (3) Modelling; (4) Decision-making; and (5) Others. It is interesting to note from Table 4.3 that research on construction management applying Fuzzy Set Theory is much more than that applying Fuzzy Logic and Other Fuzzy Techniques and decision making is the most common area of application.

Table 4.3 Summary of Literature Review on the Applications of Fuzzy Set Theory/Fuzzy Logic Theory/Other Fuzzy Concepts in Construction Management in the Last Decade

	Performance	Evaluation/ Assessment	Modelling	Decision making	Others	Total
Fuzzy Set Theory	6	5	6	9	0	26
Fuzzy Logic Theory	4	4	2	2	1	13
Other Fuzzy Techniques	4	3	1	5	1	14
Total	14	12	9	16	2	53

4.7 FUZZY SET THEORY APPLICATIONS IN CONSTRUCTION MANAGEMENT

Table 4.4 indicates that there are 26 journal papers applying Fuzzy Set Theory (FST) in construction management. Grouping these applications into related headings can be classified into four categories, including (1) decision making; (2) performance; (3) modelling; and (4) evaluation/assessment.

4.7.1 Decision Making

Singh and Tong (2005) stated that contractor selection in a multi-criteria environment is largely dependent upon the uncertainty inherent in the nature of construction projects and subjective judgement of decision makers. For this reason, they used a systematic procedure, based on Fuzzy Set Theory, to evaluate the capability of a contractor to deliver the project as per the owner's requirements. The notion of Shapley value was used to determine the global value or relative importance of each criterion in accomplishing the overall objective of the decision-making process. Seo et al (2004) attempted several alternatives to obtain the sustainable residential buildings based on the acceptable level of environmental impact and socio-economic characteristics of residential buildings. However, these criteria are in conflict with each other. Therefore, it is very difficult to assess the sustainable residential buildings. To solve this problem, Seo et al (2004) adopted a methodology, which is based on Fuzzy Set Theory, to assess a residential building that is intended to assist the decision making by the building planners or industrial practitioners.

Table 4.4 Applications of Fuzzy Set Theory in Construction Management

Journal Name	Author(s)	Theory/Concept	Field/Application	Relevance/ Classification
JCEM	Singh, D. and Tong, R.L.K. (2005)	Fuzzy Sets	Contractor selection	Decision making; performance evaluation
JCEM	Seo, S., Aramaki, T., Hwang, Y. and Hanaki, K. (2004)	Fuzzy Set Theory	Environmental sustainable buildings	Decision making; assessment
JCEM	Tam, C.M., Tong, T.K.L., Leung, A.W.T. and Chiu, G.W.C. (2002b)	Fuzzy Sets	Site preparation	Decision making
JCEM	Fayek, A. (1998)	Fuzzy Set Theory	Competitive bidding strategy	Decision making ; assessment
CME	Wang, R.C. and Liang, T.F. (2004)	Fuzzy Sets Theory	Project management decisions	Decision making
CME	Zhang, H. and Tam, C.M. (2004)	Fuzzy Sets	Dynamic resource allocation	Decision making
CME	Li, H. and Shen, Q. (2002)	Fuzzy Set Theory	Sustainable housing	Decision making
CME	Ng, S.T., Luu, D.T., Chen, S.E. and Lam, K.C. (2002)	Fuzzy Set Theory	Procurement selection criteria	Decision making
IJPM	Wang, W., Hawwash, K.I.M. and Perry, J.G. (1996)	Fuzzy Set Theory	Contract type selector	Decision making
JCEM	Zheng, D.X.M. and Ng, S.T. (2005)	Fuzzy Sets Theory	Project management; risk management; productivity	Time and cost performance
JCEM	Bonnal, P., Gourc, D. and Lacoste, G. (2004)	Fuzzy Sets	Project scheduling	Time performance
JCEM	Lorterapong, P. and Moselhi, O. (1996)	Fuzzy Sets Theory	Project network analysis	Time performance
CME	Kishk, M. (2003)	Fuzzy Set Theory	Whole-life costing (WLC)	Cost performance
ECAM	Zhang, H., Li, H. and Tam, C.M. (2004)	Fuzzy Set Theory; Fuzzy Logic	Activity duration	Time performance
IJPM	Baloi, D. and Price, A.D.F. (2003)	Fuzzy Set Theory	Risk management	Performance
CME	Okoroh, M.I. and Torrance, V.B. (1999)	Fuzzy Set Theory ; Fuzzy Logic	Subcontractor selection	Modelling
ECAM	Tong, T.K.L. amd Tam, C.M. (2003)	Fuzzy Sets	Multi-skilled labour allocation	Modelling
IJPM	Hsieh, T.Y., Lu, S.T. and Tzeng, G.H. (2004)	Fuzzy Set Theory	Planning and design tenders selection	Modelling
IJPM	Wei, C.C. and Wang, M.J.J. (2004)	Fuzzy Set Theory	Selection of Enterprise Resource Planning (ERP) system	Modelling
IJPM	Tseng, T.L., Huang, C.C., Chu, H.W. and Cung, R.R. (2004)	Fuzzy Sets Theory	Multi-functional project team formation	Modelling
IJPM	Leu, S.S., Chen, A.T. and Yang, C.H. (2001)	Fuzzy Set Theory	Construction time-cost trade off	Modelling
JCEM	Choi, H.H., Cho, H.N. and Seo, J.W. (2004)	Fuzzy Sets	Risk assessment	Assessment
CME	Lam, K.C., Hu, T., Ng, T., Skitmore, M. and Cheung, S.O. (2001a)	Fuzzy Set Theory; Fuzzy Reasoning; Neural Network Theory	Contractor prequalification	Evaluation
ECAM	Kumar, V.S.S., Hanna, A.S. and Adams, T. (2000)	Fuzzy Set Theory	Assessment of working capital requirement	Assessment
JME	Sanchez, M., Prats, F., Agell, N. and Ormazabal, G. (2005)	Fuzzy Sets	Value management	Evaluation; decision making
IJPM	Holt, G.D. (1998)	Fuzzy Set Theory (partly)	Contractor selection	Evaluation

JCEM: Journal of Construction Engineering and Management, ASCE
CME: Construction Management and Economics
JME: Journal of Management in Engineering, ASCE
ECAM: Engineering, Construction, and Architectural Management
IJPM: International Journal of Project Management

Site layout planning can affect productivity and is crucial to project success. Nevertheless, since construction is heterogeneous in the nature of its organisations, project designs and time constraints, site layout planning for each project becomes unique (Tam et al, 2002b). Therefore, site layout planning is a typical multi-objective problem because it is affected by many uncertainties and variations. In order to facilitate the decision-making process for these problems, Tam et al (2002a) proposed a Non-structural Fuzzy Decision Support System (NSFDSS). This system integrates both expert's judgement and computer decision modelling, thus making it suitable for the appraisal of complex construction problems. In fact, it can provide a reliable assessment result even under the condition of insufficient precise information.

Fayek (1998) developed a competitive bidding strategy model by using Fuzzy Set Theory to help a company achieve its objectives in bidding. He stated that the use of Fuzzy Set Theory allows assessments to be made in qualitative and approximate terms, which suit the subjective nature of the margin-size decision. He concluded that the competitive bidding strategy model can improve the quality of the decision making process used in setting a margin and can help contractors gain a competitive edge in bidding. Wang and Liang (2004) pointed out that project managers have to handle conflicting goals that govern the use of the resources within organisations in the real world. These conflicting goals are required to be optimised by the project managers in the framework of fuzzy aspiration levels.

Wang and Liang (2004) then proposed the multiple fuzzy goals programming model based on fuzzy sets in order to help project managers minimise project total costs, total completion time and total crashing costs. They believed that the proposed model can provide a systematic decision-making framework, thus enabling a decision maker to interactively modify the fuzzy data and model parameters until a satisfactory solution is generated.

Timely resource allocation is vital to avoid unnecessary waiting time of resources and delay of activities for construction activities. Zhang and Tam (2004) opined that timely resource allocation is a dynamic decision making process dependent on real-time information during a construction process. Having considered operational and stochastic characteristics of construction operations and the fuzziness of multiple-decision objectives for an appropriate allocation policy, Zhang and Tam (2004) developed a fuzzy dynamic resource allocation (FDRA) model based on the fuzzy decision making approach. They explained that this model can finally help improve construction productivity by making the best use of resource allocation. Li and Shen (2002) introduced a conceptual approach in developing a decision support tool for sustainable housing, and they illustrated an empirical decision support model for sustainable housing indicators using Fuzzy Set Theory.

Ng et al (2002) pointed out that many procurement selection models fail to address the fuzziness of selection criteria used for procurement selection. To tackle this problem, they used a modified horizontal approach to establish the fuzzy membership function of procurement selection criteria through an empirical study conducted in Australia.

Seven procurement selection criteria, including (1) speed; (2) quality level; (3) flexibility; (4) responsibility; (5) complexity; (6) risk allocation; and (7) price competition, were considered to be fuzzy in nature.

4.7.2 Performance

Zheng and Ng (2005) opined that the duration and cost of each construction activity could change dynamically as a result of many uncertain variables, such as productivity, resource availability and weather. As a matter of fact, project managers have to take these uncertainties into account so as to provide an optimal balance of time and cost based on their own knowledge and experience. For this reason, Fuzzy Set Theory was applied to model the managers' behaviour in predicting time and cost pertinent to a specific option within a construction activity. Zheng and Ng (2005) believed that by incorporating the concept of fuzzy sets, managers and planners can represent the range of possible time-cost values and their associated degree of belief. They claimed that this model can support decision makers in analysing their time-cost optimisation decision in a more flexible and realistic manner.

Bonnal et al (2004) pointed out that stochastic project-scheduling approaches are used by many project schedulers. However, the axiom associated with the theory of probabilities is always incompatible with decision making situations. They analysed that fuzzy project-scheduling approaches are most suited to fuzzy situations, and they proposed a framework to address the resource-constrained fuzzy project-scheduling problem. Lorterapong and Moselhi (1996) presented a new network scheduling method based on Fuzzy Set Theory to estimate the durations of construction activities. The proposed method incorporated a number of new techniques that facilitate: (1) the representation of imprecise activity durations; (2) the calculation of scheduling parameters; and (3) the interpretation of the fuzzy results generated. It was concluded that the proposed method was capable of providing schedules that could approximately account for the nature and the type of uncertainties normally encountered in construction projects. In addition, it was practical and could be easily computerised.

Zhang et al (2004) observed that it is always problematic to define uncertain information input for construction-oriented discrete-event simulation. Therefore, they proposed incorporating Fuzzy Set Theory with discrete-event simulation to handle the vagueness, imprecision and subjectivity in the estimation of activity duration, particularly when insufficient or no sample data are available. Based on an improved activity scanning simulation algorithm, a fuzzy distance ranking measure was used in fuzzy simulation time advancement and event selection for simulation experimentation. Baloi and Price (2003) discussed the core issues of global risk factors' modelling, assessment, and management. Their preliminary indications showed that Fuzzy Set Theory is a viable technology for modelling, assessing and managing global risk factors that affect construction cost performance and therefore a fuzzy decision framework for risk management can be successfully developed.

4.7.3 Modelling

Okoroh and Torrance (1999) developed a Subcontractor Selection and Appointment Model for analysing the subcontractor’s risk elements in construction refurbishment projects. The model is based on the use of Fuzzy Set Theory with the fuzzy set representing the overall weighted average rating of refurbishment contractors’ criterion for the selection of subcontractors. It was believed that the implementation of the model in linguistic terms enables the user to interact with the system in a very friendly manner using natural language expressions. Multi-skilled labour allocation within a defined time frame falls into the class of non-polynomial hard problems, and solutions can only be derived through repeated trials and errors (Tong and Tam, 2003). A Fuzzy Genetic Algorithms Optimisation Model, which is based on Fuzzy Sets and Genetic Algorithms, was developed by Tong and Tam (2003) to provide an efficient method to arrive at a ‘near-optimal’ solution.

Hsieh et al (2004) adopted a fuzzy multi-criteria analysis approach to select planning and design alternatives in public office buildings. The innovative Fuzzy Analytic Hierarchy Process method was used to determine the weightings for evaluation criteria amongst decision makers. On the other hand, the subjectivity and vagueness in the alternative selection process was dealt with by using fuzzy numbers for linguistic terms. By incorporating the decision makers’ attitude towards preference, a crisp overall performance value was obtained for each alternative based on the concept of Fuzzy Multiple Criteria Decision Making. Wei and Wang (2004) developed a comprehensive framework, which combined objective data obtained both from external professional report and subjective data derived from internal interviews with vendors, to select an appropriate Enterprise Resource Planning (ERP) project. By doing so, a hierarchical attribute structure was suggested to evaluate the ERP projects systematically. In addition, Fuzzy Set Theory was adopted to aggregate the linguistic evaluation descriptions and weights.

Tseng et al (2004) defined ‘a multi-functional team’ in the e-world as a group of people from various functional departments or different areas of work responsibility to work together and exchange information through networks. In fact, multi-functional teams are becoming more and more important because organisations often require group co-operation across functional lines and the members may not be in the same location. However, the literature did not provide any analytical solutions for forming multi-functional teams under uncertain information environment.

In order to handle the underlying complexities of the multi-functional teams’ formation process, Tseng et al (2004) developed a methodology based on Fuzzy Set Theory and Grey Decision Theory for the multi-functional teams formation. Fuzzy Set Theory was applied to deal with problems involving ambiguities, which were normally confronted in multi-functional teams’ formation practice and formed groups, when there was no clear boundary for relationship between customers’ requirements and project characteristics. Grey Decision Theory was used to select desired team members through abstractural information. It was concluded that the application of the fuzzy and grey approaches demonstrated its capability of forming a good multi-functional team and it was promising to deal with insufficient information at the team forming stage (Tseng et al, 2004).

It is understandable that construction activity duration is uncertain due to variations in the outside environment, such as weather, site congestion and productivity level. Because of different resource utilisation, construction activity duration might need to be adjusted and the project direct cost could also be changed accordingly. Leu et al (2001) proposed a new optimal construction time-cost trade-off model in which the effects of both uncertain activity duration and time-cost trade-off were taken into consideration. Fuzzy Set Theory was adopted to model the uncertainties of activity durations. A searching technique using genetic algorithm (GA) was used to search for the optimal construction project time-cost trade-off profiles under different risk levels. This method provided an insight into the optimal balance of time and cost under various risk levels as defined by decision makers.

4.7.4 Evaluation/Assessment

Choi et al (2004) presented a risk assessment methodology for underground construction projects, in which they developed a formalised procedure and associated tools to evaluate and manage the risks involved in underground construction. The main tool of the proposed risk assessment methodology is the risk analysis software and this software is built upon an uncertainty model based on fuzzy concept. In more details, the fuzzy-based uncertainty model was designed to consider the uncertainty range that represented the degree of uncertainties involved in both probabilistic parameter estimates and subjective judgements.

Holt (1998) pointed out that the need for judicious construction contractor selection is increasing. For this reason, he reviewed a number of contractor evaluation and selection modelling methods. The methods include: (1) Bespoke approaches; (2) Multi-attribute analysis; (3) Multi-attribute utility theory; (4) Cluster analysis; (5) Multiple regression; (6) Fuzzy Set Theory; and (7) Multivariate discriminant analysis. The merits and demerits as well as previous and future applications of each methodology were discussed. Subsequently, Lam et al (2001a) developed a Fuzzy Neural Network (FNN) Model, which was amalgamated both the Fuzzy Set and Neural Network Theories, to improve the objectiveness of contractor prequalification. Through the FNN model, the fuzzy rules as used by the pre-qualifiers could be identified and the corresponding membership functions could be transformed.

Kumar et al (2000) stated that the systematic assessment of working capital requirement in construction projects dealt with the analysis of different quantitative and qualitative factors in which information was subjective and based on uncertainty. As a matter of fact, there exists an inherent difficulty in the classical approach to assess the effect of qualitative factors for the evaluation of working capital requirement. Kumar et al (2000) developed a methodology to incorporate linguistic variables into workable mathematical propositions for the assessment of working capital using Fuzzy Set Theory after considering the uncertainty associated with many of the project resource variables.

Sánchez et al (2005) developed a fuzzy set-based approach for representing and synthesising information about the various kinds of variables involved in the evaluation of a project’s value in the context of construction in civil engineering. This methodology for summarising and normalising values aims at contributing to decision making analysis in the context of multiple-criteria evaluation and group decision making.

4.8 FUZZY LOGIC THEORY APPLICATIONS IN CONSTRUCTION MANAGEMENT

Table 4.5 shows that there are 13 journal papers applying Fuzzy Logic Theory in construction management. Similar to Fuzzy Set Theory, these applications can be classified into four categories, including (1) decision making; (2) performance; (3) modelling; and (4) evaluation/assessment, with an additional classification of “Others”. They are described in the following sub-sections in greater details.

4.8.1 Performance

Fayek and Oduba (2005) applied fuzzy logic and fuzzy expert systems to the modelling of predicting the labour productivity of two common industrial construction activities, that is, rigging pipe and welding pipe, given the realistic constraints of subjective assessments, multiple contributing factors, and limitations on data sets. Liu and Ling (2005) considered that it is difficult to estimate a contractor’s markup because the construction environment is changeable and uncertain. In a study, they constructed a fuzzy logic-based artificial neural network (ANN) model to assist contractors in making markup decision. By integrating the fuzzy logic inference system, this model provides users with a clear explanation to justify the rationality of the estimated markup output.

Table 4.5 Applications of Fuzzy Logic Theory in Construction Management

No	Journal Name	Author(s)	Theory/Concept	Field/Application	Relevance/ Classification
1	JCEM	Fayek, A.R. and Oduba, A. (2005)	Fuzzy Expert Systems; Fuzzy Logic	Construction labour productivity	Productivity performance
2	JCEM	Liu, M. and Ling, Y.Y. (2005)	Fuzzy Logic; Fuzzy Neural Network	Contractor’s markup estimation	Cost performance
3	JCEM	Oliveros, A.V.O. and Fayek, A.R. (2005)	Fuzzy Logic	Project management; activity delay analysis	Time performance
4	JCEM	Knight, K. and Fayek, A.R. (2002)	Fuzzy Logic	Cost control ; project management	Cost performance ; decision making
5	JCEM	Zayed, T.M. and Halpin, D.W. (2004)	Fuzzy Logic	Productivity	Quantitative assessment (Performance)
6	JCEM	Chao, L.C. and Skibniewski, M. (1998)	Fuzzy Logic	Construction technology	Evaluation
7	CME	Tah, J.H.M. and Carr, V. (2000)	Fuzzy Logic	Construction project risk assessment	Assessment
8	ECAM	Shang, H., Anumba, C.J., Bouchlaghem, D.M. and Miles, J.C. (2005)	Fuzzy Logic	Intelligent risk assessment system	Assessment
9	CME	Lam, K.C., Tang, C.M. and Lee, W.C. (2005)	Fuzzy Logic Theory (partly)	Construction site layout planning	Decision making
10	IJPM	Lin, C.T. and Chen, Y.T. (2004)	Fuzzy Logic	Bib/no-bid decision-making	Decision making
11	JCEM	Cheng, M.Y. and Ki, C.H. (2003)	Fuzzy Logic ; Fuzzy Sets	Construction management	Modelling
12	BIJ	Bouchereau, V. and Rowlands, H. (2000)	Fuzzy Logic	Quality function deployment	Modelling
13	BIJ	Ma, H., Deng, Z. and Solvang, W.D. (2004)	Fuzzy Logic	Distributor benchmarking	Benchmarking

JCEM: Journal of Construction Engineering and Management, ASCE
CME: Construction Management and Economics
ECAM: Engineering, Construction, and Architectural Management
BIJ: Benchmarking: An International Journal

Oliveros and Fayek (2005) developed a fuzzy logic model that integrates daily site reporting of activity progress and delays, with a schedule updating and forecasting system for construction project monitoring and control. This model can help with the analysis of the effects of delays on a project’s completion date because the use of fuzzy logic allows linguistic and subjective assessments to be made, and thereby suiting the actual practices commonly used in the construction industry. It is of relevance to researchers because it makes a contribution to project scheduling by developing a complete approach for handling the uncertainties inherent with schedule updating and activity delay analysis with advancing the application of fuzzy logic in construction. It is also relevant to industrial practitioners because it provides them with a useful technique for incorporating as-built data into the schedule, assessing the impact of delays on the schedule, and updating the schedule to reflect the consequences of delays and corrective actions taken.

Knight and Fayek (2002) developed a model by using fuzzy logic to predict potential cost overruns on engineering design projects. By doing so, it assists to assess the amount of possible risk on a project and the likelihood of making a profit on the job. In particular, the research used fuzzy logic to model the relationships between the characteristics of a project and the potential risk events that may occur, and the associated cost overruns caused by combinations of the project characteristics and risk events.

4.8.2 Evaluation/Assessment

Zayed and Halpin (2004) viewed that piling process qualitative and quantitative factors have to be considered so as to estimate productivity efficiently. To assess the effect of subjective factors on bored pile construction productivity, Zayed and Halpin (2004) developed a productivity index model based on the analytic hierarchy process and fuzzy logic to represent the subjective effect in refining productivity assessment using simulation and deterministic techniques. Chao and Skibniewski (1998) presented a fuzzy-logic-based, risk-incorporating approach to evaluating new construction technology, intended to produce consistent technology implementation decisions.

Experimental results indicate that the approach can produce a consistent evaluation of the available options, based on a set of user-defined linguistic rules that state the priorities in a given project scenario.

Tah and Carr (2000) used a hierarchical risk breakdown structure representation to develop a formal model for qualitative risk assessment. To do so, a common language for describing risks was first presented which included terms for quantifying likelihoods and impacts in order to achieve consistent quantification. The relationships between risk factors, risks, and their consequences are represented on cause and effect diagrams through the application of fuzzy logic, and the concepts of fuzzy association and fuzzy composition. Shang et al (2005) developed an innovative approach to risk assessment for distributed project teams by the prototype system, which was based on a client and server architecture and used fuzzy logic and web-based technology. It was found that the use of a web-based risk assessment system for distributed project team members had major benefits in terms of use of linguistic terms to express risk assessment, ease of communication, ease of maintenance and greater consistency.

4.8.3 Decision Making

Lam et al (2005) conducted a study on construction site layout planning and discovered that the actual closeness of relationships between site facilities ultimately governed the site layout. They had determined that the underlying factors of site layout planning for medium-sized projects included: (1) work flow; (2) personnel flow; (3) safety and environment; and (4) personal preferences. It is of interest to note that a closeness relationship must be deduced in order to find the weightings on these factors and the corresponding closeness indices between each facility. To do this, two modern mathematical approaches, Fuzzy Logic Theory and an entropy measure, were adopted to find these results so as to minimise the uncertainty and vagueness of the collected data and improve the quality of the information. Genetic algorithms (GAs) were applied to searching for the optimal site layout in a medium-sized government project using the GeneHunter software.

Lin and Chen (2004) studied bid/no-bid decision making and stated that it was associated with uncertainty and complexity. They adopted a fuzzy logic approach because subjective considerations, such as nature, competition, value of the bid opportunity, resource capabilities, and the reputation of the company are relevant to the bid/no-bid decision. By using this approach, assessments were described subjectively in linguistic terms while screening criteria were weighted by their corresponding level of importance using fuzzy values. A practical example proved that this method could provide the analyst with more convincing and reliable results and cost saving for a company.

4.8.4 Modelling

It is widely accepted that problems associated with construction industry are complex, full of uncertainty and vary with environment. Cheng and Ki (2003) stated that fuzzy logic, neural networks and genetic algorithms have been successfully applied in construction management to solve different types of problems over the past decade. Having considered the characteristics and merits of each method, Cheng and Ki (2003) combined the three methods to develop the Evolutionary Fuzzy Neural Inference Model. It was concluded that this model could be used as a multifarious intelligent decision support system for decision making to solve manifold construction management problems.

Quality function deployment is a management tool that provides a visual connective process to help teams focus on the needs of the customers throughout the total development cycle of a product or process (Bouchereau and Rowlands, 2000). It provides a means for translating customer needs into appropriate technical requirements for each stage of a product/process-development life-cycle. It helps develop more customer-oriented, higher-quality products. Although there are numerous benefits of using quality function deployment, it is not a simple tool to use. Bouchereau and Rowlands (2000) analysed that fuzzy logic, artificial neural networks, and the Taguchi method can be combined with quality function deployment to resolve some of its weaknesses, and proposed a synergy between quality function deployment and the three methods and techniques reviewed.

4.8.5 Others

Ma et al (2004) mentioned that when an enterprise intends to design its distribution chain, it first needs to assess all possible distributors, and then select the eligible ones to form the design model. In fact, this assessing process can be done by distributor benchmarking by the following three steps. The first step is to identify all factors needed for benchmarking a distributor by a systematic analysis. The second step is to develop an internet-based information acquisition module to get all needed information from possible distributors. The third step is to develop an inference module, based on the combination of fuzzy logic and array-based logic, to benchmark a distributor.

4.9 OTHER FUZZY CONCEPTS APPLICATIONS IN CONSTRUCTION MANAGEMENT

Table 4.6 shows that there are 13 journal papers applying other fuzzy concepts in construction management. In particular, other fuzzy concepts were widely applied to the area of:

- construction project management
- project selection
- cash flow analysis
- financial decisions
- construction productivity
- travel time
- construction project duration
- project teaming strategies
- safety management

- project risk management
- contractor's markup estimation
- knowledge-based expert system.

Similar to Fuzzy Logic Theory, these applications can be classified into five categories, including (1) decision making; (2) performance; (3) evaluation/assessment; (4) modelling; and (5) others.

Table 4.6 Applications of Other Fuzzy Concepts in Construction Management

No	Journal Name	Author(s)	Theory/Concept	Field/Application	Relevance/ Classification
1	CME	Lam, K.C., So,A.T.P., Ng, T., Yuen, R.K.K., Lo, S.M., Cheung, S.O. and Yang, H. (2001b)	Fuzzy Reasoning	Construction project management	Decision making
2	CME	Wong, E.T.T., Norman, G. and Flanagan, R. (2000)	Fuzzy Analysis	Project selection	Decision making
3	CME	Boussabaine, A.H. and Elhag, T. (1999)	Fuzzy techniques	Cash flow analysis	Decision making
4	CME	Lam, K.C. and Runeson, G. (1999)	Fuzzy concepts	Financial decisions	Decision making
5	JCEM	Marzhuk, M. and Moselhi, O. (2004)	Fuzzy Clustering	Travel time	Time performance
6	JCEM	Portas, J. and AbouRizk, S. (1997)	Neural Network	Estimation of construction productivity	Productivity performance
7	ECAM	Boussabaine, A.H. (2001a and 2001b)	Neuro-Fuzzy	Construction projects' duration	Time performance
8	ECAM	Boussabaine, A.H. (2001a and 2001b)	Neuro-Fuzzy	Construction projects' duration	Time performance
9	IJPM	Dzeng, R.J. and Wen, K.S. (2005)	Fuzzy Delphi Method	Project teaming strategies	Evaluation
10	IJPM	Tam, C.M., Tong, T.K.L., Chiu, G.C.W. and Fung, I.W.H. (2002a)	Non-structural Fuzzy Decision	Safety management	Evaluation
11	IJPM	Kuchta, D. (2001)	Fuzzy Numbers	Project risk assessment	Assessment
12	B&E	Liu, M. and Ling , Y.Y. (2003)	Fuzzy Neural Network	Contractors' markup	Modelling
13	BRI	Li, H. (1997)	Angular Fuzzy Sets	Knowledge-based expert system	Success factor

JCEM: Journal of Construction Engineering and Management, ASCE
CME: Construction Management and Economics
ECAM: Engineering, Construction, and Architectural Management
IJPM: International Journal of Project Management
B&E: Building and Environment
BRI: Building Research and Information

4.9.1 Decision Making

Lam et al (2001b) developed a methodical system for construction project management decision making by using a combination of fuzzy multiple-objective decision making theory and the fuzzy reasoning technique in order to solve most real world decision making problems that combine both qualitative and quantitative concepts. The model developed can be applied to construction project management problems by suggesting an optimal path of corporate cash flow that results in the minimum use of resources. Wong et al (2000) explained that by incorporating fuzzy analysis into multi-attribute utility theory, project selection problems can be dealt with when some project attributes are subject to random variations. The aggregate utility function for an individual project is derived as a fuzzy number (or interval) which, in turn, yields probabilistic information for stochastic dominance tests. A unique feature of the approach is that it dispenses with the task of selecting probability distributions for aggregate utility function.

Boussabaine and Elhag (1999) stated that fuzzy models are particularly suited to making decisions involving new technologies where uncertainties inherent in the complex situations. Based on an assumption that cash flow at particular valuation stages of a project is ambiguous, they used an innovative fuzzy cash flow analysis to analyse the cash flow curve of projects at any progress period to make sure that it is reasonable. Lam and Runeson (1999) established a decision model for a contracting firm. The model provided a methodical system for construction financial decision-making and a way of solving a financial decision problem under qualitative and fuzzy circumstances. And the model can be applied to the management of corporate cash flow, thereby facilitating the minimal use of resources. The information provided by the model also allows the planner to eliminate excess use or idleness of resources during the scheduling of a project. It was concluded that the model could lead to a compromise optimal schedule that provided the contracting firm with the optimal schedule for achieving profit and construction risk by making optimal use of the contractor’s resources.

4.9.2 Performance

Marzouk and Moselhi (2004) adopted a two-step fuzzy clustering method to estimate haulers’ travel time, and the method provided a generic tool that could be incorporated in models dedicated for estimating earthmoving production. The developed method utilized linear regression and fuzzy subtractive clustering in which seven factors affecting haulers’ travel time were first identified and their significance were then quantified using linear regression. Portas and AbouRizk (1997) developed an approach by using a three-layered network with a fuzzy output structure to estimate construction productivity for concrete formwork tasks. It was found that this structure provided the most suitable model since much of the input was subjective. Boussabaine (2001a and 2001b) developed an understanding of neurofuzzy concept modelling techniques and demonstrated the power and versatility of neurofuzzy methods when applied to the determination of construction project duration. It was concluded that the model had good generalisation ability but could be improved by considering other factors that influence the duration of building projects that are not considered in the model.

4.9.3 Evaluation/Assessment

Tam et al (2002a) conducted a study and tried to evaluate the safety management systems and prioritised a number of safety improvement measures with the consideration of different decision criteria. To do so, the Non-structural Fuzzy Decision Support System (NSFDSS) was applied to facilitate the decision making process for these multi-objective problems. It was found that the modified FDSS is appropriate for the appraisal of complicated construction problem, which allows assessment based on a pair-wise comparison of alternatives using semantic operators, even under the condition that insufficient precise information is available.

Kuchta (2001) proposed a new approach to the criticality of an activity and of the whole project. This approach considers both the decision maker attitude and the project network structure. The criticality measure obtained may serve as a measure of risk or of the supervision effort needed and can assist to make the decision on whether to accept or reject the project.

4.9.4 Modelling

Liu and Ling (2003) developed the Fuzzy Neural Network (FNN) model to help contractors to estimate markup percentage to be included in their tenders. This model provides users with a clear explanation to justify the rationality of the estimated markup output. By using this model, it is believed that the difficulties in markup estimation due to its heuristic nature can be overcome.

4.9.5 Others

Li (1997) investigated vital issues and factors related to the success of a knowledge-based expert system (KBES) development. He used angular fuzzy sets to quantitatively determine values of the surrogate items and values less than one were regarded as weak items. Deployment of corrective action is then required to enhance the weak items. It was proposed that the identified factors and their surrogate items should bring the attention of KBES developers to a number of vital issues that are crucial to a successful KBES implementation.

4.10 IMPLICATIONS FOR THE FUTURE

4.11.1 Research Implications

After conducting a comprehensive literature review on the applications of Fuzzy Set Theory, Fuzzy Logic Theory, and other Fuzzy concepts in construction management, some research areas have been identified for further study. Firstly, it has been found that when applying these theories and concepts on 'performance measures', focus is always on 'hard' performance, including time performance, cost performance, safety performance and productivity. Since partnering, alliancing, as well as relational contracting approaches are increasingly applied in procuring building and construction projects (Chan et al, 2003b, 2006), some result-oriented subjective or ‘soft’ measures, such as quality performance, professional image establishment, client’s satisfaction, customer’s satisfaction, job satisfaction, and innovation and improvement, should be studied by using Fuzzy theories and concepts in order to obtain precise performance evaluation under a complex construction environment because they are often regarded as subjective and fuzzy in nature.

Similarly, other relationship-based performances, such as trust and respect, effective communication, harmonious working relationship, long-term business relationship, and top management commitment, should also be analyzed by using fuzzy theories and concepts with the same reasoning. In addition, when solving ill-defined or complex problems, Fuzzy Set Theory, Fuzzy Logic Theory, and other Fuzzy techniques can help build up models based on ambiguous, incomplete, vague, and imprecise information that characterize the real-world situations. Similar researches on modelling were applied in subcontractor selection (Okoroh and Torrance, 1999); quality function deployment (Bouchereau and Rowlands, 2000); construction time-cost trade off (Leu et al, 2001); multi-skilled labour allocation (Tong and Tam, 2003); contractor’s markup (Liu and Ling, 2003); planning and design tenders selection (Hsieh et al, 2004); selection of ERP system (Wei and Wang, 2004); and multi-functional project team formation (Tseng et al, 2004).

Besides, the Fuzzy theories and concepts are suggested to be widely applied to construction technology and information technology. In fact, seven journal papers searched in construction technology have adopted Fuzzy theories and concepts. The areas of investigation include: (1) building thermal dynamic response (Skrijanc et al, 2001); (2) sulfate expansion (Inan et al, 2007); (3) user acceptance and adaptation (Guillemin and Molteni, 2002); (4) car-parking guidance (Leephakpreeda, 2007); (5) thermal conductivity (Singh et al, 2007); (6) heating control (Gouda et al, in press); and (7) thermal and illumination control (Lah et al, 2005). Therefore, these fields may be of great research values by using Fuzzy Set Theory, Fuzzy Logic Theory, and other Fuzzy concepts.

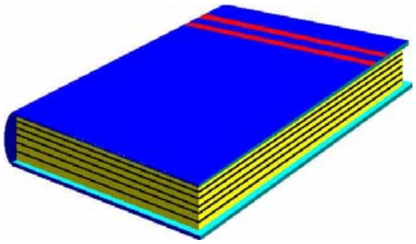
4.11.2 Practical Implications

As mentioned previously, Fuzzy theories and concepts have been widely applied to a wide range of products, such as washing machines, cameras, fuzzy controllers, control of subway systems, image stabilization of video cameras, and autonomous control of helicopters. Therefore, similar ‘fuzzy’ products may be applied to intelligent buildings and green buildings as these kinds of buildings are often constructed with high quality and innovations.

4.12 CHAPTER SUMMARY

This chapter has presented a comprehensive literature review on the application of ‘Fuzzy Theories’ in the construction management discipline. In fact, although ‘Fuzzy Theories’ have been increasingly applied in the research area of construction management during the last decade, no research study has attempted to draw up a holistic commentary of the existing ‘Fuzzy’ literature. To fill in this research gap, this chapter has launched a comprehensive review on the ‘Fuzzy’ literature that has been published in eight high quality rating journals. It has been found that ‘Fuzzy’ research, as adopted in construction management over the past decade, can be divided into three broad fields, encompassing (1) Fuzzy Set Theory (FST); (2) Fuzzy Logic Theory (FLT); and (3) Other Fuzzy Techniques, with their applications in five main categories, including: (1) Performance; (2) Evaluation/Assessment; (3) Modelling; (4) Decision-making; and (5) Others. The comprehensive literature review provided in this chapter polishes the signposts and puts forward new directions for ‘Fuzzy’ research and its application in construction management.

After reviewing ‘Fuzzy’ research in construction management discipline, Fuzzy Set Theory is selected to define reasonable quantitative ranges of different performance levels for each of the Quantitative Indicators (QIs) because only Fuzzy Set Theory can be applied to derive fuzzy membership functions when compared with Fuzzy Logic Theory and other fuzzy concepts. In fact, Fuzzy Logic Theory is often used to develop a model when facing a true-false logic decision while Fuzzy Set Theory is used to tackle these ill-defined and complex problems due to incomplete and imprecise information that characterize the determination of quantitative ranges for each of the quantitative indicators.



CHAPTER 5 CONCEPTUAL FRAMEWORK FOR IDENTIFYING KEY PERFORMANCE INDICATORS (KPIs) FOR PARTNERING PROJECTS IN CONSRUCTION

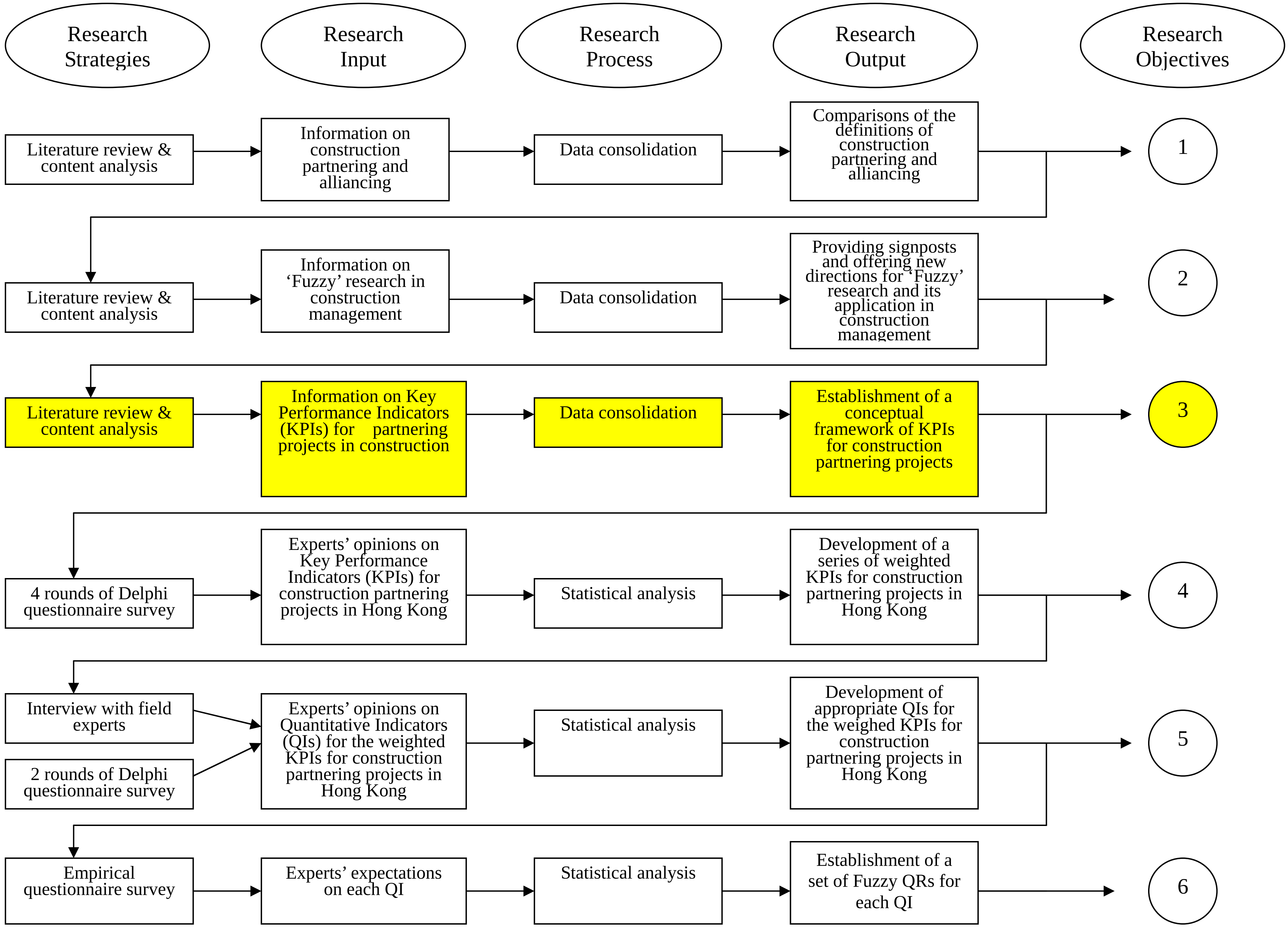


Figure 2.1 Flow of Research

Chapter 5 CONCEPTUAL FRAMEWORK FOR IDENTIFYING KEY PERFORMANCE INDICATORS (KPIs) FOR PARTNERING PROJECTS IN CONSTRUCTION

5.1 INTRODUCTION

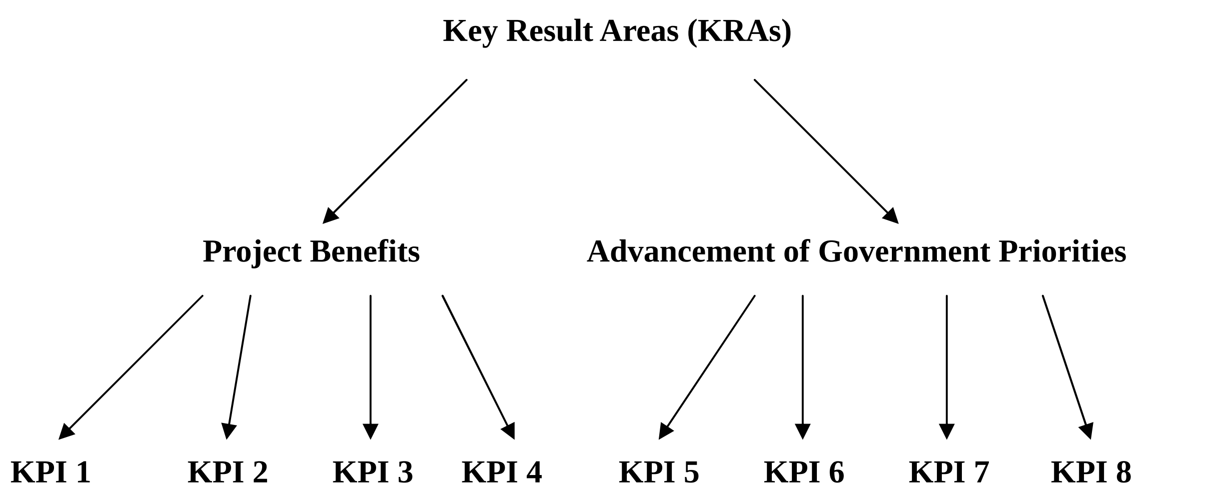
This chapter aims to develop a conceptual framework for identifying KPIs to measure the partnering performance of construction projects. Before developing such a framework, definition and functions of KPIs are first discussed. After that, a comprehensive and critical review of literature on performance measures for partnering projects over the last decade is conducted. A preliminary conceptual framework for identifying KPIs for partnering projects is formed. To verify the usefulness of the preliminary KPIs' conceptual framework for partnering projects, in-depth study of 17 Hong Kong Demonstration Projects using partnering approach (24 demonstration projects in total) derived from the Hong Kong Demonstration Projects Committee was followed. The committee was set up in Hong Kong in 2003 with the objective of establishing a framework, whereby construction industry professionals could collectively set benchmarks for delivering projects, utilising innovative techniques or process. Ultimately the goal is to improve the efficiency of the construction process within Hong Kong and Asia as a whole. The committee comprises around 25 leading industrial practitioners within the Hong Kong construction industry with many diverse roles and responsibilities, including property developers, architects, structural and civil engineers, building services engineers, government bodies, main contracting organisations, and sub-contracting organisations. Based on the previous research and the study of 17 Demonstration Projects with partnering approach in Hong Kong, a consolidated conceptual framework consisting of 25 performance measures is developed to measure the performance of partnering projects. Finally, the significance of the study in terms of educational value and practical application in the construction industry is highlighted.

5.2 DEFINITION AND FUNCTIONS OF KEY PERFORMANCE INDICATORS (KPIs)

Cox et al (2003) defined KPIs as compilations of data measures used to evaluate the performance of an operation. They are tools that management uses to assess employee performance of a particular task. These evaluations typically compare the actual and estimated performance in terms of efficiency, effectiveness, and quality in terms of both product and workmanship.

The purpose of the KPIs in construction is to enable measurement of project and organisational performance throughout the construction industry (The KPI Working Group, 2000). This information can then be used for benchmarking purposes, and will be a key component of any organisation’s move towards achieving best practice. Collin (2002) stated that the aim of introducing KPIs in evaluating project delivery initiatives is to objectively measure a range of fundamental characteristics associated with procurement systems to identify elements or aspects that have changed as a result of amendments to the procurement process; and establish the strengths and weaknesses of each procurement system. He further added that before a set of KPIs is developed, it is vital to achieve agreement on what broadly constitutes procurement performance. Such an approach is commonly referred as determining the ‘Key Result Areas’ (KRAs). Once the KRAs are agreed, then measures (KPIs) can be developed to support them. Table 5.1 shows the relationship between KRAs and KPIs.

Table 5.1 Relationship between KRAs and KPIs (Measurements of Project Success) (Adapted from Collin, 2002)



KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8
Timely Completion - was the projects completed on time - was the time allowed reasonable	Successful Commissioning - smooth commissioning and hand over - minimum of defects and disputes	Value for Money - whole of life value/contribution to government priorities	Fit for Purpose - meets functional and aesthetic requirements - community standards/public architecture	Industry Sustainability - reasonable and sustainable profits - fair treatment of supply chain	Workforce Management - fair and equitable - safe practices	Innovation - innovations incorporated in projects - scope for innovation	Environmental Sustainability - design - construction - management in use

Collin (2002) also advocated that the process of developing KPIs involved the consideration of the following 8 factors:

1. KPIs are general indicators of performance that focus on critical aspects of outputs or outcomes.
2. Only a limited, manageable number of KPIs is maintainable for regular use. Having too many (and too complex) KPIs can be time and resource consuming.
3. The systematic use of KPIs is essential as the value of KPIs is almost completely derived from their consistent use over a number of projects.
4. Data collection must be made as simple as possible.
5. A large sample size is required to reduce the impact of project specific variables.
6. For performance measurement to be effective, the measures or indicators must be accepted, understood and owned across the organization.
7. KPIs will need to evolve and it is likely that a set of KPIs will be subject to change and refinement.
8. Graphic displays of KPIs need to be simple in design, easy to be updated and accessible.

With these factors in mind, a preliminary conceptual framework is developed to identify KPIs for measuring the performance of partnering projects in construction based on a critical and comprehensive literature review on performance measures for partnering projects, followed by verification through in-depth study of 17 Demonstration Projects using partnering approach derived from the Hong Kong Demonstration Projects

Committee.

5.3 CONCEPTUAL MEASURES FOR ASSESSING PARTNERING PROJECTS

Before developing a conceptual framework for identifying KPIs for partnering projects, it is important to understand the inter-relationship between partnering goal, process, performance and feedback because it accounts for the need to develop a systematic approach to measure partnering performance. Cheung et al (2003) proposed that a partnering process can be seen as a system that encompasses 4 key elements, including (1) Goal; (2) Process; (3) Performance; and (4) Feedback (Figure 5.1). In any partnering arrangement, the first step is to identify overall project goals, followed by developing strategies that direct efforts to achieve the goals. Then, performance is monitored and measured in order to evaluate progress. In this sense, measures of partnering performance ought to be reflective of the project goals because each partnering project requires a unique set of measures. Clearly, a partnering project cannot be successful if any one of the four elements is missing. Therefore, measures must be closely related to the project goals, objectives, and strategies. Crane et al (1999) created a model called “Objectives, Goals, Strategies, Measures” (OGSM) to exemplify the systematic selection of project measures for monitoring partnering performance (Figure 5.2).

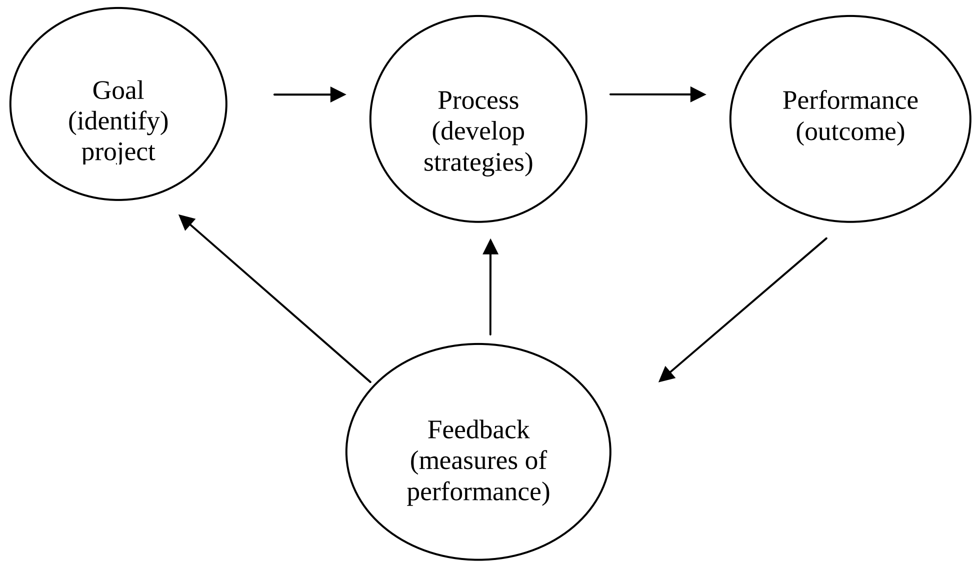


Figure 5.1 Partnering System (Source: Cheung et al, 2003)

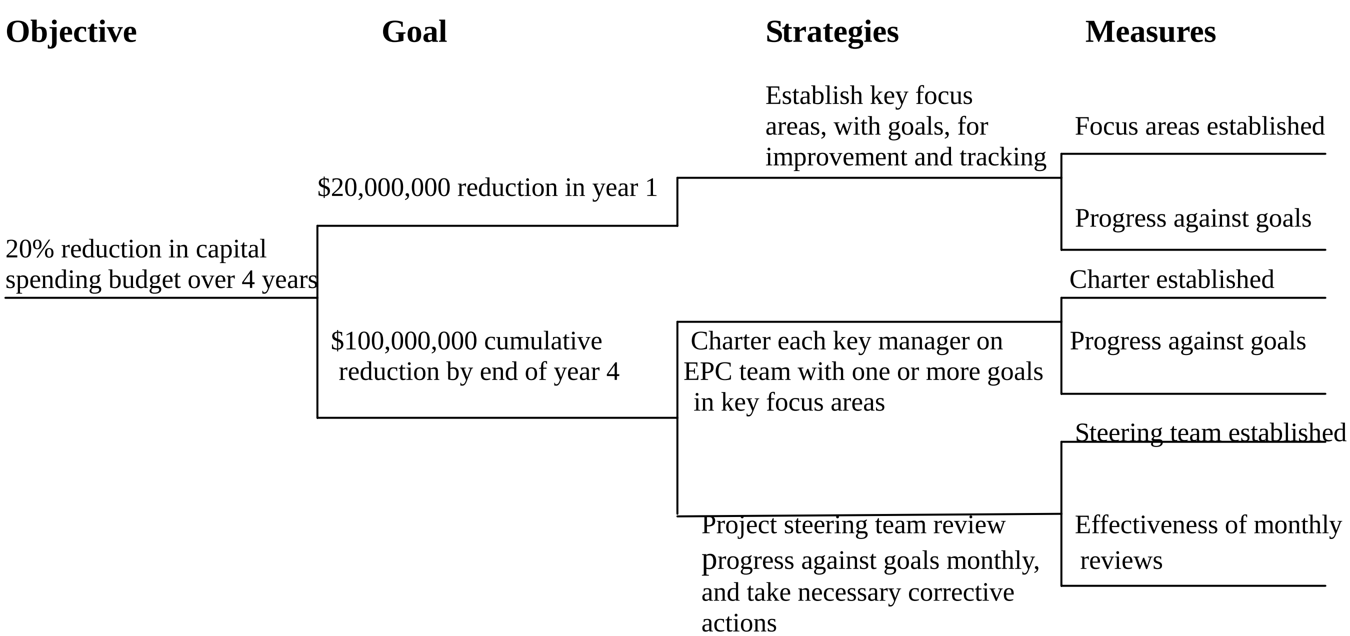


Figure 5.2 OGSM Model (Source: Crane et al, 1999)

Having conducted a comprehensive and critical literature review on performance measures, 19 performance measures for partnering projects were identified (Table 5.2). The results in Table 5.2 show that Time Performance and Cost Performance were the most frequently cited performance measures for partnering projects, with Quality Performance being the second; Claim Occurrence/Claim Magnitude; Effective Communications; Accident/Incident Rate/Safety Performance; and Environmental Performance/Number of Environmental Complaints being the third; Trust and Respect being the fourth; Harmonious Working Relationships; Litigation Occurrence/Litigation Magnitude; Dispute Occurrence/Dispute Magnitude; and Customer Satisfaction being the fifth; and Profit and Financial Objectives; Scope of Rework; Productivity; Innovation and Improvement; Pollution Occurrence/Pollution Magnitude; and Professional Image Establishment and Employee’s Attitude being the least.

After identifying 19 measures for partnering projects based on the comprehensive and critical literature review, 17 Demonstration Projects using partnering approach derived from the Hong Kong Demonstration Projects Committee were studied to validate the preliminary KPIs’ conceptual framework for partnering projects. Table 5.3 shows the KPIs used for these 17 demonstration projects adopting partnering approach. The results show that Safety Performance was the most frequently cited performance measure for Demonstration Projects with partnering approach, with Quality Performance and Time Performance being the second; Effective Communications, and Profit and Financial Objectives being the third; Environmental Performance being the fourth; Cost and Professional Image Establishment being the fifth; Innovation being the sixth; Long-term Business Relationship, Improved Working Relationship, Job Satisfaction, and Trust and Respect being the seventh; Client’s Satisfaction being the eighth; and Top Management Commitment, Reduction of Paperwork, and Partnering Workshop being the least.

Table 5.2 Summary of Literature Review on Performance Measures for Partnering Projects

Measures for partnering projects	**Crane et al (1999)**	**Chan et al (2001)**	**Zhao (2002)**	**Cheung et al (2003)**	**Bayliss et al (2004)**	**Cheng & Li (2004b)**	**Chan et al (2004b, c,d, 2006)**	**Total no. of hits for the same performance measure**
1. Construction time/Time variation/ Programme	✓	✓	✓	✓	✓		✓	**6**
2. Cost/Capital cost/Construction cost/Budget	✓	✓	✓	✓	✓		✓	**6**
3. Quality	✓	✓		✓	✓		✓	**5**
4. Claim occurrence/Claim magnitude		✓		✓	✓		✓	**4**
5. Effective communications	✓		✓	✓	✓			**4**
6. Accident/Incident rate/Safety	✓			✓	✓		✓	**4**
7. Environmental issue/Number of environmental complaints			✓	✓	✓		✓	**4**
8. Trust and respect	✓		✓	✓				**3**
9. Harmonious working relationships		✓				✓		**2**
10. Litigation occurrence/Litigation magnitude	✓						✓	**2**
11. Dispute occurrence/Dispute magnitude		✓					✓	**2**
12. Customer satisfaction			✓			✓		**2**
13. Profit and financial objectives			✓					**1**
14. Scope or rework	✓							**1**
15. Productivity			✓					**1**
16. Innovation and improvement			✓					**1**
17. Pollution occurrence/Pollution magnitude							✓	**1**
18. Professional image establishment							✓	**1**
19. Employee's attitude			✓					**1**
Total no. of performance measures identified from each publication	**8**	**6**	**10**	**8**	**7**	**2**	**10**	

Clearly, the majority of KPIs used for these partnering projects are identical to the performance measures identified in the literature as shown in Table 5.2. However, 6 performance measures identified in Table 5.3 are not mentioned in Table 5.2. Since the attributes identified in the Hong Kong Demonstration Projects are more suited to the local context, it is suggested that these additional attributes should be included in the preliminary KPIs' conceptual framework. These additional KPIs are: (1) Long-term Business Relationship; (2) Client's Satisfaction; (3) Job Satisfaction; (4) Top Management Commitment; (5) Introduction of Partnering Workshop; and (6) Reduction of Rework. In total, a consolidated framework comprising 25 performance measures has been consolidated in the framework (Figures 5.3 and 5.4) and they were classified into 4 categories, including:

(a) result-oriented objective measures

- time performance
- cost performance
- profit and financial objectives
- scope of rework
- safety performance
- environmental performance
- pollution occurrence
- productivity

(b) result-oriented subjective measures

- quality performance
- professional image establishment
- client’s satisfaction
- customer’s satisfaction
- job satisfaction
- innovation and improvement

(c) relationship-oriented objective measures

- litigation occurrence and magnitude
- dispute occurrence and magnitude
- claim occurrence and magnitude
- introduction of facilitated workshops

(d) relationship-oriented subjective measures

- trust and respect
- effective communications
- harmonious working relationships
- long-term business relationships
- top management commitment
- employee’s attitude
- reduction of paperwork

Table 5.3 Key Performance Indicators (KPIs) for 17 Demonstration Projects Using Partnering Approach in HK

	1. Safety	2. Quality/High quality	3. Anticipated delay/Programme	4. Effective communications/Teamwork	5. Profit/Financial objective	6. Environmental performance/Environmental protection/Waste reduction	7. Cost/Savings	8. Successful project/Elevated project image/Professional image	9. Innovation	10. Relationships/Improved relationship	11. Team of next project/Long-term relationship	12. Job satisfaction	13. Trust/Respect	14. Client 's Satisfaction	15. Top management commitment	16. Reduction of paperwork	17. Partnering workshop	**Total number of KPIs identified from each project**
The Orchards	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓					11
Three Pacific Palace	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓						11
Cambridge House	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓					10
Po Lam Road Phase 1	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓				10
Tsim Sha Tsui Station Modification Works	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓					9
Chater House	✓	✓			✓	✓	✓			✓		✓		✓		✓		8
Choi Yuen Phase 2	✓	✓	✓	✓	✓	✓		✓			✓							8
Stonecutters Bridge	✓	✓	✓		✓	✓		✓	✓	✓								8
Grand Promenade	✓		✓	✓			✓	✓		✓		✓	✓					7
Hong Kong Museum of Coastal Defence	✓	✓	✓	✓	✓			✓					✓					7
Tradeport Hong Kong Logistics Centre	✓			✓	✓	✓	✓	✓	✓									6
Design & Build of Improvement to Castle Peak Road	✓		✓		✓	✓				✓								5
Lok Ma Chau Viaduct	✓	✓	✓				✓							✓				5
Tseung Kwan O Technology Park		✓	✓	✓											✓		✓	5
East Hall Extension of Passenger Terminal Building of the Hong Kong International Airport	✓	✓	✓				✓											4
One Peking Road	✓			✓		✓			✓									4
Tseung Kwan O Area 73A Phase 2	✓	✓				✓												3
Total number of hits for the same KPI	**16**	**13**	**13**	**11**	**11**	**10**	**9**	**9**	**8**	**5**	**5**	**5**	**5**	**3**	**1**	**1**	**1**	

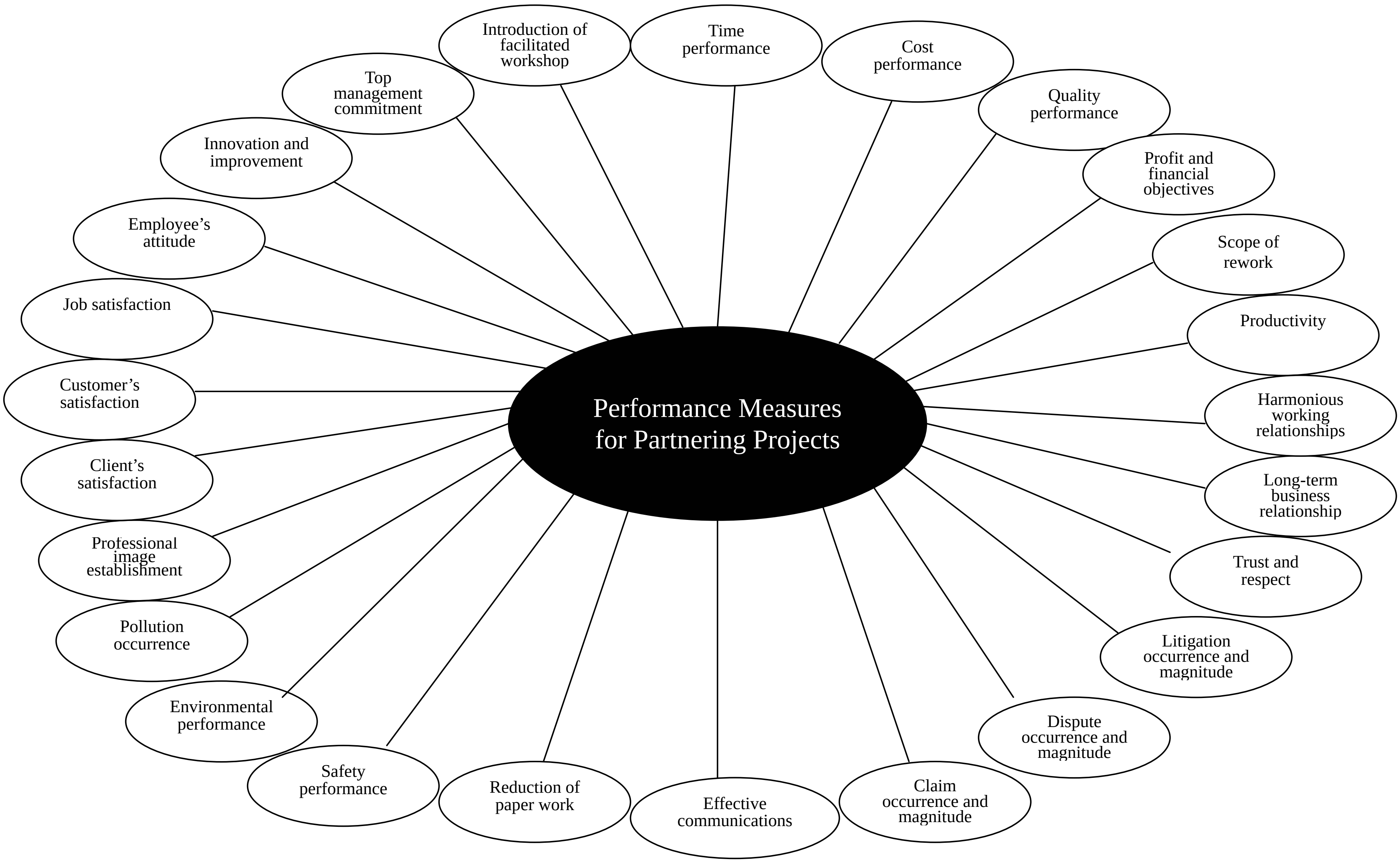


Figure 5.3 Framework of Performance Measures for Partnering Projects

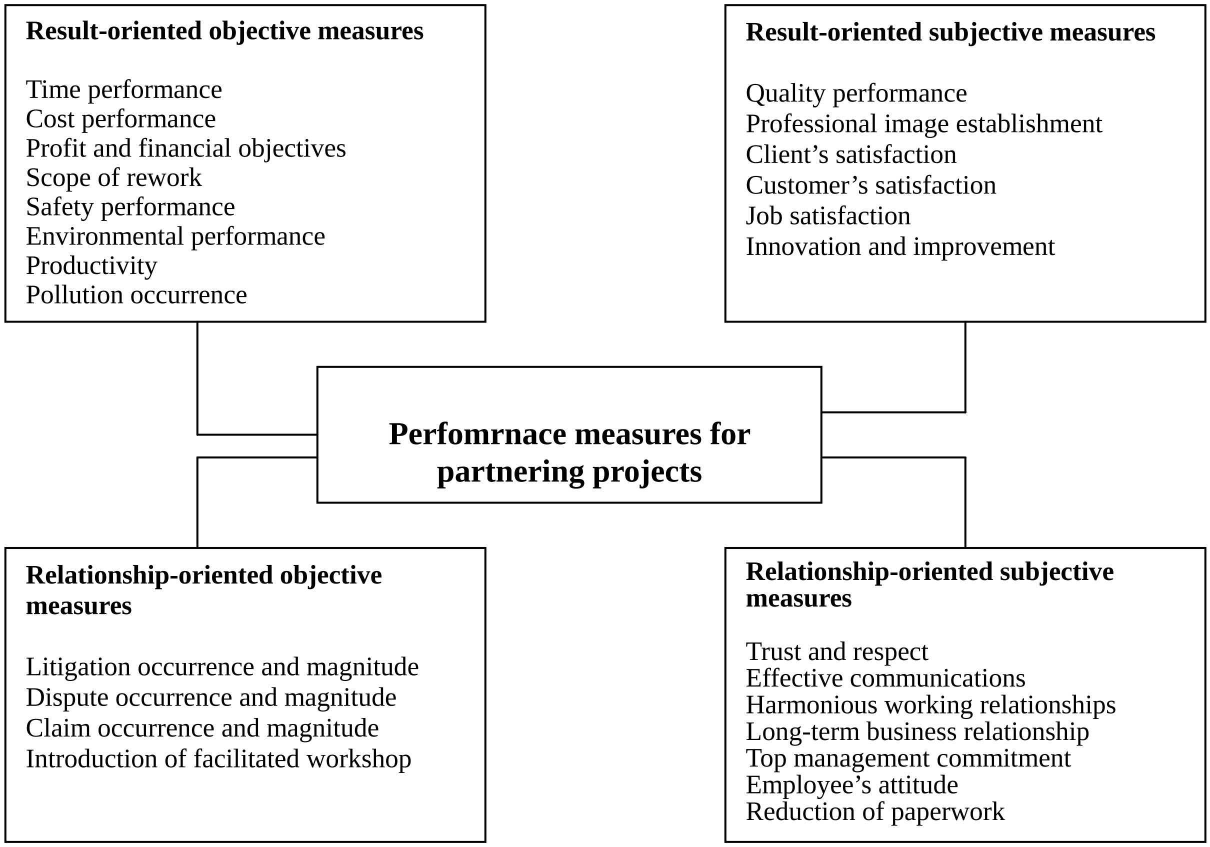


Figure 5.4 Consolidated Conceptual Framework of KPIs for Partnering Projects

The following sub-sections briefly present all the performance measures that constitute the whole framework as they are described in the literature and the 17 Demonstration Projects using partnering approach.

5.3.1 Result-oriented Objective Measures

Figure 5.4 shows that there are 7 result-oriented objective measures, including (1) Time Performance; (2) Cost Performance; (3) Profit and Financial Objectives; (4) Scope of Rework; (5) Safety Performance; (6) Environmental Performance; (7) Productivity; and

(8) Pollution Occurrence.

5.3.1.1 Time Performance

'Time' refers to the duration for completing the project (Chan and Chan, 2004). It is scheduled to enable the building to be used by a date determined by the client's future plans (Hatush and Skitmore, 1997). It can be measured by time variation (overrun, on time or underrun) (Naoum, 1994; Chan et al, 2001, 2004b, 2004c, 2004d, 2006; Collin, 2002; Zhao, 2002; Cheung et al, 2003; Cox et al, 2003; Bayliss, 2004), construction time (Chan and Kumaraswamy, 1995; Chan, 1996; Construction Task Force, 1998; Crane et al, 1999; Chan et al, 2004b, 2004c, 2004d, 2006), and speed of construction (Chan and Kumaraswamy, 1995; A1-Meshekeh and Langford, 1999; Chan et al, 2004b, 2004c, 2004d, 2006).

Table 5.4 Types of Time Performance Measurement [Adapted from Chan et al, 2002b]

Year	Author(s)	Measurement	Definition
1994 2001 2002 2002 2003 2003 2003 2004b,c,d 2004 2006	Naoum Chan et al Collin Zhao Cheung et al Cox et al Martin Chan et al Bayliss et al Chan et al	Time overrun/Time underrun	The percentage of increase or decrease in the estimated project in days/weeks, discounting the effect of Extension of Time (EOT) granted by the client
1996 1998 1999 2004b,c,d 2006	Chan Construction Task Force Crane et al Chan et al Chan et al	Construction time	Absolute time that is calculated as the number of days/weeks from start on site to practical completion of the project
1999 2004b,c,d 2006	Al-Meshekeh and Langford Chan et al Chan et al	Speed of construction	Gross floor area (in square meters) divided by the constrution time (in days)

5.3.1.2 Cost Performance

Cost performance is another vital result-oriented objective measure. It is defined as the degree to which the general conditions promote the completion of a project within the estimated budget (Bubashait and Almohawis, 1994). It can be measured by cost overrun/underrun (Yeong, 1994; Crane et al, 1999; Chan et al, 2001, 2004b, 2004c, 2004d, 2006; Zhao, 2002; Cheung et al, 2003) and unit cost (Chan, 1996; Chan et al, 2002b; Chan and Chan, 2004). Percentage net variation over final cost (%NETVAR) gives an indication of cost overrun or underrun, and it is calculated as the ratio of net variations to final contract sum expressed in percentage term. Table 5.5 shows the definitions of each measurement of cost.

Table 5.5 Types of Cost Performance Measurement [Adapted from Chan et al, 2002b]

Year	Author(s)	Measurement	Definition
1994 1999 2001 2002 2003 2004b,c,d 2006	Yeong Crane et al Chan et al Zhao Cheung et al Chan et al Chan et al	Cost overrun/underrun	Increase or decrease in budget (in dollars)
1996 2002b 2004	Chan Chan et al Chan and Chan	Unit cost	Final contract sum (in dollars) divided by gross floor area (in square meters)

5.3.1.3 Profit and Financial Objective

Profit is one of the most vital result-oriented objective measures because most projects, including partnering projects, are profit-oriented, and the clients always try to maximize their profit. Norris (1990) measured profit as the increment by which revenues exceed cost; that is, profit is measured as the total net revenue (in dollars) over total costs (in dollars). Another common measure of financial achievement is net present value (NPV) (Chan and Chan, 2004).

Table 5.3 indicates that 11 out of 17 Demonstration Projects using partnering approach use this measure to evaluate their project performance. These projects are (1) The Orchards; (2) Three Pacific Place; (3) Cambridge House; (4) Po Lam Road Phase 1; (5) Tsim Sha Tsui Station Modification Works; (6) Chater House; (7) Choi Yuen Phase 2; (8) Stonecutters Bridge; (9) Hong Kong Museum of Coastal Defence; (10) Tradeport Hong Kong Logistics Centre; and (11) Design and Build of Improvement to Castle Peak Road.

5.3.1.4 Scope of Rework

Cox et al (2003) stated that in general, rework takes 6-12% of the total expenditure for a construction project. Nevertheless, the costs arising from rework are at a premium and they sharply increase the total cost of running the project. It is an effective tool to measure overall project performance by calculating the change in the number of man-hours and material costs for repairing work in place or re-handling materials. In fact, when the amount of rework on a job is reduced, both the costs and time associated with the specific task can greatly reduce while the profits dramatically increase.

5.3.1.5 Safety Performance

Safety is defined as the degree to which the general conditions promote the completion of a project without major accidents of injuries (Bubshait and Almohawis, 1994). The issue of safety is of prime concern for partnering measures (Crane et al, 1999; Cheung et al, 2003; Bayliss et al, 2004; Chan et al, 2004b, 2004c, 2004d, 2006). It is a common practice that the measurement of safety performance mainly focuses on the construction period because most accidents occur during this stage (Construction Industry Review Commitee, 2001). The Hong Kong Labour Department uses the following formula to calculate annual accident rate in a specific project on construction sites (Construction Industry Review Commitee, 2001).:

$$\text{Annual accident rate} = \frac{\text{The total number of reportable construction site accidents}}{\text{Total number of workers employed or man-hours worked on a specific project}}$$

5.3.1.6 Environmental Performance

It is well known that construction industry has adverse effect on environmental performance. Songer and Molenaar (1997) reported that 14 million tonnages of waste are put into landfill in Australia each year, and 44% of them came from the construction and demolition industry. Three kinds of indicators (Table 5.6), including International Organisation for Standardisation 14000 (ISO14000) (Chan and Chan, 2004), Environmental Impact Assessment (EIA) score (Environmental Protection Department, 2000), and total number of complaints received caused by environmental issues (Cheung et al, 2003; Chan and Chan, 2004; Bayliss et al, 2004; Chan et al, 2004b, 2004c, 2004d, 2006), can be used to reflect the environmental performance of partnering projects. Table 5.3 shows that 10 out of 17 Demonstration Projects with partnering approach adopted environmental performance as an objective measure to assess the performance of partnering projects. These projects include (1) The Orchards; (2) Cambridge House; (3) Po Lam Road Phase 1; (4) Chater House; (5) Choi Yuen Phase 2; (6) Stonecutters Bridge; (7) Tradeport Hong Kong Logistics Centre; (8) Design and Build of Improvement to Castle Peak Road; (9) One Peking Road; and (10) Tseung Kwan O Area 73A Phase 2.

Table 5.6 Measures of Environmental Performance

Year	Author(s)	Measurement
2004	Chan and Chan	ISO14000
2000	Environmental Protection Department	EIA Score
2003 2004 2004b,c,d 2004 2006	Cheung et al Chan and Chan Chan et al Bayliss et al Chan et al	Total number of complaints received caused by the environmental issues

5.3.1.7 Productivity

Productivity is one of the result-oriented objective measures because it is a main key to the cost-effectiveness of projects (Taylor, 1992). Chan (1996) referred productivity as the amount of resource input to complete a given task and it is often evaluated on a ranked basis. Zhao (2002) measures productivity as number or percentage of collaborative projects finished within time and budget.

5.3.1.8 Pollution Occurrence and Magnitude

Complementary to environmental issues, pollution occurrence and magnitude is also an essential result-oriented objective measure because it directly reflects the impact of a construction project on the environment and the society at large.

5.3.2 Result-oriented Subjective Measures

Figure 5.4 indicates that there are 6 result-oriented subjective measures, including (1) Quality Performance; (2) Professional Image Establishment; (3) Client's Satisfaction; (4) Customer's Satisfaction; (5) Job Satisfaction; and (6) Innovation and Improvement. These measures are measured subjectively using a seven-point Likert scale ranging from 1 = extremely low level, 2 = low level, 3 = moderately low level, 4 =neutral, 5 = moderately high level, 6 = high level, to 7 = extremely high level.

5.3.2.1 Quality Performance

Quality is an important result-oriented subjective measure for partnering projects that is often cited by researchers (Crane et al, 1999; Chan et al, 2001, 2004b, 2004c, 2004d, 2006; Cheung et al, 2003; Bayliss et al, 2004). However, different people assess quality differently because it is rather subjective. Quality is defined as the degree to which the general conditions promote meeting of the project's established requirements of materials and workmanship (Bubshait and Almohawis, 1994). Crane et al (1999) used 11 measures to assess quality, including: (1) conformance to specifications; (2) achievement of operating objectives; (3) percent of rework; (4) plant output; (5) participation in design by construction/manufacturing personnel; (6) start-up performance; (7) number of engineering changes; (8) customer feed back; (9) audit deviations; (10) errors and omissions; and (11) first pass yield. Cheung et al (2003) defined quality as a measure of how well the work is completed in accordance with the design work. Bayliss et al (2004) measured quality by counting non-conformance reports and time taken to rectify. Chan et al (2001) measured quality by the satisfaction level of partnering participants towards the quality of a construction project. Later, Chan et al (2004b, 2004c, 2004d, 2006) measured quality performance by using 7-point Likert scale ranging from very high quality to very low quality. Table 5.7 shows the measures of quality for partnering projects used by previous researchers.

Table 5.7 Measures of Quality for Partnering Projects

Year	Author(s)	Measurement
1999	Crane et al	Conformance to specifications Achievement of operating objectives Percent of rework Plant output Participation in design by construction/manufacturing personnel Start-up performance Number of engineering changes Customer feedback Audit deviations Errors and omissions First pass yield
2003	Cheung et al	How well the work is completed in accordance with the design work
2001	Chan et al	Satisfaction level of partnering participants towards the quality of a construction project
2004	Bayliss et al	Counting non-conformance reports and time taken to rectify
2004b,c,d, 2006	Chan et al	7-point Likert scale ranging from very low level to very high level

5.3.2.2 Professional Image Establishment

Professional image establishment is a vital result-oriented subjective measure (Chan et al, 2004b, 2004c, 2004d, 2006) because it reflects the degree of pride and reputation of each contracting party enhanced by the successful completion of a project. Table 5.3 indicates that 9 out of 17 Demonstration Projects with partnering approach use this measure to reflect their project performance. These projects are (1) The Orchards; (2) Three Pacific Place; (3) Cambridge House; (4) Po Lam Road Phase 1; (5) Choi Yuen Phase 2; (6) Stonecutters Bridge; (7) Grand Promenade; (8) Hong Kong Museum of Coastal Defence; and (9) Tradeport Hong Kong Logistics Centre.

5.3.2.3 Client's Satisfaction

Client's satisfaction is by definition subjective, and as a consequence, is influenced by the individual client's satisfaction (The KPI Working Group, 2000). For this reason, a client's satisfaction is developed to address the specific criteria which the client feels are important. In general, the criteria include (1) client's satisfaction – product; (2) client's satisfaction – service; and (3) client satisfaction's – client-specified criteria. It is recommended that the identification of the client-specified criteria and weightings is requested in pre-tender qualifications (The KPI Working Group, 2000). In addition, regular monitoring ought to be conducted in open manner between the client and other participating organisations. This will ensure that the criteria and weightings attached to them are not only relevant and understandable but also the resultant scores are understood, accepted, and ultimately acted upon. Table 5.3 shows that 3 out of 17 Demonstration Projects using partnering approaches adopted client's satisfaction as a KPI to measure their project performance. These projects are (1) Po Lam Road Phase 1; (2) Chater House; and (3) Lok Ma Chau Viaduct. Table 5.8 indicates the measures of client's satisfaction.

Table 5.8 Measures of Client's Satisfaction (Source: The KPI Working Group, 2000)

Year	Author(s)	Measurement	Definition
2000	The KPI Working Group	Client satisfaction: product – standard criteria	How satisfied the client was with the finished product using the score against the 1 to 10 scale (10 = totally satisfied, 5/6 = neither satisfied nor dissatisfied, 1 = totally dissatisfied)
2000	The KPI Working Group	Client satisfaction: service – standard criteria	How satisfied the client was with the service of the advisor, suppliers, and contractors using the score against the 1 to 10 scale (10 = totally satisfied, 5/6 = neither satisfied nor dissatisfied, 1 = totally dissatisfied)
2000	The KPI Working Group	Client satisfaction: client-specified criteria	How satisfied the client was with certain client-specified criteria using the score, against 1 to 10 scale (10 = totally satisfied, 5/6 = neither satisfied nor dissatisfied, 1= totally dissatisfied), weighted together to determine their level of importance

5.3.2.4 Customer's Satisfaction

Zhao (2002) viewed customer's satisfaction as a KPI for measuring inter-organisational partnerships and he used customer satisfaction rate to measure the performance level of a project. Cheng and Li (2004b) considered that overall satisfaction of project stakeholders, including end-users, is one of the three general measures of the success of partnering. They emphasized that the criteria of partnering success are different from those of the project success (always measured in terms of objective project performance in terms of time, cost, and subjective project performance in terms of quality) in spite of their possible correlation. The success of partnering refers to the perceptive effectiveness of partnering by involved parties. This means that the partnering arrangement is said to be successful (i.e. achieved effectiveness) if the parties perceive that partnering assists to obtain positive outcomes.

5.3.2.5 Job Satisfaction

Job satisfaction refers to level of individual job satisfaction and career development opportunities. It was used as a KPI in 5 of the 17 Demonstration Projects using partnering approach. The 5 projects are (1) Three Pacific Place; (2) Po Lam Road Phase 1; (3) Tsim Sha Tsui Station Modification Works; (4) Chater House; and (5) Grand Promenade.

5.3.2.6 Innovation and Improvement

Innovation and improvement is used by Zhao (2002) as a KPI for inter-organisational partnerships. He measured it by counting number of new initiatives for improvement introduced. In fact, continuous improvement through innovation is a key element for partnering as suggested by (Construction Industry Institute, 1991; Bennett and Jayes, 1998). Table 5.3 indicates that innovation was adopted as a KPI in 8 out of 17 Demonstration Projects with partnering approach. The 8 projects comprise (1) The Orchards; (2) Three Pacific Place; (3) Cambridge House; (4) Po Lam Road Phase 1; (5)

Tsim Sha Tsui Station Modification Works; (6) Stonecutters Bridge; (7) Tradeport Hong Kong Logistics Centre; and (8) East Hall Extension of Passenger Terminal Building of the Hong Kong International Airport.

5.3.3 Relationship-oriented Objective Measures

Figure 5.4 reveals that there are 4 relationship-oriented objective measures, including: (1) Litigation Occurrence and Magnitude; (2) Dispute Occurrence and Magnitude; (3) Claim Occurrence and Magnitude; and (4) Introduction of Facilitated Workshops.

5.3.3.1 Litigation Occurrence and Magnitude

Crane et al (1999) perceived that litigation is a crucial result measure for partnering project. In fact, litigation is often related to outstanding claims and number of conflicts elevated to each level.

5.3.3.2 Dispute Occurrence and Magnitude

Chan et al (2001) used dispute as a KPI to compare project performance between partnering and non-partnering projects. The result reflected that 86.7% of the partnering projects had less or equal number of disputes than an average project.

5.3.3.3 Claim Occurrence and Magnitude

Claim is adopted by (Chan et al, 2001, 2004b, 2004c, 2004d, 2006, Cheung et al, 2003, Bayliss et al, 2004) as a KPI for partnering projects. Chan et al (2001) conducted a study and discovered that 86.8% of the partnering projects had less or equal number of claims than an average project. Bayliss et al (2004) measured claims by calculating how much time the claims are needed to be settled.

5.3.3.4 Introduction of Facilitated Workshops

A Demonstration Project using partnering approach, Tseung Kwan O Technology Park, indicated that facilitated workshop is one of the KPIs for partnering projects (Table 5.3). As a matter of fact, facilitated workshops are key elements for partnering although it is emphasised with less importance (Yeung et al, 2007). Green (1999) opined that partnering workshops need to be continuous and not one-off at the project start.

5.3.4 Relationship-oriented Subjective Measures

Figure 5.4 highlights that there are 7 relationship-oriented subjective measures, including: (1) Trust and Respect; (2) Effective Communications; (3) Harmonious Working Relationships; (4) Long-term Business Relationship; (5) Top Management Commitment; (6) Employee’s Attitude; and (7) Reduction of Paperwork. Like the result-oriented subjective measures, the measurements of the relationship-oriented subjective measures are measured subjectively using a seven-point Likert scale ranging from 1 = extremely low level, 2 = low level, 3 = moderately low level, 4 = neutral, 5 = moderately high level, 6 = high level, to 7 = extremely high level.

5.3.4.1 Trust and Respect

Trust is one of the most important relationship-oriented subjective measures for partnering projects (Crane et al, 1999; Zhao, 2002; Cheung et al, 2003). Crane et al (1999) divided trust into internal trust and external trust. Zhao (2002) measured trust by counting frequency of meeting one's expectation about another party's behaviour and/or having confidence in another party. Wong and Cheung (2004) undertook a comprehensive study on trust in construction partnering. They identified 14 trust attributes in affecting partners' trust level by a seven-point Likert scale (from 1 = not important to 7 = very important). These trust attributes include (1) Reputation; (2) Contract and Agreements (Satisfactory Terms); (3) Openness and Integrity of Communication; (4) Effective and Sufficient Information Flow; (5) Alignment of Effort and Rewards; (6) Adoption of ADR Techniques; (7) Financial Stability; (8) Frequency and Effectiveness of Communication; (9) Competence of Work; (10) The Sense of Unity; (11) Problem Solving; (12) Respect and Appreciation of the System; (13) Long-term Relationships; and (14) Compatibility. Figure 5.5 shows the 14 trust attitudes that affect partner's trust level. Table 5.3 shows that 5 out of 17 Demonstration Projects adopting partnering approaches use trust as a KPI to measure the performance of their partnering projects. These projects are (1) The Orchards; (2) Cambridge House; (3)

Tsim Sha Tsui Station Modification Works; (4) Grand Promenade; and (5) Hong Kong Museum of Coastal Defence.

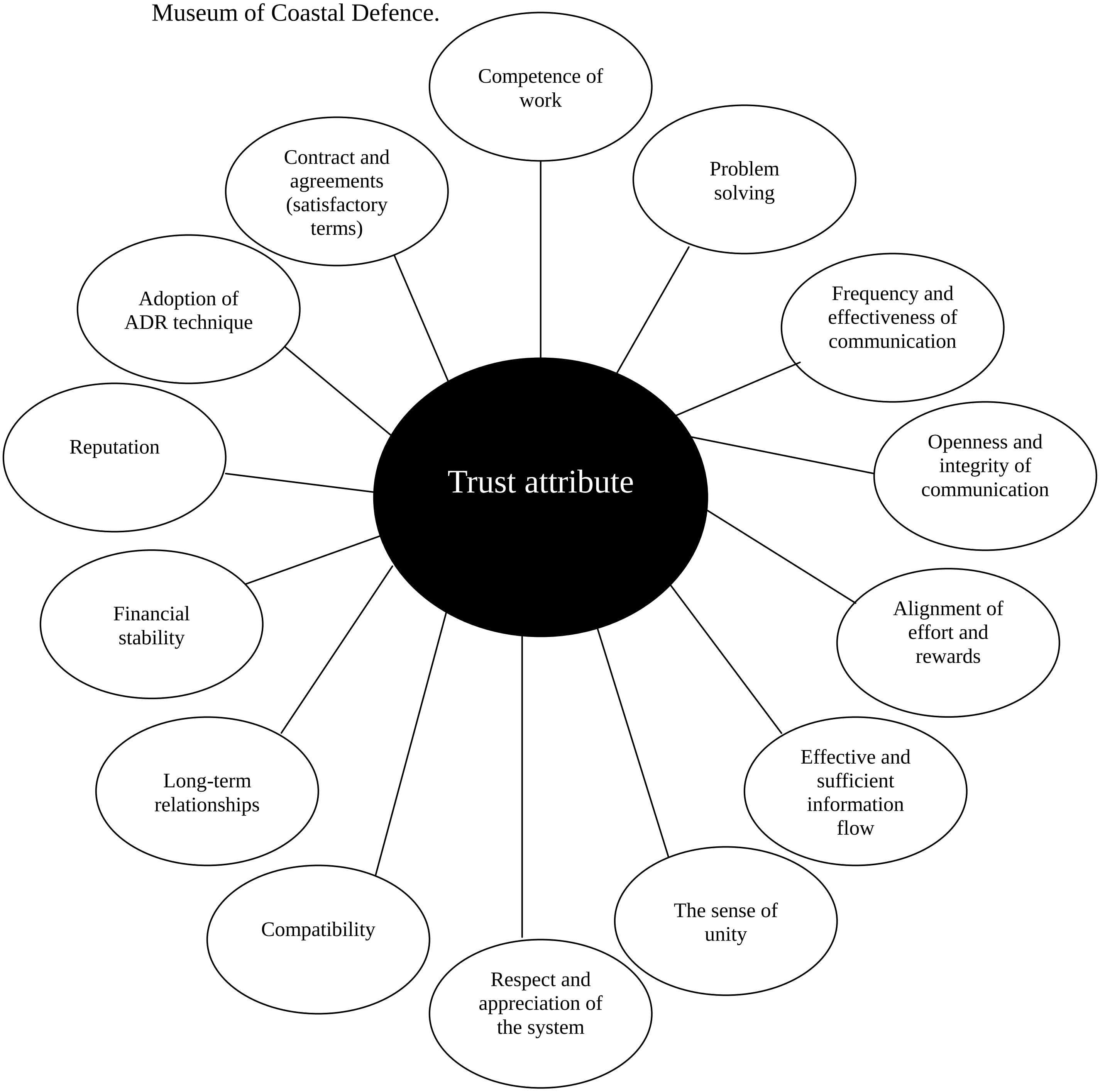


Figure 5.5 Trust attitudes for construction partnering (Source: Wong and Cheung, 2004)

5.3.4.2 Effective Communications

Effective communications is quite often adopted as a subjective measure for partnering projects (Crane et al, 1999; Zhao, 2002; Cheung et al, 2003; Bayliss et al, 2004). Crane et al (1999) divided communication into 2 types, including internal communication and external communication, to be relationship measures for partnering projects. Zhao (2002) measured communication by counting frequency and type, and calculating amount of information or data exchanges between partners. Bayliss et al (2004) measured communication by ranking level of correspondence to and from contractors. Figure 5.2 shows that 11 Demonstration Projects with partnering approaches adopt this KPI to measure their project performance.

These projects encompass (1) The Orchards; (2) Three Pacific Place; (3) Cambridge House; (4) Po Lam Road Phase 1; (5) Tsim Sha Tsui Station Modification Works; (6) Choi Yuen Phase 2; (7) Grand Promenade; (8) Hong Kong Museum of Coastal Defence; (9) Tradeport Hong Kong Logistics Centre; (10) Tseung Kwan O Technology Park; and (11) One Peking Road.

5.3.4.3 Harmonious Working Relationships

Chan et al (2001) used satisfaction level of working relationship as a KPI and they found that 78.2% of the partnering project participants strongly agreed that they were happy with the working relationship via partnering. Cheng and Li (2004b) stated that subjective measures are based on the notion that partnering is used to improve working relationships that helps to achieve predetermined common goals for fulfilling the overall satisfaction of project stakeholders. Therefore, improved or harmonious working relationship is one of the general measures of the success of partnering. Table 5.3 indicates that 5 Demonstration Projects adopting partnering approaches use this KPI to measure their project performance. These projects include (1) Three Pacific Place; (2) Chater House; (3) Stonecutters Bridge; (4) Grand Promenade; and (5) Design and Build of Improvement to Castle Peak Road.

5.3.4.4 Long-term Business Relationship

Long-term business relationship was used as a KPI in 5 out of the 17 Demonstration Projects using partnering approaches (Table 5.3). These projects included: (1) The Orchards; (2) Three Pacific Place; (3) Cambridge House; (4) Tsim Sha Tsui Station Modification Works; and (5) Choi Yuen Phase 2.

5.3.4.5 Top Management Commitment

Although top management commitment is often viewed as a critical success factor (CSF) for partnering projects (Harback et al, 1994; Slater, 1998; Cheng et al, 2000; Chan et al, 2004a), it can also be viewed as a KPI because it is both means and ends for partnering projects, depending on which perspective one considers. Table 5.3 indicates that a Demonstration Project with partnering approach, Lok Ma Chau Viaduct, uses top management commitment as a KPI to measure its project performance.

5.3.4.6 Employees' Attitude

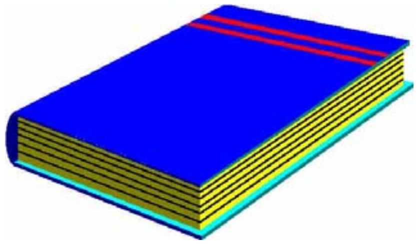
Employees' attitude refers to their attitude towards the implementation of partnering approach of a project. Zhao (2002) applied it as a KPI for inter-organisational partnerships which were measured by employee turnover rate.

5.3.4.7 Reduction of Paperwork

A demonstration project adopting partnering approach, Chater House, used reduction of paperwork as a KPI for measuring its partnering performance (Table 5.3). In fact, it is generally agreed that efficiency of communication through partnering was enhanced (Chan et al, 2004b, 2004c, 2004d, 2006), and industrial practitioners were able to get faster responses by having more informal communication and the potential problems were reduced immediately by open communication. Therefore, level of paperwork reduction can reflect level of effective communication.

5.4 CHAPTER SUMMARY

This chapter has conducted a comprehensive literature review on performance measures for construction partnering projects and a preliminary conceptual framework for identifying KPIs for construction partnering projects has been developed. To verify the validity of this conceptual framework, in-depth study of 17 Demonstration Projects using partnering approaches (24 Demonstration Projects in total) derived from the Hong Kong Demonstration Committee was conducted. A consolidated conceptual framework for identifying KPIs for construction partnering projects has thus been established. A total of 25 performance measures have been sought and discussed within this conceptual framework and they are classified into 4 major categories, including, (a) Result-oriented Objective Measures; (b) Result-oriented Subjective Measures; (c) Relationship-oriented Objective Measures; and (d) Relationship-oriented Subjective Measures. This KPIs' conceptual framework for partnering projects can assist in setting a benchmark for measuring the performance of partnering projects. As a result, construction senior executives and project managers can apply it to measure and assess the performance of their partnering projects.



CHAPTER 6 PARTNERING PERFORMANCE INDEX (PPI) FOR CONSTRUCTION PROJECTS IN HONG KONG

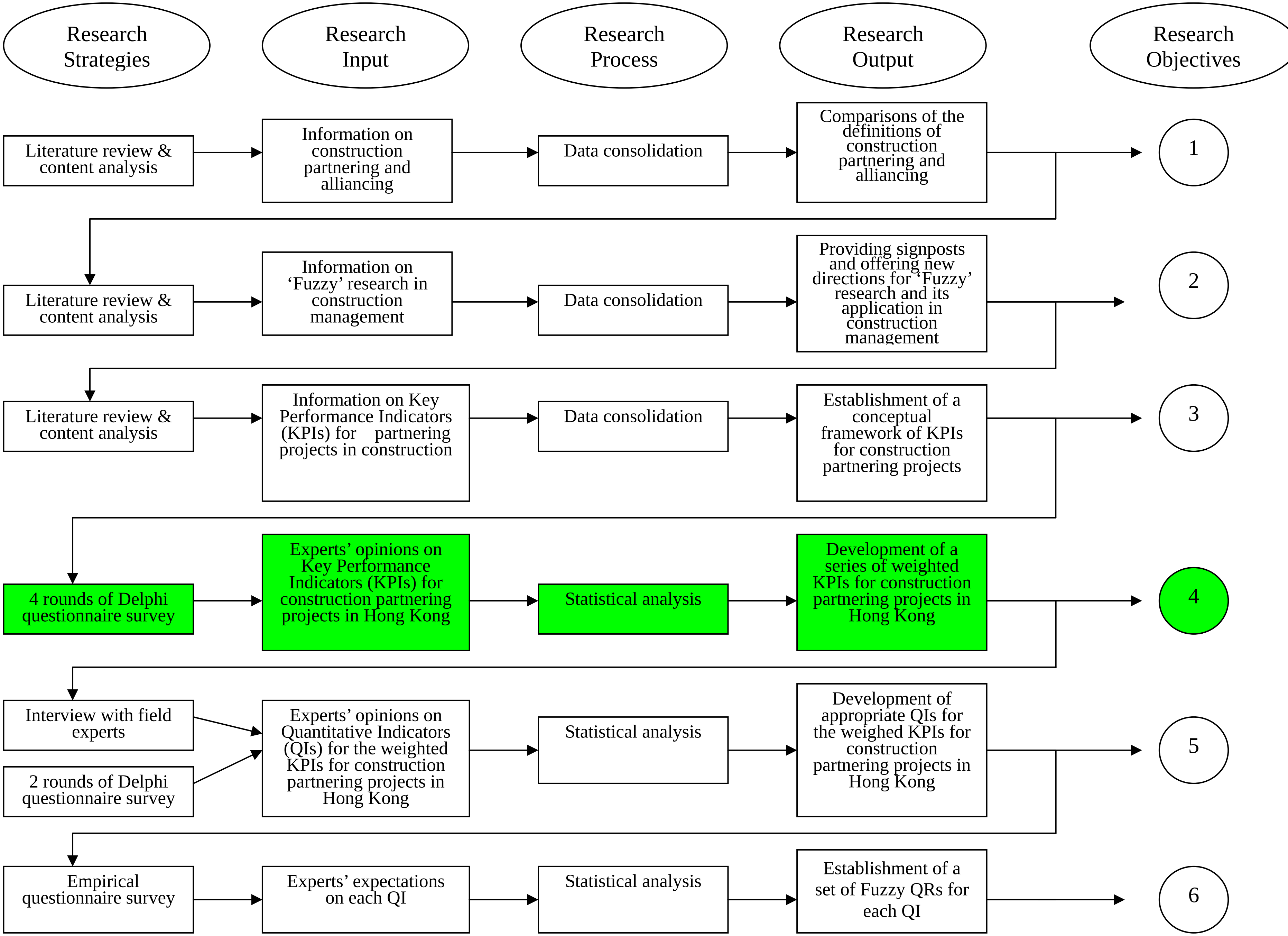


Figure 2.1 Overall Flow of the Research

Chapter 6 PARTNERING PERFORMANCE INDEX (PPI) FOR CONSTRUCTION PROJECTS IN HONG KONG

6.1 INTRODUCTION

After developing a conceptual framework for identifying KPIs to evaluate the performance of partnering projects, this chapter aims to formulate a model through applying the Delphi survey method to objectively measure the performance of partnering projects in Hong Kong. A unique Partnering Performance Index (PPI) for partnering projects can then be developed. By doing so, the performance of different partnering projects can be compared and assessed objectively. Four rounds of Delphi questionnaire survey were undertaken with 31 construction experts in Hong Kong. The selected experts were either industrial practitioners equipped with rich hands-on experience in partnering projects or prominent academics with demonstrated research experience in construction partnering. The iterations of the Delphi exercise enable the experts both to select the most appropriate KPIs for partnering projects in Hong Kong, and to provide ratings to each KPI. A more reliable result could thus be achieved. A statistically significant consensus on the weighting of each KPI was also sought from the 31 experts. The Delphi technique was first used to select a series of the most important KPIs for partnering projects in Hong Kong and second to obtain ratings to each identified KPI. Finally, a series of weighted KPIs is developed from the Delphi questionnaires. The findings of this Delphi study will be discussed. Since project partnering is still dominant in the Hong Kong construction industry when compared with strategic partnering, the model developed is mainly applied to project partnering.

6.2 FOUR ROUNDS OF DELPHI QUESTIONNAIRE

6.2.1 Round 1 of the Delphi Questionnaire: Selecting the most vital KPIs

6.2.1.1 Format

The first round of Delphi questionnaire (please refer to Appendix 1) was sent to the group of panel members both by mail and email in early September of 2005. The invitation letter explained the aim of the research, and the experts were informed that there would be a total of 4 rounds of questionnaires in the proposed survey. In this round, the identified 39 experts were asked to select a minimum of 5 to a maximum of 10 out of 25 KPIs that they believed to be the most important KPIs to evaluate the performance of partnering projects (the respondents were encouraged to propose additional KPIs for partnering projects in Hong Kong if deemed appropriate). However, only about half of the experts completed the questionnaire in two weeks' time. An email was therefore sent to remind all the experts who had not yet returned their completed questionnaires within the stipulated deadline, followed up by a phone call. Finally, 31 responses were collected and 8 experts withdrew from the study in mid

October of 2005. The main reason for their dropping out was the heavy commitment of their current workload. From the 31 replied Delphi experts, 17 are from client organizations, 6 from main contractor organizations, 2 from consultant organizations, 4 from academics and 2 from other organizations.

6.2.1.2 Results and Analysis

Table 6.1 shows the indication of relative importance of each KPI by the 31 experts. Similar to Chan et al (2001b), only KPIs which have been selected by 50% of experts or above will be selected for further consideration. Seven (7) KPIs met this criterion in the first round of the first Delphi study. The seven KPIs were: (1) Time Performance; (2) Cost Performance; (3) Quality Performance; (4) Trust and Respect; and Effective Communications (equal frequencies for both); (6) Harmonious Working Relationships; and Top Management Commitment (equal frequencies for both). In addition, 5 new KPIs which had not been identified from the literature were suggested by the panel of experts. They included: (1) Method of Procurement and Time for Closing of Final Account; (2) Job Efficiency and Reliability; (3) Minimising Impact on Operations; (4) Commitment of Staff at Work Level; and (5) Good Public Relations. Therefore, they were added to the Round 2 of the Delphi survey.

6.2.2 Round 2 of the Delphi Questionnaire: Re-assessing the Selected KPIs

6.2.2.1 Format

Similar to Round 1 of the first Delphi survey, the second round of the first Delphi questionnaire (please refer to Appendix 2) was forwarded to the group of panel members both by mail and email in mid October of 2005. In this round, the result of Round 1 was consolidated and presented and the experts were requested to reconsider whether they would like to change any of their original choices in light of the consolidated results from Round 1. Similar to Round 1, only about half of the experts completed the questionnaire within two weeks. An email was then issued to remind all the experts who had not yet returned their completed forms, followed up by a phone call. Finally, they all completed the questionnaire in mid November of 2005.

Table 6.1 Result of Round One of the Delphi Questionnaire

KPIs for Partnering Projects in Hong Kong	Total Frequency	Percentage	Rank
Time performance	**28**	**90.32**	**1**
Cost performance	**27**	**87.10**	**2**
Quality performance	**26**	**83.87**	**3**
Trust and respect	**20**	**64.52**	**4**
Effective communications	**20**	**64.52**	**4**
Harmonious working relationships	**16**	**51.61**	**6**
Top management commitment	**16**	**51.61**	**6**
Innovation and improvement	15	48.39	8
Client's satisfaction	13	41.94	9
Safety performance	10	32.26	10
Profit and financial objectives	9	29.03	11
Dispute occurrence and magnitude	9	29.03	11
Customer's satisfaction	8	25.81	13
Productivity	8	25.81	13
Scope of rework	7	22.58	15
Long-term business relationship	7	22.58	15
Reduction of paperwork	7	22.58	15
Environmental performance	6	19.35	18
Claim occurrence and magnitude	5	16.13	19
Employee's attitude	5	16.13	19
Introduction of partnering workshop	5	16.13	19
Professional image establishment	4	12.90	22
Litigation occurrence and magnitude	2	6.45	23
Job satisfaction	2	6.45	23
Good public relations	2	6.45	23
Method of procurement & Timing for closing of Final Account	1	3.23	26
Job efficiency and reliability	1	3.23	26
Minimising impact on operations	1	3.23	26
Commitment of staff at work level	1	3.23	26
Pollution occurrence	0	0.00	30

6.2.2.2 Results and Analysis

Table 6.2 shows the relative importance of each KPI assessed by the 31 experts after their second thoughts. It should be pointed out that 'Harmonious Working Relationships', originally rated as one of the seven selected KPIs in Round 1, was dropped out and replaced by 'Innovation and Improvement'. The descending order of the seven selected KPIs was slightly changed as follows: (1) Time Performance; (2) Cost Performance; (3) Quality Performance; (4) Trust and Respect; (5) Top Management Commitment; (6) Effective Communications; and (7) Innovation and Improvement.

Table 6.2 Result of Round Two of the Delphi Questionnaire

KPIs for Partnering Projects in Hong Kong	**Total Frequency**	**Percentage**	**Rank**
Time performance	**30**	**96.77**	**1**
Cost performance	**29**	**93.55**	**2**
Quality performance	**28**	**90.32**	**3**
Trust and respect	**24**	**77.42**	**4**
Top management commitment	**20**	**64.52**	**5**
Effective communications	**19**	**61.29**	**6**
Innovation and improvement	**17**	**54.84**	**7**
Harmonious working relationships	15	48.39	8
Client's satisfaction	13	41.94	9
Safety performance	10	32.26	10
Profit and financial objectives	8	25.81	11
Dispute occurrence and magnitude	8	25.81	11
Productivity	6	19.35	13
Customer's satisfaction	6	19.35	13
Scope of rework	5	16.13	15
Long-term business relationship	5	16.13	15
Reduction of paperwork	5	16.13	15
Environmental performance	4	12.90	18
Claim occurrence and magnitude	4	12.90	18
Good public relations	2	6.45	20
Introduction of partnering workshop	2	6.45	20
Method of procurement & Timing for closing of Final Account	1	3.23	22
Employee's attitude	1	3.23	22
Professional image establishment	1	3.23	22
Job satisfaction	1	3.23	22
Job efficiency and reliability	1	3.23	22
Minimising impact on operations	1	3.23	22
Commitment of staff at work level	0	0.00	28
Litigation occurrence and magnitude	0	0.00	28
Pollution occurrence	0	0.00	28

6.2.3 Round 3 of the Delphi Questionnaire: Ratings Obtained from Experts

6.2.3.1 Format

In the third round of the Delphi questionnaire (please refer to Appendix 3), the experts were asked to provide ratings on the seven selected KPIs based on a 5-point Likert scale to evaluate the performance of partnering projects. In addition, the 5-point Likert scale, ranging from 1 = least important, 2 = slightly important, 3 = important, 4 = very important, to 5 = most important, is used because the dimension for measuring KPIs should be unipolar, referring to different degrees of the same attribute, but not bipolar, referring to the presence of opposite attributes (Schwarz, 1996). Similar to Rounds 1 and 2, only about half of the experts completed the questionnaire within two weeks. An email was sent to remind those experts who had not returned their completed questionnaires in time, and a phone call was followed up. Finally, they all completed the questionnaire in mid December of 2005.

6.2.3.2 Results and Analysis

A statistical analysis was performed on the 31 questionnaires received in which the mean ratings for the seven selected KPIs were computed. A preliminary series of weighted KPIs was developed based on the mean ratings advocated by the 31 experts. Each KPI was measured using a score between 1 and 5, with 1 representing ‘least important’ and 5 representing ‘most important’ for each KPI to evaluate the performance of partnering projects. The weighting for each of the seven selected KPIs was computed by using the following equation (Chow, 2005):

$$W_{KPIa} = \frac{M_{KPIa}}{\sum_{g} M_{KPIg}} \qquad \text{for a = 1} \qquad \text{(Equation 1)}$$

where W_{KPIa} represents the weighting of a particular selected KPI

M_{KPIa} represents the mean ratings of a particular selected KPI

$\sum_{g} M_{KPIg}$ represents the summation of mean ratings of all the selected KPIs

Table 6.3 shows the seven selected KPIs and their corresponding weightings. They are: (1) Time Performance, with the weighting of 0.167; (2) Cost Performance, with the weighting of 0.161; (3) Top Management Commitment, with the weighting of 0.148; (4) Quality Performance, with the weighting of 0.147; (5) Trust and Respect, with the weighting of 0.142; (6) Effective Communications, with the weighting of 0.131; and (7) Innovation and Improvement, with the weighting of 0.104. In order to compile a composite index to evaluate the performance of partnering projects, a Partnering Performance Index (PPI) is developed which can be represented by the following formula:

Table 6.3 Result of Round Three of the Delphi Questionnaire

KPIs for Partnering Projects in Hong Kong	**Mean Rating**	**Rank**	**Corresponding weighting**
Time performance	4.48	1	0.167
Cost performance	4.32	2	0.161
Top management commitment	3.97	3	0.148
Quality performance	3.94	4	0.147
Trust and respect	3.81	5	0.142
Effective communications	3.52	6	0.131
Innovation and improvement	2.81	7	0.104
Number (n)	**31**		

Partnering Performance Index (PPI) for Round 3

PPI = 0.167 x Time Performance + 0.161 x Cost Performance + 0.148 x Top Management Commitment + 0.147 x Quality Performance + 0.142 x Trust and Respect + 0.131 x Effective Communications + 0.104 x Innovation and Improvement

(Equation 2)

The PPI is composed of the seven selected weighted KPIs identified in the Round 3 of the Delphi questionnaire and the coefficients are their individual weightings, which are calculated by their individual mean ratings divided by the total mean ratings. The index is derived based on the assumption that this is a linear and additive model. It is logical and valid to derive this linear and additive model because the correlation matrix as shown in Table 6.4 reveals that the seven selected weighted KPIs are not highly correlated with each other at 5% significance level (more than half of them are even insignificantly correlated with each other). In addition, the units of measurement for the seven selected weighted KPIs are different so it is not likely to have any multiplier effect between them. Though it seems more sophisticated to use a nonlinear model to fit the data obtained, overfitting is a common problem with nonlinear models especially when the sample size is not sufficiently large (Neter et al, 2005; Weisberg, 2005). That is why a linear, but not nonlinear model is recommended if the relationship amongst variables is not proved to be nonlinear. In fact, a linear model is assumed to be a linearized model of an unknown nonlinear model if it really exists (Morrison, 1991; Griffiths, 1993). Practically speaking, it is simpler and easier to use this model to measure the partnering performance of construction projects in the Hong Kong construction industry.

Table 6.4 Correlation Matrix Amongst the Seven Selected Weighted KPIs (for Round 3)

Correlation Matrix	Time Performance	Cost Performance	Quality Performance	Trust & Respect	Top Management Commitment	Effective Communications	Innovation & Improvement
Time Performance	1	0.505**	0.551**	-0.347	-0.248	-0.241	-0.138
Cost Performance		1	0.520**	-0.411*	-0.261	-0.388*	-0.242
Quality Performance			1	-0.360*	-0.418*	-0.129	0.172
Trust & Respect				1	0.682**	0.674**	0.249
Top Management Commitment					1	0.550**	0.248
Effective Communications						1	0.547**
Innovation & Improvement							1

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

6.2.4 Round 4 of the Delphi Questionnaire: Re-assessing the Weighted KPIs

6.2.4.1 Format

For Round 4 of the first Delphi survey (please refer to Appendix 4), the experts were provided with the consolidated results obtained in Round 3. The average ratings of the 31 experts for each KPI and the respondent's own ratings in Round 3 were provided. The respondents were asked to re-assess their ratings in the light of the mean scored by the 31 experts. The final round questionnaire was distributed to the same group of panel experts both by mail and email in mid December of 2005. Similar to the previous rounds, an email was forwarded to remind all the experts who did not return the questionnaire in time, followed up by a phone call. Finally, they all completed the questionnaire in mid January of 2006.

6.2.4.2 Results and Analysis

Most experts had reconsidered their ratings provided in the previous round and had made adjustments to their ratings. Table 6.5 shows that there is no change for the order of their mean ratings except that Trust and Respect is changed from the fifth rank to the fourth rank. In addition, their corresponding weightings are similar with those of Round 3.

Table 6.5 Comparisons of the Results of Rounds Three and Four of the Delphi Questionnaire

KPIs for Partnering Projects in Hong Kong	**Round 3**			**Round 4**		
	Mean Rating	**Rank**	**Corresponding weighting**	**Mean Rating**	**Rank**	**Corresponding weighting**
Time performance	4.48	1	0.167	4.55	1	0.167
Cost performance	4.32	2	0.161	4.35	2	0.160
Top management commitment	3.97	3	0.148	4.10	3	0.150
Quality performance	3.94	4	0.147	3.90	4	0.143
Trust and respect	3.81	5	0.142	3.90	4	0.143
Effective communications	3.52	6	0.131	3.58	6	0.131
Innovation and improvement	2.81	7	0.104	2.90	7	0.106
Number (n)	**31**			**31**		

Partnering Performance Index (PPI) for Round 4

PPI = 0.167 x Time Performance + 0.160 x Cost Performance + 0.150 x Top Management Commitment + 0.143 x Quality Performance + 0.143 x Trust and Respect + 0.131 x Effective Communications + 0.106 x Innovation and Improvement

(Equation 3)

Similar to the index derived in equation 2, this PPI is composed of the seven selected weighted KPIs identified in the Round 4 of the first Delphi questionnaire and the coefficients are their individual weightings, which are calculated by their individual mean ratings divided by the total mean ratings. The correlation matrix as shown in Table 6.6 manifests that the seven selected weighted KPIs are not highly correlated with each other at 5% significance level (more than half of them are even insignificantly correlated with each other). Therefore it is valid to assume this linear and additive model (Morrison, 1991; Griffiths, 1993).

Table 6.6 Correlation Matrix Amongst the Seven Selected Weighted KPIs (for Round 4)

Correlation Matrix	Time Performance	Cost Performance	Quality Performance	Trust & Respect	Top Management Commitment	Effective Communications	Innovation & Improvement
Time Performance	1	0.464**	-0.193	0.414*	-0.181	-0.213	-0.166
Cost Performance		1	-0.231	0.528**	-0.416*	-0.416*	-0.278
Quality Performance			1	-0.271	0.804**	0.426*	0.205
Trust & Respect				1	-0.256	-0.121	0.185
Top Management Commitment					1	0.571**	0.273
Effective Communications						1	0.495**
Innovation & Improvement							1

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

6.3 DISCUSSION AND VALIDATION OF RESEARCH FINDINGS

The research findings of this chapter indicate that the seven selected weighted KPIs for partnering projects in Hong Kong emphasize on project success, relationship, and people. Traditionally, project success is measured by project performance in terms of time, cost and quality (Chan et al, 2002b; Chan and Chan, 2004). The findings are consistent in this regard because Time Performance, Cost Performance and Quality Performance take the first, second, and fourth positions respectively. On the other hand, the findings stress on relationship and people. There is no doubt that three of the seven selected weighted KPIs, including: (1) Trust and Respect; (2) Effective Communication; and (3) Innovation and Improvement, are important goals pursued by many of the project stakeholders who procure partnering projects. The results are also in line with the previously reviewed literature on KPIs for partnering projects and the Hong Kong Demonstration Projects using partnering approach. It is noted that a number of generic KPIs have been developed in the last decades, some of which are similar to the ones identified in this study (Association for Project Management, 2005). However, most of them are generic in nature and cannot reflect the uniqueness in construction partnering. The identification of partnering-specific KPIs is believed to be a major contribution to fill this knowledge gap. It should be added that the Delphi method by its inherent nature serves as a self-validating mechanism because individual experts are given chances to re-assess their scores with reference to the consolidated mean scores as assessed by other experts. By using the Delphi method, the maximum amount of unbiased and objective information can be obtained from the panel of experts (Chan et al , 2001b).

6.4 DIFFICULTIES IN CONDUCTING THE DELPHI QUESTIONNAIRES

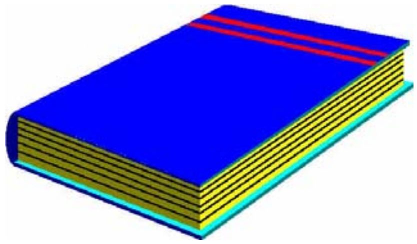
A number of difficulties were encountered in conducting the Delphi method. Firstly, the successful rounds of Delphi methods were very time consuming. The completion of the four rounds of Delphi questionnaires took about 4 and a-half months. For each round of Delphi, reminder emails were sent and follow-up phone calls were made to the non-respondents. Chan et al (2001b) experienced similar difficulty in their research study for the selection of procurement systems for construction projects. They pointed out that the turnaround times for the questionnaire by panelists were longer than expected. Secondly, the selection of the panel of experts is central to the success of the Delphi technique. Panel members must be both willing and able to do all rounds of Delphi questionnaire. It is important that panel members treat the work seriously, and devote the time necessary to provide thoughtful and reasoned responses to the questions. Thirdly, as with all Delphi studies, the wording of the questions and the presentation format of the survey are extremely vital (Robinson, 1991). In this research study, much effort was made to make the questionnaires simple and yet sufficient to convey the objectives of the study to the panel of experts. In addition, Corotis et al (1981) reported that the major difficulties were in maintaining the high level of response and in reaching and implementing a general agreement. It is therefore very vital to keep the whole panel of experts responding to each round of Delphi. Any drop out of the panel of experts would be very undesirable for the Delphi techniques. Since the extensive commitment of the experts was needed to spend over the 4 rounds of questionnaires, there is a relatively high tendency for the respondents to withdraw in the successive rounds of the Delphi (McKenna, 1994).

This study was conducted with relative success in that a response rate of 79.49% was achieved. Other Delphi studies in the medical and health fields have recorded a response rate ranging from 57.65% to 80.36%, including (1) 57.65% in Procter and Hunt's survey (1994), (2) 78.75% in Lindeman's survey (1975), (3) 78.97% in Bond and

Bond's survey (1982), and (4) 80.36% in Sleep et al's survey (1995). The 79.49% response rate achieved in the first Delphi survey is relatively high and is considered as satisfactory for the purposes of this research.

6.5 CHAPTER SUMMARY

This chapter has applied the Delphi survey technique to develop a model to objectively measure the partnering performance of construction projects in the Hong Kong construction industry. The descending order of the seven selected weighted KPIs identified were found to be: (1) Time Performance, with the weighting of 0.167; (2) Cost Performance, with the weighting of 0.160; (3) Top Management Commitment, with the weighting of 0.150; (4) Quality Performance, with the weighting of 0.143; (5) Trust and Respect, with the weighting of 0.143; (6) Effective Communications, with the weighting of 0.131; and (7) Innovation and Improvement, with the weighting of 0.106. This KPIs' framework for partnering projects helps to develop a unique composite index and set a benchmark for measuring the performance of partnering projects in Hong Kong. Different partnering projects can then be evaluated and compared objectively based on this Partnering Performance Index (PPI). As a result, construction senior executives and project managers can use this index to measure, monitor and upgrade the performance of their partnering projects. It also deepens the current body of knowledge and understanding of both academics and practitioners in the construction industry to achieve outstanding partnering performance.



CHAPTER 7 QUANTITATIVE INDICATORS FOR MEASURING THE PARTNERING PERFORMANCE OF CONSTRUCTION PROJECTS IN HONG KONG

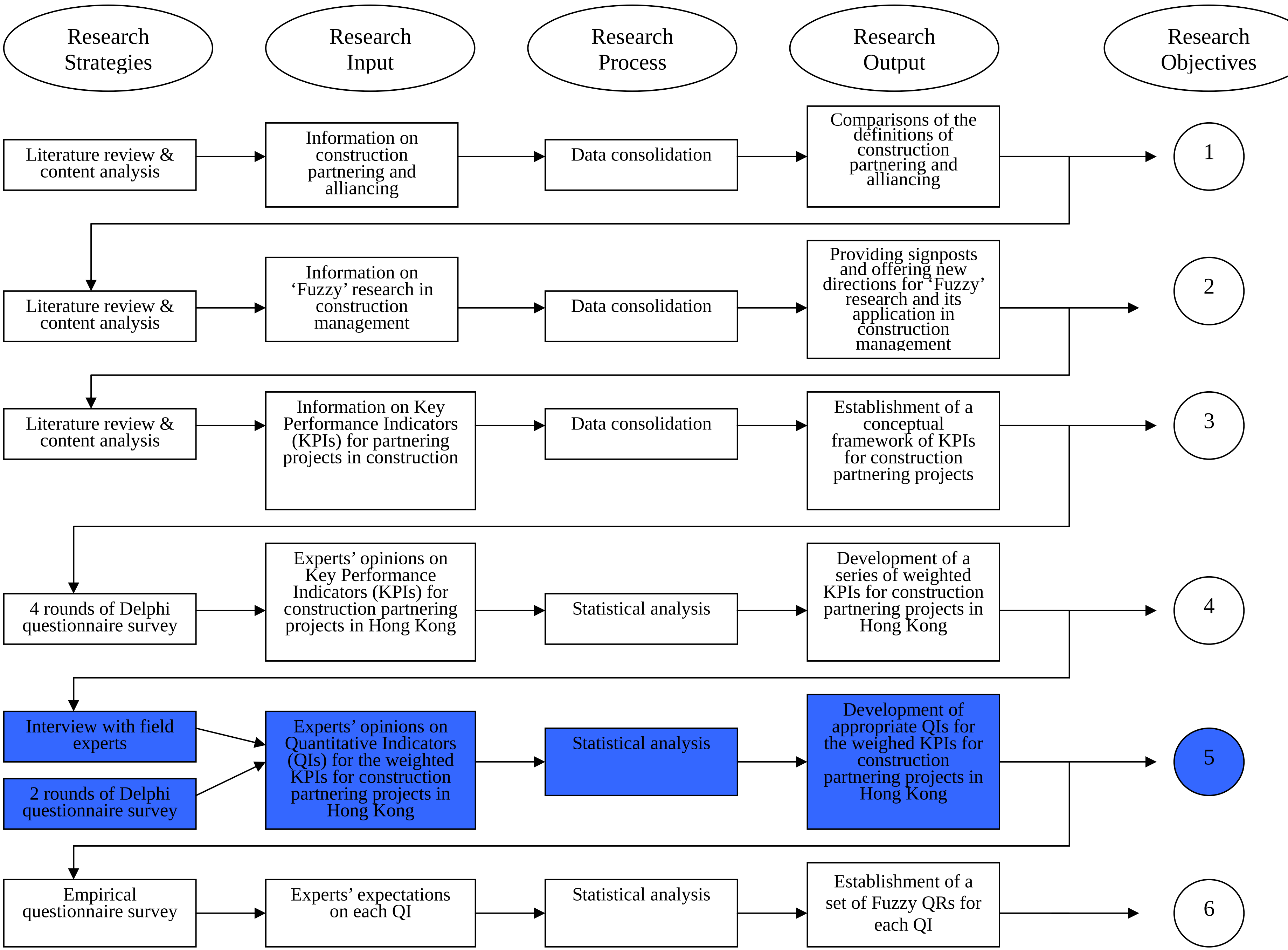


Figure 2.1 Overall Flow of the Research

Chapter 7 QUANTITATIVE INDICATORS FOR MEASURING THE PARTNERING PERFORMANCE OF CONSTRUCTION PROJECTS IN HONG KONG

7.1 INTRODUCTION

In order to measure the seven selected KPIs objectively, this chapter aims to first conduct structured face-to-face interviews with construction experts in partnering in Hong Kong so as to propose Quantitative Indicators (QIs) appropriate to measure each of the seven selected weighted KPIs. After that, the Delphi survey method is applied to objectively assess the appropriateness of the proposed QIs by rating them against their level of importance, measurability and obtainability based on 5-point Likert scales. Five leading industrial practitioners with rich hands-on experience in procuring partnering projects, including two from private sector, one from public sector, and two from infrastructure sector, were interviewed with structured interview questions. A total of 39 QIs were proposed by these five prominent practitioners and 21 QIs (3 QIs per each KPI) were finally formulated, combined, and selected for further analysis. After that, two rounds of the second Delphi questionnaire survey were conducted with the same 31 construction experts in Hong Kong, who were previously conducted the four rounds of the first Delphi survey. The iterations of the Delphi exercise enable the experts to select the most appropriate QIs for partnering projects in Hong Kong. A more reliable result could thus be achieved. The findings of this second Delphi survey will be discussed later.

7.2 ANALYSIS OF INTERVIEW DIALOGUES

Table 7.1 indicates the 39 QIs proposed by the five leading industrial practitioners in Hong Kong during the face-to-face interviews. In fact, the transcriptions of the interview dialogues were sent back to all the interviewees for their verification before conducting further analysis. The meanings of some QIs are similar in nature so they are combined and rephrased into one statement. And the QIs with the highest frequencies identified by the interviewees were selected for further analysis. Finally, 21 QIs (3 QIs per each KPI) were formulated and consolidated for further study.

Table 7.1 The QIs Proposed by the Five Leading Industrial Practitioners in Hong Kong

KPIs	The Proposed QIs
Time Performance	QI 1: Variation of project completion time against programme expressed as a percentage of project completion time
	QI 2: Variation of project completion time against completion time of best-in-class projects expressed as a percentage of completion time of best-in-class projects
	QI 3: Variation of project completion time against completion time of standard projects in similar type as a percentage of completion time of standard projects in similar type
	QI 4: Variation of initially mutually agreed completion time expressed as a percentage of finally mutually agreed completion time
	QI 5: Time predictability for design: measuring change between actual design time and predicted design time, expressed as a percentage of the estimated design time
	QI 6: Time predictability for construction: measuring change between actual construction time and predicted construction time, expressed as a percentage of the estimated construction time.
	QI 7: Time improvement: measuring how much time improvement of a project is delivered to previous projects
	QI 8: Percentage of meeting milestone dates of a project by a main contractor
	QI 9: Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule)
Cost Performance	QI 1: Variation of project completion cost against budget expressed as a percentage of project completion cost
	QI 2: Variation of project completion cost against completion cost of best-in-class projects expressed as a percentage of completion cost of best-in-class projects
	QI 3: Variation of project completion cost against completion cost of standard projects in similar type expressed as a percentage of completion cost of standard projects in similar type
	QI 4: Cost predictability for design: measuring change between actual design cost and predicted budget, expressed as a percentage of the estimated design budget
	QI 5: Cost predictability for construction: measuring change between actual construction cost and predicted construction cost, expressed as a percentage of the estimated construction cost.
	QI 6: Cost improvement: measuring how much cost improvement of a project is delivered to the previous projects
	QI 7: Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget)
Quality Performance	QI 1: Cost of rectifying major defects or non-conformances before project completion expressed as a percentage of project completion cost
	QI 2: Cost of rectifying major defects or non-conformances during defect liability period expressed as a percentage of project completion cost
	QI 3: Cost of rectifying major defects of a project expressed as a percentage of project completion cost
	QI 4: Ratio of number of non-conformance reports per month to the average number of non-conformance reports per month
	QI 5: Number of non-conformance reports (focusing on the trend over a period of time)
	QI 6: Number of complaints received by customers.
	QI 7: Composite satisfaction scores of end users by using Likert scale
Trust and Respect	QI 1: Average speed of resolving variations (for example, there are 5 major variations and the total duration to resolve them is 70 days, the average speed of resolving them is 14 days per variation)
	QI 2: Average speed of settling EOT claims (for example, there are 10 EOT claims and the total duration to settle them is 120 days, the average speed of settling them is 12 days per claim
	QI 3: Composite satisfaction scores of key stakeholders by using Likert scale
	QI 4: Frequency of meeting one's expectation about another party's behaviour and/or having confidence in another party
Effective Communications	QI 1: The difference between number of formal letter (per year) sent between parties and standard number of formal letter (per year) sent between parties
	QI 2: Number of formal letters and emails sent between parties both internally and externally per month
	QI 3: Composite satisfaction scores of key stakeholders by using Likert scale
Innovation and Improvement	QI 1: Innovation and Improvement cost saving expressed as a percentage of project completion cost
	QI 2: Innovation and Improvement time saving expressed as a percentage of project completion time
	QI 3: Number of new initiatives for improvement introduced (construction techniques)
	QI 4: Composite satisfaction scores of key stakeholders by using Likert scale
Top Management Commitment	QI 1: Partnering development cost[1] of project expressed as a percentage of project completion cost
	QI 2: Ratio of time spent by Project Director in Partnering Steering/Progress Monitoring Meetings to time by Project Director[2] in Project Steering/Progress Monitoring Meetings
	QI 3: Percentage of Partnering Steering/Progress Monitoring Meetings attended by Company Director
	QI 4: Percentage of Partnering Steering/Progress Monitoring Meetings attended by Director's/Deputy Director's Representative (very often by Project Managers/Deputy Project Managers)
	QI 5: Measuring level of top management commitment by Using Likert scale

Notes: [1] Partnering development cost is defined as a dedicated resource allocation cost from the total project completion cost, which includes (1) cost of employing facilitators, and (2) cost of organizing partnering.

[2] Project Director is defined as the most senior executive/his representative in a company responsible for managing the project.

Table 7.2 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Time Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Time Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
QI 1: Variation of project completion time against programme expressed as a percentage of project completion time	X	X	X	X	X	6
QI 2: Variation of project completion time against completion time of best-in-class projects expressed as a percentage of completion time of best-in-class projects				X		1
QI 3: Variation of project completion time against completion time of standard projects in similar type as a percentage of completion time of standard projects in similar type					X	1
QI 4: Variation of initially mutually agreed completion time expressed as a percentage of finally mutually agreed completion time			X			1
QI 5: Time predictability for design: measuring change between actual design time and predicted design time, expressed as a percentage of the estimated design time		X				1
QI 6: Time predictability for construction: measuring change between actual construction time and predicted construction time, expressed as a percentage of the estimated construction time.		X				1
QI 7: Time improvement: measuring how much time improvement of a project is delivered to previous projects		X				1
QI 8: Percentage of meeting milestone dates of a project by a main contractor	X					1
QI 9: Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule)	implied, but not directly identified	implied, but not directly identified		implied, but not directly identified		1
Remarks: QIs 1, 4, 5, and 6 are combined because their meanings are similar (selected with some wordings rewritten). QIs 2, 3, and 7 are combined because their meanings are similar (selected). QI 9 is selected because it is vital, easy to estimate and obtain (most interviewees implied that it is a useful QI to measure the time performance).						
Newly Selected QIs for Measuring the Time Performance of Partnering Projects						
QI 1: Variation of actual completion time expressed as a percentage of finally agreed completion time						
QI 2: Time improvement: measuring how much time improvement of a project is delivered to previous similar projects.						
QI 3: Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule).						

7.2.1 Perceived QIs for Time Performance

Table 7.2 indicates the QIs for measuring the Time Performance of partnering projects in Hong Kong, which were proposed by the five interviewees. Since the meanings of QIs 1, 4, 5 and 6 are similar in nature (the meanings of QIs 1 and 4 have already included the meanings of QIs 5 and 6), the four QIs were rephrased and combined into one. With the same logic, the QIs 2, 3, and 7 were reduced to one statement. Although "best-in-class projects" as mentioned in the QI 2 is different from "standard projects" as mentioned in the QI 3, the wordings "previous similar projects" as mentioned in the combined statement included both concepts. In addition, most interviewees perceived that it may not be easy to collect relevant data and during the interview, they were implicit to suggest using subjective assessment by using Likert scale to measure the time performance. Finally, the three most vital QIs were identified for further study. They were: (1) 'Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time' (also suggested by Collin, 2002); (2) 'Time Improvement: Measuring How Much Time Improvement of a Project is Delivered to Previous Similar Projects'; and (3) 'Subjective Assessment by Using Likert Scale (say Ahead Schedule, On Time, or Behind Schedule'.

7.2.2 Perceived QIs for Cost Performance

Similar approach was applied to identify QIs for other KPIs. Table 7.3 indicates the QIs for measuring the Cost Performance of partnering projects, which were proposed by the five interviewees. Similar to measure the time performance, the QIs 1, 4, and 5 were combined and rephrased into one statement because their meanings are similar (the meaning of QI 1 has already included the meanings of QIs 5 and 6). By the same logic, the QIs 2, 3, and 6 were reduced to one statement. Although “best-in-class projects” as mentioned in the QI 2 is different from “standard projects” as mentioned in the QI 3, the wordings “previous similar projects” as mentioned in the combined statement included both concepts. In addition, all interviewees perceived that it is uneasy to collect relevant data and they were implicit to recommend using subjective assessment by using Likert scale to measure the cost performance. Finally, the three most vital QIs identified for measuring the Cost Performance of partnering projects were: (1) ‘Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost Time’ (also suggested by Cheung et al, 2003); (2) ‘Cost Improvement: Measuring How Much Cost Improvement of a Project is Delivered to Previous Similar Projects’; and (3) ‘Subjective Assessment by Using Likert Scale (say Within Budget, On Budget, or Overrun Budget)’.

Table 7.3 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Cost Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Cost Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
QI 1: Variation of project completion cost against budget expressed as a percentage of project completion cost		X	X	X	X	5
QI 2: Variation of project completion cost against completion cost of best-in-class projects expressed as a percentage of completion cost of best-in-class projects				X		1
QI 3: Variation of project completion cost against completion cost of standard projects in similar type expressed as a percentage of completion cost of standard projects in similar type					X	1
QI 4: Cost predictability for design: measuring change between actual design cost and predicted budget, expressed as a percentage of the estimated design budget		X				1
QI 5: Cost predictability for construction: measuring change between actual construction cost and predicted construction cost, expressed as a percentage of the estimated construction cost.		X				1
QI 6: Cost improvement: measuring how much cost improvement of a project is delivered to the previous projects		X				1
QI 7: Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget)	X	implied, but not directly identified		implied, but not directly identified		1
Remarks: QIs 1, 4 and 5 are combined because their meanings are similar (selected with some wordings rewritten). QIs 2, 3, and 6 are combined because their meanings are similar (selected). QI 7 is selected because it is vital, easy to estimate and obtain (most interviewees implied that it is a useful QI to measure the cost performance)..						
Newly Selected QIs for Measuring the Cost Performance of Partnering Projects						
QI 1: Variation of actual project cost expressed as a percentage of finally agreed project cost						
QI 2: Cost improvement: measuring how much cost improvement of a project is delivered to previous similar projects.						
QI 3: Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget).						

7.2.3 Perceived QIs for Top Management Commitment

Similar approach was applied to identify QIs for other KPIs. Table 7.4 shows that the three most important QIs for measuring the Top Management Commitment Performance of partnering projects in Hong Kong were (1) ‘Partnering Development Cost of Project Expressed as a Percentage of Total Project Cost’; (2) ‘Percentage of Top Management Attendance in Partnering Meetings’; and (3) ‘Measuring Level of Top Management Commitment by Using Likert Scale (say High Level, Moderate Level, or Low Level)’.

7.2.4 Perceived QIs for Quality Performance

Table 7.5 indicates the three most vital QIs for measuring the Quality Performance of partnering projects in Hong Kong. They were: (1) ‘Cost of Rectifying Major Defects or Non-conformances of a Project Expressed as a Percentage of Total Project Cost’; (2) ‘Number of Non-Conformance Reports (also suggested by Bayliss et al, 2004)’; and (3) ‘Perceived End Users’ Satisfaction Scores by Using Likert Scale’ (also suggested by Chan et al, 2004; 2006).

Table 7.4 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Top Management Commitment Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Top Management Commitment Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
Partnering development cost[1] of project expressed as a percentage of project completion cost				X		1
Ratio of time spent by Project Director[2] in Partnering Steering/Progress Monitoring Meetings to time by Project Director in Project Steering/Progress Monitoring Meetings				X		1
Percentage of Partnering Steering/Progress Monitoring Meetings attended by Company Director	X					1
Percentage of Partnering Steering/Progress Monitoring Meetings attended by Director's/Deputy Director's Representative (very often by Project Managers/Deputy Project Managers)			X			1
Measuring level of top management commitment by Using Likert scale		X			X	2

Remarks: [1] Partnering development cost is defined as a dedicated resource allocation cost from the total project completion cost, which includes (1) cost of employing facilitators, and (2) cost of organizing partnering workshops.
[2] Project Director is defined as the most senior executive/his representative in a company responsible for managing the project.
QI 1 is selected because it is vital, and not difficult to measure and obtain.
QIs 2, 3, and 4 are combined because their meanings are similar (selected with some wordings rewritten).
QI 5 is selected because it is vital, easy to estimate and obtain.

Newly Selected QIs for Measuring the Top Management Commitment Performance of Partnering Projects
QI 1: Partnering development cost of project expressed as a percentage of total project cost
QI 2: Percentage of top management attendance in partnering meetings.
QI 3: Measuring level of top management commitment by using Likert scale (say high level, moderate level, or low level).

Table 7.5 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Quality Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Quality Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
Cost of rectifying major defects or non-conformances before project completion expressed as a percentage of project completion cost				X		1
Cost of rectifying major defects or non-conformances during defect liability period expressed as a percentage of project completion cost				X		1
Cost of rectifying major defects of a project expressed as a percentage of project completion cost					X	1
Ratio of number of non-conformance reports per month to the average number of non-conformance reports per month			X			1
Number of non-conformance reports (focusing on the trend over a period of time)		X				2
Number of complaints received by customers.	X					1
Composite satisfaction scores of end users by using Likert scale		X	implied, but directly identified	implied, but directly identified	implied, but directly identified	1
Remarks: QI 3 is selected because it is vital and easier to measure and obtain when compared with the QIs 1 and 2. QI 4 is not selected because QI 5 has already reflected it in a better way. QI 5 is selected with some wordings rewritten. QI 7 is selected because it is vital, easy to estimate and obtain.						
Newly Selected QIs for Measuring Quality Performance of Partnering Projects						
QI 1: Cost of rectifying major defects or non-conformances of a project expressed as a percentage of total project cost.						
QI 2: Average number of non-conformance reports generated per month.						
QI 3: Perceived end users' satisfaction scores by using Likert scale.						

7.2.5 Perceived QIs for Trust and Respect Performance

Table 7.6 shows that the three most important QIs for measuring the Trust and Respect Performance of partnering projects in Hong Kong were: (1) 'Average Duration for Settling Variation Orders'; (2) 'Frequency of Meeting Another Party's Expectation'; and (3) 'Perceived Key Stakeholders' Satisfaction Scores by Using Likert Scale' (also suggested by Cheung et al, 2003).

7.2.6 Perceived QIs for Effective Communications Performance

Table 7.7 indicates the three most vital QIs for measuring the Effective Communications Performance of partnering projects in Hong Kong. They were (1) 'Reduction of Written Communication: Measuring How Much Written Communication is Reduced as Compared to Previous Similar Projects'; (2) 'Variation of the Number of Formal Letters and Emails Sent Between Parties Per Month Against the Number With Previous Similar Projects'; and (3) 'Perceived Key Stakeholders' Satisfaction Scores by Using Likert Scale'.

Table 7.6 **Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Trust and Respect Performance of Partnering Projects in Hong Kong**

Proposed QIs for Measuring the Trust and Respect Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
Average speed of resolving variations (for example, there are 5 major variations and the total duration to resolve them is 70 days, the average speed of resolving them is 14 days per variation)	X					1
Average speed of settling EOT claims (for example, there are 10 EOT claims and the total duration to settle them is 120 days, the average speed of settling them is 12 days per claim	X					1
Composite satisfaction scores of key stakeholders by using Likert scale	X	X	X	X	X	6
Frequency of meeting one's expectation about another party's behaviour and/or having confidence in another party		X				1
Remarks: QIs 1 and 2 are combined and selected with some wordings rewritten. QI 3 is selected with some wordings rewritten. QI 4 is selected with some wordings rewritten.						
Newly Selected QIs for Measuring the Trust and Respect Performance of Partnering Projects						
QI 1: Average duration for settling variation orders.						
QI 2: Frequency of meeting another party's expectation.						
QI 3: Perceived key stakeholders' satisfaction scores by using Likert scale.						

Table 7.7 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Effective Communications Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Effective Communications Performance of Partnering Projects in Hong Kong	**Private Sector**		**Public Sector**	**Infrastructure Sector**		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
The difference between number of formal letter (per year) sent between parties and standard number of formal letter (per year) sent between parties					X	1
Number of formal letters and emails sent between parties both internally and externally per month			X			1
Composite satisfaction scores of key stakeholders by using Likert scale	X	X		X		3

Remarks: QI 1 is selected with some wordings rephrased.
QI 2 is selected with some wordings rephrased.
QI 3 is selected with some wordings rephrased.

Newly Selected QIs for Measuring the Effective Communications Performance of Partnering Projects
QI 1: Reduction of written communication: measuring how much written communication is reduced as compared to previous similar projects.
QI 2: Variation of the number of formal letters and emails sent between parties per month against the number with previous similar projects.
QI 3: Perceived key stakeholders' satisfaction scores by using Likert scale.

7.2.7 Perceived QIs for Innovation and Improvement Performance

Table 7.8 shows that the three most important QIs for measuring the Innovation and Improvement Performance of partnering projects in Hong Kong were (1) 'Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost'; (2) 'Number of Innovative Initiatives Introduced (e.g. Construction Techniques, Procurement Approaches, Management Strategies)' (also suggested by Zhao, 2002); and (3) 'Perceived Key Stakeholders' Satisfaction Scores by Using Likert Scale'.

7.3 Two Rounds of Delphi Questionnaires

7.3.1 Round 1 of the Delphi Questionnaire: Ratings Obtained from Experts

7.3.1.1 Format

In the first round of the second Delphi questionnaire, the Delphi experts were requested to assess the appropriateness of the identified QIs (3 QIs per each KPI, giving a total of 21 QIs) by rating them against their level of importance, measurability, and obtainability based on 5-point Likert scales. In addition, they were encouraged to insert additional QIs for each KPI if deemed appropriate. The 5-point Likert scales, ranging from 1 = very unimportant/very difficult to measure and obtain, to 5 = very important/very easy to measure and obtain, is used because the dimensions for measuring QIs should be bipolar,

Table 7.8 Proposed and Newly Selected Quantitative Indicators (QIs) for Measuring the Innovation and Improvement Performance of Partnering Projects in Hong Kong

Proposed QIs for Measuring the Innovation and Improvement Performance of Partnering Projects in Hong Kong	Private Sector		Public Sector	Infrastructure Sector		
	Interviewee A	Interviewee B	Interviewee C	Interviewee D	Interviewee E	Total
Innovation and Improvement cost saving expressed as a percentage of project completion cost			X	X		2
Innovation and Improvement time saving expressed as a percentage of project completion time			X	X		2
Number of new initiatives for improvement introduced (construction techniques)	X				X	3
Composite satisfaction scores of key stakeholders by using Likert scale		X				2

Remarks: QI 1 is selected with some wordings rephrased because it is better to reflect than the QI 2.
QI 3 is selected with some wordings rephrased.
QI 4 is selected with some wordings rephrased.

Newly Selected QIs for Measuring the Innovation and Improvement Performance of Partnering Projects
QI 1: Cost saving resulted from Innovation expressed as a percentage of total project cost.
QI 2: Number of innovative initiatives introduced (e.g. construction techniques, procurement approaches, management strategies).
QI 3: Perceived key stakeholders' satisfaction scores by using Likert scale.

referring to the presence of opposite attributes, but not unipolar, referring to different degrees of the same attribute (Schwarz, 1996). Only about half of the experts completed the questionnaire within one month. An individual email was sent to remind those experts who had not yet returned their completed questionnaires in time, and a phone call was followed up. Finally, 27 experts completed the questionnaire in late June 2006.

7.3.1.2 Results and Analysis

A statistical analysis was performed on the 27 questionnaires received in which the mean ratings against the level of importance, measurability, and obtainability for each of the proposed QIs were computed. Table 7.9 shows the results of Round One of the second Delphi questionnaire. It is indicated that the QIs with the highest mean ratings for the seven selected weighted KPIs were: (1) 'Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time', with the mean rating of 4.47 (for measuring the Time Performance); (2) 'Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost', with the mean rating of 4.42 (for measuring the Cost Performance); (3) 'Percentage of Top Management Attendance in Partnering Meetings', with the mean rating of 4.44 (for measuring the Top Management Commitment); (4) 'Average Number of Non-conformance Reports Generated Per Month (for Measuring Civil Works and Building Works), with the mean rating of 4.02 (for measuring the Quality Performance); (5) 'Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect by Using a 10-point Likert Scale', with the mean rating of 3.74 (for measuring the Trust and Respect Performance);

Table 7.9 Result of Round One of the Second Delphi Questionnaire

Quantitative Indicators for Measuring the Performance of Partnering Projects in Hong Kong	Average Ratings of Experts in the Round 1			
Quantitative Indicators for Measuring Time Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Variation of actual completion time expressed as a percentage of finally agreed completion time	4.52	4.56	4.33	4.47
Time improvement: measuring how much time improvement of a project is delivered to previous similar projects.	3.74	3.00	3.04	3.26
Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule).	3.15	3.41	3.44	3.33
Quantitative Indicators for Measuring Cost Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Variation of actual project cost expressed as a percentage of finally agreed project cost	4.48	4.48	4.30	4.42
Cost improvement: measuring how much cost improvement of a project is delivered to previous similar projects.	3.96	3.19	3.33	3.49
Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget).	3.22	3.67	3.96	3.62
Quantitative Indicators for Measuring Top Management Commitment Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Partnering development cost[1] of project expressed as a percentage of total project cost.	3.19	4.00	4.04	3.74
Percentage of top management[2] attendance in partnering meetings.	4.19	4.59	4.56	4.44
Measuring level of top management commitment by using Likert scale (say high level, moderate level, or low level).	3.70	3.85	4.00	3.85
Quantitative Indicators for Measuring Quality Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Cost of rectifying major defects or non-conformances of a project expressed as a percentage of total project cost.	4.19	3.56	3.11	3.62
Average number of non-conformance reports generated per month.	3.93	4.19	3.96	4.02
Perceived end users' satisfaction scores by using Likert scale.	3.81	3.37	3.59	3.59
Quantitative Indicators for Measuring Trust and Respect Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Average duration for settling variation orders.	3.70	3.59	3.56	3.62
Frequency of meeting another party's expectation.	3.52	2.44	2.67	2.88
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.78	3.63	3.81	3.74
Quantitative Indicators for Measuring Effective Communications Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Reduction of written communication: measuring how much written communication is reduced as compared to previous similar projects.	3.37	2.89	2.78	3.01
Variation of the number of formal letters and emails sent between parties per month against the number with previous similar projects.	3.04	2.78	2.78	2.86
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.63	3.30	3.56	3.49
Quantitative Indicators for Measuring Innovation and Improvement Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Cost saving resulted from Innovation expressed as a percentage of total project cost.	4.19	3.48	3.37	3.68
Number of innovative initiatives introduced (e.g. construction techniques, procurement approaches, management strategies).	3.89	3.81	3.74	3.81
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.48	3.37	3.63	3.49

Remark 1: Partnering development cost is defined as a dedicated resource allocation cost from the total project completion cost, which includes (1) cost of employing facilitators, and (2) cost of organizing partnering workshops.

Remark 2: Top management is defined as the most senior executive or his/her representative in an organization.

(6) ‘Perceived Key Stakeholders’ Satisfaction Scores on Effective Communications by Using a 10-point Likert Scale’, with the mean rating of 3.49 (for measuring the Effective Communications Performance); and (7) ‘Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost’, with the mean rating of 3.81 (for measuring the Innovation and Improvement Performance). It should be pointed out that a new QI for measuring the Effective Communications Performance of partnering projects in Hong Kong, which had not been proposed by the five interviewees, were suggested by one of the panel members. The new QI is ‘Integrated Offices; Frequency of/Attendance at Meetings’. Since only 1 panel member suggests it as a measure of Effective Communications, it was not selected for further study.

7.3.2 Round 2 of the Delphi Questionnaire: Re-assessing the Ratings

7.3.2.1 Format

For Round 2 of the second Delphi survey, the experts were provided with the consolidated results obtained in Round 1. The average ratings of the 27 experts against the level of importance, measurability, and obtainability for each QI and the respondent’s own ratings in Round 1 were shown. The respondents were asked to re-assess their ratings in the light of the mean scored by the 27 experts. The Round 2 of the second Delphi questionnaire was distributed to the same group of panel experts both by postal mail and email in late June 2006. Similar to the previous round, an individual email was forwarded to remind all the experts who had not yet returned their completed questionnaires in time, followed up by a phone call. Finally, 25 experts completed their questionnaires in late August 2006.

7.3.2.2 Results and Analysis

Most experts had reconsidered their ratings provided in the previous round and had made adjustments to their ratings. However, Table 7.10 shows that all the QIs with the highest mean ratings are still the same when compared with the consolidated results in Round 1, except that ‘Number of Innovative Initiatives Introduced (e.g. construction techniques, procurement approaches, management strategies)’ was replaced by ‘Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost’ to measure the Innovation and Improvement Performance of partnering projects in Hong Kong.

7.4 QUESTIONNAIRE RESULTS: MEAN VALUES OF THE QUANTITATIVE ASSESSMENT AGAINST THE FIVE DIFFEREENT PERFORMANCE LEVELS

Although a set of QIs established can provide a mutually agreed set of linguistic interpretation and lead to more objective performance evaluation for partnering projects in Hong Kong, it cannot fully eliminate the subjectivity of evaluation as different assessors may perceive the same performance level with different numerical figures.

Table 7.10 Result of Round Two of the Second Delphi Questionnaire

Quantitative Indicators for Measuring the Performance of Partnering Projects in Hong Kong	Average Ratings of Experts in the Round 2			
Quantitative Indicators for Measuring Time Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Variation of actual completion time expressed as a percentage of finally agreed completion time	4.56	4.64	4.38	4.53
Time improvement: measuring how much time improvement of a project is delivered to previous similar projects.	3.80	2.92	3.04	3.25
Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule).	3.12	3.30	3.46	3.29
Quantitative Indicators for Measuring Cost Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Variation of actual project cost expressed as a percentage of finally agreed project cost	4.56	4.48	4.32	4.45
Cost improvement: measuring how much cost improvement of a project is delivered to previous similar projects.	4.00	3.08	3.32	3.47
Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget).	3.12	3.62	3.68	3.47
Quantitative Indicators for Measuring Top Management Commitment Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Partnering development cost[1] of project expressed as a percentage of total project cost.	3.00	4.08	4.12	3.73
Percentage of top management[2] attendance in partnering meetings.	4.32	4.60	4.60	4.51
Measuring level of top management commitment by using Likert scale (say high level, moderate level, or low level).	3.62	3.80	3.88	3.77
Quantitative Indicators for Measuring Quality Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Cost of rectifying major defects or non-conformances of a project expressed as a percentage of total project cost.	4.26	3.76	3.22	3.75
Average number of non-conformance reports generated per month.	3.94	4.28	4.08	4.10
Perceived end users' satisfaction scores by using Likert scale.	3.74	3.46	3.74	3.65
Quantitative Indicators for Measuring Trust and Respect Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Average duration for settling variation orders.	3.64	3.56	3.48	3.56
Frequency of meeting another party's expectation.	3.50	2.46	2.64	2.87
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.82	3.66	3.84	3.77
Quantitative Indicators for Measuring Effective Communications Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Reduction of written communication: measuring how much written communication is reduced as compared to previous similar projects.	3.28	2.92	2.64	2.95
Variation of the number of formal letters and emails sent between parties per month against the number with previous similar projects.	2.84	2.76	2.70	2.77
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.62	3.34	3.58	3.51
Quantitative Indicators for Measuring Innovation and Improvement Performance	**Importance**	**Measurability**	**Obtainability**	**Mean Ratings**
Cost saving resulted from Innovation expressed as a percentage of total project cost.	4.26	3.72	3.56	3.85
Number of innovative initiatives introduced (e.g. construction techniques, procurement approaches, management strategies).	3.80	3.80	3.80	3.80
Perceived key stakeholders' satisfaction scores by using Likert scale.	3.44	3.52	3.72	3.56

Table 7.11 Mean Value of the Quantitative Assessment Figures

KPIs	The Most Important Quantitative Indicator (QI) for each of the Seven Selected KPIs	Performance Level									
		Poor		Average		Good		Very Good		Excellent	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Time Performance	Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time	-11.32%	-0.54	-1.25%	-2.90	3.86%	1.18	9.91%	0.58	15.55%	0.45
Cost Performance	Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost	-12.50%	-0.55	-1.55%	-2.36	3.89%	1.01	8.77%	0.60	14.07%	0.43
Top Management Commitment	Percentage of Top Management Attendance in Partnering Meetings	48.00%	0.34	63.64%	0.25	74.23%	0.19	82.73%	0.15	84.09%	0.14
Quality Performance (Civil Works)	Average Number of Non-conformance Reports Generated Per Month (for civil works)	11.78	0.46	6.67	0.49	4.17	0.60	2.17	0.78	0.41	2.17
Quality Performance (Building Works)	Average Number of Non-conformance Reports Generated Per Month (for building works)	25.74	0.52	14.95	0.50	10.58	0.59	5.58	0.84	1.95	1.52
Trust and Respect	Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect by using a 10-point Likert Scale	3.73	0.40	5.52	0.18	7.00	0.13	7.84	0.10	8.06	0.09
Effective Communications	Perceived Key Stakeholders' Satisfaction Scores on Effective Communications by using a 10-point Liker Scale	4.19	0.30	5.93	0.15	6.93	0.12	7.71	0.09	8.71	0.07
Innovation and Improvement	Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost	0.38%	2.02	2.55%	0.60	4.28%	0.49	6.49%	0.36	8.21%	0.38

CV = Coefficient of Variation

Note: There is a need for assurance that cost saving through Innovation and Improvement, such as construction techniques, procurement approaches and management strategies, has not been double counted in Cost Performance given that both of them are expressed as a percentage of project cost.

For example, 0% reduction in project cost may represent ‘good performance’ while 5% reduction in project cost may denote ‘very good performance’. Should a partnering project be classified as ‘good’ or ‘very good’ in terms of cost performance in case of 2.5% reduction in project cost?

To remedy this deficiency, a questionnaire survey was conducted in order to capture the perception of professionals as to the expectation of different performance levels for each of the QIs. The results of the questionnaire are summarized in Table 7.11 in which the Mean Expectation (ME) and Coefficient of Variation (CV) of each QI against the five performance levels are listed. A closer inspection to the coefficient of variation (CV) reveals that there are slight to moderate deviations from the mean value in most of the performance levels describing the QIs. Nevertheless, the deviations are high for ‘variation of actual completion time expressed as a percentage of finally agreed completion time’ (CV for the average performance = -2.90 and CV for the good performance = 1.18); ‘variation of actual project cost expressed as a percentage of finally agreed project cost’ (CV for the average performance = -2.36 and CV for the good performance = 1.01); ‘average number of non-conformance reports generated per month for civil works (CV for the excellent performance = 2.17); and ‘average number of non-conformance reports generated per month for building works (CV for the excellent performance = 1.52).

The results show that differences in expectation exist between the construction experts in the perceived performance level of each QI. Thus, in spite of the fact that the mean value can serve as a quick rule-of-thumb for evaluators to differentiate an ‘average’ and ‘good’ performance of a partnering project, it is more appropriate to identify a quantitative range/requirement (QR) of reasonable expectation for each performance level as shown in Figure 7.1. Therefore, a partnering project with ‘good’ time performance would be one with for example ahead of schedule by 0.68% to 8.82%. In this example, the lower boundary for the ‘good’ time performance was simply taken as the average of the mean expectation for the ‘average’ time performance (Mean Expectation for the ‘Average’ Performance = behind of schedule by 1.25%) and ‘good’ time performance (Mean Expectation for the ‘Good’ Performance = ahead of schedule by 3.86%) and the average of the mean expectation for the ‘good’ time performance (Mean Expectation for the ‘Good’ Performance =ahead of schedule by 3.86%) and ‘very good’ time performance (Mean Expectation for the ‘Very Good’ Performance = ahead of schedule by 9.91%). Table 7.12 shows all the QRs for each of the seven QIs.

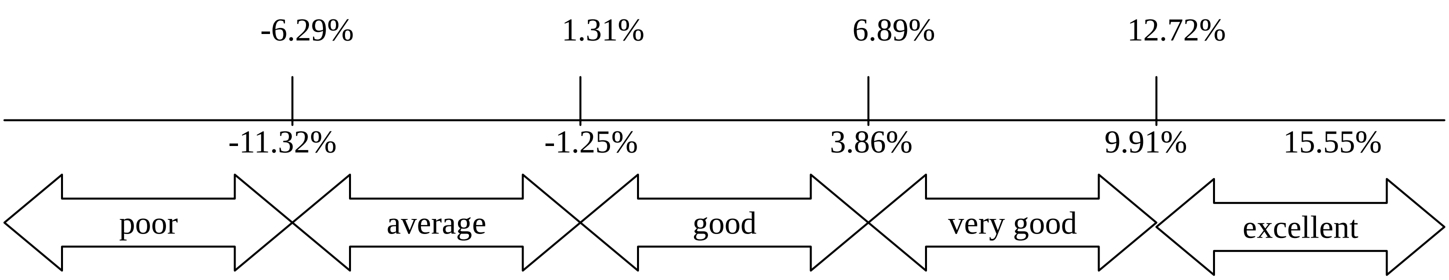


Figure 7.1. Reasonable range for each performance level in relation to QI of time performance

7.5 DISCUSSION AND VALIDATION OF RESEARCH FINDINGS

The research findings indicate that 3 QIs with the highest mean ratings were cross-referenced with the reported literature. They were: (1) ‘Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time’ (for measuring Time Performance) (also suggested by Collin, 2002); (2) Variation of Actual

Table 7.12 Quantitative Ranges/Requirements for Each of the Selected QIs

The Selected KPIs (With their Individual Weighting)	The Selected Quantitative Indicator (QI) for ach of the Seven Weighted KPIs	Quantitative Ranges (QR) for Each QI				
		Poor	Average	Good	Very Good	Excellent
Time Performance, with the weighting of 0.167	Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time	< -6%	-6% to 1%	1% to 7%	7% to 13%	> 13%
Cost Performance, with the weighting of 0.167	Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost	< -7%	-7% to 1%	1% to 6%	6% to 11%	> 11%
Top Management Commitment, with the weighting of 0.167	Percentage of Top Management Attendance in Partnering Meetings	< 56%	56% to 69%	69% to 78%	78% to 83%	> 83%
Quality Performance (Civil Works), with the weighting of 0.167	Average Number of Non-conformance Reports Generated Per Month (for civil works)	> 9	9 to 5	5 to 3	3 to 1	< 1
Quality Performance (Building Works), with the weighting of 0.167	Average Number of Non-conformance Reports Generated Per Month (for building works)	> 20	20 to 13	13 to 8	8 to 4	< 4
Trust and Respect, with the weighting of 0.167	Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect by using a 10-point Likert Scale	< 5	5 to 6	6 to 7	7 to 8	> 8
Effective Communications, with the weighting of 0.167	Perceived Key Stakeholders' Satisfaction Scores on Effective Communications by using a 10-point Likert Scale	< 5	5 to 6	6 to 7	7 to 8	> 8
Innovation and Improvement, with the weighting of 0.167	Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost	< 2%	2% to 3%	3% to 5%	5% to 7%	> 7%

Note: All the values are shown with zero decimal place.

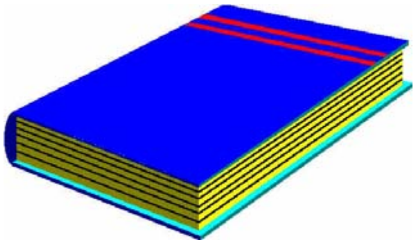
Project Cost Expressed as a Percentage of Finally Agreed Project Cost' (for measuring Cost Performance) (also suggested by Cheung et al, 2003) (it should be noted that the time/cost variation results in this study are the same with time/cost overruns percentage from other existing construction research studies); and (3) 'Average Number of Non-conformance Reports Generated Per Month' (for Measuring Civil Works and Building Works) (for measuring Quality Performance) (also suggested by Bayliss et al, 2004). It should also be noted that the Delphi method by its inherent nature serves as a self-validating mechanism because individual experts are given chances to re-assess their scores with reference to the consolidated mean scores as assessed by other experts. And it is logical and reasonable to define a range for different performance levels by taking the average of two consecutive performance levels. By doing so, assessors can have a greater flexibility to evaluate the partnering performance of construction projects without sacrificing its objectiveness and reliability.

However, the QRs defined is over simplified and therefore more appropriate to adopt a scientific way to define a range for different performance levels. Since Fuzzy Set Theory (FST) is used to model vagueness intrinstic in human cognitive process and it has been used to tackle ill-defined and complex problems due to incomplete and imprecise information that characterize the real-world systems (Baloi and Price, 2003), it is considered appropriate to use FST to establish well-defined ranges of Quantitative Ranges/Requirements (QRs) for each QI against the five performance levels. In fact, the development of QRs for each QI identified by using the Fuzzy Set Theory will be described and explained in Chapter 8.

7.6 CHAPTER SUMMARY

This chapter has established a set of QIs and has identified a range of reasonable quantitative ranges (QRs) for the five performance levels by conducting five structured face-to-face interviews; 2 rounds of the second Delphi survey; and an empirical questionnaire survey. The QIs with the highest mean ratings for each of the seven selected weighted KPIs were found to be: (1) ‘Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time’ (for measuring the Time Performance); (2) ‘Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost’ (for measuring the Cost Performance); (3) ‘Percentage of Top Management Attendance in Partnering Meetings’ (for measuring the Top Management Commitment); (4) ‘Average Number of Non-conformance Reports Generated Per Month’ (for Measuring Civil Works and Building Works) (for measuring the Quality Performance); (5) ‘Perceived Key Stakeholders’ Satisfaction Scores on Trust and Respect by Using a 10-point Likert Scale’ (for measuring the Trust and Respect Performance); (6) ‘Perceived Key Stakeholders’ Satisfaction Scores on Effective Communications by Using a 10-point Likert Scale’ (for measuring the Effective Communications Performance); and (7) ‘Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost’ (for measuring the Innovation and Improvement Performance). After identifying a set of QIs, the QRs for each of them against the five performance levels have been defined by taking the average value of two consecutive performance levels.

By incorporating these quantitative indicators and quantitative ranges into the evaluation process, assessors could perform their evaluation based on quantitative evidences. Different partnering projects can then be evaluated and compared on an objective basis with reference to this set of QIs and QRs. As a result, construction senior executives and project managers can adopt the identified QIs and QRs to measure, evaluate and upgrade the existing performance level of their partnering projects.



CHAPTER 8 FUZZY QUANTITATIVE REQUIREMENTS (QRs) FOR QUANTITATIVE INDICATORS (QIs)

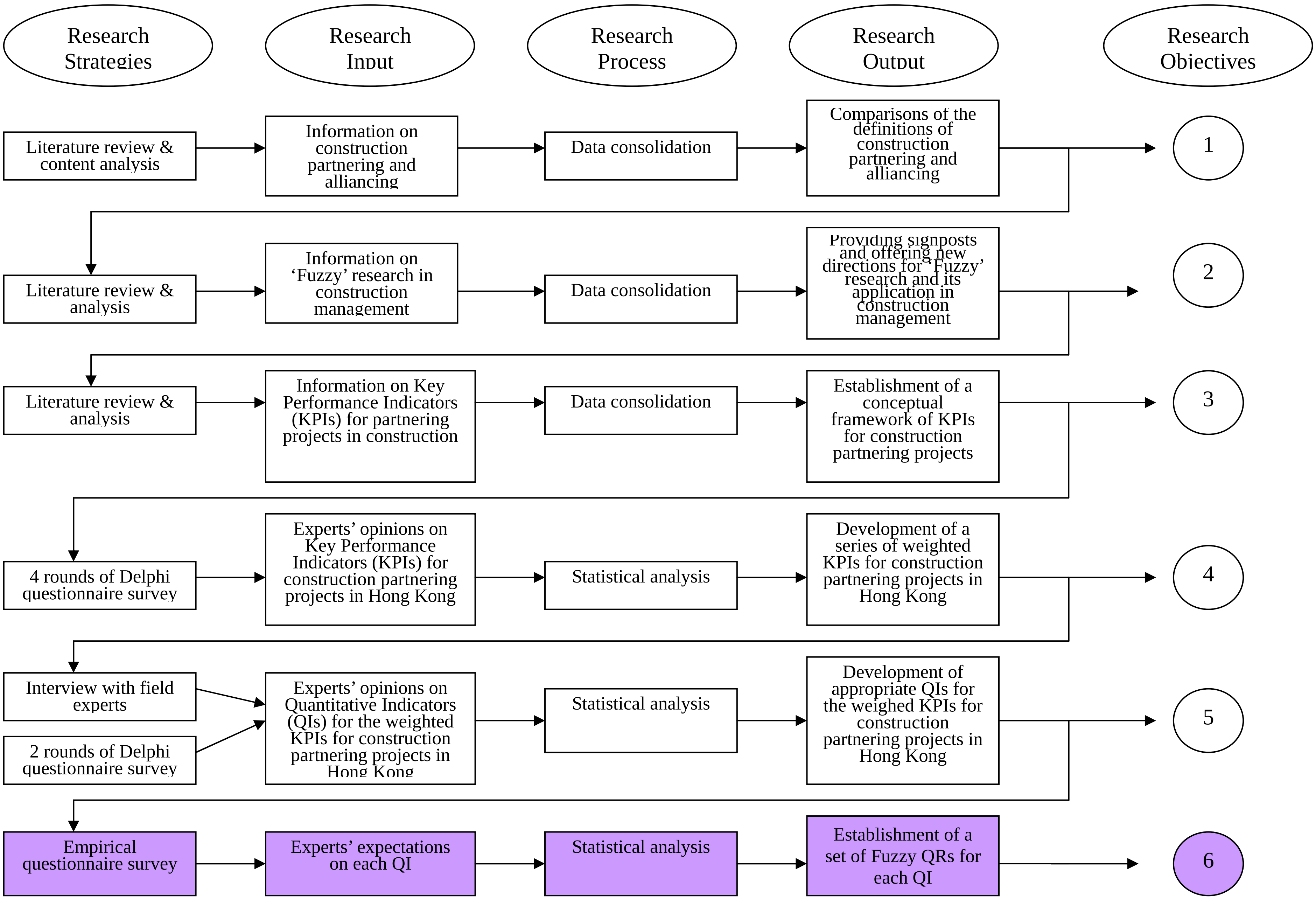


Figure 2.1 Overall Flow of Research

Chapter 8 FUZZY QUANTITATIVE REQUIREMENTS FOR QUANTITATIVE INDICATORS (QIs)

8.1 INTRODUCTION

The development of PPI, QIs, and QRs can assist in developing a benchmark for measuring the partnering performance of construction projects. However, the establishment of QRs by taking the mean expectation is too simple and may not be scientific.

The aim of this chapter is to establish well-defined ranges/requirements (QRs) for each QI within a five-point performance level by applying a Fuzzy Set Theory (FST) approach. The five-point levels are: 1. 'poor'; 2. 'average'; 3. 'good'; 4. 'very good'; and 5. 'excellent'. By doing so, assessors could evaluate the partnering performance of construction projects with greater flexibility but still retaining objectivity. With the establishment of a reliable set of QRs by using the Fuzzy Set Theory, assessors could perform their evaluation based on the established fuzzy ranges rather than applying their subjective value judgement. Consequently, assessors could determine which performance levels should be assigned in accordance with the actual performance of a partnering project, thus making the assessment more objectively, reliably and practically.

8.2 ESTABLISHMENT OF FUZZY MEMBERSHIP FUNCTIONS

Four major methods have been used for establishing the fuzzy membership function, including (1) the horizontal approach (Godal and Goodman, 1980; Bharathi-Devi and Sarma, 1985); (2) the vertical approach (Civanlar and Trussel, 1986); (3) the pairwise comparison method (Saaty, 1980); and (4) the membership function estimation approach with the aid of probabilistic characteristics (Dubois and Prade, 1983). In addition, Ng et al (2002) proposed a 'modified horizontal approach' to develop the fuzzy membership function to evaluate the performance of engineering consultants, which is based on an amalgamation of the horizontal and graphical approaches (Bandemer and Gottwald, 1995). In this research study, the modified horizontal approach was adopted for developing the fuzzy membership functions because of its higher accuracy (Ng et al, 2002; Chow, 2005) (Figure 8.1).

In fact, unlike the other approaches for establishing the fuzzy membership functions, this approach allows the final outcome to be derived from simple probability functions (Ng et al, 2002; Chow, 2005; Chow and Ng, 2007). While the horizontal approach allows the computation of an optimal value of *k* (i.e. the number of bands) which is vital to the accuracy of estimation (Bharathi-Devi and Sarma, 1985), the graphical approach further tackle the problem of discontinuity in the transition from full membership to absolute exclusion in pure horizontal methods (Othnes, 1972).

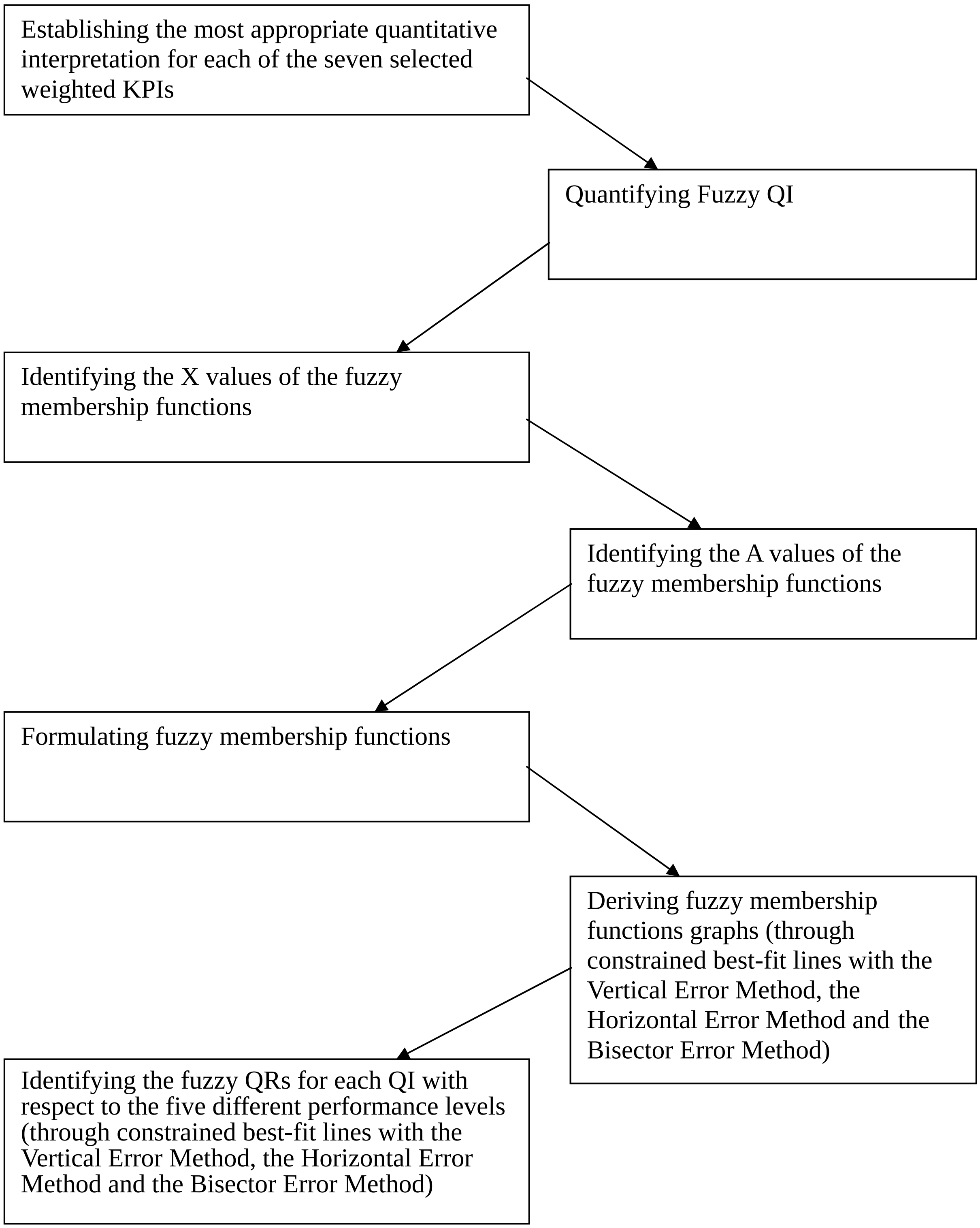


Figure 8.1 The Modified Horizontal Approach Adopted in This Research Study in Defining the Fuzzy Quantitative Requirements (Adapted from Ng et al, 2002 and Chow, 2005)

The fuzzy membership functions developed in this research study is first presented in a tabular form as shown in Table 8.1. Based on the value in the universe of discourse that defines the fuzzy set (X) and the degree of membership of that fuzzy set (A), a scatter diagram for the membership function is plotted (Figure 8.2) and the best-fit lines are generated to join all the discrete points (i.e. lines AB and AC in Figure 8.2) using the MATLAB 12.0 to plot the fuzzy membership functions. Chow (2005) and Chow and Ng (2007) stated that it is logical to construct the best-fit lines passing through the point with full membership (point A in Figure 8.2) because there must be a vertex in a Fuzzy membership function. When the line of best-fit for each of the five performance levels correspond to a quantitative indicator is generated (Figure 8.3), the intersections of the best-fit lines between two consecutive performance levels represents a same degree of membership for both performance levels. Consequently, it is logical to choose these intersecting points to identify the QRs of each QI for the five different performance levels (i.e. ‘poor’, ‘average’, ‘good’, ‘very good’, and ‘excellent’). As illustrated in Figure 8.4, the QRs for each performance level are defined in Table 8.2.

Table 8.1 X and A Values of the ‘Excellent’ Time Performance of a Partnering Project in Hong Kong (Q1 in the Questionnaire Survey)

Percentage (X)	-6.5%	-10.44%	-15%	-20%	-25%	-30%
Degree of membership (A)	0.2222	1	0.3333	0.3333	0.3333	0.1111

Note: ‘-’ represents ‘ahead of schedule’

Although the modified horizontal approach adopted by Ng et al (2002), Chow (2005) and Chow and Ng (2007) is theoretically sound, there is a major limitation for this approach because the creation of best-fit lines (the QIs against the five different performance levels) constrained to pass through the point with full membership has only considered the minimization of the residual sum of squares by vertical distance only.

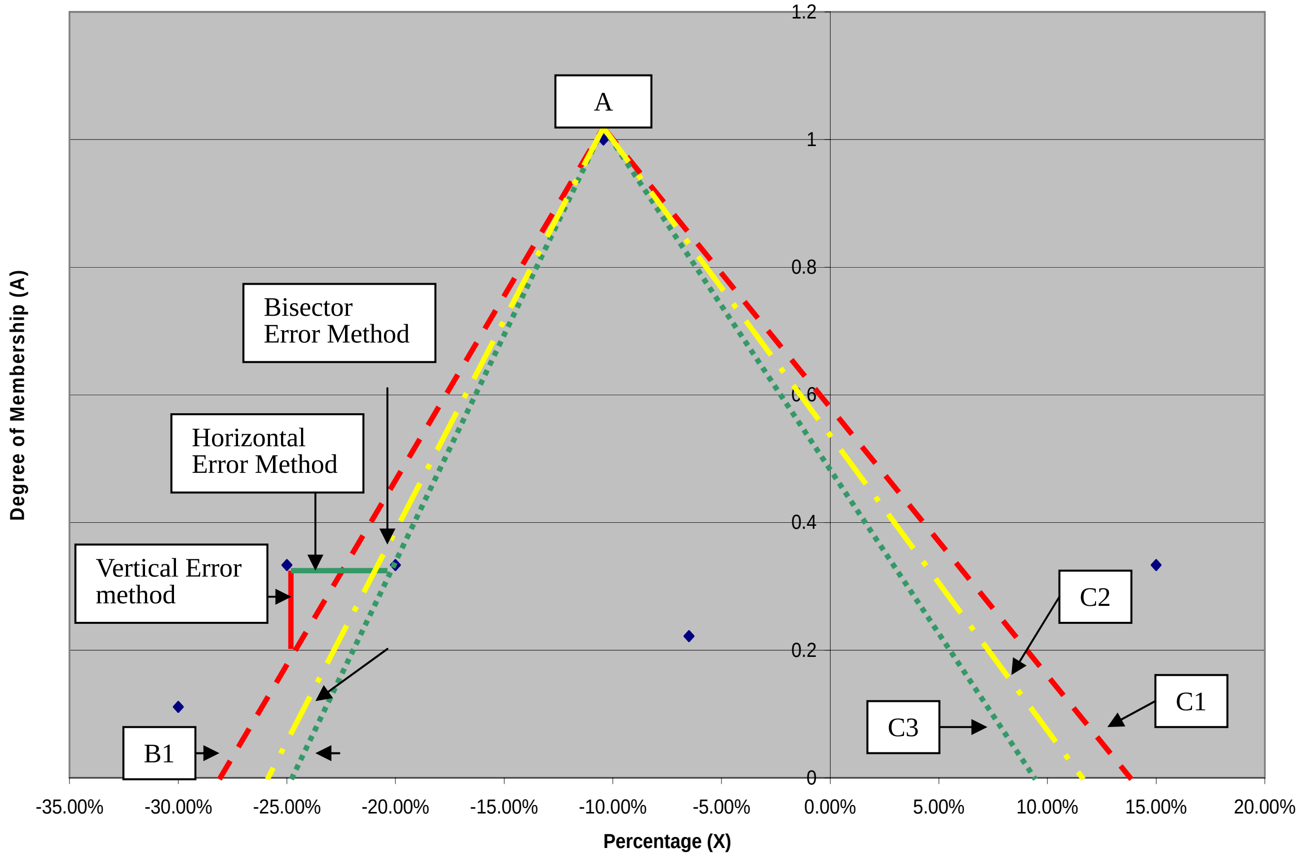
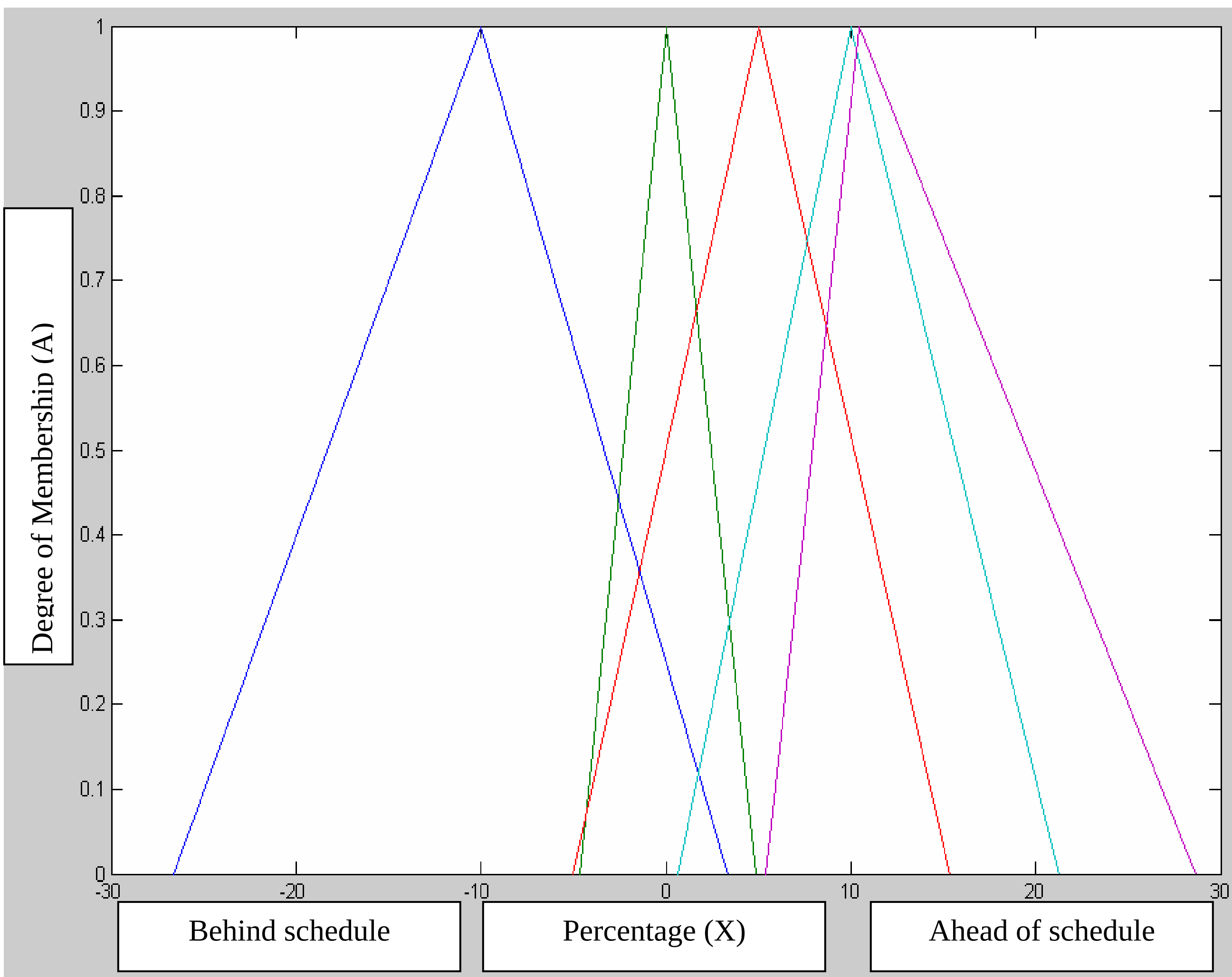


Figure 8.2 An Example of Scatter Diagram Showing the Fuzzy Membership Function

This method does not take the effect of independent variable into account. Although the modified horizontal approach was employed in this research study, fuzzy membership functions have been constructed through constrained best-fit lines with not only the Vertical Error Method (please refer to Appendix 9), but also with the Horizontal Error Method (please refer to Appendix 10) (minimizing the residual sum of squares by horizontal distance only), and the Bisector Error Method (please refer to Appendix 11) (minimizing the residual sum of squares by the average of vertical and horiztonal distances (Figure 8.2). Since the Bisector Error Method considers the errors created by both the Vertical Error Method and the Horizontal Error Method, it is taken as superior to the other two methods so it was finally chosen to establish the Fuzzy membership functions and calculate the fuzzy QRs in this research study.



denotes poor performance

denotes average performance

denotes good performance

denotes very good performance

denotes excellent performance

Figure 8.3 Using Intersecting Points with Constrained Best-fit Lines to Identify the Fuzzy Quantitative Requirements

8.3 PROCEDURES FOR DEFINING THE FUZZY QUANTITATIVE REQUIREMENTS (FQRs)

Figure 8.1 shows the six main steps of the modified horizontal approach to define the FQRs, including (1) establishing the most appropriate quantitative interpretation for each KPI; (2) quantifying fuzzy QI; (3) identifying the X values of the fuzzy membership functions; (4) identifying the A values of the fuzzy membership functions; (5) formulating fuzzy membership functions; (5) deriving fuzzy membership functions graphs; and (6) identifying the QRs for each QI with respect to the five performance levels (through constrained best-fit lines with the Vertical Error Method, the Horizontal Error Method, and the Bisector Error Method).

8.3.1 Establishment of The Most Appropriate Quantitative Indicator for Each of the Seven Weighted KPI

As mentioned earlier, Quantitative Indicators (QIs) for each of the seven selected weighted KPIs, based on the previous study of the research team, have been established for measuring the partnering performance of construction projects in Hong Kong.

8.3.2 Quantification of the Fuzzy Quantitative Indicators

Through the questionnaire survey, the 31 selected construction experts were requested to provide a numerical figure $\left(f_0\right)$ for each QI with respect to the five different performance levels namely 'poor', 'average', 'good', 'very good', and 'excellent'. The results are shown in Table 8.2.

8.3.3 Identification of the 'X' Values of the Fuzzy Membership Functions

A fuzzy membership function is basically formulated by two values: *X* and *A*. *X* represents the value in the universe of discourse that defines the fuzzy set while *A* stands for the degree of membership 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 of the questionnaire survey to the QI pertinent to the five performance levels. The X_i values are defined according to the lowest and highest values of f_0 for each QI and the number of bands *k*. To find the number of bands k for estimation, a widely used approach was proposed by Bharathi-Devi and Sarma (1985) with the following equation:

$$k = 1.87(N-1)^{\frac{2}{5}} \qquad \text{(Equation 1)}$$

where N is the total number of valid replies to the corresponding QI.

8.3.4 Identification of the 'A' Values of the Fuzzy Membership Functions

The degree of membership A_i was computed according to the equation:

$$A_i = \frac{n(B_i)}{n_{\max}} \quad \text{for i=1,2,3,……k} \quad \text{(Equation 2) (Ng et al, 2002; Chow, 2005)}$$

In equation 2, $n(B_i)$ corresponds to the number of valid replies that have the values of f_0 belonging to a certain band B_i and $n_{\max}$ represents the maximum value of all the $n(B_i)$ with i=1,2,3,……k. For the sake of examining whether the estimation of membership is valid, the standard deviation $std(A)$ was calculated. The $std(A)$ is determined by the equation 3. If the $std(A)$ has a lower value than A_i computed in Equation 2, the estimation of membership is considered acceptable (Ng et al, 2002; Chow, 2005). However, if the $std(A)$ does not have a lower value than A_i, the result is considered to be unacceptable and a possible solution is to delete the outliers. In this research study, only 10 out of 240 numbers of the values of $std(A)$ do not have a lower value than its A_i. However, by deleting the outliers, all the estimations of membership become valid.

$$std(A_i) = A_i \times \left(\frac{1 - A_i^{\frac{1}{2}}}{N} \right) \quad \text{(Equation 3)}$$

8.3.5 Identification of the Fuzzy QRs for Each QI

8.3.5.1 Time Performance

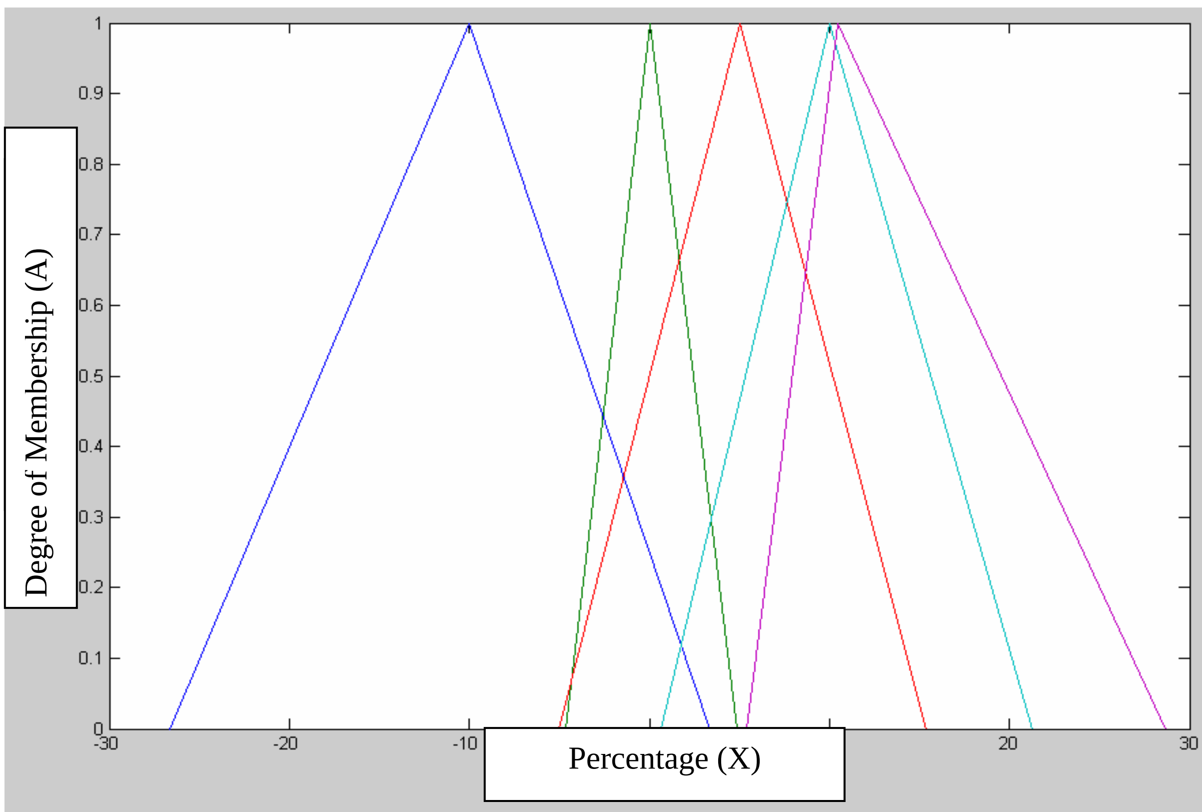
As shown in Figure 8.4, the fuzzy membership functions of ‘poor’, ‘average’, ‘good’, ‘very good’, and ‘excellent’ for measuring the time performance of partnering projects are all triangular shaped. The results indicate that the full memberships of the five different performance levels occur when -10%, 0%, 5%, 10%, and 10.44% respectively of time performance achieved. In order to cater for the vagueness of various performance levels, a range of allowable values for each performance level as shown in Table 8.2 should be referred to.

Table 8.2 The Fuzzy QRs of each QI Against the Five Different Performance Levels

The Seven Selected KPIs (with corresponding weightings) (total weighting is equal to 1)	The Most Important Quantitative Indicator (QI) for each of the Seven Selected KPIs	Performance Level				
		Poor	Average	Good	Very Good	Excellent
Time Performance (0.167)	Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time	<-3.1% <-2.0% <-2.6%	-3.1%-1.5*% -2.0%-1.8*% -2.6%-1.6*%	1.5%-7.4*% 1.8%-7.9*% 1.6%-7.6*%	7.4%-10.3*% 7.9%-10.3*% 7.6%-10.3*%	≥10.3% ≥10.3% ≥10.3%
Cost Performance (0.160)	Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost	<-2.4% <-5.3% <-2.9%	-2.4%-0*% -5.3%-0*% -2.9%-0*%	0%-4.3*% 0%-4.6*% 0%-4.4*%	4.3%-10.4*% 4.6%-10.4*% 4.4%-10.4*%	≥10.4% ≥10.4% ≥10.4%
Top Management Commitment (0.150)	Percentage of Top Management Attendance in Partnering Meetings	<56.7% <57.0% <56.8%	56.7%-72.1*% 57.0%-72.0*% 56.8%-72.1*%	72.1%-81.4*% 72.0%-82.1*% 72.1%-81.7*%	81.4%-96.1*% 82.1%-96.4*% 81.7%-96.3*%	≥96.1% ≥96.4% ≥96.3%
Quality Performance (0.143)	Average Number of Non-conformance Reports Generated Per Month (for civil works)	>8 >8 >8	4+-8 4+-8 4+-8	3+-4 3+-4 3+-4	1+-3 1+-3 1+-3	≤1 ≤1 ≤1
Quality Performance (0.143)	Average Number of Non-conformance Reports Generated Per Month (for building works)	>15 >14 >15	11+-15 11+-14 11+-15	6+-11 8+-11 7+-11	2+-6 3+-8 3+-7	≤2 ≤3 ≤2
Trust and Respect (0.143)	Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect by using a 10-point Likert Scale	<4.8 <4.7 <4.8	4.8-6.5* 4.7-6.0* 4.8-6.2*	6.5-8* 6.0-8* 6.2-8*	8-8.9* 8-8.9* 8-8.9*	≥8.9 ≥8.9 ≥8.9
Effective Communications (0.131)	Perceived Key Stakeholders' Satisfaction Scores on Effective Communications by using a 10-point Liker Scale	<5 <5 <5	5-6.8* 5-6.3* 5-6.5*	6.8-8.3* 6.3-8.3* 6.5-8.3*	8.3-9* 8.3-9* 8.3-9*	≥9 ≥9 ≥9
Innovation and Improvement (0.106)	Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost	<0.6% <0.6% <0.6%	0.6%-2.8*% 0.6%-3.1*% 0.6%-2.9*%	2.8%-6.6*% 3.1%-6.7*% 2.9%-6.7*%	6.6%-9.7*% 6.7%-9.4*% 6.7%-9.6*%	≥9.7% ≥9.4% ≥9.6%

Note 1: M*% represents "less than M%" while M+ represents "greater than M" Red: Vertical Error Method Green: Horizontal Error Method Blue: Bisector Error Method
Note 2: The fuzzy QRs of each QI in this table was establishing by using Fuzzy Set Theory while the QRs of each QI for Table 7.12 was developed by using a simple method (i.e. taking the average of the mean expectation between two consecutive grades).

For example, the Time Performance of a partnering project would be classified as ‘poor’ if the project is behind schedule by more than 2.6% (in terms of variation of actual completion time expressed as a percentage of finally agreed completion time); ‘average’ if between behind schedule by 2.6% and ahead of schedule by no more than 1.6%; ‘good’ if between ahead of schedule by 1.6% and by no more than 7.6%; ‘very good’ if between ahead of schedule by 7.6% and by no more than 10.3%; and ‘excellent’ if ahead of schedule by more than 10.3%.

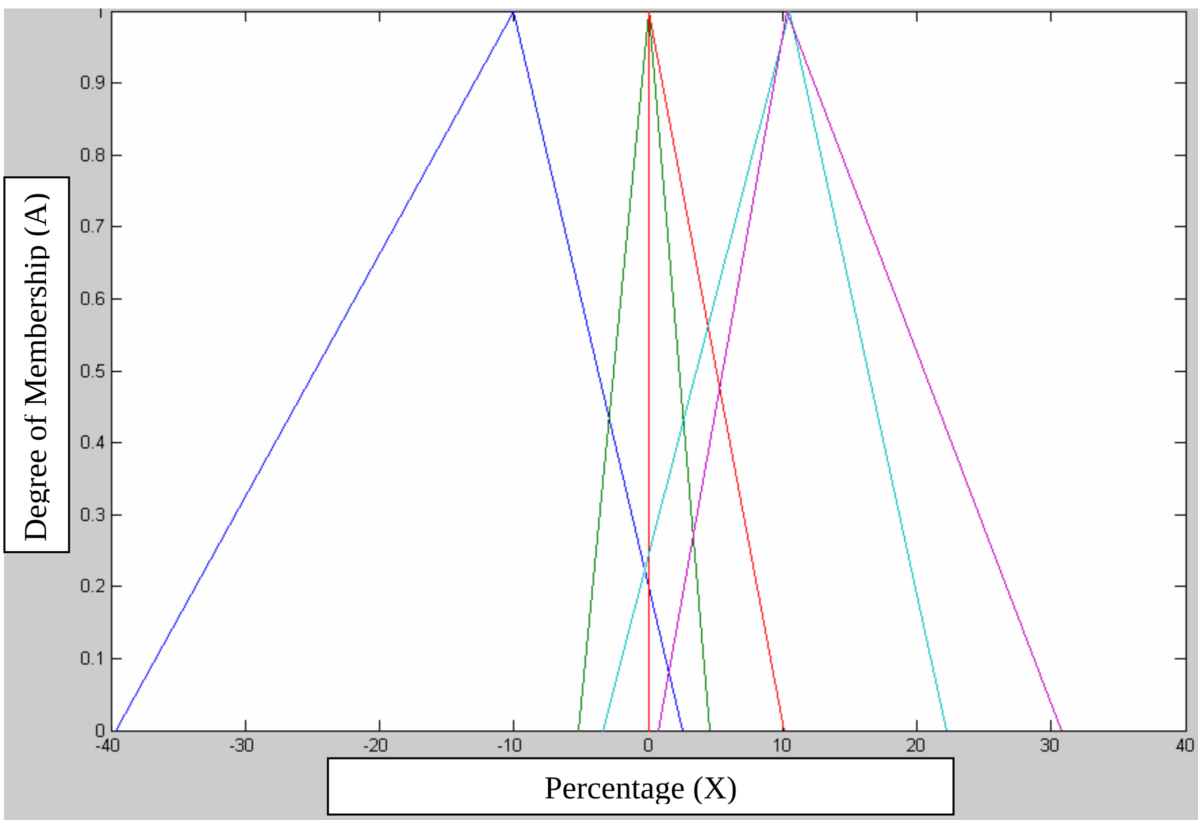


denotes poor performance
denotes average performance
denotes good performance
denotes very good performance
denotes excellent performance

Figure 8.4 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Time Performance of Construction Partnering Projects in Hong Kong

8.3.5.2 Cost Performance

The fuzzy membership functions of 'poor', 'average', 'good', 'very good', and 'excellent' for the cost performance of partnering projects are portrayed in Figure 8.5. They are all triangular shaped and the full memberships for the five different performance levels emerge at -10%, 0%, 0%, 10.33%, and 10.5%. The results also indicate that the Cost Performance of a partnering project would be categorised as 'poor' if the project is overrun budget by more than 2.9% (in terms of variation of actual project cost expressed as a percentage of finally agreed project cost); 'average' if between overrun budget by 2.9% and by no more than 0% (on budget); 'good' if between on budget and underrun budget by no more than 4.4%; 'very good' if between underrun budget by 4.4% and by no more than 10.4%; and 'excellent' if underrun budget by more than 10.4%.



denotes poor performance
denotes average performance
denotes good performance
denotes very good performance
denotes excellent performance

Figure 8.5 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Cost Performance of Construction Partnering Projects in Hong Kong

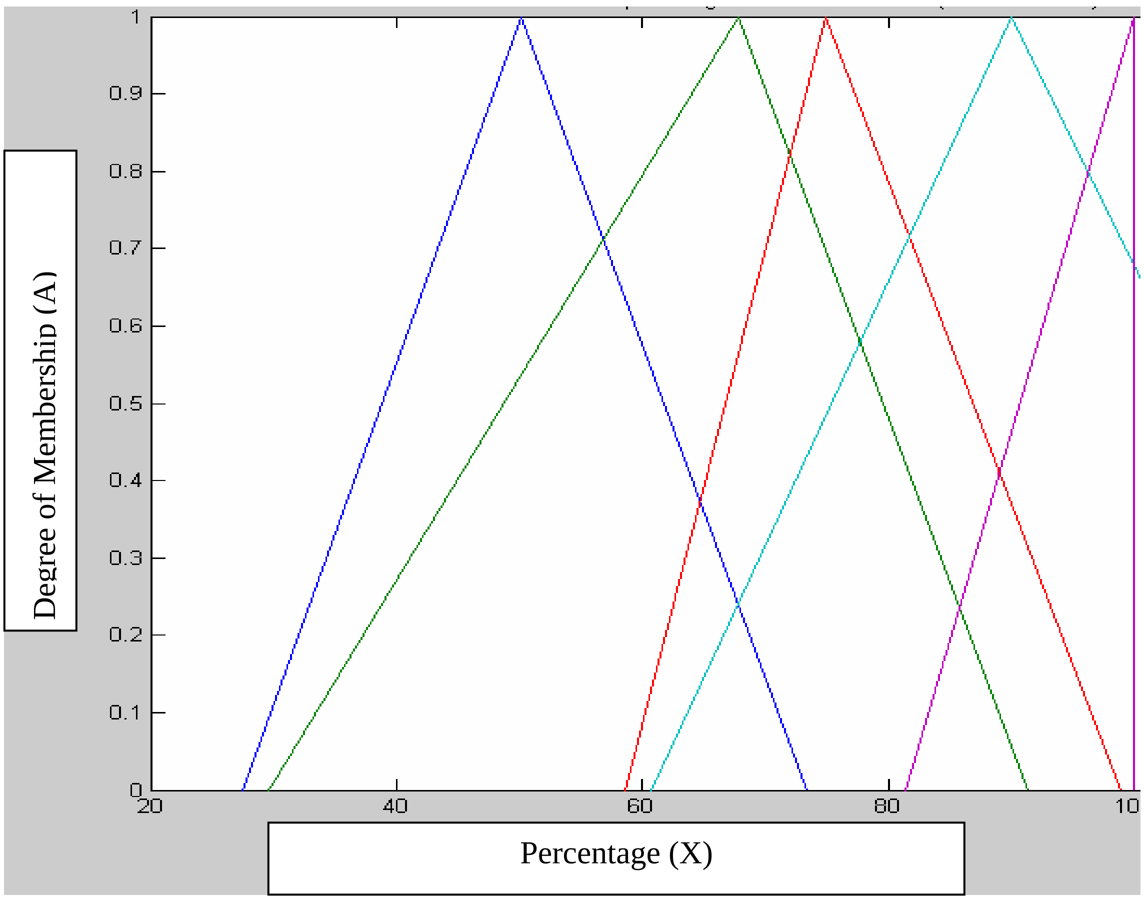
8.3.5.3 Top Management Commitment Performance

Figure 8.6 depicts the fuzzy membership functions for the five different performance levels of the Top Management Commitment Performance of a partnering project. They are all triangular shaped. The highest memberships for each level are at 50.13%, 67.86%, 75%, 90%, and 100%. Similar to the time and cost performance, a range of allowable values for each performance level is calculated by using the modified horizontal approach with the Bisector Error Method so as to cater for the vagueness of the five different performance levels. The research findings manifest that the top management commitment of a partnering project would be classified as ‘poor’ if the percentage of their attendance in partnering meetings is no more than 56.8%; ‘average’ if between 56.8% and no more than 72.1%; ‘good’ if between 72.1% and no more than 81.7%; ‘very good’ if between 81.7% and no more than 96.3%; and ‘excellent’ if equal to or greater than 96.3%.

8.3.5.4 Quality Performance (Civil Works)

As indicated in Figure 8.7, the highest memberships of ‘poor’, ‘average’, ‘good’, ‘very good’ and ‘excellent’ are at 10, 4.5, 4.2, 2, and 0 average number of non-conformance report generated per month. The least memberships of the five different performance levels take place at 3.87 and 19.13, -0.47 and 13.83, -2.31 and 15.24, -1.37 and 6.68, and 0 and 3.67. All membership functions of quality performance for civil works are triangular shaped. It was reflected from the results that the Quality Performance for

Civil Works of a partnering project would be classified as ‘poor’ if the average number of non-conformance reports generated per month is larger than 8; ‘average’ if between more than 4 and 8; ‘good’ if between more than 3 and 4; ‘very good’ if between more than 1 and 3; and ‘excellent’ if smaller than or equal to 1.



denotes poor performance

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denotes very good performance

denotes excellent performance

Figure 8.6 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Top Management Commitment of Construction Partnering Projects in Hong Kong

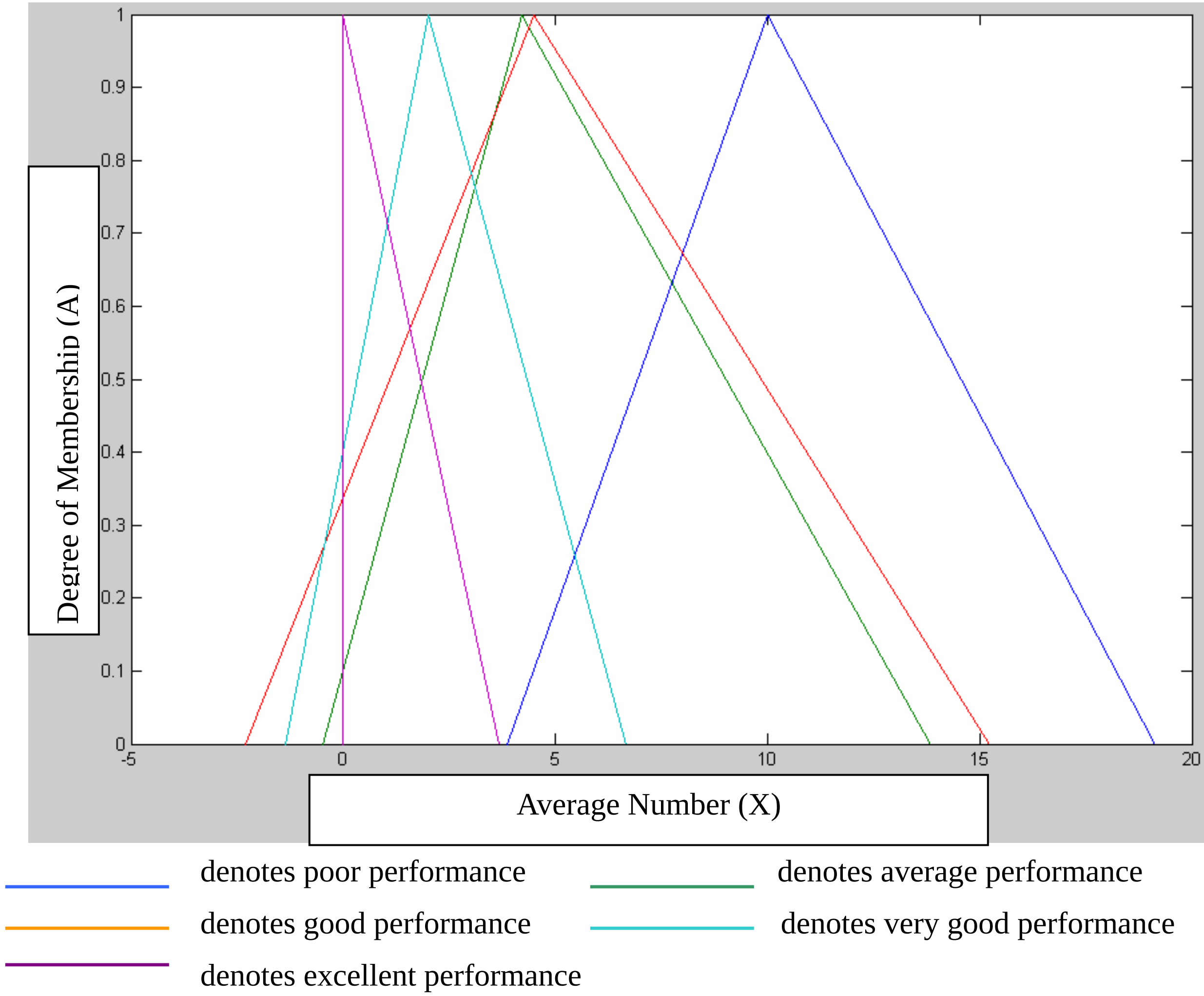


Figure 8.7 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Quality Performance (for Civil Works) of Construction Partnering Projects in Hong Kong

8.3.5.5 Quality Performance (Building Works)

The full memberships of ‘poor’, ‘average’, ‘good’, ‘very good’, and ‘excellent’ Quality Performance (for building works) of a partnering project are located at 18.33, 10.8, 10.6, 4.67 and 0 average number of non-conformance reports generated per month. Figure 8.9 shows that the least memberships of the five different performance levels are set at -7.41 and 49.06, -2.57 and 36.89, 3.39 and 24.62, 1.03 and 9.57, and 0 and 4.05. All membership functions of quality performance for building works are triangular. The

Quality Performance (for Building Works) of a partnering project would be categorised as 'poor' if the average number of non-conformance reports generated per month is larger than 15; 'average' if between more than 11 and 15; 'good' if between more than 7 and 11; 'very good' if between more than 3 and 7; and 'excellent' if smaller than or equal to 2. It should be pointed out there is a wide range for the poor performance membership function because the actual data points vary, which reflect that the opinions among the experts were quite diversified.

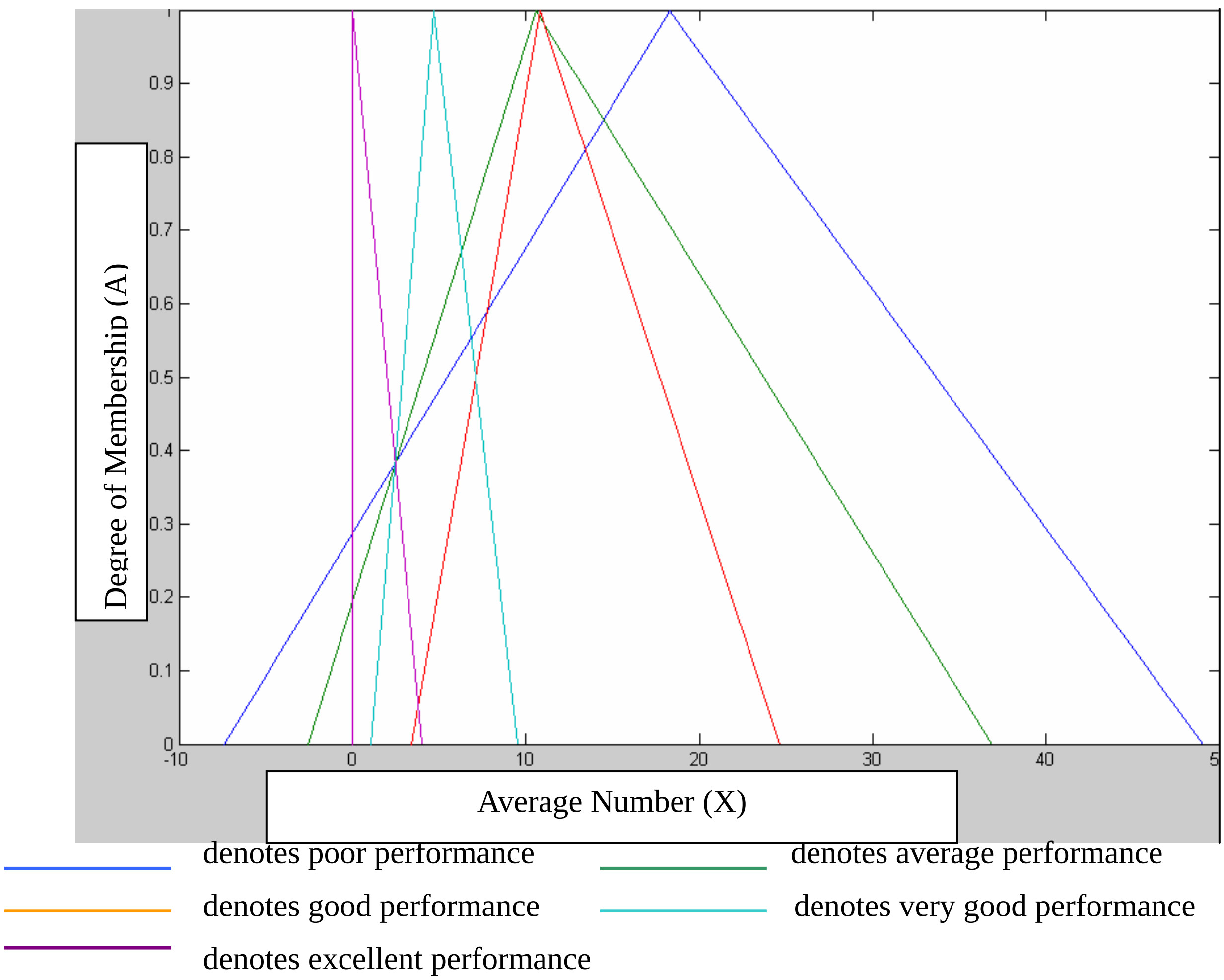


Figure 8.8 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Quality Performance (for Building Works) of Construction Partnering Projects in Hong Kong

8.3.5.6 Trust and Respect Performance

The membership functions of ‘very good’ and ‘excellent’ trust and respect performance are trapezoidal-shaped, whereas the membership functions of ‘poor’, ‘average’, and ‘good’ are triangular-shaped (Figure 8.9). The research findings indicate that the full memberships of the five different performance levels occur at 4, 5, 8, 8-8.88, and 9-9.92 as perceived key project stakeholders’ satisfaction scores on trust and respect performance by using a 10-point Likert scale. The lowest memberships of the five different performance levels are set at 0.84 and 7.07, 3.95 and 7.15, 4.92 and 8, 6.46 and 8.88, and 7.46 and 10. The results reveal that the Trust and Respect Performance of a partnering project would be regarded as ‘poor’ if the perceived key stakeholders’ satisfaction scores on trust and respect performance based on a 10-point Likert scale is smaller than 4.8 scores; ‘average’ if between 4.8 scores and no more than 6.2 scores; ‘good’ if between 6.2 scores and no more than 8 scores; ‘very good’ if between 8 scores and no more than 8.9 scores; and ‘excellent’ if equal to or greater than 8.9 scores.

8.3.5.7 Effective Communications Performance

Figure 8.10 shows that the full memberships of ‘poor’, ‘average’, ‘good’, ‘very good’, and ‘excellent’ effective communications performance of a partnering project are located at 5, 5, 8, 9, and 10. The lowest memberships of the five different performance levels occur at 1.11 and 6.33, at 4.42 and 6.98, at 5.97 and 8.57, at 3.80 and 9, and at 8.45 and 10. The results reflect that all the membership functions are triangular-shaped and the effective communications performance of a partnering project is regarded as ‘poor’ if the perceived key stakeholders’ satisfaction scores on effective communications performance according to a 10-point Likert scale is smaller than 5 scores; classified as ‘average’ if between 5 scores and no more than 6.5 scores; classified as ‘good’ if between 6.5 scores and no more than 8.3 scores; classified as ‘very good’ if between 8.3 scores and no more than 9 scores; and classified as ‘excellent’ if equal to or greater than 9 scores.

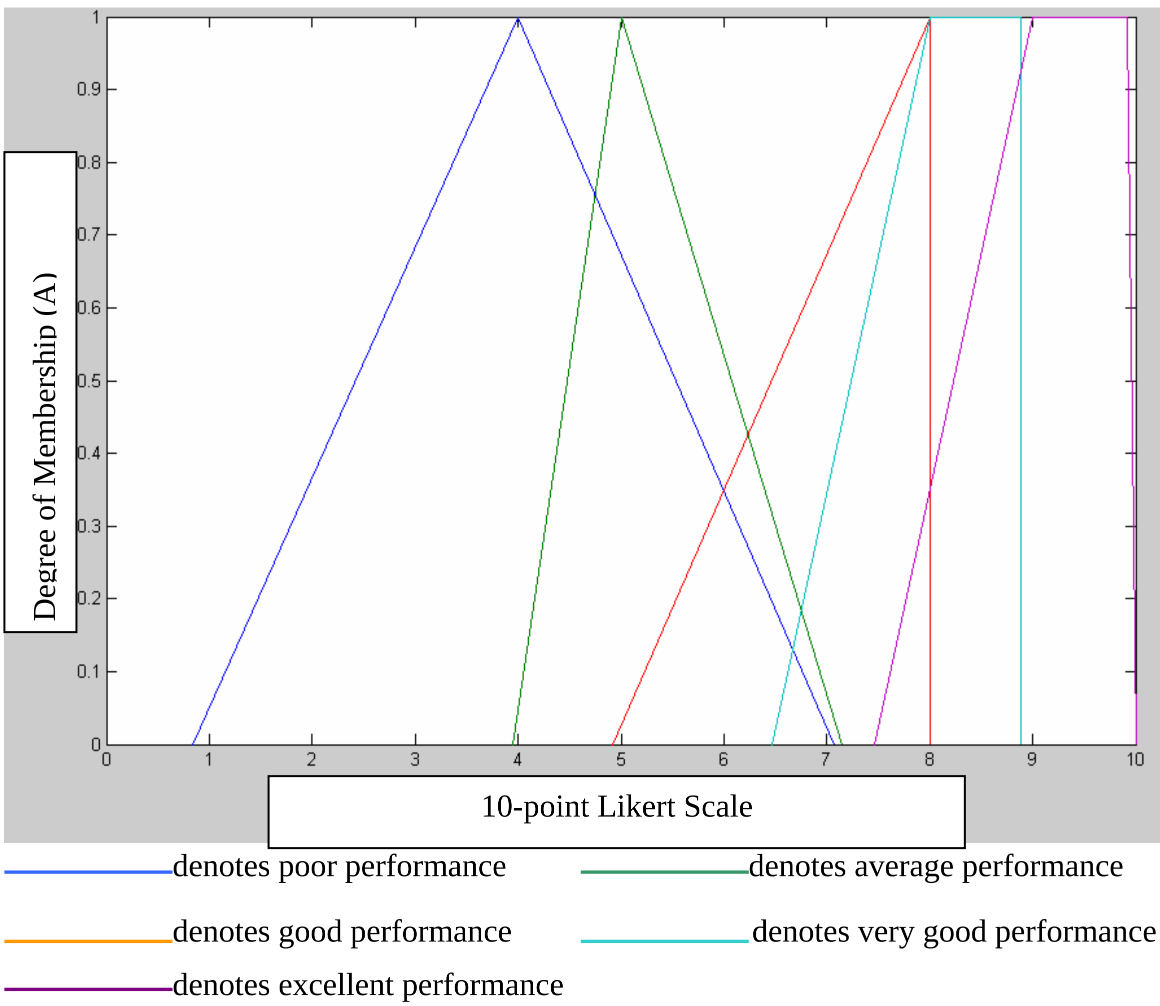
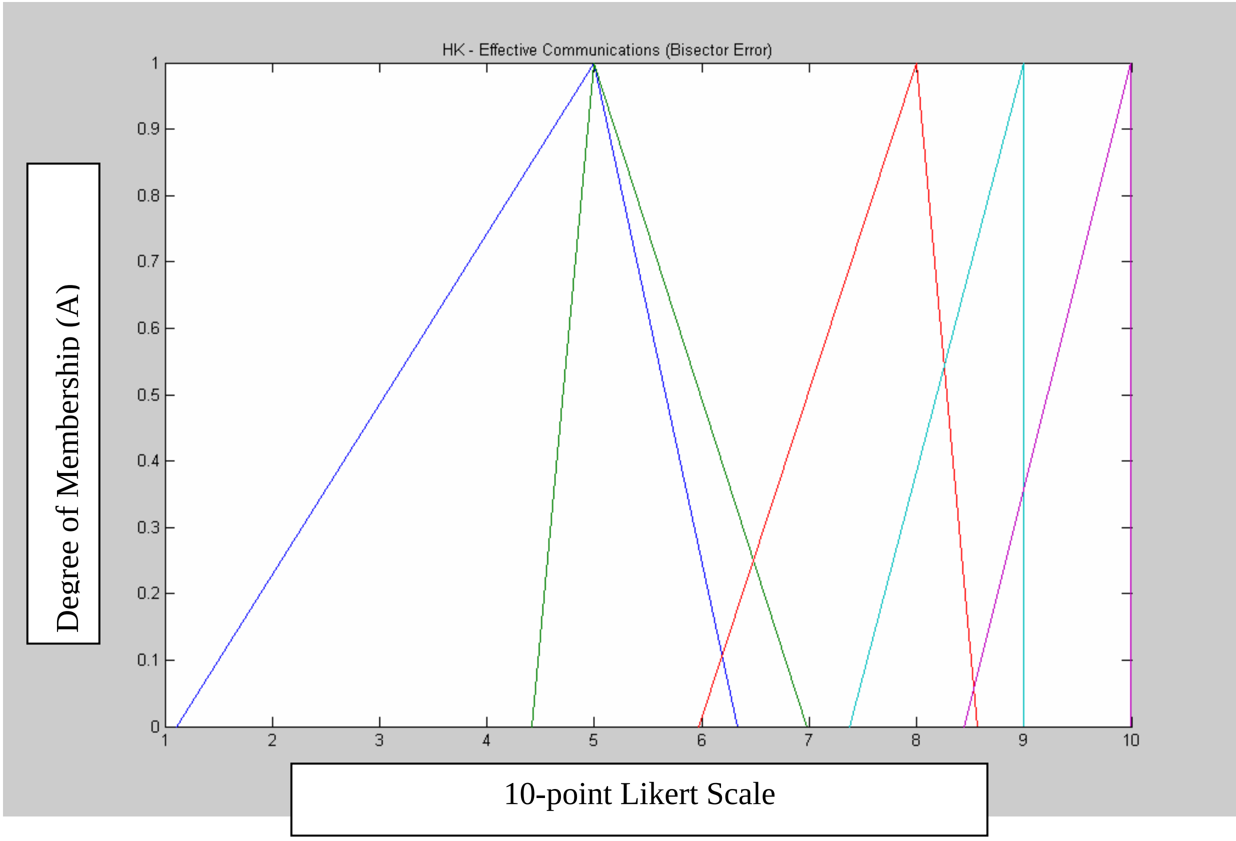


Figure 8.9 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Trust and Respect Performance of Construction Partnering Projects in Hong Kong



denotes poor performance

denotes average performance

denotes good performance

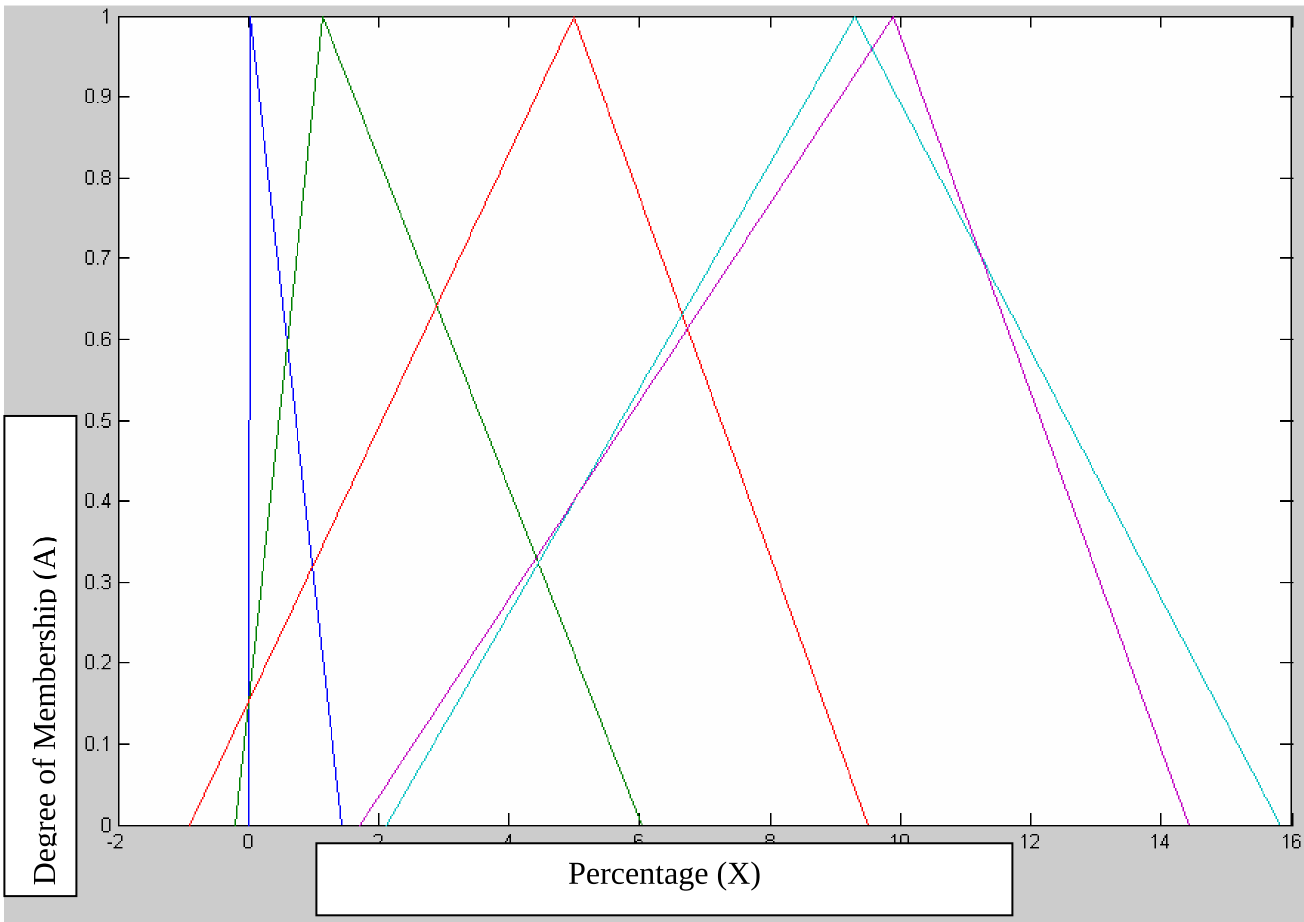
denotes very good performance

denotes excellent performance

Figure 8.10 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Effective Communications Performance of Construction Partnering Projects in Hong Kong

8.3.5.8 Innovation and Improvement Performance

Figure 8.11 depicts the fuzzy membership functions for ‘poor’, ‘average’, ‘good’, ‘very good’, and ‘excellent’ performance level of Innovation and Improvement Performance of a partnering project. They are all triangular shaped. The highest memberships for each level are at 0.02%, 1.14%, 5%, 9.3%, and 9.89%. The innovation and improvement performance of a partnering project would be classified as ‘poor’ if the cost saving resulted from innovation expressed as a percentage of total project cost is smaller than 0.6%; ‘average’ if between 0.6% and no more than 2.9%; ‘good’ if between 2.9% and no more than 6.7%; ‘very good’ if between 6.7% and no more than 9.6%; and ‘excellent’ if equal to or greater than 9.6%.



denotes poor performance

denotes average performance

denotes good performance

denotes very good performance

denotes excellent performance

Figure 8.11 Fuzzy Membership Functions and Fuzzy Quantitative Requirements for the Innovation and Improvement Performance of Construction Partnering Projects in Hong Kong

8.4 VERIFICATION AND VALIDATION OF THIS RESEARCH

Verification and validation is the final stage of each research cycle to test whether the quality of a developed system and model is good or not. In brief, verification is to examine whether a system follows its specification while validation is to determine whether the system was set up in a 'precise' manner (i.e. substantiating that a system correctly implements its specification) or whether an 'appropriate' system was developed (i.e. substantiating that a system performs with an acceptable level of accuracy (Preece, 1990; O'Keefe et al, 1987). In other words, verification is to test the completeness and accuracy of the sytem in fulfilling specifications of users while validation is to determine the adequacy of the system in meeting the needs of users (Gupta, 1991).

In general, three essential principles are used for evaluating a system, encompassing (1) what to evaluate; (2) how to evaluate; and (3) when to evaluate (Berry and Hart, 1990). Ng and Smith (1998) pointed out that 'what to evaluate' describes the components or aspects that are crucial to the evaluation; 'how to evalaute' is the method used for measuring the relevant components or aspects; 'when to evaluate' deals with the timing for verifying and validating components and aspects.

8.4.1 What to Evaluate

Verification involves the checking of consistency and completeness of the system while validation measures the accuracy, adequacy, usability, precision, etc of the system

(Botten et al, 1989). It should be pointed out that some researchers opined that accuracy and performance are the fundamental issues in validation (O'Keefe et al, 1987).

8.4.2 How to Evaluate

Verification is part of the larger process of information and data collection which aims to examine the mistakes during the process of transferring the opinions of field experts, and providing suitable correction and modification (Suwa et al, 1984).

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).

8.4.3 When to Evaluate

Verification is an ongoing process throughout the development period of an expert system (Botten et al, 1989). Validation should be conducted for intermediate and final results.

8.4.4 Verification and Validation throughout the Research Period

8.4.4.1 A List of KPIs for Partnering Projects

What to evaluate: In order to establish a performance evaluation model for partnering projects in Hong Kong, a comprehensive list of KPIs was first identified and utilized for the design of the first round of the first Delphi questionnaire survey to seek experts' opinions on the importance of each KPI. Therefore, the comprehensiveness of the identified list of KPIs was evaluated to ensure its adequacy to reflect the partnering performance of construction projects in all aspects.

How and when to evaluate: A set of KPIs was compiled through literature review and then validated by the Hong Kong Demonstration Projects using partnering approach. Six more KPIs, including (1) Long-term Business Relationship; (2) Client's Satisfaction; (3) Job Satisfaction; (4) Top Management Commitment; (5) Introduction of Partnering Workshop; and (6) Reduction of Rework, were added to the preliminary conceptual KPIs framework after validation. The compiled list was then used to produce the first round of the first Delphi questionnaire survey and all the Delphi experts were invited to validate the identified KPIs by adding additional ones in the questionnaire survey if deemed appropriate.

Evaluation result: Nearly all the Delphi experts with replies agreed that the compiled list of KPIs is comprehensive and adequate. Only 5 new KPIs which had not been identified from the literature were suggested by the panel of experts. They included: (1)

Method of Procurement and Time for Closing of Final Account; (2) Job Efficiency and Reliability; (3) Minimising Impact on Operations; (4) Commitment of Staff at Work Level; and (5) Good Public Relations.

8.4.4.2 The Seven Selected KPIs and Their Weightings

What to evaluate: For the sake of ensuring that the proposed performance evaluation model for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough, the seven selected KPIs together with their individual weightings are needed to be validated to ascertain that they are appropriate to mesasure the partnering performance of construction projects in Hong Kong.

How and when to evaluate: After carrying out statistical analysis on the first Delphi questionnaire survey, the seven KPIs were selected (based on a criterion that they were selected by at least 50% of Delphi experts) and their individual weightings were derived. The model was presented to a total of seven experts encompassing one senior project manager and three project managers from clients (one from quasi-government; two from private sector and one from infrastructure sector), one senior project manager and one project manager from contractors (both from private sector), and one consultant (from public sector) for verification and validation. They were selected for verifiying and validating the model because they have rich hands-on experience in procuring partnering projects in Hong Kong. Table 8.3 shows the details of interviewees. The interviewees were requested to examine the appropriateness of the seven selected KPIs together with their individual weightings to measure the partnering performance of construction projects in Hong Kong.

Table 8.3 Interviewees' Details for Validating the Performance Evaluation Model for Partnering Projects in Hong Kong

No.	Position	Organisation	Role	Sector
1	Project Manager	Swire Properties	Client	Private
2	Project Manager	Realty Cheng & Partners	Client	Private
3	Senior Architect	Hong Kong Housing Authority	Consultant	Public
4	Project Manager	Chevalier Construction	Main Contractor	Private
5	Project Manager	Hsin Chong Construction	Main Contractor	Private
6	Senior Project Manager	Hong Kong Polytechnic University	Client	Quasi-government
7	Project Manager	Mass Transit Railway Corporation Limited	Client	Infrastructure

Evaluation result: Although minor variation exists on the ranking of KPIs selected, most of the interviewees agreed that the seven selected KPIs and their individual weightings developed are appropriate to measure the partnering performance of construction projects in Hong Kong.

8.4.4.3 Quantiative Indicators and Questionnaire Survey

What to evaluate: With an aim to develop a quantitative evaluation platform, quantitative interpretations for each of the selected KPIs were sought through structured interviews with five experts in the field. The information collected was then consolidated to compile a draft list of QIs to represent each of the seven selected KPIs. The draft list of QIs was used to produce a design of questionnaire survey to seek experts' expectations in order to develop the QRs for each QI against different performance levels. The identified QIs should be validated to assure that it is adequate andd comprehensive without any misunderstandings and missing items during the interpretation of experts' opinions into corresponding QIs. The quality of questionnaire design should also be evaluated to ensure that all necessary data could be properly collected. After that, the most important QI for each KPI was selected by subsequently conducting two rounds of the second Delphi survey with the same group of Delphi experts.

How and when to evaluate: In order to confirm the opinions of experts which were properly translated into the QIs, the interview dialogues were sent back to the five interviewees who provided opinions on the quantitative interpretations for verification. The compiled list of QIs was then sent to the Delphi experts to seek their opinions on the appropriateness of each QI in terms of importance, measurability and obtainability. The most important QI for each KPI was selected after subsequently conducting two rounds of Delphi questionnaire survey.

Evaluation result: All the five interviewees concurred that the interpretation is appropriate and most of the seven interviewees selected for validating the model agreed that the QIs selected are objective, reliable and practical to measure the seven weighted KPIs. However, some interviewees stated that the QI 'Average Number of

Non-conformance Report Generated Per Month' should be clearly defined, and it is not good enough to measure the Quality Performance and they suggested using 'Degree of Major/Minor Reworks'; 'Educated Users' Satisfaction'; 'Cost of Rework Expressed as a Percentage of Total Contract Sum' to measure it.

8.4.4.4 Fuzzy Membership Functions and Quantiative Requirements

What to evaluate: The data collected through the questionnaire survey was modelled by Fuzzy Set Theory to develop fuzzy membership functions for each QI. A set of QRs pertinent to each QI against five different performance levels was then established. The fundamental issue of validation is to examine whether the fuzzy QRs could reduce the subjectivity of evaluation. In addition, the developed QRs should be validated to ensure that it is practical to use them to evaluate the partnering performance of each aspect.

How and when to evaluate: The author first briefly explained the reasons for developing fuzzy QRs in the performance evaluation model for patnering projects in Hong Kong. Then, the seven interviewees were asked to examine whether the fuzzy QRs could effectively eliminate the subjectivity of evaluation and is practical enough to meaure the partnering performance of construction projects in Hong Kong.

Evaluation result: All the interviewees agreed that objective judgement is difficult and the establishment of well-defined fuzzy QRs is an appropriate and innovative mitigation measure to tackle the deficiency. Most of them opined that it is practical to use the fuzzy QRs to measure the partnering performance of construction proejcts in Hong Kong although some of them had reservation on the practicality of fuzzy evaluation framework.

Table 8.4 Mean Ratings of the Validation Aspects

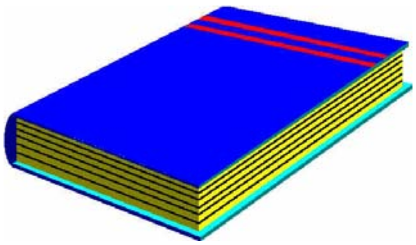
	Experts							
Validation Aspects	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mean Ratings**
Degree of appropriateness	4	4	4	4	4	3	3	3.71
Degree of objectivity	4	4	4	4	4	4	4	4.00
Degree of replicability	4	5	4	4	4	4	3	4.00
Degree of practicality	3	5	4	4	4	3	4	3.86
Overall reliability	4	5	4	3	3	3	cannot judge	3.67
Overall suitability to be adopted to measure the partnering performance of construction projects in Hong Kong	4	4	4	3	3	2.5	4	3.50

Notes: 1 = poor; 3 = average; 5 = excellent

The seven experts were also asked to complete a validation scoring sheet according to a 5-point Likert scale. Table 8.4 shows the mean ratings of each validation aspect. All the validation items were highly rated (at least 3.5) and the results of validation have confirmed that the model could improve the comprehensiveness, objectivity, reliability and practicality when a partnering project is evaluated.

8.5 CHAPTER SUMMARY

This chapter has applied a Fuzzy Set Theory approach to establish well-defined quantitative ranges/requirements (QRs) for each Quantitative Indicator (QI) with each of the five performance levels that are used to classify different levels of achievement and these five levels are 'poor', 'average', 'good', 'very good' and 'excellent'. The 'modified horizontal approach' with the Bisector Error Method was adopted to develop the fuzzy membership functions of each QI from all the data collected. The Quantitative Requirements (QRs) of each performance level are defined by the intersecting points of the best-fit lines between two consecutive performance levels of the fuzzy membership functions. Since the intersection points represent a same degree of membership for both performance levels, it is logical to choose these intersecting points to identify the QRs of each QI for the five different performance levels. With the development of a reliable set of QRs, assessors could perform their evaluation based on the established fuzzy ranges rather than applying their subjective value judgment. Consequently, assessors could determine which performance levels should be assigned in accordance with the actual performance of a partnering project. It should be pointed out that the results derived from this Chapter are similar for the three methods. However, it is theoretically better to use the Bisector Error Method to establish the Fuzzy membership functions because it considers both the errors created by the residual sum of squares by vertical and horizontal distances. It is concluded that this performance evaluation model for partnering projects is not only innovative in nature but it can also greatly improve the objectiveness, reliability and practicality when a partnering project is assessed.



CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 INTRODUCTION

Plenty of research studies into benefits, critical success factors, difficulties, process, conceptual and theoretical models of partnering have been undertaken within the construction management discipline over the last decade. However, few, if not none, comprehensive and systematic research studies on developing a comprehensive, objective, reliable and practical performance evaluation model for partnering projects. Therefore, it is difficult for construction senior executives and project managers to evaluate the performance level of their individual partnering projects objectively.

The aim of this research study was to develop a comprehensive, objective, reliable and practical performance evaluation model for partnering projects. To develop this model, six research objectives were identified, which included (1) defining and comparing the definitions of construction partnering and alliancing; (2) comprehensively reviewing 'Fuzzy' research in construction management; (3) developing a conceptual framework for identifying Key Performance Indicators (KPIs) for measuring the partnering performance of construction projects; (4) developing a Partnering Performance Index

(PPI) for construction projects in Hong Kong; (5) establishing appropriate Quantitative Indicators (QIs) for measuring the partnering performance of construction projects in Hong Kong; and (6) establishing the Fuzzy Quantitative Requirements (FQRs) for each QI.

9.2. REVIEW OF RESEARCH OBJECTIVES

9.2.1 Comparing the Definitions of Construction Partnering and Alliancing

A comprehensive literature review was carried out to define and compare the definitions of construction partnering and alliancing. By using the content analysis method, this research study makes a significant contribution to defining and distinguishing the concepts of construction partnering and alliancing by using a Sunflower Model based on the German philosopher Ludwig Wittgenstein's family-resemblance philosophy. Based on the reported literature, it is concluded that all 'family elements' of the two management techniques are similar. It is indicated that both 'trust' and 'long-term commitment' are common core soft (relationship-based) elements between partnering and alliancing. The main difference is that partnering relies on a 'partnering charter' which has no legal and contractual binding force while alliancing involves the constitution of a 'formal contract', with a 'real gain-share and pain-share arrangement' principle attained by a 'joint' rather than 'shared' commitment. Parties under an alliancing arrangement have to agree their contribution and profit levels beforehand and then place these levels at risk.

9.2.2 Reviewing 'Fuzzy' Research in Construction Management

A comprehensive review of literature on 'Fuzzy Theories' was launched in eight high-quality rating journals over the last decade. It has been found that 'Fuzzy' research, as applied in construction management in the past decade, can be divided into three broad fields, encompassing (1) Fuzzy Set Theory (FST); (2) Fuzzy Logic Theory (FLT); and (3) Other Fuzzy Techniques, with the applications in five main categories, including (1) Performance; (2) Evaluation/Assessment; (3) Modelling; (4) Decision-making; and (5) Others.

9.2.3 Developing a Conceptual Framework for Identifying Key Performance Indicators (KPIs) for Measuring the Partnering Performance of Construction Projects

Based on a comprehensive literature review on performance measures to evaluate the partnering performance of construction projects, a preliminary conceptual framework for identifying KPIs for construction partnering projects has been developed. To verify the applicability of this preliminary framework, in-depth study of 17 Demonstration Projects using partnering approach was conducted. A consolidated conceptual framework encompassing 25 performance measures has been developed, and they are classified into 4 categories.

After developing the conceptual framework for identifying KPIs for construction partnering projects, a benchmark for measuring the performance of partnering projects can be set. As a result, construction senior executives and project managers can adopt it to measure, monitor and upgrade the performance of their individual partnering projects.

9.2.4 Developing a Partnering Performance Index (PPI) for Construction Projects in Hong Kong

Having established a consolidated conceptual framework for identifying KPIs for partnering projects, a Delphi technique was used to formulate a comprehensive, objective, reliable and practical performance evaluation model for partnering projects in Hong Kong. Four rounds of Delphi questionnaire survey were conducted with 31 construction experts in Hong Kong. The results reveal that the seven selected most important weighted KPIs to evaluate the success of partnering projects in Hong Kong were: (1) Time Performance, with the weighting of 0.167; (2) Cost Performance, with the weighting of 0.160; (3) Top Management Commitment, with the weighting of 0.150; (4) Quality Performance (both for Civil and Building Works), with the weighting of 0.143; (5) Trust and Respect, with the weighting of 0.143; (6) Effective Communications, with the weighting of 0.131; and (7) Innovation and Improvement, with the weighting of 0.106. By doing so, a unique Partnering Performance Index (PPI) for partnering projects in Hong Kong was finally derived. Construction senior executives and project managers can thus use the index to measure, evaluate and improve the existing performance of their partnering projects.

9.2.5 Establishing Appropriate Quantitative Indicators (QIs) for Measuring the Partnering Performance of Construction Projects in Hong Kong

The PPI developed in Chapter 6 can assist in developing a benchmark for measuring the performance of partnering projects. However, it is worth noting that assessors may have their own semantic interpretation on each KPI. Chapter 7 established suitable quantitative interpretations/indicators (QIs) for each KPI in order to eradicate any discrepancies in interpreting the meaning of each KPI and provide objective evaluation result based on quantitative evidence. By means of five structured face-to-face interviews and two rounds of Delphi questionnaire survey in Hong Kong, a set of QIs that best represented the KPIs were found to be: (1) 'Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time', with the mean rating of 4.53 (for measuring Time Performance); (2) 'Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost', with the mean rating of 4.45 (for measuring Cost Performance); (3) 'Percentage of Top Management Attendance in Partnering Meetings', with the mean rating of 4.51 (for measuring Top Management Commitment); (4) 'Average Number of Non-conformance Reports Generated Per Month' (for Measuring Civil Works and Building Works), with the mean rating of 4.10 (for measuring Quality Performance); (5) 'Perceived Key Stakeholders' Satisfaction Scores on Trust and Respect Performance by Using a 10-point Likert Scale', with the mean rating of 3.77 (for measuring Trust and Respect Performance); (6) 'Perceived Key Stakeholders' Satisfaction Scores on Effective Communications Performance by Using a 10-point Likert Scale', with the mean rating of 3.51 (for measuring Effective Communications Performance); and (7) 'Cost Saving Resulted from Innovation

Expressed as a Percentage of Total Project Cost’, with the mean rating of 3.85 (for measuring Innovation and Improvement Performance).

By incorporating these quantitative indicators into the evaluation process, different assessors could execute their evaluation process based on quantitative evidences. Different partnering projects can then be evaluated and compared on an objective basis with reference to this set of QIs.

9.2.6 Establishing the Fuzzy Quantitative Requirements (FQRs) for each QI

The QIs established in Chapter 7 can further help generate a benchmark for measuring the partnering performance of construction projects. However, the establishment of a series of QIs cannot fully deal with the subjectivity of performance evaluation. In order to remedy this deficiency, Chapter 8 applied a Fuzzy Set Theory approach to establish a well-defined range of Quantitative Requirements (QRs), namely, ‘poor’, ‘average’, ‘good’, ‘very good’ and ‘excellent’ performance levels for each QI. By using the modified horizontal approach, Fuzzy Membership Functions (FMFs) have been constructed through constrained regression line with the Vertical Error Method, the Horizontal Error Method, and the Bisector Error Method. It was reflected that the results for the three various methods were similar, but the Bisector Error Method is taken as superior to the other two methods because it considers both the errors created by the Vertical Error Method and the Horizontal Error Method, so it was finally selected to establish the Fuzzy membership functions and calculate the fuzzy QRs in this research study. The proposed performance evaluation model is not only innovative in nature but it can also improve the objectiveness, reliability and practicality of performance evaluation for partnering projects.

9.3 VALUE AND SIGNIFICANE OF THE RESEARCH

This research study has made two significant contributions to the research area of construction partnering. The first one was to define and distinguish the concepts of construction partnering and alliancing by using a Sunflower Model based on the German philosopher Ludwig Wittgenstein's family-resemblance philosophy. By using this innovative theoretical framework to define construction partnering and alliancing, industrial practitioners may find the Sunflower Model useful in the procurement of a construction project. The Sunflower Model can be applied to explain the underlying concepts and as a common platform for discussions between a client and a contractor on how to procure a partnering or alliancing project, thus mitigating any disparties on what a partnering or alliancing project is.

The second major contribution was to develop a comprehensive, objective, reliable and practical performance evaluation model by using Delphi survey and Fuzzy Set Theory. The development of a conceptual framework for identifying KPIs for construction partnering projects provides an objective basis for measuring the partnering performance of construction projects. The development of a PPI not only enhances the understanding of clients, contractors and consultants in implementing a successful partnering project, but it also forms a solid base for industrial practitioners to measure, evaluate and improve the current performance of their partnering projects. In addition, the PPI assists in formulating a benchmark for measuring the performance of partnering projects. The establishment of QIs and fuzzy QRs could eliminate subjective interpretation and value judgement, and therefore uplift the reliability, objectiveness and practicality of the performance evaluation model. A computerized system for compiling the PPI of partnering projects has also been developed for benchmarking and monitoring purposes in Hong Kong recently (http://yeungw.rdcw.com/demo/ppi/login_admin.php). Project team members can just input their individual project information and data and the computerized system can directly provide a PPI to compare their project performances with other counterparts.

The PPI not only provides better understanding of clients, contractors and consultants in running a successful partnering project, but also helps set a benchmark for measuring the partnering performance of their construction projects. Both the clients and contractors should use the model for monitoring purposes when the partnering-based project is implemented at the very early beginning of the construction phase. And the results should be used to compare the partnering performance of a project with its counterparts for benchmarking purposes.

9.4 LIMITATIONS OF THE STUDY

Since partnering is only one kind of relational contracts, it would be better to include alliancing projects and relationship contracting projects in this research study as well.

However, owing to the constraints of time and resources, the performance evaluation model developed is primarily applicable to partnering projects.

In addition, the composition of key project stakholders involved in the Delphi surveys did not demonstrate an even distribution in the way that most of the experts came from client organizations. Therefore, it would be more representative if more contractors and consultants were added to the list of experts. Furthermore, partnering applications in other industries, such as manufacturing, retailing, aviation and service should also be reviewed should time allow because these industries have achieved maturity in the use of partnering and alliancing and the massive literature review on these areas can provide a broader view on partnering and alliancing.

Furthermore, it is likely that the variability of project nature could affect the applicability of PPI. For instance, a particular range of cost savings may be appropriate to assess one project type but less appropriate for another. Therefore, it is important to note that project and environmental specifics at the time may have significant effect on the adopted ranges of QIs. For example, the effect of different project sizes, such as small, medium-sized and large partnering projects; as well as different project natures, such as private, public and infrastructure sector partnering projects, may have an impact on the success of the project. Therefore, the performance evaluation model developed in this study should be taken as a prototype and the same research methodologies should be replicated to develop similar performance evaluation models in the future for comparisons. By doing so, different performance evaluation models, such as private, public and infrastructure sector partnering projects can be developed and compared to identify their similarities and differences.

9.5 RECOMMENDATIONS FOR FUTURE RESEARCH

This research study focuses on developing a comprehensive, objective, reliable and practical performance evaluation model for partnering projects in Hong Kong. Since the model was developed locally in Hong Kong, further research should be conducted in other geographical locations such as the USA, UK and Australia to seek their similarities and differences by adopting the same research methodology. In addition, the performance evaluation model developed is primarily applicable to partnering projects. Other similar performance evaluation models for alliancing projects and relationship contracting projects in general are recommended to be launched in order to compare and contrast the similarities and differences of KPIs, QIs, and FQRs between various categories of projects. The same research methodologies can also be applied to other types of projects, such as Public Private Partnerships (PPPs) projects.

Appendix 1
Round 1 of the First Delphi Survey

Appendix 1

Round One Delphi Survey

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A Survey of Developing a Series of Key Performance Indicators (KPIs) to Evaluate the Success of a Partnering Project

Guidance on completion

Thank you very much for participating in this research survey by making the best use of your expertise in providing valuable opinions on identifying Key Performance indicators (KPIs) to evaluate the success of a partnering project. Below are the 25 KPIs identified from previous research studies, and you are encouraged to insert additional attributes in the last row if deemed appropriate. **Please select a minimum of 5 but a maximum of 10 Key Performance Indicators (KPIs) by giving ticks in the appropriate spaces, which you believe are the most vital KPIs to evaluate the success of a partnering project.** Before completing this questionnaire, the following note on Key Performance Indicators (KPIs) may act as a useful reference.

Note:

Key Performance Indicators (KPIs)

The purpose of the Key Performance Indicators (KPIs) is to enable measurement of project and organisational performance through the construction industry. This information can then be used for benchmarking purposes, and will be a key component of any organisation's move towards achieving best practice (The KPI Working Group, 2000). Collin (2002) advocates that the process of developing KPIs involved the consideration of eight factors. Five of them are listed as follows:

1. KPIs are general indicators of performance that focus on critical aspects of outputs or outcomes;
2. Only a limited, manageable number of KPIs is maintainable for regular use;
3. The systematic use of KPIs is essential as the value of KPIs is almost completely derived from their consistent use over a number of projects;
4. Data collection must be made as simple as possible;
5. A large sample size is required to reduce the impact on project specific variables. Therefore, KPIs should be designed to be used on every project.

References

Collin, J (2002) Measuring the success of building projects – Improved project delivery initiatives, Queensland Department of Public Works, Australia.

The KPI Working Group (2000) KPI Report for the Minister for Construction. Department of the Environment, Transport and the Regions, London.

Round One Delphi Survey (Please select a minimum of 5 but a maximum of 10 KPIs by giving ticks in the appropriate spaces)

Name of Respondent: ____________________________ Position in your organisation: ______________________________

Key Performance Indicators (KPIs) for partnering projects	Your options
1. Time performance Referring to the time variation of a project, such as ahead of schedule, on schedule, or behind schedule	
2. Cost performance Referring to the total cost of a project, such as within budget, on budget or over budget	
3. Profit and financial objectives Referring to the profitability of a project, such as high profit, break even or serious loss	
4. Quality performance Referring to the quality of a project, such as high quality, average quality, or low quality	
5. Scope of rework Referring to the scale of rework of a project, such as very few rework, average rework, or many rework	
6. Productivity Referring to the amount of resource input to complete a given task	
7. Harmonious working relationships Referring to developing harmonious working relationships amongst all project stakeholders at all levels	
8. Long-term business relationships Referring to building up long-term business relationships with other contracting parties involved in a project	
9. Trust and respect Referring to level of trustfulness and respectfulness amongst different project stakeholders	
10. Litigation occurrence and magnitude Referring to litigation numbers and amounts of a project	
11. Dispute occurrence and magnitude Referring to dispute numbers and amounts of a project	
12. Claim occurrence and magnitude Referring to claim numbers and amounts of a project	
13. Effective communications Referring to level of effective cooperation, communication, and teamwork at all levels	
14. Reduction of paperwork Referring to level of paperwork reduction of a project, such as high level of paperwork reduction or low level of paperwork reduction	
15. Safety performance Referring to accident rate of a project, such as low accident rate, average, or high accident rate	
16. Environmental issues Referring to number of complaints received caused by environmental problems of a project	
17. Pollution occurrence Referring to number of pollution occurrences of a project	
18. Professional image establishment Referring to the degree of pride and reputation of each contracting party enhanced by the successful completion of a project	
19. Client's satisfaction Referring to level of satisfaction for the client organization on participating a project	
20. Customer's satisfaction Referring to level of satisfaction for the end-users on a project	
21. Job satisfaction Referring to level of individual job satisfaction and career development opportunities	
22. Employee's attitude Referring to employee's attitude towards the implementation of partnering approach of a project	
23. Innovation and improvement Referring to number of new initiatives for improvement introduced (e.g. construction techniques, procurement) in a project	
24. Introduction of partnering workshop Referring to whether a project uses a structured or unstructured approach towards implementing partnering	
25. Top management commitment Referring to level of senior management commitment on supporting partnering approach	
26. Others (Please specify)	

Appendix 2
Round 2 of the First Delphi Survey

Appendix 2

Round Two Delphi Survey

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A Survey of Developing a Series of Key Performance Indicators (KPIs) to Evaluate the Success of a Partnering Project

FORM COMPLETION GUIDANCE

Below are the results of Round 1 of the above study. The average percentage score of all experts is given in column (1). Your Round 1 option selections are given in column (2).

It is of interest to the research study to learn whether, with further thought, you would make any changes to your round 1 option selections. Hence I would be most grateful if you would **again select a minimum of 5 but a maximum of 10 Key Performance Indicators (KPIs)** which you believe are the most vital to evaluate the success of a partnering project.

Round Two Delphi Survey

Name of Respondent: ________________________ Position in your organisation: _____________________________

Key Performance Indicators (KPIs) for partnering projects	% of experts in the Round One	Your options in the Round One	Your options in the Round Two
1. Time performance	90.32		
2. Cost performance	87.10		
3. Quality performance	83.87		
4. Trust and respect	64.52		
5. Effective communications	64.52		
6. Harmonious working relationships	51.61		
7. Top management commitment	51.61		
8. Innovation and improvement	48.39		
9. Client's satisfaction	41.94		
10. Safety performance	32.26		
11. Profit and financial objectives	29.03		
12. Dispute occurrence and magnitude	29.03		
13. Customer's satisfaction	25.81		
14. Productivity	25.81		
15. Scope of rework	22.58		
16. Long-term business relationships	22.58		
17. Reduction of paperwork	22.58		
18. Environmental performance	19.35		
19. Claim occurrence and magnitude	16.13		
20. Introduction of partnering workshop	16.13		
21. Employee's attitude	16.13		
22. Professional image establishment	12.90		
23. Litigation occurrence and magnitude	6.45		
24. Job satisfaction	6.45		
25. Good public relations	6.45		
26. Method of procurement & timing for closing of final account	3.23		
27. Job efficiency and reliability	3.23		
28. Minimising impact on operations	3.23		
29. Commitment of staff at work level	3.23		
30. Pollution occurrence	0.00		

Appendix 3
Round 3 of the First Delphi Survey

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Round Three Delphi Survey

A Survey of Developing a Series of Key Performance Indicators (KPIs) to Evaluate the Success of a Partnering Project

FORM COMPLETION GUIDANCE

Below are the results of Round 2 of the above study. The average percentage score of all experts is given in column (2).

It is of interest to this Round Three Delphi Survey to study **how you give ratings on the seven selected Key Performance Indicators (KPIs) based, this time, on the 5-point Likert scale** to evaluate the success of partnering projects.

Round Three Delphi Survey
(Please give ratings for each of the top-7 KPIs from 1 = least important, 2 = slightly important, 3 = important, 4 = very important, to 5 = most important)

Name of Respondent: ___________________ Position in your organisation: ____________________________________

Key Performance Indicators (KPIs) for partnering projects	% of experts in the Round Two	Your ratings in the Round Three (from 1 = least important to 5 = most important)
1. Time performance	96.67	
2. Cost performance	93.33	
3. Quality performance	90.00	
4. Trust and respect	76.67	
5. Top management commitment	63.33	
6. Effective communications	60.00	
7. Innovation and improvement	53.33	
8. Harmonious working relationships	46.67	
9. Client's satisfaction	43.33	
10. Safety performance	33.33	
11. Profit and financial objectives	23.33	
12. Dispute occurrence and magnitude	23.33	
13. Productivity	20.00	
14. Customer's satisfaction	20.00	
15. Scope of rework	16.67	
16. Long-term business relationships	16.67	
17. Reduction of paperwork	16.67	
18. Environmental performance	13.33	
19. Claim occurrence and magnitude	13.33	
20. Good public relations	6.67	
21. Introduction of partnering workshop	6.67	
22. Method of procurement & Timing for closing of Final Account	3.33	
23. Employee's attitude	3.33	
24. Professional image establishment	3.33	
25. Job satisfaction	3.33	
26. Job efficiency and reliability	3.33	
27. Minimising impact on operations	3.33	
28. Litigation occurrence and magnitude	0.00	
29. Commitment of staff at work level	0.00	
30. Pollution occurrence	0.00	

Appendix 4
Round 4 of the First Delphi Survey

Appendix 4

Round Four Delphi Survey

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A Survey of Developing a Series of Key Performance Indicators (KPIs) to Evaluate the Success of a Partnering Project

FORM COMPLETION GUIDANCE

Below are the results of Round 3 of the above study. The average ratings of all experts are given in column (2). Your Round 3 ratings are given in column (3).

It is of interest to the research study to learn whether, with further thought, you would make any changes to your round 3 ratings. Hence I would be most grateful if you would **again give ratings on the top-7 Key Performance Indicators (KPIs) based on the 5-point Likert scale** to evaluate the success of partnering projects.

Round Four Delphi Survey

Name of Respondent: ____________________ Position in your organisation: ____________________

(Please give ratings from 1 = least important, 2 = slightly important, 3 =important, 4 = very important, and 5 = most important)

Key Performance Indicators (KPIs) for partnering projects	Average ratings of experts in the Round Three	Your ratings in the Round Three	Your ratings in the Round Four
1. Time performance	4.48		
2. Cost performance	4.32		
3. Top management commitment	3.97		
4. Quality performance	3.94		
5. Trust and respect	3.81		
6. Effective communications	3.52		
7. Innovation and improvement	2.81		

Appendix 5
Interview Dialogues for Developing QIs Model for KPIs to Evaluate the Success of Partnering Projects

Appendix 5

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Interview Questions for Developing Quantitative Indicators' (QIs) Model for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

The objective of this interview is to identify Quantitative Indicators (QIs) appropriate to each of the top-7 weighted Key Performance Indicators (KPIs) for partnering projects identified from the previous 4 rounds of Delphi questionnaires. Please note that the QIs to be identified must be vital, easy to measure and obtain so that a practical model can be finally derived.

Interviewee: Interviewee A Position: Senior Project Manager

Interviewer: John Yeung Time and Date: 2:30pm – 3:45pm 23/03/2006

Venue: Meeting Room, Hong Kong Land Ltd Record taken by: John Yeung

1. Please identify two most important QIs to evaluate the Time Performance of partnering projects.

QI 1: Percentage of meeting milestone dates of a project by a main contractor.

Example: If there are 4 milestone dates of a project and 3 of them are met by a main contractor, the project is calculated to meet 75% of the milestone dates. $\frac{3}{4} \times 100\%$

Comment: This QI is vital, easy to measure and not difficult to obtain.

QI 2: Variation of project completion time against programme expressed as a percentage of project completion time.

Example: If a project is expected to be completed at 5 years (1,826 days) and its actual completion time is 1,828 days, the project is calculated to be behind schedule by 0.11%. $\frac{(1{,}828 days - 1{,}826 days)}{1{,}828 days} \times 100\%$

Comment: This QI is vital, and easy to measure and obtain.

The interviewee A implied, but not directly identified "Subjective assessment by using Likert scale (say ahead of schedule, on time or behind schedule" as an important QI to measure the Time Performance.

2. Please identify two most important QIs to evaluate the Cost Performance of partnering projects.

   It is extremely difficult to measure Cost Performance objectively and accurately because it is very difficult to get the tender cost (the starting base) of a project.

   Subjective assessment by using Likert scale is suggested, say, within budget, on budget, and overrun budget.

3. Please identify two most important QIs to evaluate Top Management Commitment of partnering projects.

   QI: Percentage of Partnering Steering/Progress Monitoring Meetings attended by Project Director.

   Project Director is defined as the most senior executive/his representative in a company responsible for managing the project.

   Example: If there are 24 partnering steering/progress monitoring meetings in a project and the project director attends 12 of them, it is calculated that a project director attends 50% of all the partnering steering/progress monitoring meetings in the project. $\frac{12}{24}\times 100\%$

   Comment: This QI is vital, and easy to measure and obtain.

4. Please identify two most important QIs to evaluate the Quality Performance of partnering projects.

   QI: Number of complaints received by customers. (Complaints can be classified into different items, such as window, bathroom, and internal wall. In addition, buildings should be divided into 2 types: residential or commercial.)

   Comment: This QI is vital, and not difficult to measure and obtain.

5. Please identify two most important QIs to evaluate Trust and Respect of partnering projects.

   QI 1: Speed of resolving variations.

   QI 2: Speed of settling EOT claims.

   Composite satisfaction scores of key stakeholders by using Likert scale.

6. Please identify two most important QIs to evaluate Effective Communications of partnering projects.

   Composite satisfaction scores of key stakeholders by using Likert scale.

7. Please identify two most important QIs to evaluate Innovation and Improvement of partnering projects.

   Number of new initiatives for improvement introduced (construction techniques, procurement).

   Comment: This QI is vital, and easy to measure and obtain.

Thank you very much for your contributions to our research study. Your opinions will, of course, be kept confidential and we will be happy to send you a copy of the consolidated results.

- End -

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Interview Questions for Developing Quantitative Indicators' (QIs) Model for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

The objective of this interview is to identify Quantitative Indicators (QIs) appropriate to each of the top-7 weighted Key Performance Indicators (KPIs) for partnering projects identified from the previous 4 rounds of Delphi questionnaires. Please note that the QIs to be identified must be vital, easy to measure and obtain so that a practical model can be finally derived.

Interviewee: Interviewee B Position: Managing Director

Interviewer: John Yeung Time and Date: 10:45am – 11:45am 21/03/2006

Venue: USRC, Jordan Record taken by: John Yeung

1. Please identify two most important QIs to evaluate the Time Performance of partnering projects.

QI 1a: Overall Time Predictability: Measuring how closely a project is delivered to the original time table.

Example: If a project is completed at 1,828 days and the predicted completion time is 1,826 days, the project is calculated to be behind schedule by 0.11%.

$$\frac{(1{,}828days - 1{,}826days)}{1{,}826days} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 1b: Time Predictability for Design: Measuring change between actual design time and predicted design time, expressed as a percentage of the estimated design time.

Example: If the actual design time of a project is 300 days and the predicted design time is 270 days, the project is calculated to be behind schedule by 11.11% of original design time.

$$\frac{(300days - 270days)}{270days} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 1c: Time Predictability for Construction: Measuring change between actual construction time and predicted construction time, expressed as a percentage of the estimated construction time.

Example: If the actual construction time of a project is 300 days and the predicted construction time is 270 days, the project is calculated to be behind schedule by 11.11% of original construction time.

$$\frac{(300days - 270days)}{270days} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Time Improvement: Measuring how much time improvement of a project is delivered to the previous projects.

Example: If a project is completed at 1,500 days and the previous projects are completed at 1,550 days on average, the project is calculated to require shorter completion time by 3.23% of the average time of previous projects.

$$\frac{(1{,}500days - 1{,}550days)}{1{,}550days} \times 100\%$$

Comment: This QI is vital, and not difficult to measure and obtain.

The interviewee B implied, but not directly identified "Subjective assessment by using Likert scale (say ahead of schedule, on time or behind schedule" as an important QI to measure the Time Performance.

2. Please identify two most important QIs to evaluate the Cost Performance of partnering projects.

QI 2a: Overall Cost Predictability: Measuring how closely a project is delivered to the original budget.

Example: If a project is completed at 1.5 billion and the predicted completion budget is 1.6 billion, the project is calculated to be underrun budget by 6.25%.

$$\frac{(1.5billion - 1.6billion)}{1.6billion} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 2b: Cost Predictability for Design: Measuring change between actual design cost and predicted design budget, expressed as a percentage of the estimated design budget.

Example: If the actual design cost of a project is 1 billion and the predicted design cost is 1.1 billion, the project is calculated to be underrun budget by 9.09% of the original design cost.

$$\frac{(1billion - 1.1billion)}{1.1billion} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 2c: Cost Predictability for Construction: Measuring change between actual construction cost and predicted construction cost, expressed as a percentage of the estimated construction cost.

Example: If the actual construction cost of a project is 1 billion and the predicted construction cost is 1.1 billion, the project is calculated to be underrun budget by 9.09% of the original construction cost.

$$\frac{(1billion - 1.1billion)}{1.1billion} \times 100\%$$

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Cost Improvement: Measuring how much cost improvement of a project is delivered to the previous projects.

Example: If a project is completed at 1 billion and the previous projects have been completed at 1.1 billion on average, the project is calculated to cost less by 9.09% of the average cost of previous projects.

$$\frac{(1billion - 1.1billion)}{1.1billion} \times 100\%$$

Comment: This QI is vital, and not difficult to measure and obtain.

The interviewee B implied, but not directly identified "Subjective assessment by using Likert scale (say within budget, on budget or overrun budget" as an important QI to measure the Cost Performance.

3. Please identify two most important QIs to evaluate Top Management Commitment of partnering projects.

   Conducting face-to-face interviews with subordinates of a director about their perceptions on the level of top management commitment by using Likert scale.

4. Please identify two most important QIs to evaluate the Quality Performance of partnering projects.

QI 1: Number of non-conformance reports. (focusing on the trend over a period of time)

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Composite satisfaction scores of end users by using Likert scale.

5. Please identify two most important QIs to evaluate Trust and Respect of partnering projects.

   For 'trust and respect', it is better to get the average composite satisfaction scores of key stakeholders by using Likert scale.

   I have developed a list of 18 partnering attributes to measure the level of trust and respect of partnering behaviour. (I will fax it to you later, but please keep it confidential.)

6. Please identify two most important QIs to evaluate Effective Communications of partnering projects.

   To begin with, I would like to emphasize that 'Effective Communication' should not only refer to transferring effective information from one party to another party, but it should also refer to good mutual understanding between parties. Therefore, counting number of letters sent between parties may not be so good to measure 'Effective Communications'. Following this logic, I suggest using average composite satisfaction scores of key stakeholders by using Likert scale to evaluate 'Effective Communications'.

7. Please identify two most important QIs to evaluate Innovation and Improvement of partnering projects.

   QI: Improvement from one project to the next project in terms of time, cost, and quality. (Focusing on analysing the trend) (For details, please refer to the website of 'Construction Best Practice in the UK – Benchmarking'.

Thank you very much for your contributions to our research study. Your opinions will, of course, be kept confidential and we will be happy to send you a copy of the consolidated results.

- End -

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Interview Questions for Developing Quantitative Indicators' (QIs) Model for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

The objective of this interview is to identify Quantitative Indicators (QIs) appropriate to each of the top-7 weighted Key Performance Indicators (KPIs) for partnering projects identified from the previous 4 rounds of Delphi questionnaires. Please note that the QIs to be identified must be vital, easy to measure and obtain so that a practical model can be finally derived.

Interviewee: Interviewee C   Position: Deputy Project Manager

Interviewer: John Yeung   Time and Date: 3:10pm – 4:10pm 17/03/2006

Venue: Interview Room, Suite 1213, Chimachem Golden Plaza   Record taken by: John Yeung

1. Please identify two most important QIs to evaluate the Time Performance of partnering projects.

QI 1: Variation of project completion time against programme expressed as a percentage of project completion time.

Example: If a project is expected to be completed at 5 years (1,826 days) and its actual completion time is 1,828 days, the project is calculated to be behind schedule by 0.11%. $\frac{(1{,}828 days - 1{,}826 days)}{1{,}826 days} \times 100\%$

Comment: This QI is vital, and easy to measure and obtain.

Q1 2: Variation of initially mutually agreed completion time expressed as a percentage of finally mutually agreed completion time.

Example: If a project is initially mutually agreed to be completed at 1,500 days but the finally mutually agreed completion time is 1,550 days, the project is calculated to require longer completion time by 3.33% of the initially mutually agreed completion time.

Comment: This QI is vital, and easy to measure and obtain. It is better to use this QI than QI 1 to evaluate Time Performance.

2. Please identify two most important QIs to evaluate the Cost Performance of partnering projects.

   To begin with, I would like to emphasize that it is extremely difficult to measure Cost Performance because clients and contractors view Cost Performance totally different, and there are uncontrollable price fluctuating costs. Therefore, it may be better to look at the nature of the claims (normal claims or uncontrollable claims).

   I suggest using the following QI:

   Variation of project completion cost against budget expressed as a percentage of project completion cost.

   Example: If a project is expected to be completed at 1.5 billion and its actual completion cost is 1.6 billion, the project is calculated to be overrun budget by 6.25%.

$$\frac{(1.6billion - 1.5billion)}{1.6billion} \times 100\%$$

   Comment: This is a possible objective method to measure Cost Performance but it is not a good indicator because it is difficult to get a mutually agreed expected cost between clients and contractors (reason: clients and contractors view Cost completely different.)

3. Please identify two most important QIs to evaluate Top Management Commitment of partnering projects.

   QI: Percentage of Partnering Steering/Progress Monitoring Meetings attended by Director's/Deputy Director's Representative (Very often by Project Managers/Deputy Project Managers).

   Comment: This QI is vital, and easy to measure and obtain.

4. Please identify two most important QIs to evaluate the Quality Performance of partnering projects.

   QI: Ratio of number of non-compliance reports per month to the average number of non-conformance reports per month.

   Comment: This QI is vital and easy to measure and obtain.

   The interviewee C implied, but not directly identified "Composite satisfaction scores of end users by using Likert scale" as an important QI to measure the Quality Performance.

5. Please identify two most important QIs to evaluate Trust and Respect of partnering projects.

   Average composite satisfaction scores of key stakeholders by using Likert scale.

6. Please identify two most important QIs to evaluate Effective Communications of partnering projects.

   QI: Number of formal letters and emails sent between parties both internally and externally per month.

   Comment: This QI is vital, easy to measure and obtain.

7. Please identify two most important QIs to evaluate Innovation and Improvement of partnering projects.

   QI 1: Innovation and Improvement (I & I) cost saving expressed as a percentage of project completion cost.

   QI 1: Innovation and Improvement (I & I) time saving expressed as a percentage of project completion time.

   Comment: Both QI 1 and QI 2 are vital, and easy to measure and obtain.

Thank you very much for your contributions to our research study. Your opinions will, of course, be kept confidential and we will be happy to send you a copy of the consolidated results.

- End -

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Interview Questions for Developing Quantitative Indicators' (QIs) Model for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering/Alliancing Projects

The objective of this interview is to identify Quantitative Indicators (QIs) appropriate to each of the top-7 weighted Key Performance Indicators (KPIs) identified from the previous 4 rounds of Delphi questionnaires. Please note that the QIs to be identified must be vital, easy to measure and obtain so that a practical model can be finally derived.

Interviewee: Interviewee D Position: Corporate Efficiency Manager

Interviewer: John Yeung Time and Date: 4:00pm – 5:00pm 14/03/2006

Venue: Meeting Room C, MTR Tower Record taken by: John Yeung

1. Please identify two most important QIs to evaluate the Time Performance of partnering projects.

QI 1: Variation of project completion time against programme expressed as a percentage of project completion time.

Example: If a project is expected to be completed at 5 years (1,826 days) and its actual completion time is 1,828 days, the project is calculated to be behind schedule by 0.11%. $\frac{(1{,}828 days - 1{,}826 days)}{1{,}828 days} \times 100\%$

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Variation of project completion time against completion time of best-in-class projects expressed as a percentage of completion time of best-in-class projects.

Example: If a project is completed at 6 years (2,191 days) and the best-in-class projects is 5 years (1,826 days), the project is calculated to require longer completion time by 19.99% of the best-in-class projects. $\frac{(2{,}191 days - 1{,}826 days)}{1{,}826 days} \times 100\%$

Comment: This QI is vital, but difficult to measure and obtain because it is difficult to define the standard project duration of the best-in-class projects.

The interviewee D implied, but not directly identified “Subjective assessment by using Likert scale (say ahead of schedule, on time or behind schedule)” as an important QI to measure the Time Performance.

2. Please identify two most important QIs to evaluate the Cost Performance of partnering projects.

QI 1: Variation of project completion cost against budget expressed as a percentage of project completion cost.

Example: If a project is expected to be completed at 1.5 billion and its actual completion cost is 1.6 billion, the project is calculated to be overrun budget by 6.25%. $\frac{(1.6billion - 1.5billion)}{1.6billion} \times 100\%$

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Variation of project completion cost against completion cost of best-in-class projects expressed as a percentage of completion cost of best-in-class projects.

Example: If a project is completed at 1.5 billion and the best-in-class projects is 1.3 billion, the project is calculated to cost more by 15.38% of the best-in-class projects. $\frac{(1.5billion - 1.3billion)}{1.3billion} \times 100\%$

Comment: This QI is vital, but difficult to measure and obtain because it is difficult to define the standard completion cost of the best-in-class projects.

The interviewee D implied, but not directly identified "Subjective assessment by using Likert scale (say within budget, on budget or overrun budget)" as an important QI to measure the Cost Performance.

3. Please identify two most important QIs to evaluate Top Management Commitment of partneringprojects.

QI 1: Partnering development cost of project expressed as a percentage of project completion cost.

Partnering development cost is defined as a dedicated resource allocation cost from the total project completion cost, which includes (1) cost of employing facilitators, and (2) cost of organising partnering workshops.

Example: If the partnering development cost of a project is 2 million and its total project completion cost is 2 billion, the partnering development cost is calculated to be 0.1% of the total project completion cost. $\frac{2million}{2billion} \times 100\%$

Comment: This QI is vital, and easy to measure and obtain.

QI 2: Ratio of time spent by Project Director in Partnering Steering/Progress Monitoring Meetings to time by Project Director in Project Steering/Progress Monitoring Meetings.

Project Director is defined as the most senior executive/his representative in a company responsible for managing the project.

Project Steering/Progress Monitoring Meetings include all Progress Meetings and Cost Control Meetings.

Comment: Although this QI is important, it is difficult to obtain and measure.

4. Please identify two most important QIs to evaluate the Quality Performance of partnering projects.

   QI 1: Cost of rectifying defects or non-conformances before project completion expressed as a percentage of project completion cost.

   Comment: It is more practical to obtain cost of major defects rather than cost of all defects.

   QI 2: Cost of rectifying defects or non-conformances during defect liability period as a percentage of project completion cost.

   Comment: It is more difficult to obtain QI 2 than QI 1. Reason behind: QI 1 is concerned with contractor's cost and QI 2 is concerned with contractor's and client's costs.

   Remark: Some practitioners use number of non-conformance reports to evaluate Quality Performance but this method is not good because a single serious defect is likely to cost more than several medium-sized defects.

   The interviewee D implied, but not directly identified "Composite satisfaction scores of end users by using Likert scale" as an important QI to measure the Quality Performance.

5. Please identify two most important QIs to evaluate Trust and Respect of partnering projects.

   Composite satisfaction scores of key stakeholders by using Likert scale.

6. Please identify two most important QIs to evaluate Effective Communications of partnering projects.

   Composite satisfaction scores of key stakeholders by using Likert scale.

7. Please identify two most important QIs to evaluate Innovation and Improvement of partnering projects.

   QI 1: Innovation and Improvement (I & I) cost saving expressed as a percentage of project completion cost

   QI 2: Innovation and Improvement (I & I) programme saving expressed as a percentage of project completion time.

   Comment: Both QI 1 and QI 2 are vital, easy to measure and obtain.

   Thank you very much for your contributions to our research study. Your opinions will, of course, be kept confidential and we will be happy to send you a copy of the consolidated results.

- End -

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Interview Questions for Developing Quantitative Indicators' (QIs) Model for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

The objective of this interview is to identify Quantitative Indicators (QIs) appropriate to each of the top-7 weighted Key Performance Indicators (KPIs) identified from the previous 4 rounds of Delphi questionnaires. Please note that the QIs to be identified must be vital, easy to measure and obtain so that a practical model can be finally derived.

Interviewee: Interviewee E Position: Manager – Property Projects

Interviewer: John Yeung Time and Date: 6:45pm – 8:00pm 16/03/2006

Venue: The Venue was changed to Mc Cafe, Mei Foo Record taken by: John Yeung

1. Please identify two most important QIs to evaluate the Time Performance of partnering projects.

QI 1: Variation of project completion time against completion time of standard projects in similar type as a percentage of completion time of standard projects in similar type.

Example: If a project is completed at 1,828 days and the completion time of standard projects in similar type is 1,826 days, the project is calculated to require longer completion time by 0.11% of the standard projects in similar type. $\frac{(1{,}828 days - 1{,}826 days)}{1{,}826 days} \times 100\%$

Comment: This QI is vital, but it may be difficult to measure/evaluate because the completion time of standard projects may not always be available, bearing in mind there are always differences between different projects. It may be easier for the public housing sector where similar building design is used at different estates.

Many practitioners use "Variation of project completion time against programme expressed as a percentage of project completion time" to evaluate Time Performance. However, this method is not so good because it depends on how individual practitioner sets the expected duration. If the expected duration is set to be relatively loose, it is easier to result in better time performance (ahead of schedule by some percentages, and the vice versa.)

2. Please identify two most important QIs to evaluate the Cost Performance of partnering projects.

QI 1: Variation of project completion cost against completion cost of standard projects in similar type expressed as a percentage of completion cost of standard projects in similar type.

Example: If a project is completed at 1.6 billion and the completion cost of standard projects in similar type is 1.5 billion, the project is calculated to cost more by 6.67% of the standard projects in similar type. $\frac{(1.6billion - 1.5billion)}{1.5billion} \times 100\%$

Comment: This QI is vital but again, it is difficult to measure and obtain because it is difficult to define the completion cost of standard projects in similar type. (It may be easier for the public rental housing and the HOS.)

Many practitioners use "Variation of project completion cost against budget expressed as a percentage of project completion cost" to evaluate Cost Performance. However, this method is not so good because it depends on how individual practitioner sets the expected cost. If the expected cost is set to be relatively loose, it is easier to result in better cost performance (underrun budget by some percentages, and the vice versa.)

3. Please identify two most important QIs to evaluate Top Management Commitment of partnering projects.

QI 1: The difference between promised commitment and actual commitment.

Comment: This QI is vital, but difficult to measure and obtain in quantitative term. Above all, commitment should not be measured on its own account because there may be other factors driving for more or less Top Management Commitment. For example, a project being carried out smoothly at the working level may need little involvement of the top management and so resulting in lower quantitative commitment of the top management. Therefore, it is better to use Likert scale to measure Top Management Commitment.

4. Please identify two most important QIs to evaluate the Quality Performance of partnering projects.

QI 1: Cost of rectifying major defects of a project expressed as a percentage of project completion cost.

Comment: This QI is vital and not difficult to measure. However, the contractors may be reluctant to reveal their details of their poor performance.

The interviewee E implied, but not directly identified "Composite satisfaction scores of end users by using Likert scale" as an important QI to measure the Quality Performance.

5. Please identify two most important QIs to evaluate Trust and Respect of partnering projects.

For 'trust and respect', it is better to get the average composite satisfaction scores of key stakeholders by using Likert scale.

6. Please identify two most important QIs to evaluate Effective Communications of partnering projects.

   The difference between number of formal letter (per year) sent between parties and standard number of formal letter (per year) sent between parties.

   Comment: This QI is vital, and easy to measure and obtain once the standard number of formal letter sent between parties has been obtained.

7. Please identify two most important QIs to evaluate Innovation and Improvement of partnering projects.

   Average composite satisfaction scores of key stakeholders by using Likert scale.

Thank you very much for your contributions to our research study. Your opinions will, of course, be kept confidential and we will be happy to send you a copy of the consolidated results.

- End -

Appendix 6
Round 1 of the Second Delphi Survey

Round One Delphi Survey

Appendix 6

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A Survey of Establishing Quantitative Indicators (QIs) for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

FORM COMPLETION GUIDANCE

Thank you very much for participating in the previous 4 rounds of Delphi questionnaires from early September 2005 to mid January 2006. Below are the results of the previous Round 4 of the Delphi questionnaire survey. The average ratings of all experts are given in column (2) while the corresponding weightings are shown in column (3). The weighting for each of the seven selected KPIs is calculated by the mean ratings of a particular KPI divided by the summation of the mean ratings of all the seven selected KPIs. Having developed the seven selected weighed KPIs through the 4 rounds of Delphi, the following equation for calculating the Performance Index (PI) for partnering projects has been thus established.

Performance Index (PI) = 0.167 x Time Performance + 0.160 x Cost Performance + 0.150 x Top Management Commitment + 0.143 x Quality Performance + 0.143 x Trust and Respect + 0.131 x Effective Communications + 0.106 x Innovation and Improvement

Results of Previous Round Four Delphi Survey

Key Performance Indicators (KPIs) for partnering projects	Average ratings of experts In the Round Four	Corresponding Weightings
1. Time performance	4.55	0.167
2. Cost performance	4.35	0.160
3. Top management commitment	4.10	0.150
4. Quality performance	3.90	0.143
5. Trust and respect	3.90	0.143
6. Effective communications	3.58	0.131
7. Innovation and improvement	2.90	0.106

Name: ____

Below are the Quantitative Indicators (QIs) identified from leading industry practitioners during face-to-face interviews to measure the seven selected weighted KPIs to evaluate the success of partnering projects in Hong Kong. In order to verify their appropriateness, you are cordially invited to provide us with your expertise by filling in the following questionnaire. The appropriateness of each potential QI is measured by its level of importance, measurability, and obtainability as they are the most vital dimensions to reflect how important and practical a QI is to measure its corresponding KPI. Please give a score according to the following 5-point Likert scales against importance, measurability, and obtainability of each potential Quantitative Indicator. You are encouraged to insert additional attributes in the last row under each KPI if deemed appropriate.

For measuring Level of Importance, 1 = very unimportant, 2 = unimportant, 3 = neutral, 4 = important, and 5 = very important
For measuring Level of Measurability, 1 = very difficult to measure, 2 = difficult to measure, 3 = neutral, 4 = easy to measure, and 5 = very easy to measure.
For measuring Level of Obtainability, 1 = very difficult to obtain, 2 = difficult to obtain, 3 = neutral, 4 = easy to obtain, and 5 = very easy to obtain**.**

Quantitative Indicators for Measuring Time Performance	**Importance**	**Measurability**	**Obtainability**
Variation of actual completion time expressed as a percentage of finally agreed completion time			
Time improvement: measuring how much time improvement of a project is delivered to previous similar projects			
Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule)			
Others (Please specify)			

Quantitative Indicators for Measuring Cost Performance	Importance	Measurability	Obtainability
Variation of actual project cost expressed as a percentage of finally agreed project cost			
Cost improvement: measuring how much cost improvement of a project is delivered to previous similar projects			
Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget)			
Others (Please specify)			

Quantitative Indicators for Measuring Top Management Commitment	Importance	Measurability	Obtainability
Partnering development cost[1] of project expressed as a percentage of total project cost			
Percentage of top management[2] attendance in partnering meetings			
Measuring level of top management commitment by using Likert scale (say high level, moderate level, or low level)			
Others (Please specify)			

Remark 1: Partnering development cost is defined as a dedicated resource allocation cost from the total project completion cost, which includes (1) cost of employing facilitators, and (2) cost of organizing partnering workshops.
Remark 2: Top management is defined as the most senior executive or his/her representative in an organization.

Quantitative Indicators for Measuring Quality Performance	Importance	Measurability	Obtainability
Cost of rectifying major defects or non-conformances of a project expressed as a percentage of total project cost			
Average number of non-conformance reports generated per month			
Perceived end users' satisfaction scores by using Likert scale			
Others: (Please specify)			

Quantitative Indicators for Measuring Trust and Respect	Importance	Measurability	Obtainability
Average duration for settling variation orders			
Frequency of meeting another party's expectation			
Perceived key stakeholders' satisfaction scores by using Likert scale			
Others (Please specify)			

Quantitative Indicators for Measuring Effective Communications	Importance	Measurability	Obtainability
Reduction of written communication: measuring how much written communication is reduced as compared to previous similar projects			
Variation of the number of formal letters and emails sent between parties per month against the number with previous similar projects			
Perceived key stakeholders' satisfaction scores by using Likert scale			
Others (Please specify)			

Quantitative Indicators for Measuring Innovation and Improvement	Importance	Measurability	Obtainability
Cost saving resulted from Innovation expressed as a percentage of total project cost			
Number of innovative initiatives introduced (e.g. construction techniques, procurement approaches, management strategies)			
Perceived key stakeholders' satisfaction scores by using Likert scale			
Others (Please specify)			

Please kindly return the questionnaire by email at bsjyeung@ or by fax at (852) 27645131 for the attention of Mr. John Yeung (Research Associate) or by mail at Room TU541,The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, within one week. If you have any queries, please feel free to contact me at Tel: (852) 27665814 or by e-mail at bsachan@

- End -

Appendix 7
Round 2 of the Second Delphi Survey

Appendix 7

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Round Two Delphi Survey

A Survey of Establishing Quantitative Indicators (QIs) for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

FORM COMPLETION GUIDANCE

Below are the results of Round 1 of the above study. The average ratings of all experts against importance, measurability, and obtainability of each Quantitative Indicators (statements) are given in columns (2), (5), and (8) respectively. Your Round 1 ratings against importance, measurability, and obtainability are given in columns (3), (6), and (9) respectively. Based on the information presented, please enter your reconsidered scores.

Name: ___________________

Quantitative Indicators for Measuring Time Performance	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2
Variation of actual completion time expressed as a percentage of finally agreed completion time	4.52	5		4.56	5		4.33	5	
Time improvement: measuring how much time improvement of a project is delivered to previous similar projects	3.74	3		3.00	2		3.04	3	
Subjective assessment by using Likert scale (say ahead of schedule, on time, or behind schedule)	3.15	2		3.41	5		3.44	5	

For measuring Level of Importance, 1 = very unimportant, 2 = unimportant, 3 = neutral, 4 = important, and 5 = very important
For measuring Level of Measurability, 1 = very difficult to measure, 2 = difficult to measure, 3 = neutral, 4 = easy to measure, and 5 = very easy to measure.
For measuring Level of Obtainability, 1 = very difficult to obtain, 2 = difficult to obtain, 3= neutral, 4 = easy to obtain, and 5 = very easy to obtain.

Quantitative Indicators for Measuring Cost Performance	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2
Variation of actual project cost expressed as a percentage of finally agreed project cost	4.48	5		4.48	5		4.30	5	
Cost improvement: measuring how much cost improvement of a project is delivered to previous similar projects	3.96	3		3.19	2		3.33	3	
Subjective assessment by using Likert scale (say within budget, on budget, or overrun budget)	3.22	2		3.67	5		3.96	5	

Quantitative Indicators for Measuring Top Management Commitment	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2
Partnering development cost of project expressed as a percentage of total project cost	3.19	5		4.00	5		4.04	5	
Percentage of top management attendance in partnering meetings	4.19	5		4.59	5		4.56	5	
Measuring level of top management commitment by using Likert scale (say high level, moderate level, or low level)	3.70	2		3.85	5		4.00	5	

Quantitative Indicators for Measuring Quality Performance	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2
Cost of rectifying major defects or non-conformances of a project expressed as a percentage of total project cost	4.19	3		3.56	5		3.11	5	
Average number of non-conformance reports generated per month	3.93	4		4.19	4		3.96	4	
Perceived end users' satisfaction scores by using Likert scale	3.81	2		3.37	5		3.59	5	

Quantitative Indicators for Measuring Trust and Respect	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2
Average duration for settling variation orders	3.70	5		3.59	4		3.56	4	
Frequency of meeting another party's expectation	3.52	3		2.44	3		2.67	3	
Perceived key stakeholders' satisfaction scores by using Likert scale	3.78	2		3.63	5		3.81	5	

Quantitative Indicators for Measuring Effective Communications	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round	Your rating in the Round 1	Your rating in the Round 2
Reduction of written communication: measuring how much written communication is reduced as compared to previous similar projects	3.37	4		2.89	3		2.78	3	
Variation of the number of formal letters and emails sent between parties per month against the number with previous similar projects	3.04	3		2.78	3		2.78	3	
Perceived key stakeholders' satisfaction scores by using Likert scale	3.63	2		3.30	5		3.56	5	

Quantitative Indicators for Measuring Innovation and Improvement	Importance			Measurability			Obtainability		
	1	2	3	4	5	6	7	8	9
	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2	Average ratings of experts in the Round 1	Your rating in the Round 1	Your rating in the Round 2
Cost saving resulted from Innovation expressed as a percentage of total project cost	4.19	4		3.48	4		3.37	4	
Number of innovative initiatives introduced (e.g. construction techniques, procurement approaches, management strategies)	3.89	3		3.81	2		3.74	2	
Perceived key stakeholders' satisfaction scores by using Likert scale	3.48	2		3.37	5		3.63	5	

Please kindly return the questionnaire by email at bsjyeung@ or by fax at (852) 27645131 for the attention of Mr. John Yeung (Research Associate) or by mail at Room TU541,The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, within one week. If you have any queries, please feel free to contact me at Tel: (852) 27665814 or by e-mail at bsachan@

- End -

Appendix 8
Research Questionnaire for Developing FQRs for KPIs to Evaluate the Success of Partnering Projects

Appendix 8

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Research Questionnaire

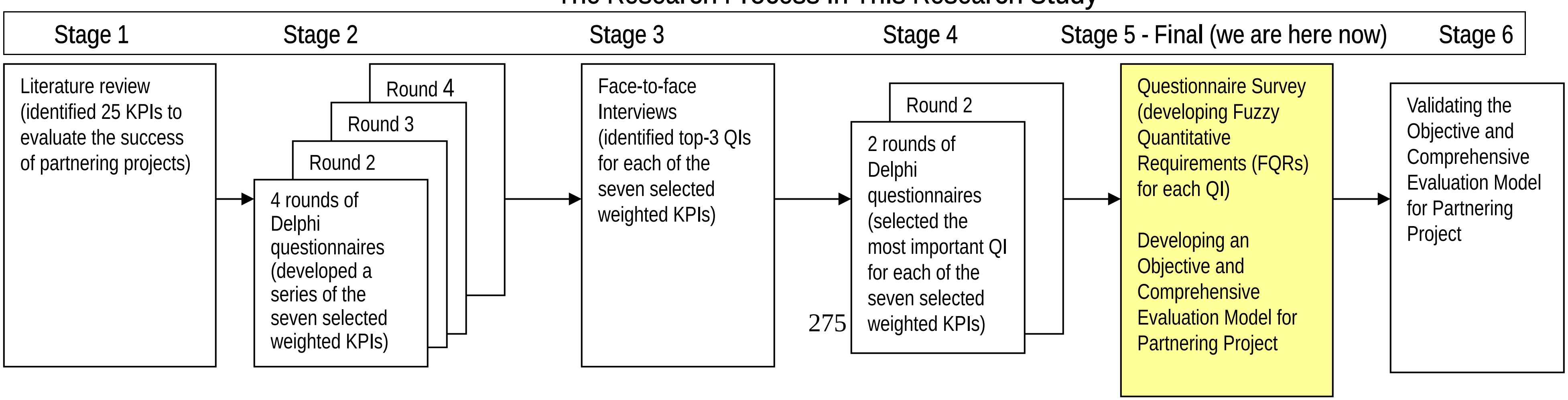
A Research Questionnaire for Developing Fuzzy Quantitative Requirements (FQRs) for Key Performance Indicators (KPIs) to Evaluate the Success of Partnering Projects

Results of Previous Final Round of the Delphi Questionnaire for the Development of Quantitative Indicators (QIs)

Sincere thanks for your kind and enormous support to participate in this research study. Below are the results of the previous Final Round of the Delphi questionnaire for the development of Quantitative Indicators (QIs) for Key Performance Indicators (KPIs) to evaluate the success of partnering projects. The overall research process in this research study is also described below.

The Seven Selected Weighted KPIs (with corresponding weightings) (total weighting is equal to 1)	The Most Important Quantitative Indicator (QI) for each of the Seven Selected Weighted KPIs	Mean Ratings of Level of Importance, Measurability, and Obtainability for each QI
Time Performance (0.167)	Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time	4.53
Cost Performance (0.160)	Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost	4.45
Top Management Commitment (0.150)	Percentage of Top Management Attendance in Partnering Meetings	4.51
Quality Performance (0.143)	Average Number of Non-conformance Reports Generated Per Month	4.10
Trust and Respect (0.143)	Perceived Key Stakeholders' Satisfaction Scores by using Likert Scale	3.77
Effective Communications (0.131)	Perceived Key Stakeholders' Satisfaction Scores by using Likert Scale	3.51
Innovation and Improvement (0.106)	Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost	3.80

The Research Process in This Research Study



Opinions on Developing Fuzzy Quantitative Requirements (FQRs) for Key Performance Indicators (KPIs) to Evaluate the Performance of Partnering Projects in Hong Kong

Since the QIs selected are still fuzzy in nature which requires assessors' subjective value judgement, it is better to have a well-defined range (Quantitative Requirements (QRs)) as the evaluation basis. **In order to define Fuzzy Quantitative Requirements (FQRs) for each QI, this questionnaire aims to solicit your perception on the performance evaluation criteria for partnering projects based on the most important KPIs and QIs previously identified by you and other experts (we are at stage 5 - final now).** We are sure that your contributions are of great significance to help us to develop a more objective and comprehensive evaluation framework for partnering projects, thus enabling us to further identify critical success factors and develop a best practice framework for implementing partnering projects. After developing Fuzzy Quantitative Requirements (FQRs), an objective and comprehensive performance evaluation model for partnering projects in Hong Kong will be established.

This questionnaire should take you no longer than 15 minutes to complete. Thanks so much for your kind cooperation and contribution. Please express your perception in the perspective of being an <u>ASSESSOR</u> to evaluate the performance of partnering projects against the five performance levels. Answers should be provided by <u>either putting a circle on the scale or filling up the "Others" column against the five performance levels</u>. The performance levels are defined as follows.

<u>Performance Demand Level</u>	<u>Description</u>
Level A	Poor Performance Expectation
Level B	Average Performance Expectation
Level C	Good Performance Expectation
Level D	Very Good Performance Expectation
Level E	Excellent Performance Expectation

Example

Time Performance (calculated in terms of variation of actual completion time expressed as a percentage of finally agreed completion time)

Put a circle on the scale

		Others
Poor Performance Expectation	Behind Schedule On Time Ahead Schedule |--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| -25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	____%

Or Filling up the "Others" Column (if the scale is not applicable)

		Others
Excellent Performance Expectation	Behind Schedule On Time Ahead Schedule |--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| -25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	30%

Opinions on Developing Fuzzy Quantitative Requirements (FQRs) for Key Performance Indicators (KPIs) to Evaluate the Performance of Partnering Projects in Hong Kong

Name: ______________________

1. Time Performance

In assessing the time performance of partnering projects, what is your expected percentage of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Time Performance:
Variation of Actual Completion Time Expressed as a Percentage of Finally Agreed Completion Time

<table>
<tr><td></td><td>Behind Schedule   On Time   Ahead Schedule</td><td>Others</td></tr>
<tr><td>Poor Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%</td><td>_____%</td></tr>
<tr><td>Average Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%</td><td>_____%</td></tr>
<tr><td>Good Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%</td><td>_____%</td></tr>
<tr><td>Very Good Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%</td><td>_____%</td></tr>
<tr><td>Excellent Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%</td><td>____%</td></tr>
</table>

2. Cost Performance

In assessing the cost performance of partnering projects, what is your expected percentage of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Cost Performance:
Variation of Actual Project Cost Expressed as a Percentage of Finally Agreed Project Cost

	Overrun Budget / On Budget / Underrun Budget	Others
Poor Performance Expectation	-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	______%
Average Performance Expectation	-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	______%
Good Performance Expectation	-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	______%
Very Good Performance Expectation	-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	______%
Excellent Performance Expectation	-25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25%	______%

3. Top Management Commitment Performance

In assessing the top management commitment performance of partnering projects, what is your expected percentage of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Top Management Commitment Performance:
Percentage of Top Management Attendance in Partnering Meetings

	% of Top Management Attendance in Partnering Meetings	Others
Poor Performance Expectation	|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%	_____%
Average Performance Expectation	|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%	_____%
Good Performance Expectation	|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%	_____%
Very Good Performance Expectation	|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%	_____%
Excellent Performance Expectation	|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--| 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%	_____%

4a. Quality Performance (for Measuring Civil Works)

In assessing the quality performance of partnering projects, what is your expected number of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Quality Performance: **Average Number of Non-conformance Reports Generated Per Month (for Measuring Civil Works)**

	Average Number of Non-conformance Reports Generated Per Month (for Measuring Civil Works)	Others
Poor Performance Expectation	20 18 16 14 12 10 8 6 4 2 0	________
Average Performance Expectation	20 18 16 14 12 10 8 6 4 2 0	________
Good Performance Expectation	20 18 16 14 12 10 8 6 4 2 0	________
Very Good Performance Expectation	20 18 16 14 12 10 8 6 4 2 0	________
Excellent Performance Expectation	20 18 16 14 12 10 8 6 4 2 0	________

4b. Quality Performance (for Measuring Building Works)

In assessing the quality performance of partnering projects, what is your expected number of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Quality Performance: **Average Number of Non-conformance Reports Generated Per Month (for Measuring Building Works)**

	Average Number of Non-conformance Reports Generated Per Month (for Measuring Building Works)	Others
Poor Performance Expectation	50 45 40 35 30 25 20 15 10 5 0	______
Average Performance Expectation	50 45 40 35 30 25 20 15 10 5 0	______
Good Performance Expectation	50 45 40 35 30 25 20 15 10 5 0	______
Very Good Performance Expectation	50 45 40 35 30 25 20 15 10 5 0	______
Excellent Performance Expectation	50 45 40 35 30 25 20 15 10 5 0	______

5. Trust and Respect Performance

In assessing the trust and respect performance of partnering projects, what is your expected score of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Trust and Respect Performance:
Perceived Key Stakeholders' Satisfaction Scores by using 10-point Likert scale (ranging from 1 = lowest to 10 = highest)

	Trust Score	Others
Poor Performance Expectation	1 2 3 4 5 6 7 8 9 10	________
Average Performance Expectation	1 2 3 4 5 6 7 8 9 10	________
Good Performance Expectation	1 2 3 4 5 6 7 8 9 10	________
Very Good Performance Expectation	1 2 3 4 5 6 7 8 9 10	________
Excellent Performance Expectation	1 2 3 4 5 6 7 8 9 10	________

6. Effective Communications Performance

In assessing the effective communications performance of partnering projects, what is your expected score of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Effective Communications Performance:
Perceived Key Stakeholders' Satisfaction Scores by Using 10-point Likert Scale (ranging from 1 = lowest to 10 = highest)

	Effective Communications Score	Others
Poor Performance Expectation	|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| 1 2 3 4 5 6 7 8 9 10	________
Average Performance Expectation	|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| 1 2 3 4 5 6 7 8 9 10	________
Good Performance Expectation	|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| 1 2 3 4 5 6 7 8 9 10	________
Very Good Performance Expectation	|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| 1 2 3 4 5 6 7 8 9 10	________
Excellent Performance Expectation	|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| 1 2 3 4 5 6 7 8 9 10	________

7. Innovation and Improvement Performance

In assessing the innovation and improvement performance of partnering projects, what is your expected percentage of the following Quantitative Indicator (QI) against the five performance levels?

Quantitative Indicator for Measuring Innovation and Improvement Performance:
Cost Saving Resulted from Innovation (e.g. construction techniques, procurement approaches, management strategies) Expressed as a Percentage of Total Project Cost

<table>
<tr><th></th><th>Cost Saving Resulted from Innovation
Expressed as a Percentage of Total Project Cost</th><th>Others</th></tr>
<tr><td>Poor Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10%</td><td>___%</td></tr>
<tr><td>Average Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10%</td><td>___%</td></tr>
<tr><td>Good Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10%</td><td>___%</td></tr>
<tr><td>Very Good Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10%</td><td>___%</td></tr>
<tr><td>Excellent Performance Expectation</td><td>|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10%</td><td>___%</td></tr>
</table>

Appendix 9

Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by VERTICAL Error

Appendix 9: Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by VERTICAL Error

Suppose given a constraint that a best-fit line must pass through $(x_0,1)$ (full membership function when $y=1$) and (x_i, y_i) for $1 \le i \le N$, we need to minimize $\sum_{i=1}^{N}(Y_i - y_i)^2$

Let the error function be $E=\sum_{i=1}^{N}(Y_i - y_i)^2$ and theoretically, $Y_i = mX_i + b$ (slope-intercept form) and so $y_0 = mX_0 + b$

Hence, we need to find m , b such that $E(m, b)$ is minimized and $y_0 = mX_0 + b$

Based on the above constraint, $b = y_0 - mX_0 = 1 - mX_0$

$$E=\sum_{i=1}^{N}(mX_i + b - y_i)^2 = \sum_{i=1}^{N}(mX_i + (1 - mX_0) - y_i)^2$$

Now, the error function is a single variable of m.

To compute error derivative with respect to m,

$\frac{dE}{dm} = \frac{d}{dm}\left(\sum_{i=1}^{N}(m(x_i - x_0) + 1 - y_i)\right)^2$ by using composite function rule in calculus.

$$= \sum_{i=1}^{N} 2(m(x_i - x_0) + 1 - y_i) \times (x_i - x_0)$$

Since it is a necessary condition to set $\frac{dE}{dm} = 0$ for finding minimum/maximum value, the following equation is set.

$$\sum_{i=1}^{N} 2\left(m\left(x_i - x_0\right) + 1 - y_i\right)\left(x_i - x_0\right) = 0$$

$$m \times \sum_{i=1}^{N} \left(x_i - x_0\right)^2 + \sum_{i=1}^{N} \left(1 - y_i\right)\left(x_i - x_0\right) = 0$$

$$m \times \sum_{i=1}^{N} \left(x_i - x_0\right)^2 = \sum_{i=1}^{N} \left(y_i - 1\right)\left(x_i - x_0\right)$$

$$m = \frac{\sum_{i=1}^{N} \left(y_i - 1\right)\left(x_i - x_0\right)}{\sum_{i=1}^{N} \left(x_i - x_0\right)^2}$$

By substitution, $b = y_0 - mX_0 = 1 - \frac{\sum_{i=1}^{N} \left(y_i - 1\right)\left(x_i - x_0\right)}{\sum_{i=1}^{N} \left(x_i - x_0\right)^2} \times x_0$

Appendix 10

Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by HORIZONTAL Error

Appendix 10: Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by <u>HORIZONTAL</u> Error

Suppose given a constraint that a best-fit line must pass through $(x_0,1)$ (full membership function when $y=1$) and (x_i, y_i) for $1 \le i \le N$, we need to minimize $\sum_{i=1}^{N}(X_i - x_i)^2$

Let the error function be $E = \sum_{i=1}^{N}(X_i - x_i)^2$ and theoretically, $X_i = pY_i + q$ (slope-intercept form) and so $x_0 = pY_0 + q$ and $y_i = \frac{1}{p}X_i - \frac{q}{p}$

Therefore, $m = \frac{1}{p}$ and $b = \frac{q}{p}$

Now, we need to find p, q such that $E(p, q)$ is minimized and $x_0 = py_0 + q$

Based on the above constraint, $q = x_0 - p$

$$E(p,q) = \sum_{i=1}^{N}(py_i + q - x_i)^2 = \sum_{i=1}^{N}(py_i + x_0 - p - x_i)^2$$

$$= \sum_{i=1}^{N}(p(y_i - 1) + (x_0 - x_i))^2$$

Now, the error function is a single variable of p.

To compute error derivative with respect to p,

$$\frac{dE}{dp} = \frac{d}{dp}\left(\sum_{i=1}^{N}(p(y_i - 1) + (x_0 - x_i))\right)^2$$ by using composite function rule in calculus.

$$= \sum_{i=1}^{N}2(p(y_i - 1) + (x_0 - x_i))(y_i - 1)$$

Since it is a necessary condition to set $\frac{dE}{dm} = 0$ for finding minimum/maximum value, the following equation is set.

$$\sum_{i=1}^{N} 2\left(p\left(y_i - 1\right) + \left(x_0 - x_i\right)\right)\left(y_i - 1\right) = 0$$

$$\sum_{i=1}^{N} \left(p\left(y_i - 1\right) + \left(x_0 - x_i\right)\right)\left(y_i - 1\right) = 0$$

$$p \times \sum_{i=1}^{N} \left(y_i - 1\right)^2 + \sum_{i=1}^{N} \left(x_0 - x_i\right)\left(y_i - 1\right) = 0$$

$$p \times \sum_{i=1}^{N} \left(y_i - 1\right)^2 = \sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)$$

$$p = \frac{\sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)}{\sum_{i=1}^{N} \left(y_i - 1\right)^2}$$

By substitution, $q = x_0 - p = x_0 - \frac{\sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)}{\sum_{i=1}^{N} \left(y_i - 1\right)^2}$

Therefore, $m = \frac{1}{\dfrac{\sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)}{\sum_{i=1}^{N} \left(y_i - 1\right)^2}}$

$$b = \left(x_0 - \frac{\sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)}{\sum_{i=1}^{N} \left(y_i - 1\right)^2} \right) \times \frac{\sum_{i=1}^{N} \left(y_i - 1\right)^2}{\sum_{i=1}^{N} \left(x_i - x_0\right)\left(y_i - 1\right)}$$

Appendix 11

Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by Bisector Error

Appendix 11: Constructing Fuzzy Membership Function by Using Modified Horizontal Approach through Calculating Constrained Regression Line by Minimizing Residual Sum of Square by Bisector Error

$$m = \tan\left(\frac{\vartheta_1 + \vartheta_2}{2}\right) = \frac{\tan\frac{\vartheta_1}{2} + \tan\frac{\vartheta_2}{2}}{1 - \tan\frac{\vartheta_1}{2} \times \tan\frac{\vartheta_2}{2}}$$

$$(x_0 \times m) + c = 1$$

$$x = 1 - (x_0 \times m)$$

Appendix 12
Interview Dialogues for Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

Appendix 12

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Interview Questions for Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interviewee A Position: Project Manager (Swire)

Interviewer: John Yeung Time and Date: 10:15am-11:15am, 18/06/07

Venue: Meeting Room, 33/F, One Pacific Place Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Broadly speaking, the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong. As a project manager of a client, it is fine for me to use Cost Performance to measure one of the partnering performances. However, it seems that contractors are more interested to use Profit Performance instead of Cost Performance.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: Yes.

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs. However, Cost Performance should be used with other wordings (consider both views of clients and contractors); 'Non-conformance Reports' should be clearly defined (more serious or also including site memos); and 'Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost should be rewritten as 'Benefits Resulted from Innovation' because Innovation is also used for improving quality and environment.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: The ranges defined are appropriate to measure all of the seven QIs.

Note: The interviewee viewed that the newly developed computerised system is user friendly and industrial practitioners may be interested in comparing its own PPI score with PPI scores of other partnering projects. In order to attract more practitioners to use the PPI system, he suggested that all the PPI scores should be disclosed with anonymity and the timing for setting the login name and password should be carefully designed (because it is easy for users to forget the user name and password.) However, he opined that it is sensitive to disclose the Time and Cost Performances and it is likely for most industrial practitioners to be unwilling to compare its time and cost performances with other partnering projects (especially for those with poor performance). Therefore, he suggested that only the comparison of PPI among partnering projects is good enough and interesting. In addition, as a project manager, he think it is good to calculate the PPI score monthly or weekly or even daily for achieving good project control and management.

- End -

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Interview Questions for Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interivewee B

Position: Project Manager (Realty Cheng & Partners Construction Ltd)

Interviewer: John Yeung

Time and Date: 10:30pm-11:30pm, 18/06/07

Venue: Garden Area, PolyU

Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: I agree that the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong. In fact, the first three KPIs (Time Performance, Cost Performance and Top Management Commitment) should be the top-3 KPIs (but their sequence may change with different partnering projects) for assessing the partnering performance of all construction projects in Hong Kong.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: Yes.

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: Yes.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: Yes, it is logical and makes sense.

Note: The interviewee viewed that the newly developed computerised system is user friendly and convenient to be used by industrial practitioners. He agreed that that the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong and it is good to have 'standard' KPIs applicable to all partnering projects in Hong Kong. However, he opined that some other KPIs should also be added with different partnering projects because practitioners may have different preferences with different projects (project specific: they should have their own KPIs). In order to attract more practitioners to use the PPI system, he suggested that Certification System should be established and Certificate of Merit or similar certificate/letter can be awarded to the top-10 partnering projects (based on the principle of recognition) in the database. In addition, the database should be updated regularly and frequently.

- End -

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Interview Questions for Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interviewee C Position: Senior Architect (HKHA)

Interviewer: John Yeung Time and Date: 10:00am-11:15am, 20/06/07

Venue: Demonstration Room, 13/F, Block 3, HKHA Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Broadly speaking, the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong. In fact, it seems that the performance evaluation model can be a tool for project managers to control and monitor their projects through continuous improvement.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: The weightings should be validated through sensitivity analysis/reliability analysis. In fact, the weightings between Time Performance/Cost Performance/Quality Performance and other KPIs should be carefully balanced and adjusted with different types of projects.

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs. However, it is better to use 'Degree of Major/Minor Reworks' (Qualitative

Indicator) rather than ‘Average Number of Non-conformance Reports Generated Per Month’ to measure Quality Performance because a non-conformance report with major reworks is more serious than a number of non-conformance reports with minor reworks. In addition, the wordings ‘Non-conformance Reports’ should be clearly defined (whether encompassing major reworks only or also including site memos). On the other hand, in order to measure the Top Management Commitment objectively, it should be clearly defined.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: The ranges defined are appropriate to measure all of the seven weighted QIs.

Note: The interviewee viewed that the newly developed computerised system can be a tool for project managers to achieve continuous improvement through project control and management. She stated that it is important to compare partnering performance of construction projects with similar natures (i.e. civil works; building works, projects from private, public and infrastructure sectors) because comparisons with unequal base are invalid. She also pointed out that the ICAC takes an important role in affecting the partnering performance of construction projects in Hong Kong.

- End -

THE HONG KONG
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香港理工大學

Interview Questions for Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interviewee D Position: Project Manager (Chevalier)

Interviewer: John Yeung Time and Date: 11:15am-12:15pm, 21/06/07

Venue: TU531, PolyU Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Yes, the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: In general, the weightings are appropriate for each KPI.

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs. However, it may be better to use number of emails and formal letters to measure Effective Communications Performance rather than Perceived Stakeholders' Satisfaction Scores based on a 10-point Likert Scale.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: The ranges defined are appropriate to measure each of the seven QIs.

- End -

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Interview Questions for Verifying and Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to verify and validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interviewee E Position: Project Manager (Hsin Chong)

Interviewer: John Yeung Time and Date: 03:10pm-04:40pm, 23/06/07

Venue: Tseung Kwan O Industrial Centre Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Generally speaking, the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong except that Cost Performance (from clients point of view) should be adjusted because Profit Performance should also be considered (from contractors' point of view).

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: In general, the weightings are appropriate for each KPI except that the weighting for Top Management Commitment should be reduced to the fifth rank (lower than Trust and Respect Performance but higher than Effective Communications Performance) .

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs except that Cost Performance should be adjusted to include Profit Performance (from contractors' point of view) as well; and 'Average Number of

Non-conformance Reports Generated Per Month' should be replaced by 'Cost of Rework Expressed as a Percentage of Total Contract Sum'; or 'Average Number of Non-conformance Reports Generated Per Month (Excluding those from the Nominated Subcontractors)'; and 'Non-conformance Reports' needs to be clearly defined.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: In general, the ranges defined are appropriate to measure the seven selected QIs except that the Time Performance of a partnering project should be classified as good if it is completed on time; and Innovation & Improvement Performance should be classified as good if the cost saving resulted from Innovation ranges from 1% to 3%.

- End -

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Interview Questions for Verifying and Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to verify and validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interviewee F Position: Senior Project Manager (CDO, HKPolyU)

Interviewer: John Yeung Time and Date: 11:35am-12:40pm, 25/06/07

Venue: Rm M1007, PolyU Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Generally speaking, the seven selected KPIs (the seven components of the PPI) are suitable and comprehensive to evaluate the partnering performance of construction projects in Hong Kong.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: In general, the weightings are appropriate for each KPI except that the weighting for Quality Performance should be increased to one of the top-3 KPIs. (should be higher than Top Management Commitment Performance).

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs except that Cost Performance should be clearly defined (e.g. Overall Cost Variation; and the Percentage of the Difference between Actual Project Cost and Finally Agreed/Reasonably Estimated Project Cost Expressed as Finally Agreed/Reasonably Estimated Project Cost); 'Average Number of

Non-conformance Reports Generated Per Month' should be replaced by 'Educated Users' Satisfaction'; and 'Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost' should be replaced by 'Life Cycle Cost Saving Resulted from Innovation Expressed as a Percentage of Total Project Cost'.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: In general, the ranges defined are appropriate to measure the seven selected QIs except that the Cost Performance of a partnering project should be classified as 'poor' if it is overrun budget by at least 10%; 'average' if it is between overrun budget by 10% and on budget.

- End -

THE HONG KONG
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Interview Questions for Verifying and Validating the Performance Evaluation Model with a Computerised System for Partnering Projects in Hong Kong

The objective of this interview is to verify and validate whether the performance evaluation model with a computerised system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong.

Interviewee: Interview G   Position: Project Manager (MTRCL)

Interviewer: John Yeung   Time and Date: 02:00pm-03:15pm, 26/06/07

Venue: Meeting Room B, 22/F, MTR Tower   Record taken by: John Yeung

Evaluation of the Appropriateness of the Selected KPIs for Partnering Projects in Hong Kong

Q1. Are the seven selected KPIs suitable to evaluate the partnering performance of construction projects in Hong Kong?

Ans: Generally speaking, the seven selected KPIs (the seven components of the PPI) are suitable to evaluate the partnering performance of construction projects in Hong Kong.

Evaluation of the Appropriateness of the Weightings of Each KPI

Q2. Are the weightings of each KPI appropriate?

Ans: In general, the weightings are appropriate for each KPI except that the weighting for Top Management Commitment should be decreased to at least the fourth rank.

Evaluation of the Appropriateness of the Selected Quantitative Indicators (QIs)

Q3. Are the Selected QIs appropriate to measure each of the 7 weighted KPIs?

Ans: In general, the selected QIs are appropriate to measure each of the seven weighted KPIs except that both Cost Performance and Top Management Commitment should be clearly defined; and ‘Average Number of Non-conformance Reports Generated Per Month’ is better replaced by ‘Approval Rate as Expressed in terms of Number of Approved Inspections divided by the Total Number of Inspections.

Evaluation of Quantitative Requirements/Ranges (QRs)

Q4. Are the ranges defined appropriate to measure a particular QI?

Ans: In general, the ranges defined are appropriate to measure the seven selected QIs except that it is doubtful for the ranges defined for Top Management Commitment.

- End -

Appendix 13 Performance Evaluation Model Validation Scoring Sheet

* Performance Evaluation Model Validation Scoring Sheet *

The purpose of this questionnaire is to validate whether the performance evaluation model with a computerized system for partnering projects in Hong Kong is comprehensive, objective, reliable and practical enough to evaluate the partnering performance of construction projects in Hong Kong. Please put a circle on the scoring scale to represent the extent of satisfaction (i.e. 1 presents "poor" and 5 indicates "excellent") to the model against each validation aspect.

Validation Aspects	Scoring Scale Poor →→→→→→Excellent **--- 1 --- 2 --- 3 --- 4 --- 5 ---**
Degree of appropriateness	--- 1 --- 2 --- 3 --- 4 --- 5 ---
Degree of objectivity	--- 1 --- 2 --- 3 --- 4 --- 5 ---
Degree of replicability	--- 1 --- 2 --- 3 --- 4 --- 5 ---
Degree of practicality	--- 1 --- 2 --- 3 --- 4 --- 5 ---
Overall reliability	--- 1 --- 2 --- 3 --- 4 --- 5 ---
Overall suitability to be adopted to measure the partnering performance of construction projects in Hong Kong	--- 1 --- 2 --- 3 --- 4 --- 5 ---

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