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A Fuzzy Consensus Building Framework for Early Alignment of Construction Project Teams on the Extent of their Roles and Responsibilities

by

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Abstract

This thesis presents a Fuzzy Consensus Building Framework (FCBF), which enables construction project parties to align their teams on their roles and responsibilities early on in their projects. The framework introduces a model that (1) incorporates consensus of construction project teams in aggregating their opinions to decide on the party responsible for every standard task of a construction project; (2) classifies the quality of experts in the decision making process by weighting their responses during aggregation, based on their attributes; and (3) resolves residual conflicts between project teams on their perceived shared tasks, using a consensus reaching process. A template of project and construction management tasks is extracted from relevant standard guidelines and interviews with industry peers. Different extents of the roles and responsibilities of the owner and contractors are described using seven linguistic terms. A modified similarity aggregation method (SAM) aggregates experts' opinions in a linguistic framework, using a consensus weight factor for each expert. A fuzzy expert system (FES) determines an importance weight factor for each expert, representing expert quality; opinions are aggregated using this factor and the consensus weight factor. Based on the aggregated opinions of experts, the tasks are classified into three responsibility lists: the owner's, the contractors', and the shared responsibility list. The fuzzy preference relations consensus (FPRC) approach is applied to the tasks of shared responsibility, and a linguistic

consensus measure is applied to resolve potential conflicts between team members on their perceived shared tasks. Using a case study approach, the FCBF is applied to aid a project owner organization in the field of oil and gas to determine its roles and responsibilities in a customized project delivery system, called owner managing contractor (OMC). The FCBF contributes to the construction industry by solving a fundamental problem for project owners: it helps identify and reduce potential conflicts over the extent of project teams' responsibilities prior to the construction stage. It also provides an improvement over previous consensus-based approaches, which rely on a subjective assessment of experts' importance weights in aggregating their opinions, and it modifies the SAM to adapt it to a linguistic environment.

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1. Chapter One - Introduction

1.1 Background

Construction projects owners are continuously changing and adapting their approaches to handling construction projects. The approaches that project owners previously used to manage and control construction projects have evolved by time, which has created more complicated environments for handling construction projects. Different project delivery systems have their own merits and drawbacks in terms of the structure of the contract, the differences in the areas of risk, and the obligations of both the owner and the contractors.

Historically, owners tended to control and manage projects closely, with most project functions carried out in-house. In order to deliver projects in this fashion, owners controlled project design, procurement, and management functions in-house, whereas contractors handled the project execution. Traditionally, this was accomplished through the design-bid-build model (Construction Management Association of America (CMAA) 2002; Bender 2003). One of the major problems of this approach is that the design team is not directly involved in the project execution stage. As such, failure of the project team to control construction costs may result in both potential cost increase and project delays if the design documents have to be reworked to reduce construction costs. Also, general contractors may be encouraged to hire cheaper sub-contractors to reduce their construction costs. This may result in increased risk for the general contractor, and it can also compromise the quality of construction. In the extreme, it can lead to serious disputes involving quality of the project, which usually impact project owners.

In recent times, construction projects have become more complicated and capital-intensive due to high levels of competition and the push for technology advancement. This trend has prompted the introduction of innovative project delivery systems, including: engineering, procurement, and construction (EPC) (Construction Owners Association of Alberta (COAA) EPC Contract Committee 2007); design-build (DB), with its various methods of application (Bender 2003; Kramer 2004); and engineering, procurement, and construction management (EPCM) (Construction Owners Association of Alberta (COAA) EPCM Contract Committee 2007). Kirschenman (1986) categorized these systems under "total project delivery systems" that require the contractor to "perform an array of diverse yet integrated activities for a project", such as project conceptualisation, design and procurement of equipment and services from various sources, construction, installation and commissioning. The primary difference between EPC and EPCM project delivery systems is that the EPC contractor is paid a lump sum price to deliver the project and to directly hire the subcontractors. Conversely, the EPCM contractor is an "extension of the owner" (Agnitsch et al. 2001). Thus, all contracts and procurements are carried out under the name of the owner, whereas, the EPCM contractor is either paid on a lump sum fee, or a cost reimbursable basis to perform engineering and management services (Agnitsch et al. 2001).

Accordingly, owners' organization structures have changed considerably as owners outsource various project functions in order to reduce their own risks in exceeding project costs. As a result, project owners focus on overseeing projects' major phases through a reduced number of owner representatives (CMAA 2002; Sullivan et al. 1997). Unfortunately, the tendency of project owners to outsource project functions has resulted in less control over their projects, while the majority of their competencies, including detailed design, project management, process engineering, construction management, technical expertise, and project controls, are reduced or eliminated with the downsizing of in-house qualified personnel (Elbarkouky and Fayek 2010; Sullivan et al. 1997).

In addition to the above, some of the currently used project delivery systems have their drawbacks. For example, although the EPC strategy, also known as Lump Sum-Turn Key (LSTK) (Agnitsch et al. 2001), may help reducing project delays and cost overruns, an efficient owner's project in-house team may not be present in this project delivery system (Agnitsch et al. 2001). Thus, a project owner may have less control over a project's cost and time due to his or her reduced project control function. This is because the contractor has a "single-point responsibility" for most of project functions, which means that cost overruns may not be within the owner's control (Agnitsch et al. 2001).

As for the EPCM contracts, according to Agnitsch et al. (2001), “the scope definition of the project is usually low and the scope is more likely to grow substantially.” Also, the schedule is often recognized as the top priority in EPCM contracts (Agnitsch et al. 2001). However, the adoption of cost reimbursable contracts, which is common in EPCM contracts, may reduce the effectiveness of applying liquidated damages in case of delays because the liquidated damages are “typically low in value with limited liabilities that can provide a no incentive attitude to the contractors” (Agnitsch et al. 2001). Also, according to Agnitsch et al. (2001), project owners perceive that project risks are all carried by the contractors in the EPCM project delivery systems. Nevertheless, the overall risk of not meeting the project objectives of time, cost, quality, and safety is carried by the owner, because all review and approval processes for scope, engineering, design, procurement, and contractual issues are the responsibility of the project owner (Project Management Institute (PMI) 2008; Agnitsch et al. 2001). As such, the owner’s failure to manage the above risks may affect the progress of the project, and will possibly minimize the advantages of using the EPCM strategy.

On the other hand, with regard to the design-build approaches, the design documents may change throughout the project life cycle, which may result in inaccurate cost estimates. As a result, final project costs may vary greatly from the original estimate. This also means that the owner will rely on the integrity of the design-builder, because project construction costs may not be revealed to the owner before the completion of project designs, due to his limited involvement during the design stage (Bender 2003; Kramer 2004).

As such, owners wishing to pay closer attention to managing projects in-house need an innovative project delivery system that could be customized from an existing project delivery system, to help regain their lost control. However, project owners need a tool that allows their project teams to participate in determining the extent of their roles and responsibilities in the selected project delivery system to ensure early alignment of the teams to their new roles and responsibilities. Accordingly, at an early stage of the project, project owners would be able to incorporate project teams' common agreement into the owners' decisions on their proper roles and responsibilities in the selected project delivery system.

1.2 Problem Statement

Construction projects are distinctive in nature, even for similar projects, based on their characteristics, contract type, and delivery system (PMI 2008). Accordingly, project management (PM) and construction management (CM) tasks that define the roles and responsibilities of construction project owners versus those of their contractors may vary from one project to another. The way these tasks are handled may have an impact on the success of the construction project (Bennett 2003). Noting the differences between projects, there is still a general roles and responsibilities structure that the owner may follow based on the adopted project delivery system. This structure is mainly determined by the construction industry standards and the owner's internal structure, which may aid the owner in defining its roles and responsibilities as well as those of its contractors. Several factors, however, may affect the decision to allocate project tasks between the owner and its contractors, which may vary even for projects that are executed using the same delivery system. Some of these factors are: confidentiality of the company's business, owner risks, project control methodology, project complexity, schedule delays, frequency of change orders, level of communication within the project, and the significance of minimizing claims (Oyetunji and Anderson 2006; Bennett 2003; Sullivan et al. 1997; CMAA 2002; Bender 2003; Gordon 1994).

Since construction projects are unique, it is very difficult for project teams to agree on their roles and responsibilities by evaluating all the above factors. It is also difficult to define a general model that can simply decide on an optimum method to allocate a project's variable tasks between the owner and its contractors. This is why experts are frequently solicited to make judgments based on their experiences (Lee 2002). In general, owner organizations are more likely to depend on expert judgment— which is guided by the knowledge base of construction project experts and construction industry standards—in deciding on their responsibilities based on the selected project delivery system.

One common problem, however, that faces construction project owners and their contractors, is how to involve project teams in deciding the extent of their roles and responsibilities in a given project delivery system prior to contract formulation. By incorporating common agreement of project teams into this decision at an early stage of the project, project owners will be able to align project teams to their roles and responsibilities in the best way possible. Common agreement is required between project teams in order to minimize the problem of having unnecessary duplication or gaps in the allocation of project tasks, which potentially may create conflicts between project teams during the project execution phase, if teams' roles and responsibilities are not clearly outlined. Reducing misunderstanding amongst individual team members by reaching a collective decision at an early stage of the project will allow project teams to focus on the execution of project tasks, rather than wasting project time in resolving responsibility conflicts. Thus, the bottom line is to obtain project teams' alignment on the aggregated extents of their roles and responsibilities, as opposed to choosing the best project delivery system. Owners should communicate their specific needs to project teams prior to the teams being interviewed on their collective opinion regarding the extent of the roles and responsibilities of the owner versus the contractors, so that the final decision will incorporate this important information. Oyetunji and Anderson (2006) stress this fact, stating that the objective of the decision-making problem is to meet the needs of both the project and the owner.

The difficulty in reaching common agreement between project teams may be due to the fact that the extent of various teams' roles and responsibilities sometimes overlap, which is one of the challenges of using natural language when solving problems of a linguistic basis. Thus, this problem adds an element of vagueness and imprecision to the decision-making process. The above challenges imply that assessing the quality of expert judgment and determining experts' level of agreement on the extent of project teams' roles and responsibilities are of extreme importance in order to ensure that their collective decision is satisfactory. The need for quality expert judgment raises the concern of defining an efficient method for aggregating experts' individual opinions into a quality group decision. This method should also be capable of dealing with the qualitative aspects in defining the level of expertise and knowledge of the experts in order to determine and incorporate their credibility in decision-making. Also, in order to minimize potential conflicts between project teams, an efficient method is necessary to determine whether their experts can reach a consensus on the extent of their roles and responsibilities. Thus, a proper consensus measure that deals with linguistic assessments is required to assess quality feedback of experts by measuring their level of agreement on a given topic.

Various statistical approaches, including linear averaging, have been proposed to aggregate experts' opinions (Genest and Zidek 1986; Clemen and Winkler 1999). The linear averaging approach aggregates experts' opinions by assigning equal weights to their assessments to determine an average value, which is expressed as the sum of their assessments divided by their number. Despite its appeal, linear averaging suffers from several limitations. The major problem that limits the use of linear averaging amongst other simple statistical approaches, such as using the mode or the median, is its inability to provide a concrete decision if experts are incoherent or inconsistent on their respective domains (Predd et al. 2008). Some statistical-based algorithms managed to solve the problem of aggregating incoherent experts' opinions, such as the coherent approximation principle (CAP) (Osherson and Vardi 2006), and the scalable algorithm of aggregation (SAA) (Predd et al. 2008). The major limitation of these approaches is that they only deal with problems related to aggregating judgments about numerical quantities. Thus, these approaches do not deal with the problem of aggregating opinions on vague or imprecise linguistic concepts. Moreover, most of the statistical-based aggregation algorithms are computationally difficult to implement. On the other hand, the majority of the conventional statistical approaches do not encourage consensus building or measuring the level of consensus between experts during the data elicitation stage. Thus, they do not allow the project team to agree on their roles and responsibilities as opposed to providing an optimized aggregated decision.

Fuzzy set theory (Zadeh 1965) has also been proposed to aggregate experts' opinions, yet it has not been used to aggregate opinions of project teams to determine the extent of their roles and responsibilities, especially in the construction domain. Fuzzy set theory is characterized by the ability to assign membership values expressing a degree of belief that a certain value of a factor corresponds to a linguistic concept. Fuzzy set theory is intended to treat uncertainties that emerge as a result of linguistic approximation and measurement imprecision. The approach of using linguistic terms addresses the problem of uncertainty and vagueness, especially when it comes to determining the extent of the roles and responsibilities of project teams in a given project delivery system.

Fuzzy set theory also addresses the limitations of statistical approaches in aggregating experts' opinions in a linguistic framework. Solving the aggregation problem in a linguistic framework is one of the main objectives of this research, due to the vagueness and imprecise nature of using natural language in describing different overlapping extents of the roles and responsibilities of project teams, which cannot be solved using numerical-based models. Fuzzy set theory also deals with the problem of experts who are inconsistent on their respective domains, as various fuzzy logic-based consensus approaches, such as the similarity aggregation method (SAM) (Hsu and Chen 1996), have incorporated common agreement and reduced inconsistency of experts in aggregating their opinions. Fuzzy set theory also provides solutions to the inability of statistical approaches to create a proper consensus measure that deals with linguistic assessments, as several fuzzy logic consensus-based approaches have introduced different approaches for reaching consensus from opinions of experts and introduced linguistic consensus measures to advise experts on their level of agreement in a consensus reaching process (Herrera et al. 1996).

Based on the above, fuzzy set theory is proposed in this thesis to help in aligning project teams on their roles and responsibilities using fuzzy logic consensus-based aggregation approaches.

1.3 Research Objectives

The overall aim of this thesis is to develop a framework consisting of data collection, the aggregation of experts' opinions, and consensus reaching by building and measuring consensus between experts in a linguistic framework, which addresses the limitations of the commonly used statistical approaches for aggregating opinions by incorporating fuzzy logic. This framework, the Fuzzy Consensus Building Framework (FCBF), introduces a model that provides project owners with a useful tool that incorporates consensus and the quality of project teams in determining their fundamental roles and responsibilities in a given project delivery system. The detailed objectives of this research can be listed as follows:

- To propose a flexible methodology, based on expert judgment and fuzzy consensus aggregation, that helps project teams gather information and reach agreement (be aligned) on their roles and responsibilities in a given project delivery system.

- To classify the quality of experts by defining an importance weight factor for each expert, which is used to weight his or her response during aggregation based on his or her attributes: years and diversity of experience, role and years in role in the company, and enthusiasm and willingness to participate.

- To incorporate a fuzzy consensus measure in decision-making that allows experts to measure and reach an adequate level of consensus when deciding on their individual responsibilities.

- To use a literature review and expert judgment to create and classify a standardized template of project and construction management tasks, which can be used by both the owner and its contractors as the basis for determining their roles and responsibilities in a given project delivery system.

- To verify the reliability of the proposed fuzzy consensus model by undertaking three case studies and illustrating the results of the model's outputs.

The case studies demonstrate how the Fuzzy Consensus Building Framework (FCBF) can be utilized by a group of project owner organizations in the field of oil and gas to involve their project teams in deciding on the extent of their new roles and responsibilities in an owner-customized project delivery system (PDS), namely owner managing contractor (OMC). The framework is applied as a tool for early alignment of the different project teams on the extent of their new roles and responsibilities, by building consensus and resolving conflicts that may arise between them in the decision-making process. The OMC project delivery system is discussed in this thesis as a case study because the literature did not provide a clear roles and responsibilities structure that could guide the owner and its contractors in deciding their OMC roles and responsibilities. A previous study by Elbarkouky and Fayek (2009) provides a basic understanding of the OMC project delivery system, which is similar in nature to the construction management (CM) approach, yet it encourages owners to rely less on the use of external expertise, such as CM consultants or EPCM contractors. The OMC is also different from partnering (Chan et al. 2003), as it allows the owner to manage its projects using its internal resources for most project functions.

1.4 Expected Contributions

This thesis extends the fuzzy set application in the construction domain by providing a Fuzzy Consensus Building Framework (FCBF) that incorporates the use of fuzzy consensus approaches to solve a construction industry problem. This research is practical and unique in that it integrates different fuzzy consensus approaches in a comprehensive framework to establish a roles and responsibilities structure of project teams in any project delivery system, a framework which has not been previously attempted. The FCBF creates a more powerful modeling tool capable of aligning project teams and reducing conflicts in the assignment of the responsibility of tasks between the owner and its contractors as early as the project initiation phase. Thus, the project teams can concentrate on the work to be done, rather than dealing with responsibility conflicts during project execution. The FCBF introduces a model that is relevant to researchers, and makes various academic contributions and industrial contributions to the construction industry as follows:

1.4.1 Academic Contributions

- The proposed FCBF improves on previous fuzzy consensus approaches to aggregate experts' opinions in decision-making using linguistic assessment in order to overcome the limitations of the commonly used statistical approaches for aggregating opinions by incorporating fuzzy logic.

- The proposed FCBF incorporates the subjective quality aspects of experts in decision-making using a fuzzy expert system, which improves on previous approaches that rely on subjective assessments for experts' weights in aggregating their opinions.
- The proposed FCBF incorporates a fuzzy consensus measure that supports consistency in decision-making by allowing experts to measure and reach an adequate level of consensus linguistically, which guides the experts on their level of consensus in every round of the consensus reaching process.

1.4.2 Industrial Contributions

- The proposed FCBF contributes to industry by combining fuzzy logic, the Delphi approach, and expert systems in a comprehensive framework to ensure early alignment between the project teams on their proper roles and responsibilities in any project delivery system.
- The proposed FCBF accounts for the subjective opinions of multiple experts in classifying project roles and responsibilities, as well as the quality of experts, to develop a valuable decision support tool for construction project owners for determining their roles and responsibilities in any project delivery system.
- The proposed FCBF introduces a standardized template of project and construction management tasks, which can help the owner and

its contractors in determining their roles and responsibilities in a given project delivery system.

- The proposed FCBF supports the creation of membership functions to represent the extent of the roles and responsibilities of project owners versus their contractors, using a three-step Delphi consensus approach.
- The concept of fuzzy preference relations is applied as an extension to the FCBF that provides the owner with an additional tool that measures the degree of consensus of its experts on any perceived shared responsibilities, and thereby reduces potential conflicts between project teams.

1.5 Model Components and Research Methodology

The proposed model is composed of four main components:

- Data collection strategy and methods, in which an integrated standardized template of project and construction management tasks is developed to help project teams determine the different extents of their roles and responsibilities for each task in a given project delivery system, using a fuzzy linguistic rating scale and a web-based survey questionnaire.

- Modified similarity aggregation method (SAM), which proposes an algorithm that aggregates the linguistic assessments of experts regarding the extent of their roles and responsibilities. The modified

SAM determines which managerial tasks are the responsibilities of the owner versus its contractors, and which are shared responsibilities.

- Fuzzy expert system (FES), which classifies the quality of experts by defining an importance weight factor for each expert. The importance weight factor is used to weight each expert's response during aggregation, based on individual attributes.
- Fuzzy preference relations consensus (FPRC) approach, which is used to reduce conflicts that arise when the modified SAM determines tasks should be shared between the owner and its contractors, and tests the possibility of transferring any of the shared tasks to either the owner or its contractors. This component of the model creates a fuzzy consensus measure that identifies the degree of consensus among different experts at every stage of the consensus reaching process.

The research study is conducted in six stages:

Stage 1 involves the collection of data and a literature review of project management (PM) and construction management (CM) tasks that can be used by both the owner and its contractors as the basis for classifying and determining roles and responsibilities for project teams in a given project delivery system. A standardized template of the proposed

PM and CM tasks is created based on the literature review of standard project delivery systems, work structures, and expert judgment.

Stage 2 involves the preparation of a structured web-based survey that solicits experts' opinions to rate the PM and CM tasks in terms of the extent of the responsibility of the owner versus its contractors. This survey uses a standardized problem elicitation approach, which attempts to extract meaningful information from experts. A three-step Delphi approach helps create the fuzzy rating scale that is used to rate the extent of the roles and responsibilities of the owner versus those of its contractors linguistically.

Stage 3 involves the creation and application of the fuzzy expert system (FES), which defines an importance weight factor for each expert, based on his or her attributes: years and diversity of experience, role and years in role in the company, and enthusiasm and willingness to participate. This factor is used to weight each expert's response during aggregation. Direct interviews and a survey questionnaire are used to define and collect information on the input and output variables of the FES. The shapes of the membership functions of the input and output variables are determined using the modified horizontal approach combined with an interpolation technique (Marsh 2008). The survey questionnaire also helped in ranking the input variables in terms of their influence on the output variable, which facilitated the creation of the knowledge base of fuzzy if-then rules that connect the inputs to the output.

FuzzyTECH® is used as an interface that automatically generates the rules based on the influence of the input variables on the output.

Stage 4 involves combining the fuzzy similarity aggregation method (SAM) (Hsu and Chen 1996)—which is modified in the FCBF to support aggregation of responses in a linguistic framework—with the output importance weight factor of experts from stage three to aggregate experts' responses, which are collected in stage two. The output of this stage is a preliminary classification of the extent of the roles and responsibilities of the owner versus its contractors. The results of this stage are listed on one of three task lists, namely owner responsibility, contractors' responsibility, and shared responsibility.

Stage 5 involves the application of the fuzzy preference relations consensus (FPRC) approach to perceived shared tasks between the owner and its contractors, using expert judgment in a consensus reaching process. The FPRC approach allows the owner and its contractors to measure the degree of consensus of their experts linguistically regarding whether a shared task should be shifted to the owner's responsibility, shifted to the contractors' responsibility, or remain shared. This approach allows experts to compare their linguistic information on pairs of responsibility alternatives, similar to the Analytical Hierarchy Process (AHP) (Saaty 1980), which is efficient and practical in resolving conflicts between experts' opinions on a set of similar alternatives. A fuzzy preference scale is created using the modified horizontal approach combined with an interpolation technique (Marsh 2008), which helped experts to compare their linguistic preferences on pairs of responsibility alternatives. A survey questionnaire is used to collect information on the shapes of the membership functions that form the scale. The degree of consensus among experts is determined using a fuzzy linguistic consensus measure, which helps monitor the consensus status amongst experts before determining their final aggregated preferences on each pair of responsibility alternatives for every perceived shared task. The three task lists that are created in stage five are updated accordingly.

Stage 6 involves the demonstration of the results of the integrated model, in terms of final responsibility assessments, which are presented and compared to actual responsibilities in successful large oil and gas construction projects to illustrate the validity and the suitability of the model.

1.6 Thesis Organization

Chapter 1 provides background and a statement of the problem. This chapter also explains the expected contribution and the methodology of this research.

Chapter 2 contains the literature review of previous research studies conducted on fuzzy consensus approaches.

Chapter 3 explains the steps involved in data collection: creation of a standardized template of the proposed project and construction management tasks, development of the structured web-based survey, and creation of the fuzzy linguistic rating scale that is used to rate the extent of the roles and responsibilities of the owner versus that of its contractors with the aid of the web-based questionnaire.

Chapter 4 demonstrates the methodology and application of the fuzzy expert system (FES) to define an importance weight factor for each expert, which is used to weight his or her response during aggregation.

Chapter 5 explains the methodology and application of the modified fuzzy similarity aggregation method (SAM) and the application of the fuzzy preference relations consensus (FPRC) approach to aggregate experts' opinions.

Chapter 6 explains the application of the FCBF model to three case studies and the final results of the thesis, which includes the methodology of model testing and validation of its output results based on the case studies.

Chapter 7 describes the conclusions of this research, the contribution, limitations, and recommendations for future research.

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2. Chapter Two - Literature Review

2.1 Introduction

There is a wide variety of fuzzy logic-based consensus approaches that have been discussed in the literature; each has its own merits. The origins and perspectives from which the concept of fuzzy logic-based consensus approaches has been developed are presented in this chapter, in order to determine a proper aggregation method, based on the consensus of experts, which is applicable to the problem at hand. First, an overview of the statistical-based aggregation approaches is presented. This overview explains why the statistical methods may not be the best approach to allow for the alignment of project teams on the extent of their roles and responsibilities in a given project delivery system. Then, fuzzy logic-based consensus approaches are discussed in terms of their applicability to solve the problem. Finally, a summary table compares the different statistical and fuzzy logic-based consensus approaches, and the fuzzy logic-based consensus approach that best solves the problem is determined.

2.2 Overview of Statistical-Based Aggregation Approaches

In general, there is a lot of associated uniqueness and uncertainty that may affect the decision-making process in the construction industry, especially when it comes to determining the roles and responsibilities of project teams in a given project delivery system, which is a very important decision that may affect the success of any project (Karamouz and Mostafavi 2010). Under these circumstances, decision-makers often rely on expert opinion when making decisions (Tam et al. 2002). Many factors may affect experts' opinions, such as differences in their personalities, perception, and problem subjectivity level, which is very difficult to deal with because of the limited abilities of humans (Karamouz and Mostafavi 2010). According to Predd et al. (2008), two major problems may affect the decision-making process: the elicitation problem and the aggregation problem. Predd et al. (2008) defined the elicitation problem as a problem that "requires the decision-makers to extract meaningful information from a group of experts", while they described the aggregation problem as a problem that "requires the decision-makers to combine experts' subjective opinions by resolving disagreements."

The stage of problem elicitation requires defining a structured approach for data collection that deals with the imprecision and elusiveness that are inherent in making a subjective opinion. Wright and Bolger (1992) stated "recent developments in expert and intelligent decision support systems require providing quality information elicitation in order to obtain quality results out of an intelligent model," which implies that the problem of elicitation needs a method that classifies the quality of each expert in order to reflect his or her importance or credibility in decision-making. This method should be also capable of dealing with the qualitative aspects in defining the level of expertise and knowledge of the experts.

The aggregation problem requires combining experts' beliefs and resolving disagreements in opinions, in order to determine their collective opinion, which may be expressed either numerically or linguistically in a group decision-making problem (Predd et al. 2008; Herrera et al. 1996). Herrera et al. (1997) defined the group decision-making problem as "a decision situation in which there are two or more experts, and each of them is characterized by his or her own perception, attitudes, motivations, and personalities; recognizes the existence of a common problem; and attempts to reach a collective decision." Thus, the bottom line of any decision-making problem is to reach a final decision—under all these circumstances—that may represent a collective opinion of all experts. That decision can be reached either through statistical-based aggregation approaches, or consensus-based models.

There are many statistical-based aggregation approaches that have been proposed in the literature to aggregate experts' opinions. Some of these approaches, such as linear averaging, are simple in application.

Others are relatively complicated, and may involve using statistical aggregation algorithms. These algorithms apply several mathematical operations or optimization techniques, such as the scalable algorithm of aggregation (SAA) (Predd et al. 2008)—which is discussed later in this section—to aggregate experts' opinions.

Simple statistical-based aggregation approaches may involve equal weighting of experts' opinions, and usually assume no bias in opinions in order to give valid results. However, when experts are suspected to have some degree of bias, then the errors of one expert may be shared by some other experts as well (Hallowell and Gambates 2010). In this situation, simple statistical aggregation approaches would be "centering upon the mean of erroneous judgment rather than the true value" (Reagan-Cirincione and Rohrbaugh 1992). An example of simple statistical-based aggregation approaches is the linear averaging method. Its simplicity, clear justification, and "documented empirical success" (Predd et al. 2008) make it a popular method for aggregating experts' opinions that have been collected using surveys (Genest and Zidek 1986; Clemen and Winkler 1999). The linear averaging approach aggregates experts' opinions by assigning equal weights to their assessments to determine an average value, which is expressed as the sum of their assessments divided by their number. For example, if three experts provided their numerical assessments as 3, 5, and 7, then their aggregated opinion would be calculated as (3+5+7)/3 = 5. Although linear averaging approach has been applied to aggregate experts' opinions in many applications, it suffers from several limitations. The major problem that limits use of linear averaging—or any other simple statistical approach, such as use of mode, geometric mean, or median—is its inability to provide a concrete decision if experts are incoherent on their respective domains, or their opinions are inconsistent within the group (Predd et al. 2008). In this regard, Stevens (1951) described the process of using simple statistical approaches to aggregate experts' opinions as a "frustrating business" because of the "fluctuating" behaviour of experts.

In general, inconsistency or incoherence between experts is one of the major challenges that contribute to the problem of deciding on the roles and responsibilities of project teams. This is mainly because the extent of the roles and responsibilities of project teams may overlap, which may create some conflicts between experts on making their individual judgment. The calculation of the skewness coefficient and standard deviation around the average may demonstrate the problem, yet shall not provide an undisputed decision with regard to whether the final judgment may represent a collective opinion of the experts. As a solution for the problem, researchers may work to maintain coherence within experts using different elicitation techniques (Alpert and Raiffa 1982). For example, Von Winterfeldt and Edwards (1986) dealt with the problem of incoherence by soliciting convergent assessments from experts and instilling consistency among them, rather than following the statistical approaches. Conversely, Dalkey and Helmer (1963) used the Delphi technique, which helped experts reach common agreement on their individual opinions. Arguably, elicitation techniques may be considered excellent strategies that can be adopted before applying a given statistical approach to aggregate experts' opinions, as elicitation techniques encourage reaching a semi-consensus state between experts before aggregation. However, most elicitation techniques require "nontrivial interaction" between the experts and the researcher (Predd et al. 2008), which may not be viable if the surveys solicit extensive responses from a large number of experts on several domains of a given problem. Furthermore, according to (Predd et al. 2008), there may be situations where the necessary "training and direct communication" are not efficient. In conclusion, investigating methods that can aggregate incoherent opinions is a fundamental issue, which Predd et al. (2008) and Osherson and Vardi (2006) have previously addressed by using statistical aggregation algorithms.

Osherson and Vardi (2006) proposed a coherent approximation principle (CAP) that could be applied to inconsistent experts' forecasts. Using the least square method, Osherson and Vardi (2006) determined a coherent forecast that accommodated the forecasts of individual experts by incorporating constraints to their relative opinions. Coherent approximation principle (CAP) proposes that the coherent forecast of a given expert should lie within the limits of those constraints. According to

Predd et al. (2008), CAP provides results similar to those of the linear average method if the experts are consistent on their domains. The coherent approximation principle (CAP), however, is considered a complex statistical aggregation approach that is difficult to implement and is limited by constraints (Predd et al. 2008), it only deals with problems related to aggregating judgments about numerical quantities, and it does not deal with vague or imprecise linguistic concepts.

Predd et al. (2008) have developed an optimization aggregation tool for implementing CAP: a scalable algorithm of aggregation (SAA). This tool is unique in that implements an index that incorporates the credibility of experts in the decision-making process, yet It is similar to CAP in that it deals with incoherent and abstaining experts. According to Predd et al. (2008), SAA proposes a practical methodology for expert elicitation in which experts have no constraints in choosing the events they assess, which addresses the limitations of CAP. Although this approach is practical and more precise than CAP, it deals with problems of numerical basis, such as project forecasting and cost estimation. It does not allow for the vagueness and the imprecise nature of the problem of overlapping opinions between experts. Moreover, since this approach does not build consensus or measure the level of consensus between experts during the data elicitation stage, it may not encourage the project teams to agree on their overlapping roles and responsibilities that are defined linguistically.

Furthermore, Wright and Bolger (1992) stated that aggregation of expert judgment given in a qualitative manner for alternatives is favoured over using quantitative statistical approaches when "sufficient data are not available, when dependant variables cannot be dealt with in isolation, when the data gathered changes over time, when experts are biased, and when precision is not a factor in deciding on an opinion as opposed to giving a simple judgment under uncertainty or vagueness." Some of these challenges are inherent in dealing with the problem of aggregating experts' opinions on the extent of their roles and responsibilities in a given project delivery system. As such, the problem of aggregating experts' opinions under the aforementioned circumstances requires a tool that accounts for the vagueness and uncertainties that are inherent in experts' judgment (Kickert 1978). This tool should also account for incorporating consensus and quality of project teams in determining their fundamental roles and responsibilities. As such, the problem of aggregation can be dealt with successfully by means of fuzzy logic-based consensus tools (Bahat 1982; Kuncheva and Krishnapuram 1996), which stem from the pioneering work by Zadeh (1965) on fuzzy sets.

2.3 Fuzzy Logic-Based Consensus Approaches

The concept of aggregation of fuzzy opinions to reach consensus has been discussed in the literature in many forms using different methods. Kuncheva and Krishnapuram (1996) have described the notion of consensus as "one class of aggregation paradigms (i.e., obtaining a general agreement on an opinion), which is mainly required under the uncertainties found in any decision-making problem.” The relevant literature discusses various methods to aggregate experts’ fuzzy opinions to reach consensus. In general, these methods fall under one of the following categories:

- Category One: Combining opinions, given in the form of fuzzy numbers, using either additive or non-additive non-probabilistic methods (Bardossy et al. 1993; Kuncheva and Krishnapuram 1996)
- Category Two: Using interval values to represent experts’ opinions (Dubois, Kerre, and Mesiar 2000; Ishikawa et al. 1993; Xu and Zhai 1992)
- Category Three: Using fuzzy similarity measures to aggregate experts’ opinions (Rezaei et al. 2006; Lee 2002; Hsu and Chen 1996; Zwick et al. 1987)
- Category Four: Using fuzzy social or individual preference relations to aggregate fuzzy opinions and measure consensus between experts (Herrera and Herrera-Viedma 2000a and b; Herrera et al. (1996,1997); Herrera and Verdegay 1993; Kacprzyk et al. 1992; Kacprzyk and Fedrizzi 1988; Kacprzyk and Roubens 1988; Tanino 1984; Nurmi 1981; Spillman et al. 1979; Bezdek et al. 1977, 1978, and 1979; Blin 1974)

The methods classified in each category have been reviewed in order to determine the appropriate method or combination of methods that may ensure that the aggregated opinion is a result of common agreement between experts, which would help in aligning project teams to their roles and responsibilities. The advantages and disadvantages of each method are highlighted based on the applicability of each method to solve the aggregation problem at hand.

The methods discussed in category one by Bardossy et al. (1993) outlined several approaches for combining the opinions of different experts by means of fuzzy numbers representation. Bardossy et al. (1993) defined five techniques for combining fuzzy numbers into a single fuzzy number estimate: crisp weighting, fuzzy weighting, minimal fuzzy extension, convex fuzzy extension, and mixed linear extension. The methods discussed by Bardossy et al. (1993) proposed simple fuzzy arithmetic approaches to aggregate experts' opinions. The major gap in the work by Bardossy et al. (1993) is that it did not address a particular method that ensures the aggregated opinion is a result of common agreement. Also, Bardossy et al. (1993) did not consider measuring consensus during the decision-making process, which was the same limitation of the work by Kuncheva and Krishnapuram (1996) in their efforts to determine a fuzzy consensus aggregation operator. Finally, although Bardossy et al. (1993) incorporated the quality of experts in decision-making by assuming subjective importance weights of experts, they did not provide a method to calculate these weights. Thus, the above methods are not applicable to the problem at hand.

The methods discussed in category two were introduced by Ishikawa et al. (1993) and Xu and Zhai (1992), who proposed interval values to represent judgment of experts. Xu and Zhai (1992) proposed that each expert represents his subject judgment by an interval value rating of each criterion for each alternative. Then, they constructed a cumulative frequency distribution to derive a group consensus judgment. Based on the work of Xu and Zhai (1992), Ishikawa et al. (1993) identified two types of membership functions that may decrease the time required for conducting repeated surveys to gather experts' opinions. They used the Delphi technique to reach a duration forecast under consensus by implementing the max-min fuzzy Delphi method and the Delphi method via fuzzy integration. Results were compared with the results obtained from the traditional Delphi approach to validate the proposed methods. The ordinary Delphi method applied a three-point estimation method to forecast values. This estimation method helped in constructing triangular membership functions. Then, the distance between the expected values and those provided by each expert were computed. If a distance that would satisfy a given "convergence criterion" was found, the process was considered complete and the corresponding expected value became a forecast value. It should be noted that the Delphi fuzzy method has some advantages over the ordinary Delphi method. For example, the findings successfully dealt with imprecision and vagueness of the collected data, the number of survey rounds were relatively reduced, and the individual attributes of the expert were classified in the model. However, the process still requires repetitive and time-consuming numbers of surveys. Also, the applied algorithms are more efficient in dealing with forecasting numerical values, such as time units, rather than aggregating opinions on a set of alternatives that are defined linguistically, which make these algorithms unsuitable to solve the problem at hand.

The methods classified in category three proposed use of fuzzy similarity measures to aggregate experts' opinions that can be either expressed numerically or linguistically. Similarity measures are used to classify similar elements or distinguish between similar groups of individual decisions to ensure that the aggregated opinion is a result of common agreement (Rezaei et al. 2006). Fuzzy similarity measures, which reflect consensus in the aggregated decision, are easy to implement. These measures apply mathematical models to fuzzy numbers to compute an aggregated fuzzy opinion, which is based on similarity agreement between experts' opinions. The major advantage of these techniques is that they can be directly applied to various fuzzy opinions of an unlimited number of experts on several alternatives, and can still provide a reasonable consensus decision. The major gap in the approaches classified under this category is that they do not measure the level of consensus between experts in each stage of data collection. Instead, they aggregate only the experts' opinions that exhibit a high level of consensus regarding their decision, and exclude those whose decisions are far from common agreement.

Hsu and Chen (1996) proposed a similarity aggregation method (SAM) to aggregate fuzzy opinions under group decision-making. SAM is a simple algorithm that is based on fuzzy arithmetic and similarity agreement, which was used to aggregate numerical forecasts made by experts. Hsu and Chen (1996) developed a procedure to aggregate experts' forecasts by defining an "index of consensus" of each expert to the other experts using a similarity measure function, which was previously developed by Zwick et al. (1987). Then, they aggregated experts' opinions by combining this index of consensus with an importance weight factor, which they assumed for each expert. Although SAM was used in forecasting problems using fuzzy numbers, it can be modified to aggregate experts' opinions in a linguistic environment. Nevertheless, there are some gaps in the methodology presented by Hsu and Chen (1996) that need to be addressed before applying the SAM algorithm to aggregate experts' opinions, which are expressed linguistically to describe different extents of the roles and responsibilities of the project teams in the problem at hand. First, Hsu and Chen (1996) did not explain clear methodology to construct membership functions (MFs) that would represent individual experts' linguistic opinions. Although they mentioned that the Delphi approach could be used to identify the overlap between fuzzy numbers, they did not provide a detailed procedure to collect data from experts regarding their shapes and supports. They rather implied that each expert might assume an arbitrary trapezoidal shape of the fuzzy number that would represent his or her individual opinion (Hsu and Chen 1996). Second, Hsu and Chen (1996) did not discuss a method to determine how close or far the aggregated fuzzy number is from the original fuzzy opinions, which is one of the major challenges in applying SAM in a linguistic environment to derive a meaningful output. Finally, Hsu and Chen (1996) used weighting criteria to incorporate the quality of experts in the aggregation procedure, yet they did not define a clear methodology to determine these weights. In conclusion, the lack of proper definition of the shapes of the fuzzy numbers may prevent the user from obtaining meaningful aggregation results, while the overall methodology, as outlined by Hsu and Chen (1996), cannot be applied to linguistic variables, which need some modifications to be applied to the problem at hand.

By contrast, Lee (2002) proposed an iterative optimization procedure, the optimal aggregation method (OAM), to aggregate individual fuzzy opinions into an optimal consensus opinion. The optimization analytical procedure adopted by Lee (2002) is similar to that of the fuzzy c-means problem (Bezdek 1981). According to Lee (2002), "a criterion of optimal consensus was given and an iterative algorithm" was proposed to determine a final decision that entails consensus between experts. Experts' opinions were given in the form of trapezoidal fuzzy numbers.

Lee (2002) then used OAM to calculate an "optimal approximated aggregation weight" for each expert opinion by calculating the minimum distances between the fuzzy numbers given by experts (Dubois et al. 2000). As opposed to SAM, OAM did not consider the overlap between the fuzzy numbers in calculating the optimal aggregation weights of experts. Thus, it can be best used in dealing with situations where the supports of the fuzzy numbers, or membership functions, do not intersect. This is not the case in the problem at hand, due to the overlapping nature of the different extents of the roles and responsibilities of project teams (e.g., sole responsibility, significant involvement, limited involvement, etc.). In other words, OAM could be best applied to the category of problems that does not involve an overlap between the meanings of the linguistic terms on a fuzzy scale. The optimal aggregation method (OAM) also incorporated an importance weight factor of each expert in aggregating his or her final decision. However, the importance weights of experts were assumed by Lee (2002) in a subjective manner, which is considered a gap in Lee's approach, similar to that of Hsu and Chen (1996). Also, Lee (2002) did not consider developing a fuzzy linguistic scale to reflect experts' linguistic opinions, which is another limitation of his approach. Finally, although Lee (2002) asserted that the OAM algorithm might provide a "better optimal" than "just correct" solution, OAM is time-consuming and complicated compared to SAM, as it involves conducting several iterations to reach an arguably optimal solution. Dubois et al.

(2000) supported this argument, mentioning that it is very difficult to determine which similarity aggregation approach is optimal since approximation is inherent in fuzzy set theory. Furthermore, the similarity between experts' opinions also depends on their subjective point of view (Rezaei et al. 2006) and their importance weights (Hsu and Chen 1996; Lee 2002), which are all determined based on approximation. In conclusion, OAM cannot be the best approach to apply to the problem at hand, as compared to SAM.

Category four presents fuzzy preference relations consensus approaches that are different from the similarity agreement approaches to aggregate fuzzy opinions. Most of the fuzzy preference relations consensus approaches propose solving the problem of disagreement between experts by means of a consensus reaching process (Tanino 1984; Carlsson et al. 1992; Kacprzyk et al. 1992; Mich et al. 1993; Herrera and Verdegay 1993). Fuzzy preference relations depend mainly on collecting numerical or linguistic data in the form of preference ratings for pairs of alternatives in order to form a matrix of preferences. This allows experts to compare the alternatives in pairs rather than making absolute ratings, which is similar to Saaty's (1980) analytical hierarchy process (AHP). Pairwise comparison becomes more efficient and practical when it comes to resolving conflicts between experts on a final decision from a set of similar alternatives. Consensus degrees are then calculated to determine the level of consensus between experts on their aggregated preferences on the pairs of alternatives, which facilitate consensus reaching by identifying and reducing the conflicts between experts during the aggregation of their opinions.

The main advantage of using fuzzy preference relations over similarity aggregation methods is that fuzzy preference relations can be directly applied to aggregation problems that are addressed in a linguistic environment. Also, fuzzy preference relations consensus approaches enable measuring the level of consensus of experts on a given opinion because they are conducted in a consensus reaching process. However, most of these approaches are iterative in nature and may require conducting several consensus rounds between experts before aggregating the final opinion on a given alternative. As such, these approaches might not be efficient if the numbers of experts or alternatives are large, because the required consensus rounds will increase drastically.

Historically, there were several attempts to define the concept of fuzzy preference relations, which did not create a comprehensive framework that aggregates linguistic opinions or measures consensus. For example, Blin (1974) proposed to represent a relative group preference as a fuzzy preference matrix from individual preferences. Fung and Fu (1975) outlined the concept of aggregation of individual preferences into a group preference from an "axiomatic" point of view. Bezdek et al. (1977, 1978, and 1979) developed scalar measures of consensus in the space of fuzzy preference relation matrices, and considered ways of determining a group preference between experts. Kuzmin and Ovchinnikov (1980) introduced a distance measure in the space of fuzzy relation matrices, and analysed the group decision-making problem.

Nurmi (1981) was one of the leaders in applying the concept of fuzzy preference relations in a comprehensive framework to aggregate experts' opinions. He presented basic fuzzy solution concepts to solve collective decision-making problems using individual and group fuzzy preference ordering. He summarized the uses of fuzzy preference relations in the collective decision-making process and described the reciprocal nature of the fuzzy preference relations in a non-linguistic environment. Moreover, Nurmi (1981) described some basic relevant terms that are considered the basis for all recent papers, which recommended fuzzy preference relations as a powerful tool in reaching collective decisions on a set of alternatives. Although Nurmi (1981) did not provide a comprehensive model to solve group decision-making problems, his paper was considered one of the basic historical efforts that introduced the concept of fuzzy preference relations to reach collective agreements or decisions. On the basis of the work by Nurmi (1981), Kacprzyk and Fedrizzi (1988) and Kacprzyk and Roubens (1988) outlined the fundamentals of using fuzzy preference relations in group decision-making using numerical preference values that were assessed on an interval of 0 to 1. Kacprzyk and Fedrizzi (1988) pointed out the main advantage of using fuzzy preference relations over subjective probability of occurrence of an event by stating that the concept of fuzzy preference relations provides a "more general and richer representation of individual testimonies."

One of the leading models that applied a significant measure of consensus to resolve conflicts between experts was introduced by Kacprzyk et al. (1992). They measured the level of consensus of experts on a set of numerical preference values based on individual fuzzy preference relations and calculus of linguistically quantified propositions. Linguistically quantified propositions were first introduced by Zadeh (1983), and may be exemplified using the following examples: "most engineering students are intelligent" or "almost all engineering students are good in mathematics" and they may be generally written as (Q *y*'s are F). Where Q is a linguistic quantifier, $Y=\{y\}$ is the set of experts, and F is a property (e.g., intelligent). Kacprzyk et al. (1992) proposed use of non-strict proportional fuzzy linguistic quantifiers, such as "*as most as"* and *"almost all"* to measure the level of consensus between experts (linguistically) based on the concept of fuzzy majority. Non-strict quantifiers, such as "*as most as*" are those quantifiers that do not represent an exact value, which are different from strict quantifiers that represent an exact value, such as "*all*" or "*exactly half.*" The concept of fuzzy majority is one of the basic elements underlying group decision-making (Kacprzyk et al. 1992). It stipulates that a given opinion is deemed acceptable by the group as a whole if the majority or the largest group of its members agree to it, since in no real situation would it be accepted by all. For example, the linguistic quantifier *“at least half”* represents a very strict representation of the majority, which the user may accept if 50 percent of the number of experts agreed on a given opinion. The main gap, however, in the work by Kacprzyk et al. (1992) is that some experts may not be able to determine an exact numerical value for their preferences on pairs of responsibility alternatives, which makes it more practical to use linguistic assessments rather than numerical values in determining the preferred responsibility alternative. Nevertheless, the work by Kacprzyk et al. (1992) set the foundation for creating the linguistic models introduced by Herrera et al. (1996,1997) that enabled the aggregation of linguistic assessments using fuzzy linguistic preference relations.

Herrera et al. (1996, 1997) created several consensus measures that were used to measure the level of consensus of experts using fuzzy linguistic preference relations instead of numerical values. They also described additional consistency measures to evaluate individuals’ distances from common opinion using a fuzzy linguistic preference scale, and applied the importance weight of experts in calculating their consensus degrees using linguistic terms instead of numerical values. Herrera et al. (1996, 1997) incorporated the importance weight of experts in determining the consensus degrees on pairs of alternatives using the minimum operator. The minimum operator was applied between the average importance weight of experts and the frequency of their responses relative to their total number. The major limitation in using the minimum operator is that it only considered the minimum value between the average importance weight of experts, and their frequency of responses, in calculating the consensus degrees. This means that if the value of the average importance weight of experts is less than the value that represents their frequency of responses, then their frequency of responses will not be considered in determining their consensus degree for a certain opinion. Another gap in the work by Herrera et al. (1996, 1997) is that the researchers did not involve experts in determining the shapes of the membership functions (MFs) of the fuzzy linguistic preference scale, which they determined based on the assumption that the MFs may have symmetrical standardized shapes. These gaps need to be addressed in order to apply the fuzzy preference relations consensus approach proposed by Herrera et al. (1996, 1997) to the problem at hand. Finally, Herrera and Herrera-Viedma (2000a) outlined steps and classified different approaches for solving decision-making problems using linguistic information in terms of the choice of the linguistic term set, the choice of the aggregation operator, and the choice of the best alternatives. Their classification provided an integrated summary of previous research efforts that used a consensus reaching process in group decision-making. Table 2.1 summarizes the methods discussed in this chapter, and briefly describes each method, and its limitations and applicability in dealing with the aggregation problem at hand.

Based on the results of the literature review and the comparison of different methods, in terms of their limitations and applicability to solve the aggregation problem at hand, the similarity aggregation method (SAM) is selected as the most appropriate method to aggregate experts' opinions in the Fuzzy Consensus Building Framework (FCBF). First, SAM uses a flexible aggregation algorithm that can be modified to aggregate the overlapping meanings of experts' linguistic assessments of the project teams' roles and responsibilities. Second, it ensures that the aggregated opinion is based on common agreement between experts, ensuring early alignment of project teams on the roles and responsibilities of the owner versus those of its contractors. Third, it incorporates the importance weights of experts in the aggregation algorithm; these weights can be computed using a standalone model. In order to address its limitations in solving the problem at hand, SAM is modified (Elbarkouky and Fayek 2010a) and the modifications are summarized as follows:

- A standard fuzzy linguistic rating scale is created, on which project teams define different extents of the roles and responsibilities of the project owner versus those of its contractors, using linguistic terms.

- A standalone fuzzy expert system (FES) is created, to determine an importance weight factor for each expert in the decision-making process, rather than subjectively assuming expert weights.
- The importance weight factor of each expert (output of FES) is combined with his or her consensus weight factor in SAM; this produces an aggregated fuzzy number, depicted on the fuzzy linguistic scale.
- The Euclidean distance measure function (Heilpern 1997) is used to determine the best linguistic term for the aggregated fuzzy number (output of the SAM algorithm) to derive a meaningful linguistic output of SAM. The linguistic term whose MF has the minimum Euclidean distance to the aggregated fuzzy number describes the final extent of the roles and responsibilities of the project owner versus its contractors for a given task.

Based on the aggregated extent of responsibility (output of SAM), the task is classified under one of three responsibility task lists: the owner's, contractors', or shared responsibility task list (Elbarkouky and Fayek 2010a).

Table 2.1. Comparison of different aggregation methods of experts' opinions

Category	References	Description	Limitations	Applicability
Simple Statistical-Based Aggregation Approaches	Stevens 1951; Genest and Zidek 1986; Clemen and Winkler 1999; Elbarkouky and Fayek 2009	• Simplistic statistical-based aggregation approaches are simple aggregation techniques, which can be applied to aggregate experts' opinions that are collected using surveys. • Example: Simple Averaging Technique	• Simplistic statistical-based aggregation approaches can aggregate judgments about numerical quantities, but they cannot deal with vague or imprecise linguistic judgments. • In case of inconsistent or biased experts, some simplistic statistical approaches center upon the mean of erroneous judgment rather than the opinion that entails common agreement.	• Not applicable to aggregate linguistic opinions. Also, the aggregation problem at hand requires a tool that account for the vagueness and uncertainties inherent in expert judgment. • These methods cannot be used to reduce conflicts between experts, as they consider neither the level of agreement between experts in aggregating their opinions, nor the need for consensus reaching.
Statistical-Based Aggregation Algorithms	Osherson and Vardi 2006; Predd et al. 2008	• Statistical-based aggregation algorithms apply optimization methods or weighted average techniques to aggregate the opinions of incoherent or inconsistent experts. • Examples: CAP, SAA	• Most of the statistical-based aggregation algorithms are iterative in nature and may be computationally difficult to implement. • These algorithms are not designed to aggregate judgments about imprecise linguistic concepts.	• Not applicable to the problem at hand because these approaches do not account for the vagueness and uncertainties that are inherent in the linguistic judgment of experts.

Table 2.1. Comparison of different aggregation methods of experts' opinions (continued)

Category	References	Description	Limitations	Applicability
Fuzzy Interval Values	Dubois et al. 2000; Ishikawa et al. 1993; Xu and Zhai 1992	• These methods propose that each expert shall provide his or her forecast using interval value rating, and then a cumulative frequency distribution is constructed to derive a group consensus judgment. • Example: max-min fuzzy Delphi method	• These approaches are applicable to forecasting problems where experts may provide their forecasts numerically. • These methods require repetitive and time-consuming numbers of surveys for the purpose of data collection.	• These approaches are not applicable to the aggregation problem at hand because they do not aggregate experts opinions in a fully supported linguistic framework.
Fuzzy Preference Relations	Herrera and Herrera-Viedma 2000a; Herrera et al. 1996 and 1997; Kacprzyk et al. 1992; Kacprzyk and Roubens 1988; Tanino 1984; Nurmi 1981; Spillman et al. 1979; Bezdek et al. 1977, 1978, and 1979; Blin 1974	• Fuzzy preference relations are used to aggregate numerical or linguistic judgments that are collected in the form of fuzzy preference values using a consensus reaching process. • Example: Herrera et al. (1996 and1997) fuzzy linguistic models	• These approaches are iterative in nature and may require conducting several consensus rounds before aggregating the final opinion of experts. • Fuzzy linguistic scales are not created based on experts' opinions. • The importance weights of experts are assumed in a subjective manner.	• The fuzzy preference relations consensus approach proposed by Herrera et al. (1996) can be modified and applied as a second step to reduce conflicts between experts and align the project teams to their roles and responsibilities by measuring the consensus degrees of experts on their opinions in a consensus reaching process.

Table 2.1. Comparison of different aggregation methods of experts' opinions (continued)

Category	References	Description	Limitations	Applicability
Fuzzy Similarity Measures	Rezaei et al. 2006; Lee 2002; Hsu and Chen 1996; Zwick et al. 1987; Elbarkouky and Fayek 2010a	• Fuzzy similarity measures are used to aggregate experts' opinions based on the level of agreement between experts. • Examples: SAM, OAM	• None of these approaches discuss a clear methodology to create fuzzy linguistic scales based on expert judgment. • The importance weights of experts are assumed in a subjective manner.	• SAM can be applied, after introducing proper modifications, as a first step to solve the aggregation problem at hand by incorporating the level of agreement of experts in aggregating their opinion.
Simple Fuzzy Arithmetic Techniques	Bardossy et al. 1993; Kuncheva and Krishnapuram 1996	• These methods combine opinions, given in the form of fuzzy numbers, using either additive or non-probabilistic methods. • Example: Minimal Fuzzy Extension Method	• These methods do not consider consensus in aggregating experts' opinions.	• Not applicable because simple fuzzy arithmetic techniques do not propose a comprehensive approach that may resolve conflicts between experts to help align the project teams.

As a next step, the fuzzy preference relations consensus (FPRC) approach (Herrera et al. 1996) is adopted in this thesis to facilitate consensus reaching by identifying and reducing the conflicts between project teams on their perceived shared tasks. A modifier (λ) (Elbarkouky and Fayek 2010b), which will be explained in chapter 5, is used to determine the degree of consensus of experts instead of using the minimum operator previously proposed by Herrera et al. (1996). Also, the model developed by Herrera et al. (1996) is modified in this thesis to involve project teams in determining the shapes of the membership functions (MFs) of the fuzzy linguistic preference scale, which will be also discussed in chapter 5.

2.4 Conclusion

The literature review conducted in this chapter lays out the theoretical foundation behind this thesis. Different statistical-based and consensus-based aggregation approaches were discussed to determine a viable approach to aggregate the opinions of project teams, to establish the extent of their roles and responsibilities in a given project delivery system. The limitations of every method were explained to determine both the gaps as well as the applicability of each method, in dealing with the problem at hand. Based on the literature review conducted and the comparison of different methods, in terms of applicability to solve the problem at hand, the similarity aggregation method (SAM) is selected to aggregate experts' opinions after proposing proper modifications; a fuzzy expert system (FES) is proposed to determine experts' importance weight factors; and fuzzy preference relations is proposed as an additional step to resolve residual conflicts between experts on perceived shared tasks.

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3. Chapter Three - Data Collection Strategy of Fuzzy Consensus Building Framework

3.1 Introduction

A wide variety of project and construction management guidelines and construction industry standards recommend typical roles and responsibilities of project teams in handling construction projects, based on the project delivery system selected by the project owner organization. However, some owner organizations may need to customize their roles and responsibilities based on a set of predefined criteria, e.g., owners' required competencies to maintain in individual projects (Prahlad and Hamel 1990). A competency is a "work process that is comprised of functions and associated critical capabilities needed to develop or execute a capital project" (Anderson et al. 2004). Project owners also need to ensure project teams' alignment in deciding on their roles and responsibilities in any standard or owner-customized project delivery system, in order to minimize project teams' confusion during the project execution phase. Project teams' alignment can be reached by involving the teams in making a collective opinion on the extent of their roles and responsibilities in a given project delivery system—as early as the project initiation phase—on a predetermined set of tasks.

In order to involve project teams in the decision-making process, a list of standard project management (PM) and construction management (CM) tasks should be introduced by the owner to its project teams to determine the extent of their roles and responsibilities (Anderson et al. 2004). Also, in order to enable the project teams to make their decision in a linguistic framework (since it is more realistic to express different extents of roles and responsibilities using linguistic terms rather than numerical values), a fuzzy linguistic rating scale should be created, to allow project teams to rate the extent of their roles and responsibilities using linguistic terms (Herrera et al. 1996). Developing a list of standard PM and CM tasks, and constructing a fuzzy linguistic scale are two basic components of the Fuzzy Consensus Building Framework (FCBF) proposed in this thesis.

Based on the above, the proposed Fuzzy Consensus Building Framework (FCBF) sets out a data collection strategy and defines data collection methods and tools, which are discussed in this chapter, that enable owner organizations or contractors to solicit the opinions of their project teams in determining the extent of their roles and responsibilities in any project delivery system in a linguistic framework. Figure 3.1 illustrates the data collection strategy, which is composed of six steps in the FCBF.

Step 1 and step 2 are carried out to develop a standardized template of project management (PM) and construction management (CM) tasks. The basic methods used in these steps are a literature review of different project and construction management standard guidelines, and interviews conducted with industry peers to develop the standardized template. This template can be used by the owner or its contractors to enable their project teams to classify and determine the extent of their roles and responsibilities in a given project delivery system, based on predefined competencies determined by project owner (Construction Industry Institute (CII) 1997). Step 3 involves creating a fuzzy linguistic scale that determines the appropriate linguistic terms defining different extents of the roles and responsibilities of the owner versus those of its contractors. The method used to create the fuzzy rating scale, namely the three-step Delphi approach, is explained in detail in this chapter. Step 4 involves the preparation of a questionnaire using a web-based tool to enable the collection of the linguistic assessments of project teams on every task, using the fuzzy linguistic scale. Step 5 involves conducting a pilot survey across a panel of experts of the participating organization to confirm or modify the wording of the tasks and determine the effectiveness of the fuzzy linguistic scale. Step 6 involves conducting the actual survey. The steps proposed for data collection are described in detail in the next sections.

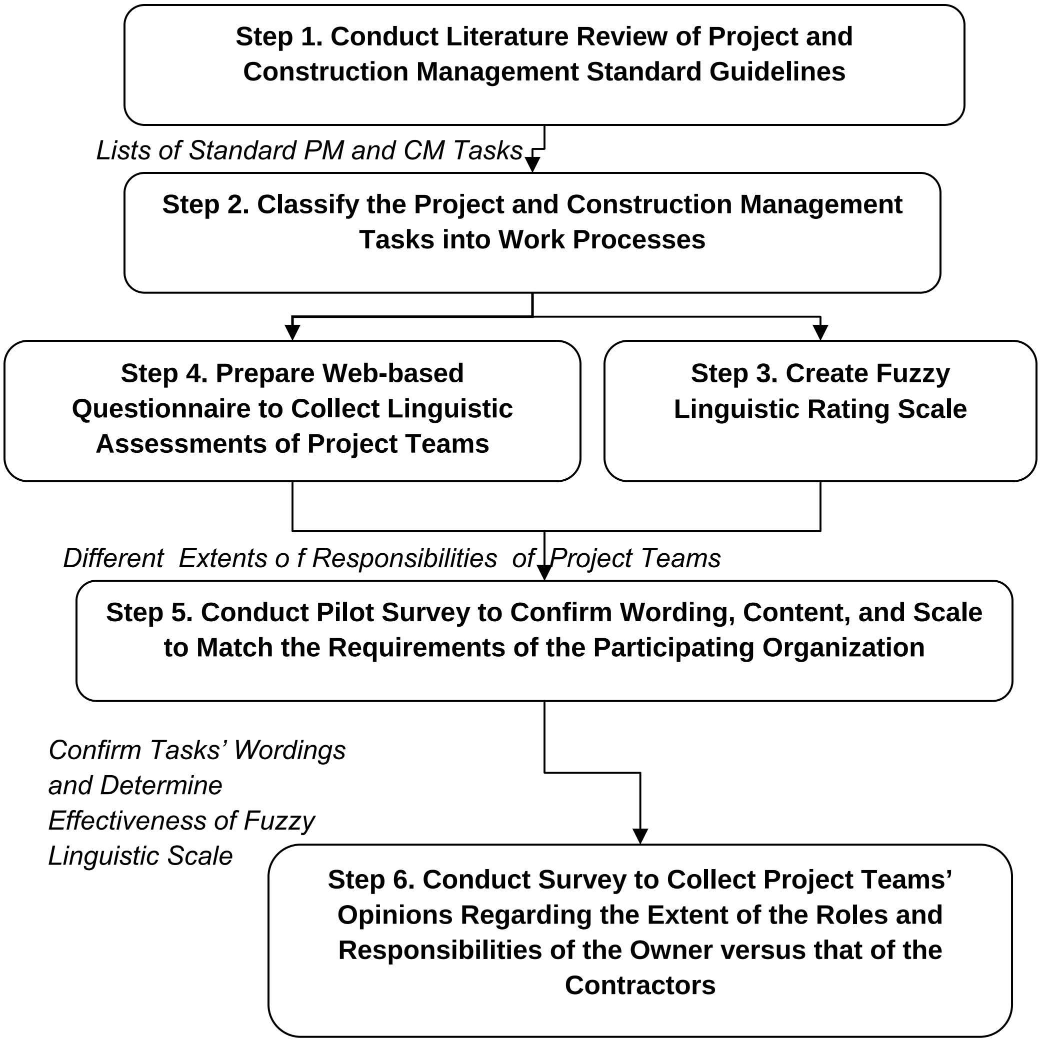

Figure 3.1. Data collection strategy and methods of the FCBF

3.2 Overview of Project and Construction Management Standard Guidelines (Steps 1 and 2)

Step 1 involves conducting a literature review of different project and construction management standard guidelines, work structures, and project delivery systems to create a standardized template of PM and CM tasks that helps project teams in determining the extent of their roles and responsibilities in a given project delivery system (Project Management Institute (PMI) 2008, Construction Owners Association of Alberta (COAA) EPCM Contract Committee 2007, Oyetunji and Anderson 2006, Chan et al. 2003, Chan et al. 2005, Bennett 2003, Bender 2003, Kramer 2004, Construction Management Association of America (CMAA) 2002, Agnitsch et al. 2001, Sullivan et al. 1997, CII 1997, Gordon 1994, Kirschenman 1986). Also, a review of in-house models of construction companies, and interviews conducted with construction project experts, helped in extending the PM and CM tasks lists.

The Construction Management Association of American (CMAA) (2002) provided a wide range of the roles and responsibilities of construction managers in project planning, design, execution and control. According to the CMAA (2002), a construction manager can be a firm, a team of firms, or an individual. Some of the roles that could be handled by construction management (CM) firms are: providing expertise in project scope development, acquiring lands, furnishing permits, financing projects, managing project cash flow, designing and managing acquisitions, estimating project cost, controlling project cost and schedule, administering contracts, controlling project documents, inspecting construction works, controlling project quality, determining value engineering strategies, managing project risks, conducting constructability reviews, determining project delivery systems, setting dispute avoidance and resolution strategies, commissioning and operating projects, and managing project construction. Typically, construction management (CM) firms organize the effort, develop the management plans, monitor the participants' progress against the plan, and identify actions to be taken in the event of any deviation from the plan. Construction management firms also apply and integrate comprehensive project controls in order to manage the critical issues of time, cost, scope, and quality. Also, CM firms provide expert advice in support of the owner's decisions in the implementation of the project, and help the owner choose the delivery system and contract format. To use the functions of the construction manager on a project, the owner either contracts directly with a CM consultant company to act as its agent, or hires an engineering, procurement, and construction management (EPCM) contractor to manage the different phases of the projects as well as the owner's numerous EPC contractors (COAA 2007). Construction management firms offer their services in one of two methods:

- Construction Management (CM) Agency: The CM Agency acts in the owner's interests at every stage of the project and is reimbursed for services but it does not guarantee the final cost of the project.
- Construction Management (CM) at Risk: The CM firm guarantees the final cost of the project based on a guaranteed maximum price (GMP).

In the CM at Risk model, the owner hires a construction manager for consultation in the pre-design and design phases of a project. However, contractors contract directly with the construction manager and not with the owner organization. The construction manager's roles also include monitoring project performance during the construction phase to ensure that the project activities are completed on time, within budget, and within the specified quality. On the other hand, according to Liebing (2001), the CM Agency shall have the following roles and responsibilities:

1- Pre-construction Services

- Consulting with the owner's engineer during project development
- Preparing detailed schedules and monitoring of project progress
- Preparing detailed budgets for the project
- Coordinating and preparing bid documents
- Selecting qualified bidders
- Evaluating tenders

2- Construction Services

- Supervising projects during construction
- Controlling project costs and providing scheduling services
- Assisting in getting required permits
- Establishing change order processes
- Consulting and coordinating with owner and engineer
- Inspecting project works
- Interpreting contracts with owner/engineer/subcontractors/vendors

- Establishing shop drawing processing procedures
- Reviewing, recording, and processing all reports and site documentation
- Determining substantial completion and preparing lists of incomplete and unacceptable items
- Monitoring start-up and testing of equipment (i.e., commissioning phase)
- Collecting, reviewing, and approving close-out documents
- Assuring warranty and guaranteeing the work is performed

By comparison, Hendrickson (1989) described the construction management team as "a team consisting of a professional construction manager and other participants who will carry out the tasks of project planning, design, and construction in an integrated manner." Hendrickson (1989) described a professional construction manager as a firm specializing in the practice of professional construction management, including:

- Working with the owner and the design firms from the beginning, and making recommendations on design improvements, construction technology, schedules, and construction economy
- Proposing design and construction alternatives if appropriate, and analyzing the effects of the alternatives on the project cost and schedule

- Monitoring subsequent development of the project so that these targets are not exceeded without the knowledge of the owner
- Coordinating procurement of material and equipment and the work of all construction contractors, approving monthly payments to contractors, managing project changes, handling claims, and conducting inspections to ensure conformance to design requirements
- Performing other project-related services as required by owners

The above roles and responsibilities of construction management firms helped in formulating construction management standard tasks that can be introduced to owner's and contractors' project teams in order to classify the extent of their roles and responsibilities in any owner-customized project delivery systems, based on the owner's and contractors' value interests (Construction Industry Institute (CII) 2010), or any other preset requirements. These requirements were classified by Oyetunji and Anderson (2006), who listed 20 factors that may impact the decision to allocate responsibilities between the owner and the contractor: "control cost growth, ensure lowest cost, delay or minimize expenditure rate, facilitate early cost estimates, reduce risks or transfer risks to contractors, control time growth, ensure shortest schedule, promote early procurement, incorporate ease of change, capitalize on expected low levels of changes, capitalize on familiar project conditions, maximize owner's controlling role, minimize owner's controlling role, maximize owner's involvement, minimize owner's involvement, capitalize on well-defined scope, efficiently utilize poorly defined scope, minimize number of contracted parties, and efficiently coordinate project complexity or innovation." Karamouz and Mostafavi (2010) used the same factors to help project teams decide on the owner's roles and responsibilities versus those of its contractors. The final decision is made by the owner or contractor, by involving project teams in making the decision. This helps ensure the alignment of the project teams on their roles and responsibilities, based on the preset criteria of the participating organization.

Anderson et al. (2004) described different owner-contractor work relationships to assist project teams in defining the different extents of the roles and responsibilities of project owner organization versus those of its contractors for capital projects based on the owner's required competencies. This process was based on the CII (1997) Owner-Contractor Work Structure (OCWS) process. According to Anderson et al. (2004), work relationships define the extent of involvement of the owner and the supplier/contractor, in performing, leading, and/or providing input with respect to the required competencies in the construction project. In the model formulated by Anderson et al. (2004), five types of owner-contractor work relationships were illustrated as possible models. The five relationships are identified by Anderson et al. (2004) as follows:

1- **Owner Performs (OP):** “The owner performs all functions involved in the competency, using owner resources and the owner’s work process.”

2- **Owner Performs-Contractor Input (OPCI):** “The owner performs most functions using the owner work process with contractor input. The majority of the work is performed using owner resources. The contractor provides input, or acts as a consultant.”

3- **Owner Leads-Contractor Performs (OLCP):** “The owner leads the performance of functions using the owner’s work process, and the contractor provides the resources. The owner leads by setting guidelines, and directing, reviewing, and approving the work. The contractor performs most of the competency work functions according to the owner’s work process. In that case, the owner acts as a project manager.”

4- **Contractor Performs-Owner Input (CPOI):** “The contractor performs most functions using the contractor’s work process, with input from the owner. The majority of the work is performed using the contractor’s resources.”

5- **Contractor Performs (CP):** “The contractor performs all functions involved in the competency, using contractor resources and the contractor’s work process. The owner can still supply input and guidance by performing project management oversight.”

The above owner-contractor work relationships help describe different extents of the roles and responsibilities of a project owner organization versus those of its contractors, based on preset requirements, as proposed by the CII (1997) in the form of project owner's required competencies.

The CII (1997) proposes 30 different competencies that should exist within the owner organization in order to ensure successful delivery of its projects. In the same context, the PMI (2008) presents a project management framework that discusses the essentials of maintaining a work process approach by the owner organization using nine project management knowledge areas, which include 42 work processes that provide an efficient owner-contractor project management framework. The COAA EPCM Contract Committee (2007) also provides extensive knowledge on the owner-contractor work relationship in the EPCM project delivery system, which mainly focuses on the EPC contractors' roles and responsibilities. Elements of these standardized project management guidelines were combined and modified, based on expert judgment, to create an overall structure for defining a standard template of project and construction management tasks.

Table 3.1 illustrates a comparison between the PMI (2004) project management knowledge areas and the CII (1997) core competencies. Note that the 30 competencies were categorized under the nine project management knowledge areas based on their relevance to illustrate the relationship between the two standard guidelines, which helps in classifying standard project and construction management tasks.

Table 3.1. A comparison between the PMI (2008) project management knowledge areas and the CII (1997) competencies

PMI Knowledge Area (PMBOK)	CII Competencies
1. Scope Management	(1) Business Development (2) Financial Approval (3) Preliminary Design/Scope Development (4) Process/Conceptual Design (5) Convert New Technology to Project (6) Setting Project Goals, Objectives and Priorities (7) Detailed Design (8) Environmental/Permits
2. Time Management	(9) Project Controls (10) Project Planning/Scheduling
3. Risk Management	(11) Risk Management
4. Procurement Management	(12) Legal/Contract Administration (13) Procurement
5. Cost Management	(14) Conceptual Cost Estimating (15) Definitive Cost Estimating
6. Quality Management	(16) Total Quality Management (17) Field Quality Control
7. Human Resource Management	(18) Team Building
8. Communication Management	(19) Project Management (20) Overseeing of Project Management
9. Integration Management	(21) Commissioning/Start-up/Performance Testing (22) Lessons Learned (23) Maintenance and Operability (24) Safety Management (25) Alliance/Partnering (26) Benchmarking/Metrics (27) Technical Expertise (28) Constructability (29) Construction Site (30) Construction Management

Using the general tasks collected from the above standard models, including the PMI, CII, CMAA, and COAA; a set of relevant tasks extracted from the internal project management model of a large Canadian oil and gas owner organization; and several interviews conducted with industry peers, a list of 324 PM and CM tasks was prepared. In step 2, the tasks were classified in 18 standard work processes (Table 3.2) that accommodated the PMI (2008) knowledge areas, the CII (1997) competencies, and the standard in-house model of the oil and gas owner organization. The 18 standard work processes presented in this section, and the 324 tasks classified under each work process, are the basis for collecting project teams' opinions regarding the extent of the roles and responsibilities of the owner versus that of its contractors, which will be further discussed in details in the case study in chapter 6.

Table 3.2. Eighteen standard work processes used to classify the PM and CM tasks

1- Initiation	10- Engineering
2- Organization	11- Procurement
3- Project Management	12- Contracting
4- Safety Management	13- Construction Management
5- Regulation Compliance	14- Ready for Operation
6- Quality Management	15- Administration
7- Document Management	16- Change Management
8- Financial Controls	17- Information Systems
9- Project Controls	18- Operation and Maintenance

Appendix A illustrates the 324 PM and CM tasks categorized under each of the 18 work processes that are outlined in Table 3.2, which represent the standard template of the PM and CM tasks that the owner and contractors organization need to introduce to their project teams, to define the extent of their roles and responsibilities on a task-by-task basis. After finalizing the integrated template of project and construction management tasks, the fuzzy linguistic scale, which describes different extents of responsibilities of project teams, is constructed to help project teams determine the extent of the roles and responsibilities of the owner versus that of its contractors on a task-by-task basis. The next section describes step 3, which involves creating the fuzzy linguistic rating scale.

3.3 Creation of Fuzzy Linguistic Rating Scale (Step 3)

In order to create the fuzzy linguistic rating scale, the range (universe of discourse) of the scale and the number of linguistic terms that form the scale, which define different extents or degrees of responsibility of the owner versus those of its contractors, had to be determined.

According to Herrera and Herrera-Viedma (2000), “the cardinality of the linguistic term set must be small enough so as not to impose unnecessary precision on the experts, and it must be rich enough in order to allow a discrimination of the assessments in a limited number of degrees.” Typical values of cardinality used in linguistic models are odd in number, preferably 7 or 9, where the mid-term value represents an average assessment and the rest of the terms are “placed symmetrically around that value” (Bonissone and Decker 1986). These classical cardinality values conform to the observation of Miller (1956) that "human beings can reasonably assess seven simultaneous alternatives" (Herrera and Herrera-Viedma 2000).

Based on the above guidelines, a meeting with five key experts of a large oil and gas construction project owner organization was held to define seven linguistic terms that describe different degrees of responsibility of the owner versus those of its contractors. The universe of discourse of the rating scale ranged from a rating of 1—"No Responsibility"—to a rating of 7—"Sole Responsibility" of the owner. The linguistic terms and their description adapted the five types of owner-contractor work relationships of Anderson et al. (2004) and incorporated two additional ratings in the scale to allow a discrimination of experts' assessments using seven different extents of the roles and responsibilities of project teams. Table 3.3 illustrates the seven ratings, their respective linguistic terms, and the meaning of each linguistic term.

After defining the linguistic terms, experts were asked to construct the membership functions (MFs) of the linguistic terms in a consensus reaching process using a typical three-step Delphi approach, which was conducted in three rounds (Saaty 1980). Use of the three-step Delphi approach allowed experts to develop a common understanding on the different meanings of the linguistic terms by defining the degree of overlap of their meanings on the fuzzy linguistic rating scale.

Table 3.3. Description of linguistic terms forming fuzzy linguistic rating scale

Rating	Linguistic Term	Description
1	No Responsibility	Project owner is not responsible for carrying out the task. The owner may be consulted based on the contractor's sole discretion.
2	Limited Involvement	Project owner is not responsible for carrying out the task. Minor input is required from the owner to enable the contractor to perform the task.
3	Active Involvement	Project owner is not responsible for carrying out the task. The owner must be involved in all task-related discussions and provide considerable input.
4	Shared Equally	Both parties carry out the task with equal levels of involvement.
5	Significant Involvement	Project owner is responsible for carrying out the task. The contractor must be involved in all task-related discussions and provide considerable input.
6	Principal Responsibility	Project owner is responsible for carrying out the task. Minor input is required from the contractor to enable the owner to perform the task.
7	Sole Responsibility	Project owner is fully responsible for carrying out the task. The contractor may be consulted based on the owner's sole discretion.

Before defining the methodology of data collection using the three-step Delphi approach, a literature review was conducted to explore the mechanics of applying Delphi approaches to reach consensus between experts. The Delphi approach is defined in the literature as a consensus reaching process, used to collect experts' opinions and done in an iterative manner (Hartman and Baldwin 1995, Hyun et al. 2008, Hallowell and Gambates 2010). According to Shields et al. (1990), this method is proven and effective for allowing a group of people to deal with complex problems. For example, Pressoir (1989) has used the Delphi method in evaluating contract administration procedures, while Hyun et al. (2008) have used it in studying the effect of delivery methods on design performance. Robinson (1991) mentioned that the Delphi approach was first developed by the U.S. defense industry during a research study by the U.S. Air Force's Rand Corporation in the early 1950s. Goldfisher (1993) highlighted the use of the Delphi approach in developing market research and providing sales forecasting. Typically, three rounds of questions are used to solicit the required information (Saaty 1980, Hartman and Baldwin 1995, Hyun et al. 2008). According to Hyun et al. (2008), the first round solicits a very generic opinion and is to be conducted individually with each expert isolated from the others.

The data collected from a first Delphi round may not be exactly accurate. After proper analysis of its outcomes, the first round is typically followed by two more rounds that address more specific questions or provide more information or ideas, in order to reach consensus between opinions (Hartman and Baldwin 1995). Round two typically focuses on addressing major areas of concerns, whereas some additional information may be provided by the investigator in order to identify areas for improvement and reach consensus. During rounds two and three, each expert is allowed to review other experts' opinions and make comments or modify his or her original responses until consensus is reached by the end of round three. According to Hartman and Baldwin (1995), "interaction between participants could be limited or unlimited depending on the procedure followed by the researcher or investigator, which differs from one application to another."

Based on the above literature, three Delphi rounds were held with experts to reach consensus on the shapes of the membership functions of the fuzzy linguistic rating scale. The first round solicited generic opinions regarding the preliminary shapes of the MFs from 20 experts of a Canadian oil and gas construction project owner organization and its contractors, whose years of experience ranged from 5 to 20 years. Experts were kept anonymous to avoid bias in opinion (Hyun et al. 2008). In order to capture the meaning of the seven linguistic terms in a simple form, the MF that represents each linguistic term was assumed to have a triangular shape, with a peak located at the numerical rating that represents its respective linguistic term. One question was posed regarding each linguistic term: "*What are the ranges of elements (x_i) that may represent this linguistic term on the scale? Please circle as many answers as applicable.*" This round resulted in 18 different responses from the experts, who proposed different shapes of the fuzzy linguistic terms on the scale based on the different ranges of elements chosen (Figure 3.2).

In round two, the proposed 18 fuzzy scales were sent back to each expert with additional information, in the form of two simple rules that highlighted the relevance of each response. The rules used to define the relevance of responses were: *"The membership functions should have some symmetry because the scale is reciprocal,"* and *"The membership functions should have certain degrees of overlap to represent the overlap between their linguistic meanings."* Other than these two rules, experts were free to change the shapes of their membership functions and compare their responses to the other responses. The results were documented and categorized into 9 different responses (from 14 available experts from those who participated in round one), and showed more convergence in opinions. The frequency of responses on the shapes of each side (leg) of each triangular fuzzy number was determined, and is illustrated in Figure 3.3.

In round three, the results of round two were revealed to the experts graphically in a meeting. Nine of the experts who participated in rounds one and two were available to attend the meeting. The experts were asked to assess how reflective each MF was of its linguistic term by voting on the support (i.e., range) of each side of the triangular MF representing the term. Two rounds of open voting—through the show of hands—were conducted until consensus was reached on a single fuzzy scale. After the first round of voting, the frequency of responses on the shapes of each side (leg) of each triangular fuzzy number was determined and the results were illustrated graphically to experts in a way similar to that illustrated in Fig. 3.3.

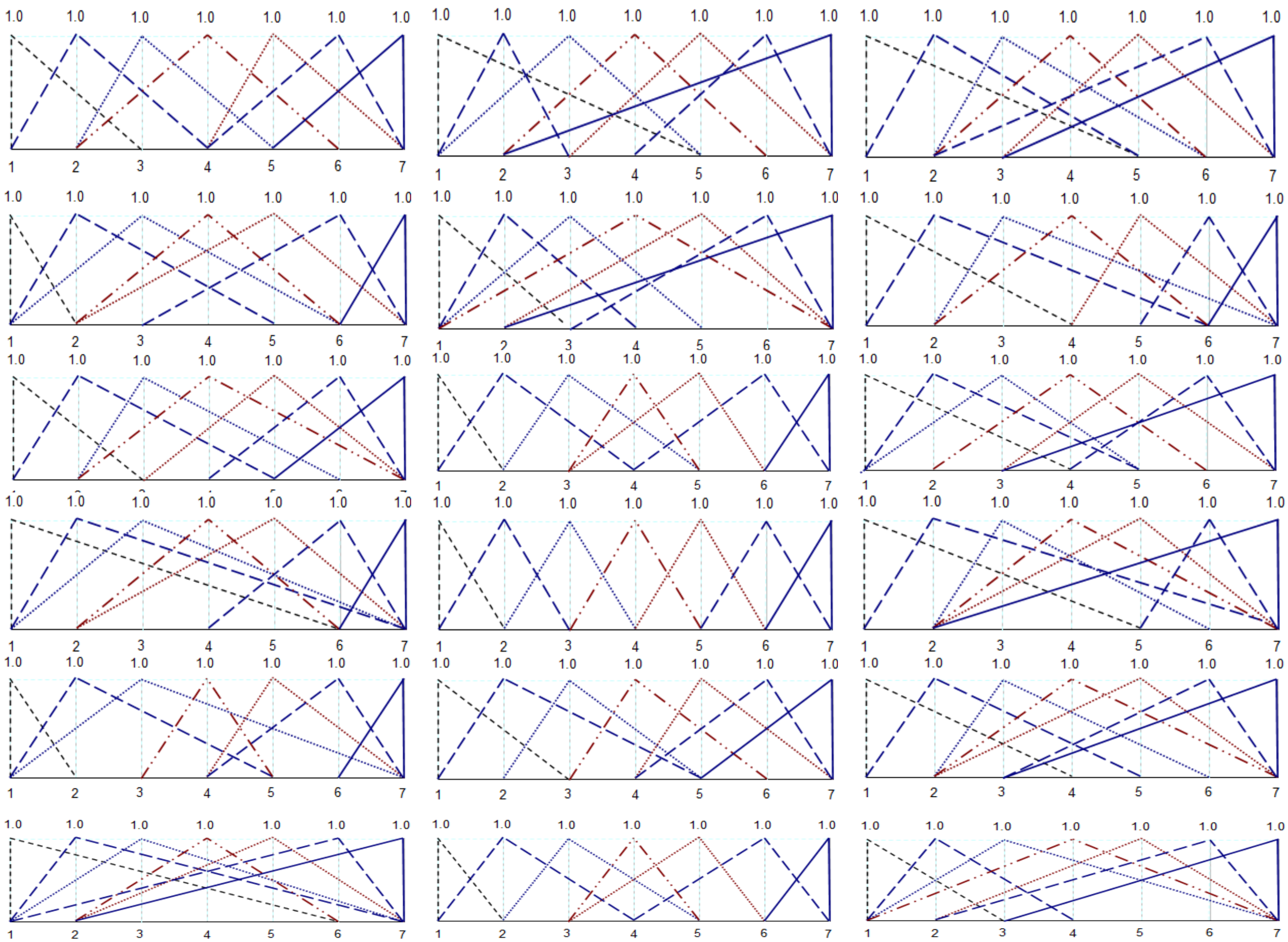

Figure 3.2. Different fuzzy linguistic scales collected in round one of the three-step Delphi approach

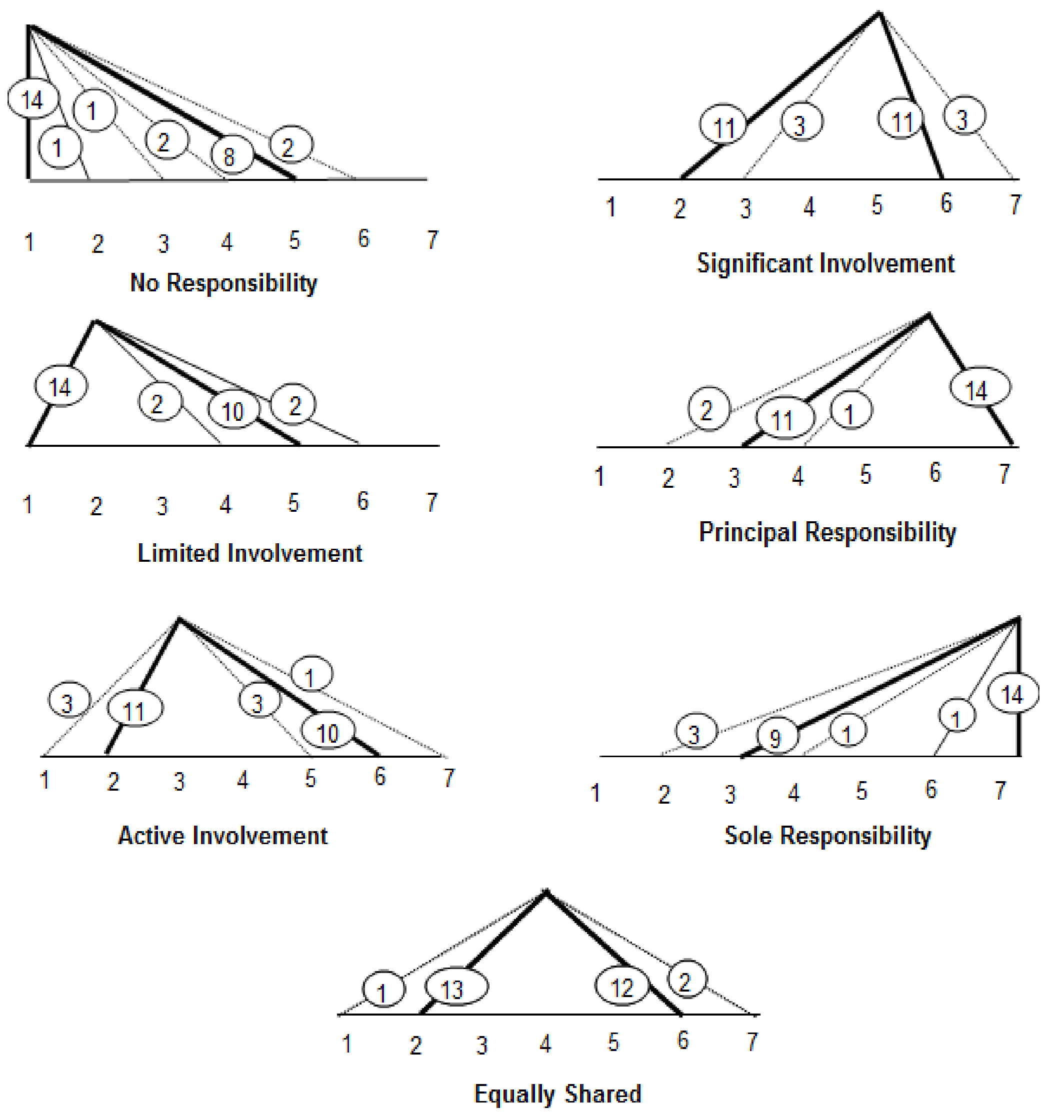

Figure 3.3. Frequency of experts' responses after round two of the three-step Delphi approach

After illustrating the results to experts, the experts who provided differing opinions from the group were asked to reconsider their opinion, or give a reason behind their divergence, based on their perception of the overlap between the different meanings of the linguistic terms. The second round of voting was then conducted in order to determine the final shapes of the membership functions. After the second round of voting, only one expert did not concur with the other experts on the shapes of 4 fuzzy numbers, and therefore his opinion was disregarded. Based on the consensus reaching process, the final fuzzy linguistic rating scale (Figure 3.4) was determined. This scale is used to collect the responses of project teams on the extent of the owner's roles and responsibilities versus that of its contractors on any predetermined set of tasks.

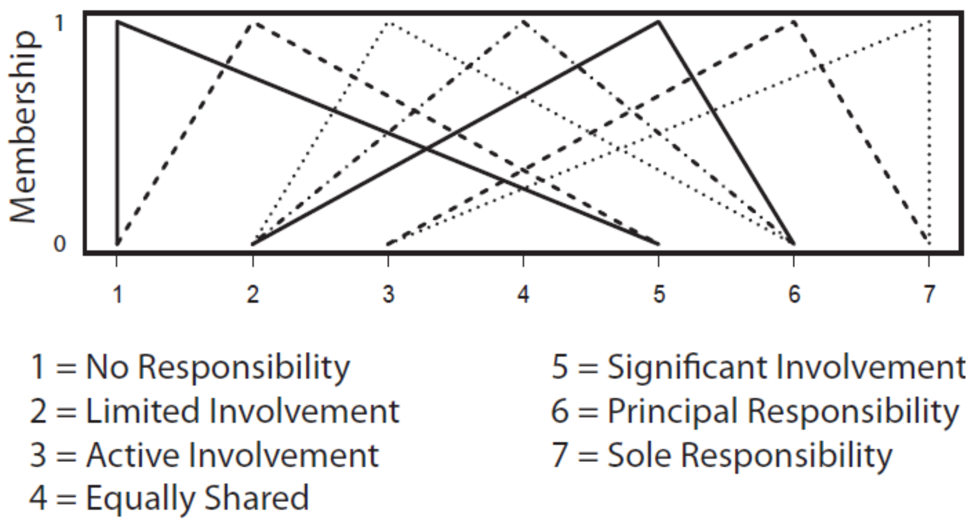

Figure 3.4. Final fuzzy linguistic rating scale after round three of the three-step Delphi approach

The next section describes steps 4, 5, and 6 of the data collection strategy, which defines a simple method to collect the opinion of project teams using a structured web-based survey questionnaire. This survey is prepared to collect data from project teams regarding the extent of the roles and responsibilities of the owner organization versus that of its contractors in a given project delivery system.

3.4 Web-Based Survey Questionnaire (Steps 4, 5, and 6)

A web-based survey questionnaire is developed to collect project teams' opinions regarding the extent of the roles and responsibilities of the owner versus that of its contractors, using the seven linguistic terms that were created in step 3. This questionnaire can be used to help the owner organization identify the conflicts and develop common understanding between its project teams on their proper roles and responsibilities in any owner-customized or standardized project delivery system.

The web-based questionnaire is created using a commercially available web-based survey tool. The general methodology of data collection using the web-based questionnaire, which can be used by the owner or contractor organization, is described briefly in this section, which will be further explained in detail in the case study in chapter 6. First, multiple choice questions that address the characteristics of the project team members and their projects are developed. These provide information on the attributes of individual experts, such as their years of experience and role in the company. These questions are helpful in collecting the attributes of the input variables to the fuzzy expert system (FES) in order to calculate individual experts' importance weights, as will be discussed in chapter 4. Second, the predetermined tasks that the project team members will rate are categorized into standard work processes to facilitate the grouping of individual tasks based on the in-house work processes of the participating organization. The question for each task is: "*To what extent would you rate the roles and responsibilities of the owner versus that of its contractors?*" Project team members are asked to choose the linguistic terms that represent their choices from the list of the seven linguistic terms, as illustrated in Table 3.3. For example, a project team member can determine that the project owner is fully responsible for carrying out the task "develop the preliminary work breakdown structure," which is classified in the "initiation" work process, by selecting the linguistic term "sole responsibility."

The survey is conducted in two stages, as described in steps 5 and 6. Step 5 involves conducting a pilot survey across the key managers of the participating organization, to ensure that "the level of detail is appropriate for the study, the role of the experts is well-defined, and survey instructions are easy to follow" (Hallowell and Gambates 2010). The pilot survey also confirms the wording of the standard tasks and the format of the survey, and assists in collecting feedback on the effectiveness of the linguistic terms in rating each task. After analysing the results of the pilot survey, the final survey (step 6) is conducted to collect the required project teams' responses. The data collected from experts is analyzed using the modified similarity aggregation method (SAM), as will be explained in chapter 5.

3.5 Conclusion

A data collection strategy is explained in detail in this chapter to help the owner organization or its contractors to align their project teams in determining the extent of their roles and responsibilities in any standard or customized project delivery system. The data collection strategy, which is one of the basic components of the Fuzzy Consensus Building Framework (FCBF), is explained in 6 steps that can be applied by the participating organization to collect project teams' opinions prior to applying the fuzzy consensus building and aggregation methods, which are explained in chapter 5. The next chapter describes the steps used in creating the fuzzy expert system (FES) that determines the importance weight of experts involved in the decision-making process.

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4. Chapter Four - Fuzzy Expert System for Determining Experts' Importance Weights

4.1 Introduction

In any decision-making process, there are individuals (experts or decision-makers) who are called on to express their opinions on a predetermined set of alternatives in order to select the best one(s) (Herrera and Herrera-Viedma 2000). The experience of these experts may vary based on different criteria, such as the expert's years of experience, position in the company, and seniority in his or her position (Elbarkouky and Fayek 2009), which may impact his or her judgement in the decision-making process. The level of importance of individual experts, therefore, is an important factor in aggregating their opinions to ensure that the result of their collective opinion is not flawed (Herrera et al. 1996). Almost every consensus-based aggregation approach reviewed in the literature incorporated the level of importance of experts in its aggregation algorithm or method, which was either expressed as an importance weight factor defined as real number (Lee 2002, Hsu and Chen 1996, Herrera et al. 1996), or a linguistic term defined on a linguistic scale (Herrera et al. 1997). Most of these approaches, however, did not define a clear methodology for the determination of the expert weighting.

The Fuzzy Consensus Building Framework (FCBF) fills in this gap using a standalone fuzzy expert system (FES) (Elbarkouky and Fayek 2010), which is developed in this chapter to incorporate the quality of experts in the decision-making process. This FES determines an importance weight factor for each expert, based on his or her specific attributes, and provides an improvement over previous consensus-based aggregation approaches. In this chapter, the general components of the FES model and the stages of model development are discussed in section 4.2. Then, the results of the model, based on actual data collected for the purpose of model validation, are illustrated, and sensitivity analysis is conducted in section 4.3.

4.2 Components of the Fuzzy Expert System (FES) and Model Development

4.2.1 Fuzzy Expert System (FES) Model Components

In general, fuzzy expert systems (FES) provide a method of representing qualitative data and describing input and output variables using natural language. The FES used in this chapter was developed in two stages using FuzzyTECH®, which is composed of a model interface, a knowledge base, and an inference engine.

The first stage was to develop the components of the knowledge base: a method that defines membership functions of the input (experts' attributes) and output (importance weight factor) variables of the FES model, and fuzzy if-then rules that connect the inputs to the output. Both the input and output variables are described by linguistic terms defined by the membership functions (MFs). The second stage in developing the FES model was to define the inference process, which fuzzifies the input, performs fuzzy operations on the rules using fuzzy operators, and defuzzifies the output using a defuzzifier component. Figure 4.1 illustrates the components of FES, which are described in detail in the next subsections. While both subsections discuss the two stages of model development, subsection 4.2.2 specifically deals with developing the knowledge base, while subsection 4.2.3 is concerned with defining the inference process.

4.2.2 Fuzzy Expert System Knowledge Base Development

The knowledge base is composed of a method that defines the membership functions of the input and output variables of FES, which is explained in subsections 4.2.2.1 and 4.2.2.2; and fuzzy if-then rules that link the input to output variables, which are explained in subsection 4.2.2.3.

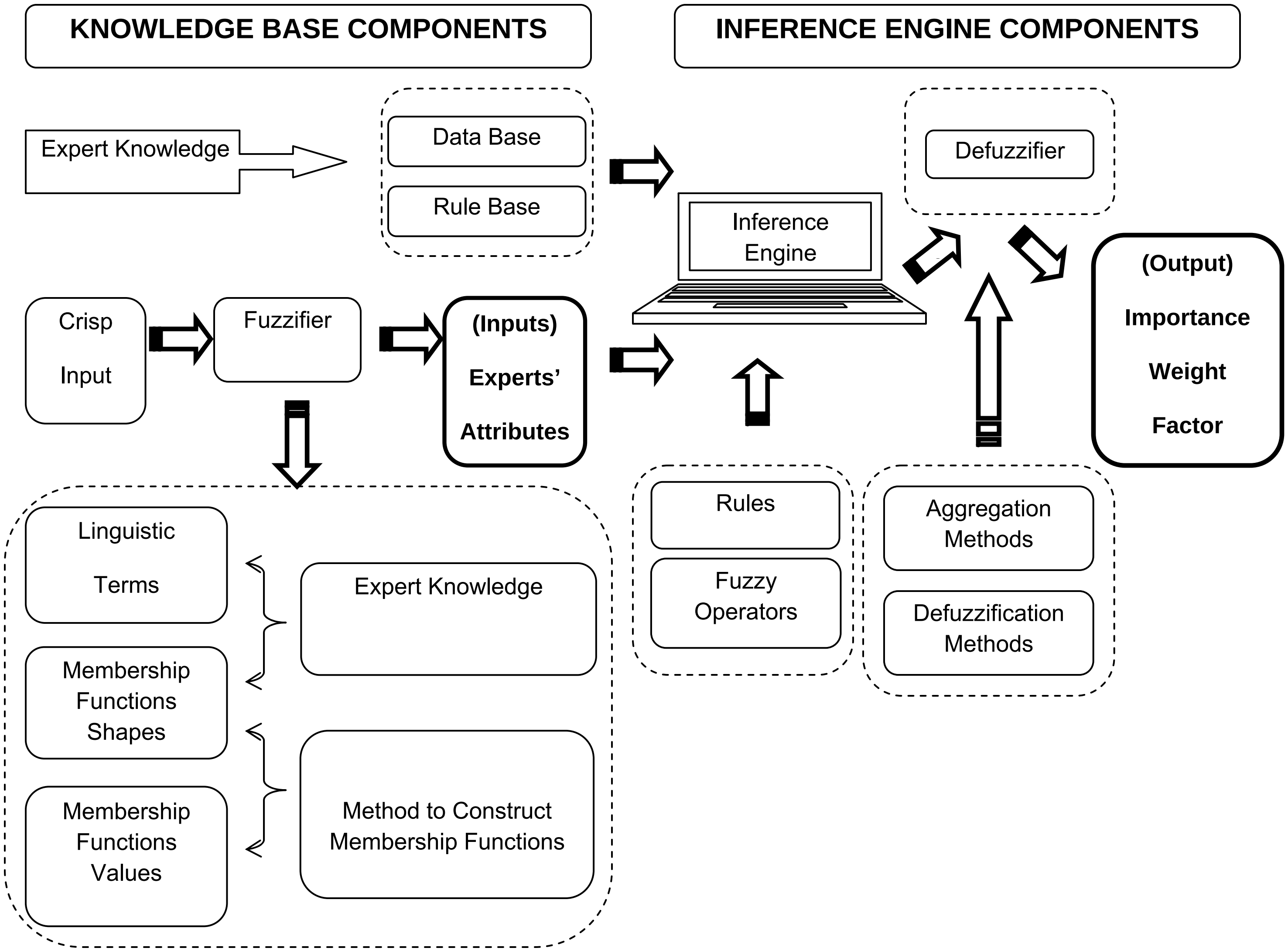

Figure 4.1. Components of fuzzy expert system (FES)

4.2.2.1 Input and Output Variables of FES and Membership Functions

Expert knowledge was used to determine the input and output variables of the fuzzy expert system (FES). Five key decision-makers in a large Canadian oil and gas project owner organization, each with over 15 years of experience in oil and gas construction, participated in several interviews to define the input and output variables.

The interviews resulted in five independent input variables, and one output variable, as well as the linguistic terms that describe each variable, which were defined on a 7-point scale. Table 4.1 illustrates a summary of the information related to input and output variables, in terms of their names, the linguistic terms describing their membership functions, and the values of the elements forming the scale.

The first input variable, "*years of experience,*" indicates construction industry experience. This variable ranges from "less than one year" to "more than twenty years" of experience. Experts with a high number of years of experience tend to have a better understanding of the construction project as a whole, the advantages and disadvantages of different project delivery systems, and an awareness of different systems' requirements. The variable is described by three MFs (small, medium, and large). The second input variable, "*diversity of experience,*" determines an expert's

Table 4.1. Summary sheet of input and output variables

Input variables	Scale elements	Linguistic terms
Years of experience	(<1), (1–4), (5–8), (9–12), (13–16), (17–20), and (>20) years	Small, medium, and large
Diversity of experience	Extremely low, very low, low, average, high, very high, extremely high	Low, medium, and high
Years in role	(<1), (1–4), (5–8), (9–12), (13–16), (17–20), and (>20) years	Small, medium, and large
Role in the company	Project leader, project engineer, senior project engineer, project manager, senior project manager, project director, and general manager	Low, medium, and high
Enthusiasm and willingness	Extremely low, very low, low, average, high, very high, extremely high	Low, medium, and high
Output variable	**Scale elements**	**Linguistic terms**
Importance weight factor	Elements are continuous on the universe of discourse with a range of 0 to 1	Very small, small, medium, large, and very large

experience in working with various owner and contractor organizations, and increases an opinion's importance if the expert has previous experience working with different types of organizations and in different work structures. It is described by three MFs (low, medium, and high) and ranges from "extremely low" to "extremely high." The third input variable, "*role in the company,*" specifies each expert's managerial skill level, and indicates each expert's judgment regarding appropriate roles and responsibilities in a given project delivery system, and his or her ability to interpret and categorize the tasks to be rated under each work process. This third variable ranges from "project leader" to "general manager," and is described by three MFs (low, medium, and high). The fourth input variable, "*years in role,*" determines an expert's managerial experience, complementing the "*role in the company*" factor so that a rating provided by a more senior manager in his or her role has significant reliability. This variable ranges from "less than one year" to "more than 20 years" of experience, and is described by three MFs (small, medium, and large). The last input variable is "*enthusiasm and willingness,*" which indicates an expert's potential to evaluate roles and responsibilities. This final variable helps assess the validity of responses, and ranges from "extremely low" to "extremely high." It is described by three MFs (low, medium, and high). The output variable of FES is described as an "*importance weight factor*" (w_i) of each expert. The elements of the output variable are continuous on the universe of discourse, with a range of 0 to 1. The output variable is represented by five membership functions, as determined by the experts: “very small”, “small”, “medium”, “large”, and “very large.”

The next subsection discusses the modified horizontal approach, a method used to construct the membership functions of the input and output variables of the FES.

4.2.2.2 Construction of the MFs of the Input and Output Variables

Fuzzy sets are described by membership functions. A membership function is a group of individuals in the universe of discourse, $x_1, x_2,\ldots,x_n$, each assigned a degree of belonging to that group, $A(x)$ (Pedrycz and Gomide 1998). The degree of belonging is a value in the range 0 and 1. A value of 0 indicates zero membership and a value of 1 indicates full membership. Constructing membership functions is one of the most important and difficult steps in creating a fuzzy expert system (Medasani et al. 1998, Klir and Yuan 1995, Pedrycz and Gomide 1998). Medasani et al. (1998) point out that for most applications, several methods must be incorporated to construct membership functions. Table 4.2 summarizes the various methods previously used in the construction of MFs, and presents major comments or critiques of each method or technique.

After reviewing each method and determining its basic features, it can be concluded that data-driven techniques, such as statistical methods (Civanlar and Trussell 1986, Dissanayake 2006), fuzzy clustering and fuzzy C-means (Bezdek 1981), and sample data techniques (Klir and

Yuan 1995) cannot be used to solve the problem at hand because they can be only applied when sufficient historical data is available. Unfortunately, no historical information is available to derive the membership functions of the inputs and output MFs in the problem at hand. In addition, some of these techniques may have their drawbacks, as discussed in Table 4.2. For example, membership values determined by the fuzzy C-means technique represent a degree of sharing, not belonging, while the technique is very sensitive to noise (Marsh 2008).

The artificial neural networks (ANN) method (Wang 1994) is limited by constraints, and it may not provide a clear methodology to the user in deriving the values of the output membership functions (Marsh 2008). This is why the ANN method is described as a “black box-modeling” technique (Mjalli et al. 2006). In addition, the ANN method may also require historical data to determine the shapes of the MFs.

The most appropriate methods that are investigated to construct the MFs in the FES discussed above are expert-driven techniques, which were previously applied in several construction management applications (Poveda 2008, Marsh 2008, Dissanayake and Fayek 2007). Expert-driven techniques engage experts in the decision-making process to provide reliable data that is used to generate the MFs, based on the experts’ experience in the construction industry.

Table 4.2. Methods of construction of membership functions

Authors' citation	Method(s)	Brief description	Comments/critique
1- Saaty (1980)	Pairwise comparison method	A series of pairwise comparisons are made between elements describing fuzzy set (F) in a finite universe of discourse (X) to determine the level of preference in one element over another by giving it a numerical value ranging from 0 to 1. The higher the value, the more the element is preferred over another. The results are arranged in a matrix form. The eigenvector associated with the largest eigenvalue is the desired vector of membership (Marsh 2008).	This method is simple and practical, yet it involves bias. It is very time consuming, and it requires feedback from lots of experts. Also, aggregation of different experts' opinions might not be an easy task.
2- Klir and Yuan (1995)	• Direct (expert judgment) • Indirect (expert judgment) • Sample data techniques	Direct methods require experts respond to questions to construct membership functions directly. Indirect methods allow experts to answer questions that do not directly involve personal opinion, and membership functions are constructed implicitly. Sample data techniques need a lot of sample data, as opposed to soliciting expert opinions to construct membership functions.	Direct methods may have one fundamental disadvantage over indirect methods, in that they require the experts to give direct answers that are overly precise and, hence, unrealistic as expressions of their qualitative subjective judgements. As for sample data techniques, they might not be efficient if data size is not large enough.
3- Singh and Tiong (2005), Dissanayake (2006), Fayek and Oduba (2005)	Heuristic methods	These methods involve selecting shapes and parameters for membership functions based on historical knowledge, experience, and rules of thumb. Typical shapes, piecewise linear functions (e.g., triangular MFs) or piecewise monotonic functions (e.g., S-shape MFs) are generally chosen, and parameters are selected according to expert opinions.	These are simple methods that are applicable to construction. It is difficult, however, to select the proper shapes and parameters of MFs when the complexity of the variables is not well understood.

Table 4.2. Methods of construction of membership functions (continued)

Authors' citation	Method(s)	Brief description	Comments/critique
4- Pedrycz and Gomide (1998)	• Horizontal method • Vertical method	The horizontal method allows experts to answer questions pertaining to a certain concept (linguistic term). Each linguistic term is represented by a given membership function. This method enables experts to check the compatibility of every element in the universe of discourse to the concept by giving a binary "yes" or "no" answer. The ratio of the total number of positive replies that the element belongs to the linguistic term, to the total number of replies, determines a certain membership value. All membership values are then plotted against elements to create membership functions for each linguistic variable. The vertical method assumes a range of elements as opposed to setting one single value for every element. The concept of alpha cuts is used to construct the membership functions. Alpha cuts are determined by the researcher prior to the holding of interviews with a single expert. The expert identifies subsets of the universe of discourse whose elements belong to a certain degree greater than or equal to alpha. Successive alpha cuts are then used to build the membership function.	The horizontal method is very simple, straightforward, practical, and easy to understand by experts. However, all the elements that belong to the universe of discourse should be predetermined so that experts would neither change the elements nor create new elements. The vertical method is simple and practical, but the results might be inconsistent due to the use of discrete elements in obtaining experts' knowledge.

Table 4.2. Methods of construction of membership functions (continued)

Authors' citation	Method(s)	Brief description	Comments/critique
5- Civanlar and Trussell (1986), Dissanayake (2006)	Statistical methods	These methods are based on probability theory. They depend on generating membership functions using the possibility-probability consistency principle. Elements most likely to occur in a statistical set should be given a high membership value in a fuzzy set. These methods work as follows: • The probability density function is first determined from a data set. • The probability distributions are then transformed, using a proposed algorithm, into possibility distributions. • The algorithm is based on the consistency principle that states that the degree of possibility of an event is greater than or equal to its probability. • Histograms are generally used to represent the case data, and identify the distributions for input or output values. Membership functions derived from probability theory represent frequency of occurrence instead of subjective judgment, which in many cases is what the fuzzy membership function is trying to capture (Dissanayake 2006).	• These methods are suitable for determining membership functions when experts are not available to provide subjective assessment, and when a sufficiently large number of experimental data are available to derive probability-possibility distributions. • Many problems take place with these methods in the transformation step.

Table 4.2. Methods of construction of membership functions (continued)

Authors' citation	Method	Brief description	Comments/critique
6- Bedzek (1981)	Fuzzy clustering and fuzzy C-means	Fuzzy clustering differs from conventional clustering in that an element can belong to one cluster to a certain degree, instead of having to completely belong or not belong (Marsh 2008). It separates numerical data into a series of overlapping clusters, whose degrees of belonging to the cluster are used as membership values.	The fuzzy C-means can be used as an unsupervised algorithm and can generate multi-dimensional membership functions (Medasani et al. 1998). It requires large amounts of data. Membership values represent degrees of sharing, not belonging, and the method is very sensitive to noise.
7- Chen and Otto (1995), Klir and Yuan (1995)	Interpolation and curve-fitting	Interpolation is the process of finding a polynomial that fits the sample data, while curve-fitting involves fitting a mathematical function to sample data. One of the most popular interpolation techniques that is used to construct membership functions is the Lagrange interpolation. Chen and Otto (1995) proposed a method based on interpolation and measurement theory, such that MF values are initially determined using measurement theory, membership values are assigned to x-axis values by experts, and interpolation theory is used to determine the remaining membership values to smooth out the membership function.	Lagrange interpolation requires sufficient data sample and results in a very complex function that increases in complexity as the number of data samples increase. The resulting membership function may have lots of peaks and valleys (Chen and Otto 1995), while data may be over-fitted in this technique. Chen and Otto's (1995) technique does not require large amounts of data as compared to Lagrange interpolation.
8- Wang (1994)	Artificial neural networks (ANN)	This method uses the back-propagation least mean square error (BPLMS) learning algorithm to generate membership functions. Neural networks learn from a training data set that is generally normalized by a linear transformation. Once the neural network learns the training set, it generates a function that fits the points defined by the training set.	BPLMS learning algorithm has some difficulties in interpolation, and the final fit is irregular. The neural network is limited by constraints (Marsh 2008).

The pairwise comparison method (Saaty 1980) is considered an expert-driven technique, yet it may not be an appropriate method to solve the problem at hand because it involves the inclusion of personal bias, and it is very time consuming. Furthermore, the aggregation of different experts' opinions—collected in pairs—might not be an easy task (Marsh 2008).

Heuristic methods (Singh and Tiong 2005, Dissanayake 2006, Fayek and Oduba 2005) are also considered expert-driven techniques that consist of selecting shapes and parameters of membership functions in accordance with "previous experience and rules-of-thumb" (Marsh 2008). Although these methods are simple methods that are commonly applied in construction management applications (Poveda 2008, Dissanayake and Fayek 2007), it is difficult to select the proper shapes and parameters of MFs using rules-of-thumb when the variables are purely subjective in nature. This is the case of some of the input variables described in the aforementioned FES, such as "*enthusiasm and willingness*."

Another expert-driven technique is the horizontal method (Pedrycz and Gomide 1998), which is very simple, straightforward, practical, and easy to understand by experts. When coupled with an interpolation or a curve-fitting technique (Chen and Otto 1995, Klir and Yuan 1995), the horizontal method can be applied to construct membership functions for concepts associated with both quantitative and qualitative variables. This is the case in the FES discussed above, which uses both types of variables. Also, according to Dissanayake and Fayek (2007), the horizontal method, coupled with an interpolation technique, can be used for constructing membership functions of complex qualitative variables. Marsh (2008) applied a modified horizontal approach in developing a FES decision-making model to assist surety underwriters in the construction industry, which simplified the horizontal method by reducing the number of questions asked to expert to construct the MFs.

The modified horizontal approach (Marsh 2008) coupled with an interpolation technique was selected to construct the MFs in the FES discussed above. The modified horizontal approach was selected because it is a simple expert-driven technique that can be applied to the problem at hand. It addresses experts' opinions in constructing the membership functions, which is preferred over data-driven techniques in the case of unavailability of relevant historical data (as is the case of the problem at hand) to derive the membership functions. The modified horizontal approach is also selected because it helps reduce the number of questions asked to experts, and it is practically proven in constructing MFs of linear shapes (Marsh 2008). The application of the modified horizontal approach and interpolation technique is conducted in two steps to construct the MFs of both the input and output variables of the model.

In the first step, the initial non-uniform shapes of the MFs were determined using the modified horizontal approach. Then, the MFs were transformed in the second step by interpolation to fit standard triangular or trapezoidal shapes, as recommended by Lorterapong and Moselhi (1996), who indicated that in many applications, linear shape approximations—triangular and trapezoidal—are the most practical.

First, data related to the MFs was collected using a simple questionnaire (Appendix B). Then, the modified horizontal approach was applied to determine the supports and shapes of the MFs describing the input variable and output variables of FES. The questionnaire was completed by five key decision-makers in a large Canadian oil and gas project owner organization in a meeting, with each decision-maker having over 15 years of experience in oil and gas construction. For each linguistic term describing a MF, the experts were asked: "*What are the ranges of elements (x_i) that may represent this linguistic term on the scale? Please circle as many answers as applicable."* For example, for the input variable "*years of experience*", which was described by three MFs (small, medium, and large), the modified horizontal approach asks the following question:

"What are the ranges of elements (x_i) that may represent the MF "small" number of years of experience on the scale? Please circle as many answers as applicable.

a. <1 year

b. 1–4 years

c. 5–8 years

d. 9–12 years

e. 13–16 years

f. 17–20 years

g. >20 years”

This single question was repeated for the other two MFs (medium and large), effectively incorporating responses to the following seven questions for each membership function that would need to be asked using the traditional horizontal method:

- Can <1 years be considered a “small” number of years of experience?
- Can 1–4 years be considered a “small” number of years of experience?
- Can 5–8 years be considered a “small” number of years of experience?
- Can 9–12 years be considered a “small” number of years of experience?
- Can 13–16 years be considered a “small” number of years of experience?
- Can 17–20 years be considered a “small” number of years of experience?
- Can >20 years be considered a “small” number of years of experience?

In the case of the traditional horizontal method, as indicated by Pedrycz and Gomide (1998), only questions with “yes” or “no” answers are permitted (Marsh 2008). This means that approximately 21 questions [(3

MFs) X (7 questions)] for each input variable and 35 questions [(5 MFs X (7 questions)] for the output variable are required. By comparison, the modified horizontal approach enabled experts to provide their answers in the form of a range on the scale, which drastically reduced the number of questions posed to experts.

The replies of experts were then counted in terms of frequencies of responses ($P(x_i)$) to the total number of responses (N) for every element x_i (as shown in Equation 4.1) to calculate its membership value ($A(x_i)$), resulting in the initial non-uniform shapes of each MF.

$$A(x_i) = \frac{P(x_i)}{N} \qquad [4.1]$$

Figures 4.2, 4.3, 4.4, 4.5, and 4.6 illustrate the initial non-standard shapes of the membership functions of the five input variables, while Figure 4.7 illustrates the initial shapes of the membership functions of the output variable.

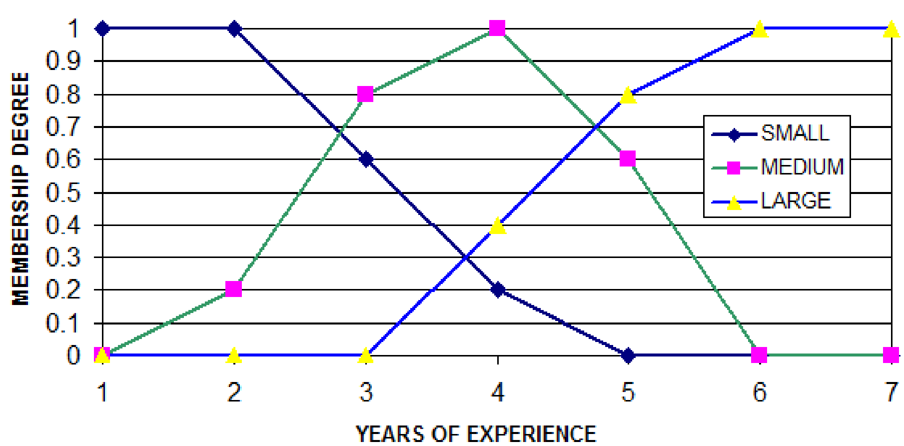

Figure 4.2. Initial shapes of the MF of the input variable "years of experience"

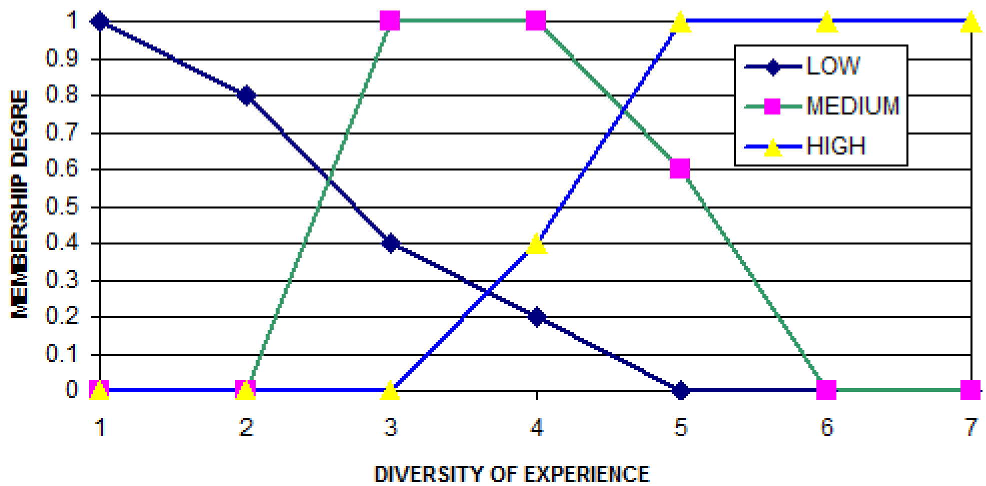

Figure 4.3. Initial shapes of the MF of the input variable "diversity of experience"

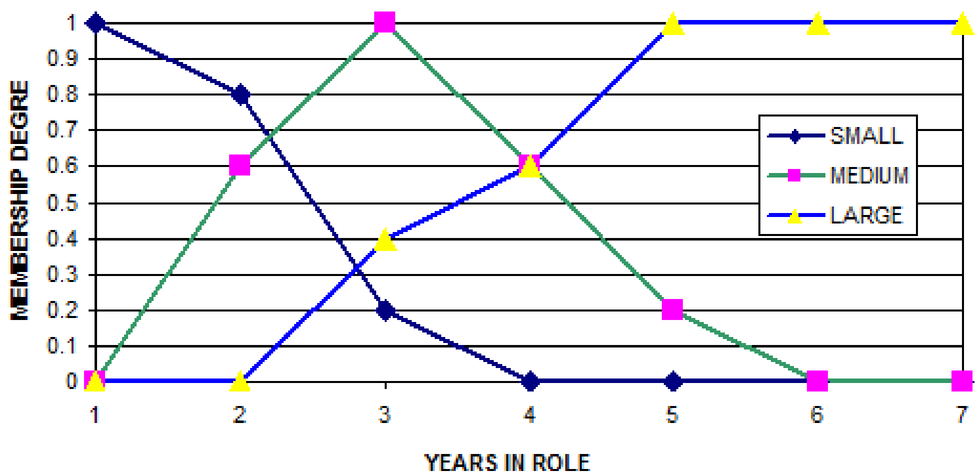

Figure 4.4. Initial shapes of the MF of the input variable "years in role"

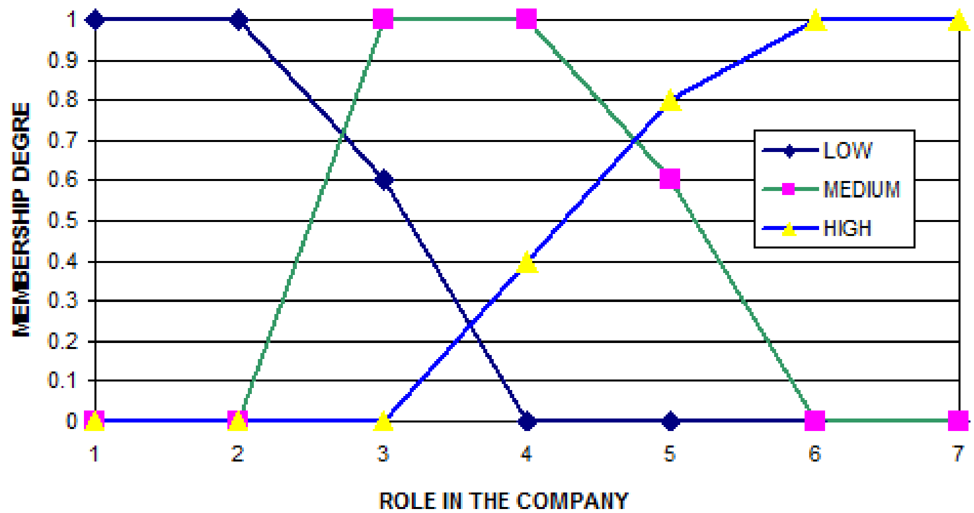

Figure 4.5. Initial shapes of the MF of the input variable "role in the company"

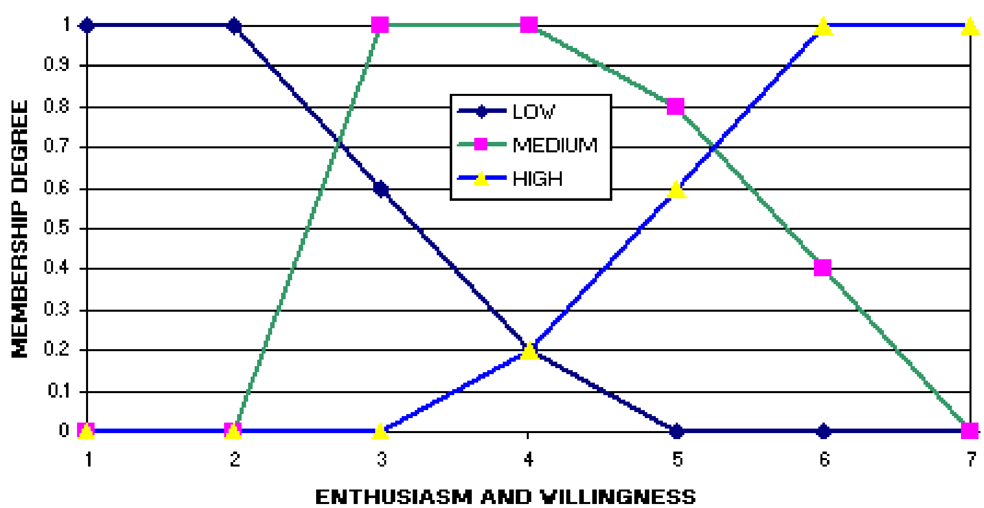

Figure 4.6. Initial shapes of the MF of the input variable "enthusiasm and willingness"

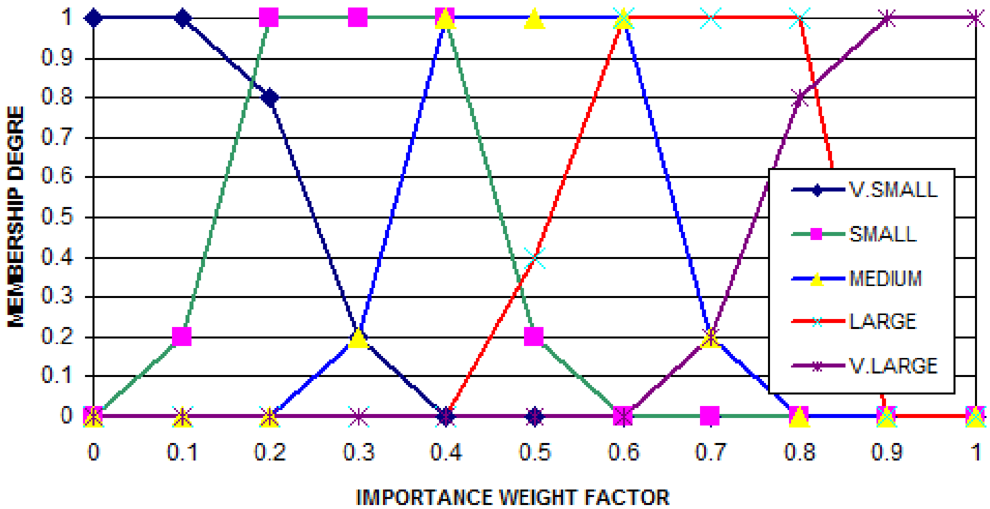

Figure 4.7. Initial shapes of the MF of the output variable "importance weight factor"

In the second step, the initial non-uniform shapes of the membership functions are checked as to whether they fit standard triangular or trapezoidal shapes based on the calculation of the least total error. The total error is computed, on a piece-by-piece basis (i.e., right and left pieces of each MF), between the membership values of the data points of the non-uniform MFs, and the corresponding values of the data points forming the proposed linear piece alternative of the standard MF (Equation 4.2).

$$Total\ \ Error = \sum_{i=1}^{n} \frac{A(x_i)_{actual} - A(x_i)_{estimated}}{A(x)_{\max} - A(x)_{\min}} \qquad [4.2]$$

where, n is the number of data points for which the total error is to be calculated; $A(x_i)_{actual}$ is the membership value of each data point forming the initial membership functions; $A(x_i)_{estimated}$ is the membership value of the corresponding data points of each linear piece of the standard shape; $A(x)_{max}$ is the maximum membership value, which is equal to 1.0 for normal membership functions; and $A(x)_{min}$ is minimum membership value, which is equal to 0.0.

Based on Equation 4.2, the parameters of each standard membership function that would fit a non-uniform membership function are selected based on the points that produce the least total error compared to the other possibilities, restricting the possibilities of parameters' locations to the indicated element values (x_i) on the scale. Some of the actual data points that represent the non-uniform membership functions show definite peaks, and are therefore represented by triangular functions. However, for the non-uniform membership functions that do not have definitive peaks, trapezoidal shapes may provide the best fit. The triangular and trapezoidal functions used to fit the data are characterized by four parameters, *a*, *b*, *c,* and *d*, such that in triangular functions, *b* = *c* (Equation 4.3) (Pedrycz and Gomide 2007).

$$A(x) = \begin{cases} 0 & , x < a \\ \dfrac{x-a}{b-a} & , x \in [\mathrm{a}, \mathrm{b}) \\ 1 & , x \in [\mathrm{b}, \mathrm{c}) \\ \dfrac{d-x}{d-c} & , x \in [\mathrm{c}, \mathrm{d}] \\ 0 & , x > d \end{cases} \qquad [4.3]$$

The standard membership functions are determined visually for the actual data points that showed obvious minimal distances to their proposed standard linear pieces after checking the validity of the visual inspection. The validity of visual inspection was checked by calculating total errors for some cases that were randomly selected. After computing the total error for the random cases, it was determined that if the vertical difference between the membership value of an actual data point and that of its corresponding point on the standard shape equals to 0.20 or more, then the proposed linear piece alternative does not fit the data. Figure 4.8 illustrates an example that demonstrates the only two possible standard shapes (Option 1 and Option 2) that may fit the membership function "large" of the input variable "*years of experience,*" which was fitted to the trapezoidal standard shape indicated by Option 1 using visual inspection.

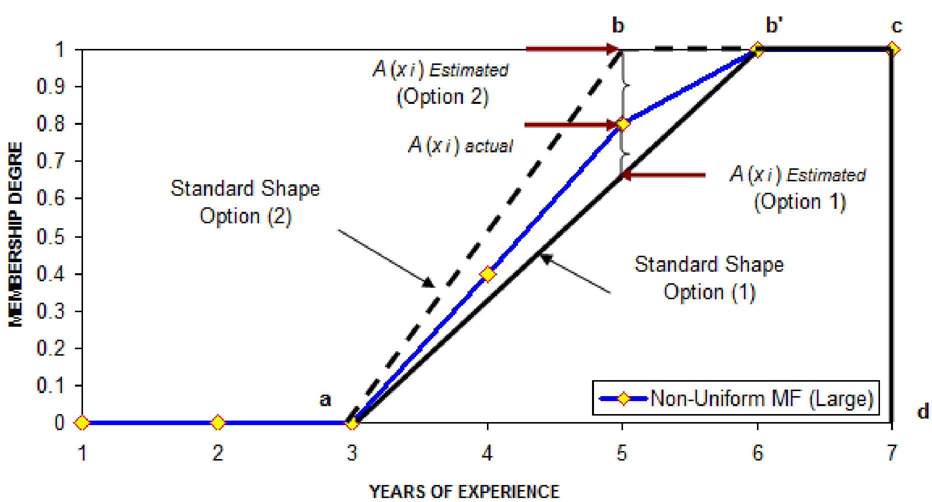

Figure 4.8. Example of fitting the non-uniform MF "large" of the input variable "years of experience" to a standard shape

In order to validate the visual inspection, the total error was calculated for the two possibilities (Options 1 and 2). The parameters of the standard trapezoidal MF indicated by Option 1 are (a = 3, b = 6, c = 7, d = 7) and those indicated by Option 2 are (a = 3, b = 5, c = 7, d = 7). Equation 4.4 illustrates the total error calculation for Option 1, while Equation 4.5 illustrates the total error calculation for Option 2.

$$
\begin{aligned}
TotalError &= \frac{A(x_3)_{actual} - A(x_3)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_4)_{actual} - A(x_4)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \\
&\frac{A(x_5)_{actual} - A(x_5)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_6)_{actual} - A(x_6)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_7)_{actual} - A(x_7)_{estimated}}{A(x)_{\max} - A(x)_{\min}} \\
&= \frac{|0-0|}{1-0} + \frac{|0.40-0.33|}{1-0} + \frac{|0.80-0.67|}{1-0} + \frac{|1-1|}{1-0} + \frac{|1-1|}{1-0} \\
&= 0 + 0.07 + 0.13 + 0 + 0 = 0.20
\end{aligned} \qquad [4.4]
$$

$$
\begin{aligned}
TotalError &= \frac{A(x_3)_{actual} - A(x_3)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_4)_{actual} - A(x_4)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \\
&\frac{A(x_5)_{actual} - A(x_5)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_6)_{actual} - A(x_6)_{estimated}}{A(x)_{\max} - A(x)_{\min}} + \frac{A(x_7)_{actual} - A(x_7)_{estimated}}{A(x)_{\max} - A(x)_{\min}} \\
&= \frac{|0-0|}{1-0} + \frac{|0.40-0.50|}{1-0} + \frac{|0.80-1|}{1-0} + + \frac{|1-1|}{1-0} + \frac{|1-1|}{1-0} \\
&= 0 + 0.10 + 0.20 + 0 + 0 = 0.30
\end{aligned} \qquad [4.5]
$$

From the previous total error calculations, the least total error is the one calculated for Option 1 = 0.20, which justifies the original decision based on the visual inspection. Accordingly, visual inspection was enough in this case to eliminate the possibility of Option 2 because the vertical difference between the membership value of the actual data point corresponding to element x_5 and that of its corresponding point on the standard shape = 1-0.80 = 0.20. Figure 4.9 illustrates the final shapes of the membership functions of the input and output variables of the FES model, as implemented in FuzzyTECH®, based on the calculations of the least total error.

4.2.2.3 Developing Fuzzy If-Then Rules of FES

To create the rule base for each inference system, the questionnaire that was used to collect data on the input and output variables (Appendix B) helped the experts in ranking the input variables in terms of their influence on the output variable, facilitating the creation of the knowledge base of fuzzy if-then rules using the FuzzyTECH® rule wizard. Figure 4.10 illustrates the input and output variables prior to the implementation of the fuzzy if-then rules using the FuzzyTECH® rule wizard.

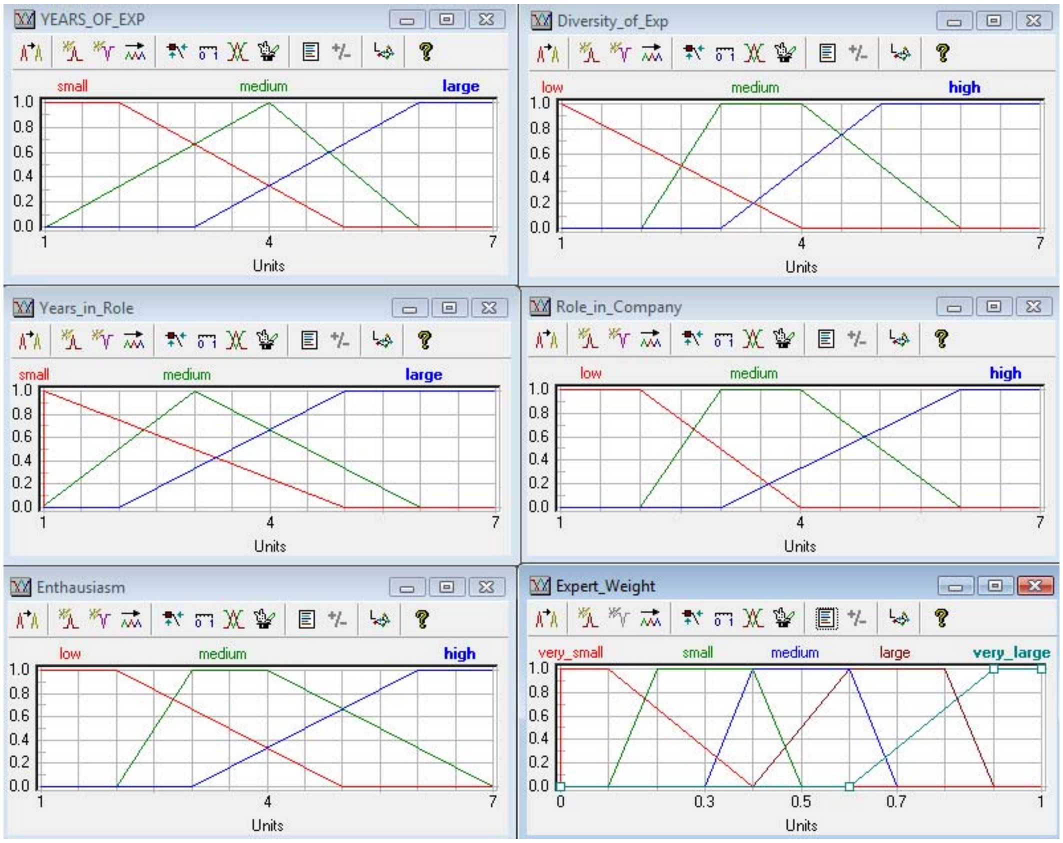

Figure 4.9. Final shapes of the MF of the inputs and output of FES

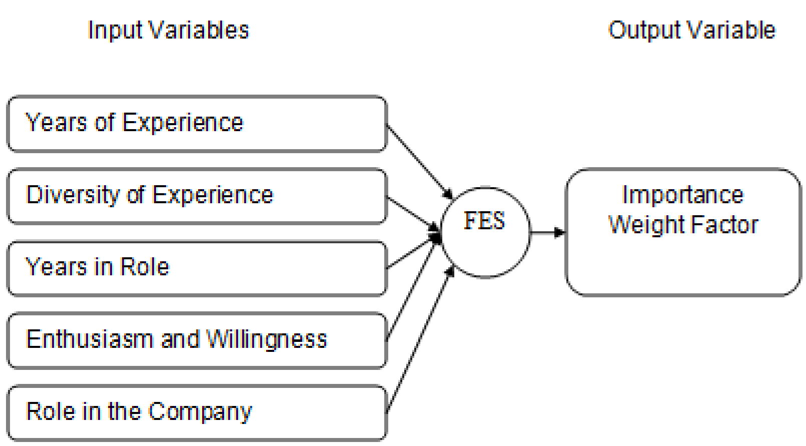

Figure 4.10. Input and output variables of the FES

The knowledge base in FuzzyTECH® consists of fuzzy if-then rules in the form of: If A is LOW and B is HIGH then C is MEDIUM, where A and B are the input variables, C is the output variable, and LOW, HIGH, and MEDIUM are examples of the linguistics terms describing each variable.

The rule base was created for the fuzzy expert system using data obtained from the questionnaire, in which respondents rated the five input variables on a scale of 1 to 7 in terms of their influence on the output variable, where 1 means "no influence," 4 means "medium influence," and 7 means "extremely high influence." The ratings of 2, 3, 5, and 6 represent intermediate values on the scale. Experts' assessments were combined using their average rating.

The linguistic terms that described the ratings on the scale only addressed degrees of positive influences of the input variables on the output variable, as it was already decided by the experts that there was no possibility that the input variable could have a negative influence on the output variable. Figure 4.11 illustrates the 7-point rating scale that was transformed to match the 3-point positive side of the scale in the FuzzyTECH® rule wizard, which is described on the right side of the scale by the terms "not at all," "positive," and "very positive." As shown in Figure 4.11, the linguistic term "4:medium influence" represents the term "positive" in the FuzzyTECH® scale, while the linguistic terms ""1:no influence" and "7:extremely high influence" represent the terms "not at all" and "very positive" in the FuzzyTECH® scale, respectively. On the other hand, the linguistic terms “2:very low” and “3:low” are placed between the terms “not at all” and “positive” in the FuzzyTECH® scale with equal increments. Also, the linguistic terms “5:high” and “6:very high” are placed between the terms “positive” and “very positive” in the FuzzyTECH® scale with equal increments.

Table 4.3 illustrates the results of the individual ratings of experts and their average rating, which determines the influence of each input variable on the output variable. The average rating of influence was placed for each input variable in its relevant location on the 3-point scale in the FuzzyTech® rule wizard based on Figure 4.11—after approximating the average rating to the lower 0.5 decimal, as illustrated in Table 4.3.

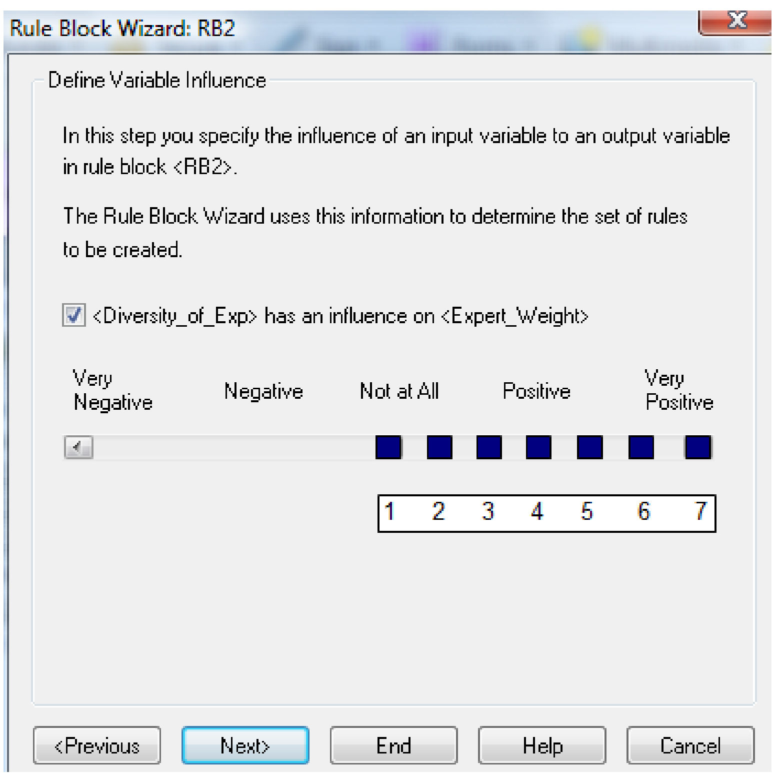

Figure 4.11 Rule wizard in FuzzyTECH®

Table 4.3. Results of the final ratings of the influence of each input variable on the output variable

	1. No influence	2. Very low	3. Low	4. Medium	5. High	6. Very high	7. Extremely high	Average rating	Average rating approximated
Years of experience						4 experts	1 expert	6.2	6.0
Diversity of experience			1 expert	1 expert		2 experts	1 expert	5.2	5.0
Years in role			1 expert		3 experts	1 expert		4.8	4.5
Enthusiasm and willingness				4 experts		1 expert		4.4	4.0
Role in the company			1 expert	2 experts	2 experts			4.2	4.0

After incorporating the influence rating in FuzzyTECH®, an initial set of the fuzzy if-then rules was generated "automatically" by FuzzyTECH® based on the influence of the input variables on the output. Then the logic of these rules was verified to ensure that there were no conflicts between the output results of the rules. Two hundred and forty-three rules (3^5) (Appendix C) were implemented in FES. based on all available combinations of linguistic terms comprising the five input variables (each represented by three membership functions). The average rating of experts (Table 4.3) for each input variable was used to determine the output of a given rule for a given set of inputs by accounting for the relative influence of the input variables on the output. For example, "If *years of experience* is LARGE and *diversity of experience* is HIGH and *role in the company* is HIGH and *years in role* is SMALL and *enthusiasm and willingness* is LOW (Rule # 187—illustrated in Figure 4.12), then *importance weight factor* is LARGE." The output variable is LARGE because *years of experience* and *diversity of experience* were rated by experts—after approximation to the lower 0.5 decimal—to be of "very high influence" (approximated average rating 6.0) and "high influence" (approximated average rating 5.0) on the output factor, respectively. At the same time, *role in the company*, *years in role,* and *enthusiasm and willingness* were each rated by experts to be of "medium influence" on the output factor, according to their individual approximated average ratings (average rating 4.0, 4.5, and 4.0, respectively). If the *years in role* were

LARGE and *enthusiasm and willingness* were HIGH, and the other three input variables remained constant, the output would be VERY LARGE, as all input variables would be represented by their maximum linguistic terms (Rule # 243—illustrated in Figure 4.12). Figure 4.12 illustrates an example of some of the fuzzy if-then rules generated by the FuzzyTech® rule wizard, noting that all rules are weighted equally (DoS = 1.0). The next subsection discusses the development of the FES inference process.

Spreadsheet Rule Editor - MAINRB

#	IF					THEN	
	YEARS_OF_E:	Years_in_Role	Role_in_Comp.	Diversity_of_E:	Enthausiasm	DoS	Expert_Weight
186	large	small	high	medium	high	1.00	large
187	large	small	high	high	low	1.00	large
226	large	large	medium	low	low	1.00	medium
227	large	large	medium	low	medium	1.00	medium
228	large	large	medium	low	high	1.00	large
229	large	large	medium	medium	low	1.00	large
230	large	large	medium	medium	medium	1.00	large
231	large	large	medium	medium	high	1.00	large
232	large	large	medium	high	low	1.00	large
233	large	large	medium	high	medium	1.00	large
234	large	large	medium	high	high	1.00	large
235	large	large	high	low	low	1.00	medium
236	large	large	high	low	medium	1.00	medium
237	large	large	high	low	high	1.00	large
238	large	large	high	medium	low	1.00	large
239	large	large	high	medium	medium	1.00	large
240	large	large	high	medium	high	1.00	large
241	large	large	high	high	low	1.00	large
242	large	large	high	high	medium	1.00	large
243	large	large	high	high	high	1.00	very_large

Figure 4.12. Example of the fuzzy IF-Then rules generated by FuzzyTECH®

4.2.3 Development of Fuzzy Expert System Inference Process

The second stage in developing FES was to develop the inference process by determining the fuzzy operators, implication method, and defuzzification method. Fuzzy inference creates a map from the system's input to the system's output using fuzzy logic if-then rules (Marsh 2008). Different fuzzy inference methods determine outputs differently. Mamdani's fuzzy inference method, which is commonly used in most FES applications, is used in the FES model discussed above to determine the importance weight factor of experts (Marsh 2008). Mamdani assumes the output membership function is a fuzzy set as opposed to a crisp function, the latter of which is adopted in the Sugeno type fuzzy inference method (Mamdani and Assilian 1975; Marsh 2008). The inference process of a fuzzy expert system consists of five steps:

- Step 1: Fuzzification of input variables
- Step 2: Applying fuzzy operators to aggregate input condition(s)
- Step 3: Implication from the condition(s) to the conclusion(s)
- Step 4: Aggregation of the conclusions from each rule
- Step 5: Defuzzification of the output fuzzy set

Step 1, fuzzification, is the process of fuzzifying user input crisp values (x-axis values) using predetermined membership functions (previously constructed in subsection 4.2.2.2) to find the membership value of input variables. For example, as illustrated in Figure 4.13, when the user input for "*role in the company*" is 3, it is a member of the fuzzy set "high" to a degree of 0.0, "medium" to a degree of 1.0, and "low" to a degree of 0.5.

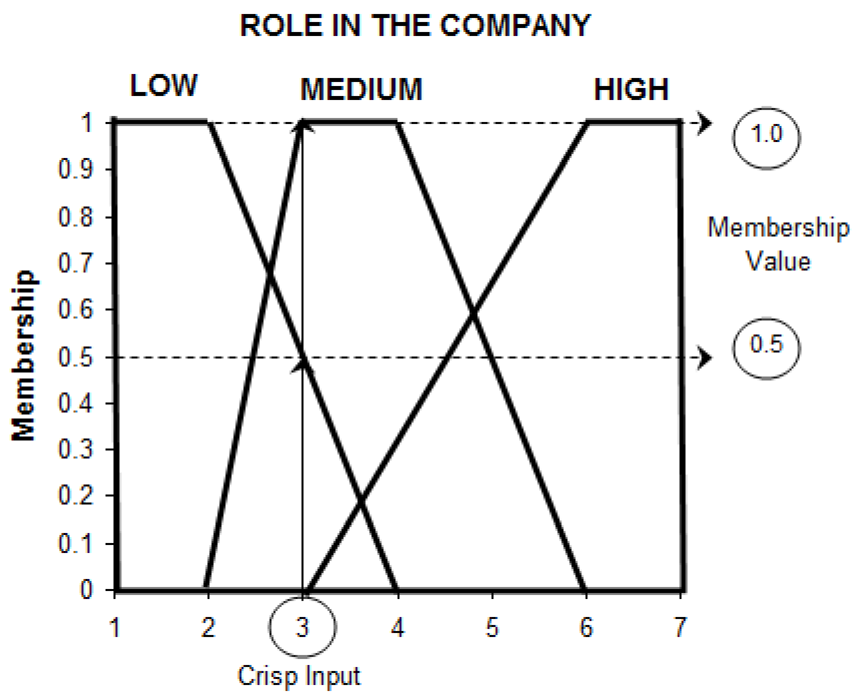

Figure 4.13. Example of fuzzification

Step 2 in the inference process is to apply standard fuzzy operators to combine the degree of membership for each input variable for each rule into a single value. A rule-of-thumb is that the fuzzy operator AND is used to connect independent input variables, and the fuzzy operator OR is used to combine correlated input variables. The AND fuzzy operator has two common methods, MIN (minimum) (Equation 4.6), or PROD (product)

(Equation 4.7), where (a) and (b) are the membership values corresponding to the crisp input values fuzzified according to step 1.

MIN (a, b) = MIN {a, b} [4.6]

PROD (a, b) = ab [4.7]

The fuzzy operator OR also has two common methods, MAX (maximum) (Equation 4.8), and PROBOR (probabilistic) (Equation 4.9).

MAX (a, b) = MAX {a, b) [4.8]

PROBOR (a, b) = a + b – ab [4.9]

In the program used to create the fuzzy expert system, FuzzyTECH®, operators MIN, MAX, and PROD can be selected to combine the degree of membership for each input variable for each rule into a single value. The fuzzy operator AVG (average) (Equation 4.10) is also available in FuzzyTECH®.

AVG (a, b) = AVG {a, b} [4.10]

The fuzzy operator MIN was chosen for the initial base case FES configuration to obtain a single membership value in the premise (if part of the rule) because the input variables were determined by experts as independent variables. The accuracy of the base case FES configuration was determined using sensitivity analysis, as will be discussed in section 4.3.

Figure 4.14 illustrates the first and second steps of the inference process. Crisp values for the input variables "*role in the company*" and "*diversity of experience"* are 6 and 3, respectively. Fuzzification occurs for both inputs producing the membership values 1.0 for the HIGH membership function of the "*role in the company*" and 0.3 for the LOW membership function of the "*diversity of experience*." The fuzzy operator MIN is then applied to these membership values producing a single value 0.3.

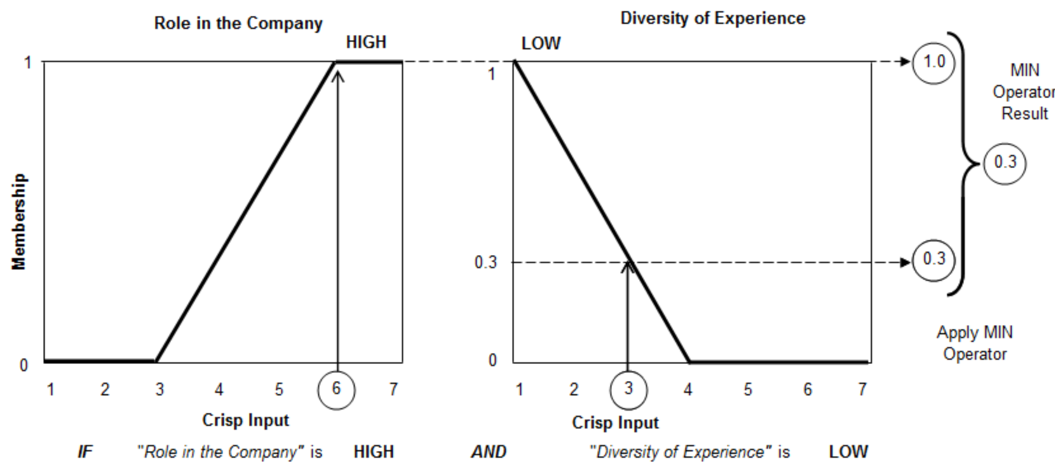

Figure 4.14. Example of applying fuzzy operator MIN

Step 3, implication, involves the process of applying the single membership value obtained from the previous step to the consequent of each rule (Marsh 2008). The single value is the input of the implication process, and a fuzzy set is the output. Two common implication methods are MIN (minimum) (Equation 4.6), which truncates the membership function of the output variable; or PROD (product) (Equation 4.7), which scales the membership function of the output variable by mapping the degree of belongings of its elements to fit a scaled membership function, based on a common attribute that they share (Saaty 1986). The two methods are illustrated in Figure 4.15. FuzzyTECH® only allows the use of one implication method PROD, which was chosen for the initial base case FES configuration.

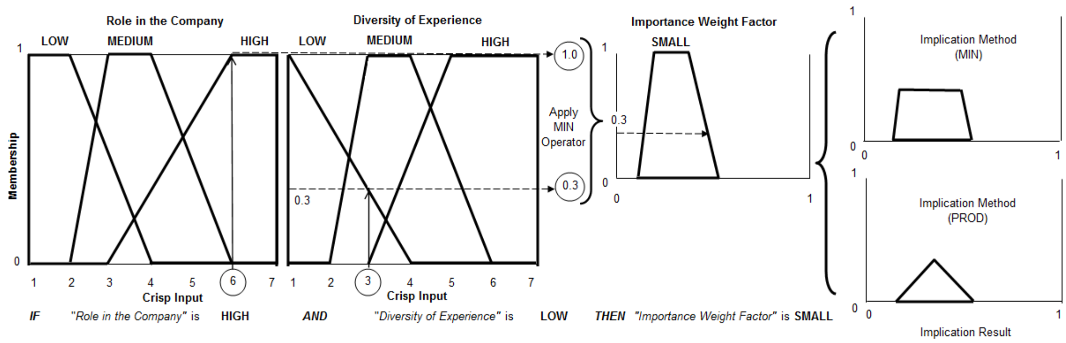

Figure 4.15. Example of applying implication methods MIN or PROD

As illustrated in Figure 4.15, crisp values for the input variables "*role in the company*" and "*diversity of experience"* are 6 and 3, respectively. Fuzzification occurs for both inputs producing the membership values 1.0 for the HIGH membership function of the "*role in the company*" and 0.3 for the LOW membership function of the "*diversity of experience*." The fuzzy operator MIN is then applied to these membership values producing a single membership value of 0.3. The implication process is then applied to the consequent of the sample rule "If *role in the company* is HIGH and *diversity of experience* is LOW then *importance weight factor* is SMALL," which is illustrated in Figure 4.15. In this case, the membership value 0.3 is applied either to truncate (MIN operator) or to scale (PROD operator) the SMALL membership function of the output variable "*Importance Weight Factor.*"

Step 4 involves aggregation of the conclusions from each rule, which occurs once for the rules in a rule base. It involves combining the fuzzy output of each rule in the rule base to obtain a single fuzzy set. There are three common aggregation methods: MAX, SUM, and PROBOR, as shown in Equations 4.11, 4.12, and 4.13.

$$\text{MAX}(a, b) = \text{MAX}\{a, b\} \quad [4.11]$$

$$\text{SUM}(a, b) = \text{MIN}\{1, a + b\} \quad [4.12]$$

$$\text{PROBOR}(a, b) = a + b - ab \quad [4.13]$$

The fuzzy aggregation operator MAX (maximum) combines the maximum value from the output of each rule, while the aggregation operator PROBOR (probabilistic) combines the algebraic sum of the output from each rule, in order to determine the single output fuzzy set. The aggregation operator SUM adds the degrees of membership together. FuzzyTECH® allows for the application of the two possibilities MAX and SUM. The aggregation operator MAX (maximum) was chosen for the initial base case FES configuration. Figure 4.16 illustrates an example of the aggregation of sample rules: "If *role in the company* is HIGH and *diversity of experience* is LOW then *importance weight factor* is SMALL" and "If *role in the company* is HIGH and *diversity of experience* is MEDIUM then *importance weight factor* is MEDIUM." In this example, MIN fuzzy operator is used to aggregate input conditions, MIN implication method is used in the implication process, and MAX aggregation operator is used to aggregate final membership function.

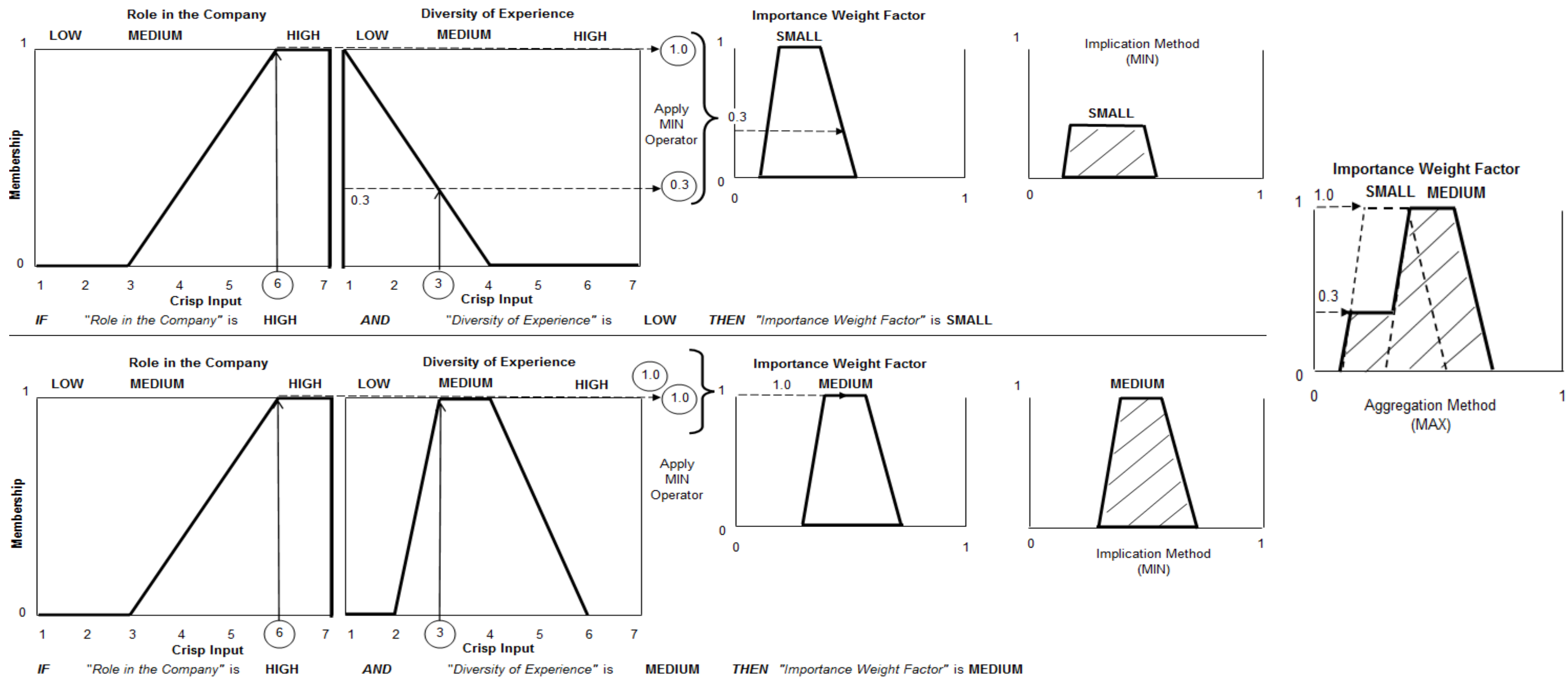

Figure 4.16. Example of applying aggregation operator MAX

Step 5, defuzzification, is the process of transforming a fuzzy set to a crisp number. It is one of the most important operations in the theory of fuzzy sets. This operation, along with the operation of fuzzification, is critical to the design of fuzzy systems, as both of these operations "provide a connection between the fuzzy set domain and the real valued scalar domain" (Poveda 2008).

There are many defuzzification methods, among which are the centre of area (COA) (x-axis value that corresponds to the center of gravity of the aggregated membership function), the bisector (x-axis value that bisects the area in half), the mean of maxima (the average x-axis value of all elements whose membership value is equivalent to the largest membership value), the middle of maxima (MOM) (the middle of a range of x-axis values with the largest membership value), the largest of maxima (LOM) (the largest of the range of x-axis values with the largest membership value), and the smallest of maxima (SOM) (the smallest of the range of x-axis values with the largest membership value).

The defuzzification methods SOM, MOM, and LOM are shown in Figure 4.17, while Equation 4.14 is used to calculate the COA, where x equals the x-axis value and $\mu_A(x)$ is the membership degree associated with x.

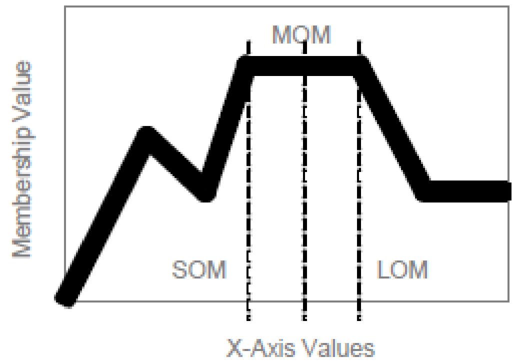

Figure 4.17. Examples of different defuzzification methods (Marsh 2008)

$$COA = \frac{\sum_{x\,\min}^{x\,\max} \mu_A(x) * x}{\sum_{x\,\min}^{x\,\max} \mu_A(x)} \qquad [4.14]$$

FuzzyTECH® uses different defuzzification methods, such as centre of maxima (COM), middle of maxima (MOM), and fast centre of area (COA). The COM aggregation operator was chosen for the initial base case FES configuration.

As discussed in each of the above steps, different default values for the inference process were used in the base case system configuration for the fuzzy expert system built in FuzzyTECH®. In summary, in the base case system configuration, the minimum (MIN) t-norm fuzzy operator (corresponding with linguistic AND) was used for combining the input variables, the product (PROD) t-norm was used for rule implication, and the maximum (MAX) s-norm was used for rule aggregation. The centre of maxima (COM) was used as the defuzzification method. The base case system configuration provided crisp importance weight values for individual experts (Table 4.4), which was based on actual case data collected for a group of 37 experts, whose attributes were collected for the purpose of FES model validation (Table 4.5). Note that the opinions of the same 37 experts were solicited in the case study discussed in chapter 6 to validate the outputs of the Fuzzy Consensus Building Framework (FCBF).

Table 4.4. Results of the base case system configuration

Experts	Importance weight factor	Experts	Importance weight factor
Expert 1	0.8428	Expert 26	0.4599
Expert 2	0.8428	Expert 27	0.4599
Expert 3	0.8428	Expert 28	0.4599
Expert 4	0.8071	Expert 29	0.4599
Expert 5	0.7150	Expert 30	0.4599
Expert 6	0.6909	Expert 31	0.4599
Expert 7	0.6909	Expert 32	0.4599
Expert 8	0.6700	Expert 33	0.4200
Expert 9	0.6333	Expert 34	0.4143
Expert 10	0.6182	Expert 35	0.3800
Expert 11	0.6182	Expert 36	0.3364
Expert 12	0.6083	Expert 37	0.3364
Expert 13	0.6083		
Expert 14	0.6083		
Expert 15	0.6000		
Expert 16	0.5179		
Expert 17	0.5179		
Expert 18	0.5000		
Expert 19	0.5000		
Expert 20	0.5000		
Expert 21	0.4818		
Expert 22	0.4777		
Expert 23	0.4769		
Expert 24	0.4600		
Expert 25	0.4599		

Table 4.5. Actual attributes of experts

Experts	Years of experience	Diversity of experience	Years in role	Enthusiasm and willingness	Role in the company
Expert 1	>20	Extremely high	>20	High	Sr. Project Manager
Expert 2	>20	High	>20	Very High	Sr. Project Manager
Expert 3	>20	Very High	>20	Average	Sr. Project Manager
Expert 4	>20	Average	>20	High	Project Director
Expert 5	>20	Average	9 to 12	High	Sr. Project Manager
Expert 6	>20	High	5 to 8	Low	General Manager
Expert 7	>20	Average	5 to 8	Average	Project Director
Expert 8	9 to 12	Extremely high	9 to 12	Low	Project Director
Expert 9	13 to 16	Very High	13 to 16	High	Sr. Project Engineer
Expert 10	9 to 12	High	9 to 12	Very High	Project Manager
Expert 11	9 to 12	High	9 to 12	Average	Sr. Project Manager
Expert 12	9 to 12	High	9 to 12	High	Project Manager
Expert 13	9 to 12	Average	9 to 12	Very High	Sr. Project Manager
Expert 14	9 to 12	High	9 to 12	High	Project Manager
Expert 15	13 to 16	Average	5 to 8	High	Sr. Project Engineer
Expert 16	5 to 8	High	5 to 8	High	Sr. Project Manager
Expert 17	5 to 8	High	5 to 8	Low	Sr. Project Manager
Expert 18	9 to 12	Low	5 to 8	Average	Project Director
Expert 19	5 to 8	Very High	5 to 8	Average	Project Manager
Expert 20	>20	Very Low	1 to 4	High	Project Manager
Expert 21	5 to 8	Average	5 to 8	High	Project Engineer
Expert 22	5 to 8	High	5 to 8	Very Low	Project Director
Expert 23	1 to 4	High	1 to 4	High	Project Director

Table 4.5. Actual attributes of experts (continued)

Experts	Years of experience	Diversity of experience	Years in role	Enthusiasm and willingness	Role in the company
Expert 24	5 to 8	Low	5 to 8	High	Project Manager
Expert 25	5 to 8	Low	5 to 8	Average	Project Manager
Expert 26	5 to 8	Low	5 to 8	Average	Project Manager
Expert 27	5 to 8	Low	5 to 8	Average	Project Manager
Expert 28	5 to 8	Low	5 to 8	Average	Project Manager
Expert 29	5 to 8	Average	5 to 8	Average	Project Engineer
Expert 30	5 to 8	Low	5 to 8	Average	Project Manager
Expert 31	5 to 8	Low	5 to 8	Average	Project Manager
Expert 32	5 to 8	Low	5 to 8	Average	Project Manager
Expert 33	1 to 4	High	1 to 4	Average	Project Engineer
Expert 34	1 to 4	High	1 to 4	High	Leader
Expert 35	1 to 4	Average	1 to 4	Average	Project Engineer
Expert 36	5 to 8	Low	5 to 8	Average	Sr. Project Engineer
Expert 37	5 to 8	Low	5 to 8	Average	Sr. Project Engineer

After calculating the importance weights of experts using the base case system configuration, FES model validation was carried out, and then a sensitivity analysis was done to determine how sensitive the model was to changing the fuzzy operator, implication method, aggregation method, and defuzzification method that were previously chosen in the base case system configuration. FES model validation and sensitivity analysis results are included in the next section.

4.3 Fuzzy Expert System (FES) Model Validation and Sensitivity Analysis

The fuzzy expert system to determine the importance weight factor of experts was validated using actual data collected for the 37 experts, as illustrated in Table 4.5. Of these 37 experts, twenty-six worked for a large project owner organization in Canada in the field of oil and gas, and 11 worked for different Engineering, Procurement, and Construction (EPC) contractors that handled projects located in North America and Europe for the owner organization. Experts' attributes were collected using a database that stored information related to the employees of both the owner and its contractors, which was provided by the human resource (HR) department of the owner organization. The HR department also provided an actual value of the overall importance weight factor of each of the 37 experts, based on a previous appraisal of employees that was made by the HR department manager of the owner organization on a continuous rating scale that ranged from 0 to 1. Thus, the actual output data collected for the experts was based on historical data and expert opinion against which the FES model is validated.

In order to validate the FES model, Average % Error was calculated between the crisp outputs obtained through the defuzzification process of FES, based on the base case system configuration, and the actual overall ratings that were given by the HR department manager of the owner organization. Also, the 95% confidence interval for the percent error was calculated. The Average % Error was calculated using Equation 4.15.

$$\text{Average \% Error} = \frac{\left| \sum_{i=1}^{n} \frac{FESOutput_i - ActualRating_i}{ActualRating_i} \right|}{n} \times 100 \qquad [4.15]$$

where, *FESOutput* is the crisp output importance weight value generated by the FES model for every expert, *ActualRating* is the actual overall rating of the importance weight value of every expert given by the HR department manager, *i* is equal to the individual expert number, and *n* equals the total number of experts.

Table 4.6 illustrates the Average % Error found in the base case system configuration as well the 95% confidence interval for the percent error. As illustrated in Table 4.6, the Average % Error was calculated as 9.56% and its 95% confident interval was between 5.46%-13.65%, which means that the output of the FES model was close to a subjective judgement made by an expert in the field of assessing the experts' qualifications.

However, it is to be noted that the Percentage (%) Error was relatively high for experts' cases # 14, 16, 17, and 22, which was 52.08%, 26.01%, 39.07%, and 40.29%, respectively (Table 4.6). The discrepancy, however, between the *FESOutput* and *ActualRating* of experts # 17 and 22 is rational. As illustrated in Table 4.5, the two experts' had "*low*" and "*very low*" "*enthusiasm and willingness*" factor that was assessed by the researcher in the data collection stage based on their unreasonable delays in providing proper feedback, compared to other experts; and their low enthusiasm in supporting the study, a subjective factor that the HR department manager of the owner organization did consider in making his assessments, which resulted in a lower *FESOutput* for the two experts than their *ActualRating*.

As for expert case # 16, the HR department manager of the owner organization described this expert as a "very credible expert to the organization," notwithstanding the experts' relatively small number of "*years of experience*" and "*years in role*" of (5 to 8) years (Table 4.5).

Unfortunately, the HR department manager did not provide a reason why he made a low assessment in case of expert # 14, which was an assessment that was based on the HR department manager's subjective judgement.

Table 4.6. Percentage (%) error calculation of the base case system configuration

i	*FES output*	*Actual rating*	*% Error*	*i*	*FES output*	*Actual rating*	*% Error*
1	0.8428	0.8500	0.85%	20	0.5000	0.4000	25.00%
2	0.8428	0.8500	0.85%	21	0.4818	0.4500	7.07%
3	0.8428	0.8500	0.85%	22	0.4777	0.8000	40.29%
4	0.8071	0.8500	5.05%	23	0.4769	0.4500	5.98%
5	0.7150	0.8500	15.88%	24	0.4600	0.4500	2.22%
6	0.6909	0.8000	13.64%	25	0.4599	0.4500	2.20%
7	0.6909	0.7000	1.30%	26	0.4599	0.4500	2.20%
8	0.6700	0.6500	3.08%	27	0.4599	0.5000	8.02%
9	0.6333	0.6000	5.55%	28	0.4599	0.4500	2.20%
10	0.6182	0.5000	23.64%	29	0.4599	0.4500	2.20%
11	0.6182	0.5000	23.64%	30	0.4599	0.4500	2.20%
12	0.6083	0.6500	6.42%	31	0.4599	0.4500	2.20%
13	0.6083	0.6000	1.38%	32	0.4599	0.4500	2.20%
14	0.6083	0.4000	52.08%	33	0.4200	0.4000	5.00%
15	0.6000	0.5500	9.09%	34	0.4143	0.4000	3.58%
16	0.5179	0.7000	26.01%	35	0.3800	0.4000	5.00%
17	0.5179	0.8500	39.07%	36	0.3364	0.3500	3.89%
18	0.5000	0.5000	0.00%	37	0.3364	0.3500	3.89%
19	0.5000	0.5000	0.00%	**Average % Error = 9.56% 95% Confidence interval = 5.46%–13.65%**			

Based on the above results, one of the basic advantages of this FES model is its ability to substitute subjective opinions made by qualified experts, by capturing their knowledge and making it available to non-knowledgeable individuals. The FES model discussed above also incorporates consistency in the decision-making process using a finite set of fuzzy if-then rules that connect its input variables to its output variable, as opposed to relying on subjective judgements made by individuals who may not be capable of processing different subjective attributes of experts to provide a consistent output.

After the model validation was completed on the base case system, a sensitivity analysis was done to ensure that the fuzzy operators, aggregation method, and defuzzification method used were the best choices for this application. Twelve systems were compared to the base case system configuration, which consisted of linear membership functions, the MIN (minimum) fuzzy operator for input aggregation, the MAX (maximum) rule aggregation method, the PROD (product) implication method, and the center of maximum defuzzification method, as shown in Table 4.7.

Table 4.8 illustrates the results of the different systems, in terms of the values of the importance weight factors of the 37 individual experts, which were calculated using the FES model and compared to the base case system configuration.

Table 4.7. Sensitivity analysis and Average % Error of the different systems

System #	MF shape	Input aggregation method	Implication method	Rule aggregation method	Defuzzification method	Avg. % error	95% Confidence interval
Base case system	Linear	MIN	PROD	MAX	COM	9.56%	5.46%–13.65%
System # 1	Linear	MIN	PROD	MAX	MOM	23.86%	18.98%–28.74%
System # 2	Linear	MIN	PROD	MAX	COA	10.25%	6.46%–14.04%
System # 3	Linear	MIN	PROD	SUM	COM	9.61%	5.42%–13.81%
System # 4	Linear	AVG	PROD	MAX	COM	16.19%	12.51%–19.87%
System # 5	Linear	MAX	PROD	MAX	COM	22.18%	18.16%–26.21%
System # 6	Linear	PROD	PROD	MAX	COM	12.67%	9.05%–16.28%
System # 7	Linear	PROD	PROD	MAX	COA	13.66%	10.37%–16.96%
System # 8	Linear	PROD	PROD	MAX	MOM	22.92%	19.00%–26.85%
System # 9	Linear	AVG	PROD	SUM	COM	21.11%	17.40%–24.82%
System # 10	Linear	MAX	PROD	SUM	COM	22.44%	18.46%–26.43%
System # 11	Linear	AVG	PROD	MAX	COA	16.91%	13.18%–20.63%
System # 12	Linear	MAX	PROD	MAX	COA	20.36%	16.11%–24.61%

Table 4.8. Results of the sensitivity analysis of *FESOutput* based on the different systems

Experts	Base case system	System # 1	System # 2	System # 3	System # 4	System # 5	System # 6	System # 7	System # 8	System # 9	System # 10	System # 11	System # 12
Expert 1	0.8428	0.9500	0.7634	0.8250	0.6635	0.6125	0.8428	0.7634	0.9500	0.6125	0.6125	0.6179	0.5750
Expert 2	0.8428	0.9500	0.7634	0.8250	0.6753	0.6125	0.8428	0.7634	0.9500	0.6125	0.6125	0.6283	0.5750
Expert 3	0.8428	0.9500	0.7634	0.8250	0.6470	0.5718	0.8428	0.7634	0.9500	0.6038	0.5718	0.6049	0.5440
Expert 4	0.8071	0.7000	0.7372	0.8250	0.6500	0.6125	0.7833	0.7210	0.7000	0.6125	0.6125	0.6082	0.5750
Expert 5	0.7150	0.7000	0.6672	0.7169	0.6182	0.5814	0.6889	0.6500	0.7000	0.6060	0.5814	0.5829	0.5513
Expert 6	0.6909	0.7000	0.6543	0.6444	0.6026	0.5369	0.7100	0.6687	0.7000	0.5833	0.5369	0.5716	0.5171
Expert 7	0.6909	0.7000	0.6543	0.6875	0.5949	0.5537	0.6650	0.6385	0.7000	0.5913	0.5537	0.5659	0.5301
Expert 8	0.6700	0.7000	0.6355	0.6500	0.5893	0.5369	0.6750	0.6421	0.7000	0.5814	0.5369	0.5610	0.5171
Expert 9	0.6333	0.7000	0.6200	0.6000	0.6121	0.5537	0.6600	0.6412	0.7000	0.5996	0.5537	0.5798	0.5301
Expert 10	0.6182	0.7000	0.5882	0.5958	0.5989	0.5718	0.6419	0.6212	0.7000	0.5975	0.5718	0.5698	0.5540
Expert 11	0.6182	0.7000	0.5882	0.5958	0.5954	0.5718	0.6471	0.6186	0.7000	0.5893	0.5718	0.5659	0.5440
Expert 12	0.6083	0.7000	0.5811	0.5958	0.5869	0.5718	0.5951	0.5825	0.5000	0.5975	0.5718	0.5603	0.5540
Expert 13	0.6083	0.5000	0.5811	0.5958	0.5924	0.5718	0.6133	0.5964	0.7000	0.5975	0.5718	0.5643	0.5440
Expert 14	0.6083	0.7000	0.5811	0.5958	0.5869	0.5718	0.5951	0.5825	0.5000	0.5975	0.5718	0.5603	0.5440
Expert 15	0.6000	0.5000	0.5923	0.6000	0.5446	0.5220	0.6000	0.5923	0.5000	0.5754	0.5537	0.5286	0.5082
Expert 16	0.5179	0.5000	0.5169	0.5000	0.5663	0.5369	0.5523	0.5490	0.5000	0.5833	0.5369	0.5357	0.5171
Expert 17	0.5179	0.5000	0.5169	0.5000	0.5419	0.5369	0.5524	0.5489	0.5000	0.5681	0.5369	0.5247	0.5171
Expert 18	0.5000	0.5000	0.5000	0.5000	0.5389	0.5537	0.5222	0.5214	0.5000	0.5697	0.5537	0.5230	0.5301
Expert 19	0.5000	0.5000	0.5000	0.5000	0.5389	0.5369	0.5220	0.5213	0.5000	0.5697	0.5369	0.5223	0.5171
Expert 20	0.5000	0.5000	0.5000	0.5000	0.5269	0.5289	0.5000	0.5000	0.5000	0.5593	0.5289	0.5140	0.5110
Expert 21	0.4818	0.3000	0.4613	0.4750	0.4774	0.4750	0.4230	0.4240	0.3000	0.5222	0.5067	0.4708	0.4891
Expert 22	0.4777	0.5000	0.4786	0.4428	0.5066	0.5067	0.4816	0.4822	0.5000	0.5548	0.5067	0.4971	0.4938
Expert 23	0.4769	0.5000	0.4777	0.5144	0.5238	0.5067	0.4675	0.4683	0.5000	0.5699	0.5067	0.5084	0.4938

Table 4.8. Results of the sensitivity analysis of *FESOutput* based on the different systems (continued)

Experts	Base case system	System # 1	System # 2	System # 3	System # 4	System # 5	System # 6	System # 7	System # 8	System # 9	System # 10	System # 11	System # 12
Expert 24	0.4600	0.3000	0.4613	0.4428	0.4895	0.5051	0.4157	0.4165	0.3000	0.5300	0.5369	0.4852	0.4953
Expert 25	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 26	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 27	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 28	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 29	0.4599	0.3000	0.4612	0.4750	0.4738	0.5067	0.4228	0.4238	0.3000	0.5150	0.5067	0.4705	0.4938
Expert 30	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 31	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 32	0.4599	0.3000	0.4612	0.4428	0.4826	0.5369	0.4052	0.4055	0.3000	0.5223	0.5369	0.4852	0.4953
Expert 33	0.4200	0.5000	0.4200	0.4130	0.4728	0.5067	0.4333	0.4333	0.5000	0.5100	0.5067	0.4710	0.4938
Expert 34	0.4143	0.5000	0.4143	0.4130	0.4693	0.5067	0.4333	0.4333	0.5000	0.5168	0.5067	0.4687	0.4938
Expert 35	0.3800	0.3000	0.3800	0.4130	0.4459	0.5067	0.3667	0.3367	0.3000	0.4885	0.5067	0.4487	0.4938
Expert 36	0.3364	0.3000	0.3519	0.3578	0.4609	0.5369	0.3954	0.3966	0.3000	0.4963	0.5369	0.4614	0.5171
Expert 37	0.3364	0.3000	0.3519	0.3578	0.4609	0.5369	0.3954	0.3966	0.3000	0.4963	0.5369	0.4614	0.5171

The results of the sensitivity analysis (Table 4.8) and the calculated Average % Error (Table 4.7) of the twelve system configurations, compared to the base case system configuration, showed that the choice of the MAX fuzzy operator for input aggregation was not the best choice (systems # 5, 10, and 12). Table 4.7 shows that the values of the Average % Error calculated for systems # 5, 10, and 12 were 22.18%, 22.44%, and 20.36%, respectively, which are relatively high compared to an Average % Error of 9.56% for the base case system configuration, which used the MIN fuzzy operator for input aggregation. Also, using different rule aggregation methods and defuzzification methods in the three systems did not have significant variation on the output results of the FES model, as the Average % Error was between 20.36% and 22.44% for the three systems. Moreover, Table 4.8 shows that the variation in the FES outputs for the group of experts in the three systems was not high, and ranged between 0.4750 and 0.6125. Variations in the system outputs for the group of experts for these three systems do not match the high variation in the actual experts' attributes (Table 4.5). Conversely, the base case system configuration showed high variation in the system outputs for the group of experts that ranged between 0.3364 and 0.8428, which was very close to the actual subjective assessment made by the expert (Table 4.6).

The middle of maxima (MOM) defuzzification method was also not the best choice (systems # 1 and 8). Table 4.7 shows that the values of the Average % Error calculated for systems # 1 and 8 were 23.86% and

22.92%, respectively. These two systems have the maximum Average % Error amongst the twelve systems. It is also to be noted that the Average % Error calculated for both systems was very close because the operators and methods used in both systems were the same, except that the minimum (MIN) fuzzy operator was used for input aggregation in system # 1, while the PROD (product) fuzzy operator was used for input aggregation in system # 8. Thus, it is concluded that changing the fuzzy operators for input aggregation did not have considerable impact on the output when the MOM (middle of maxima) defuzzification method was used in these two systems. It is finally to be mentioned that these two configuration systems did not reflect adequate variations in system input on the system output, which only resulted in one of four output values: 0.3, 0.5, 0.7, and 0.95 (Table 4.8) for the 37 experts' cases. This means that the middle of maxima (MOM) defuzzification method does not properly allow for FES system' output variation.

Use of the AVG (average) fuzzy operator for input aggregation (systems # 4, 9, and 11) slightly improved the accuracy of the FES model. Table 4.7 shows that the values of the Average % Error of systems # 4, 9, and 11 were 16.19%, 21.11%, and 16.91%, respectively, which—except for system # 9, that used SUM as its rule aggregation method instead of MAX—are relatively lower than those calculated for the previously discussed systems # 1, 5, 8, and 10. However, the values of the Average % Error are still relatively high, compared to that of the base case system.

Use of the PROD fuzzy operator for input aggregation (systems # 6 and 7) provided better accuracy of the FES model than the previously discussed systems, yet these two systems did not provide the best results in terms of Average % Error, compared to the base case system configuration. Table 4.7 shows that the values of the Average % Error for systems # 6 and 7 were 12.67% and 13.66%, respectively, compared to 9.56% for the base case system configuration. It is to be noted, however, that the COM (centre of maxima) defuzzification method (system # 6) provided lower Average % Error than the COA (centre of area) defuzzification method (system # 7).

Finally, the COA (centre of area) defuzzification method used in system # 2, which used the MIN (minimum) fuzzy operator for input aggregation, provided a very close result to that of the base case system in terms of its Average % Error, which was 10.25%. However, system # 3, which used a fuzzy operator (MIN) for input aggregation and a defuzzification method (COM) similar to the base case system configuration, yet a different aggregation method (SUM), provided better accuracy of the FES model for all twelve systems, as its Average % Error is 9.61%, which is the closest result to that of the base case system. Notwithstanding this fact, the confidence interval for the percent error calculated in system # 3 (5.42%–13.81%) was slightly higher than that in the base case system (5.46%–13.65%).

In conclusion, based on sensitivity analysis, Average % Error, and confidence interval calculations, the base case system configuration provided the least Average % Error (9.56%), which provided the best accuracy of the FES model (i.e., 90.44% accuracy). The best case system configuration also reflected adequate variations in system input on system output, as previously discussed. As a result, based on applying the base case system configuration, the FES model output—the importance weights of the 37 experts, as shown in Table 4.4—was used in the case study presented in chapter 6 to demonstrate the results of the Fuzzy Consensus Building Framework (FCBF) discussed in this thesis.

4.4 Conclusion

A standalone fuzzy expert system (FES) model (Elbarkouky and Fayek 2010) was developed in this chapter to incorporate the quality of experts in the decision-making process by determining an importance weight factor for each expert based on his or her specific attributes. The main components of the FES model—a knowledge base and an inference engine, which was built using FuzzyTECH®—were described in detail. The stages of model development were explained. Five input variables, describing different attributes of experts, and an output variable, describing the importance weight factor of experts, which were developed using expert judgement, were implemented in the FES model. The membership functions of the input and output variables were constructed using the modified horizontal approach coupled with an interpolation technique. These techniques were selected based on the results of a comprehensive literature review that explained the advantages and disadvantages of each approach. The knowledge base of fuzzy if-then rules used in the FES model was created using expert judgement and FuzzyTECH®. The inference process of FES was explained, and it included an input aggregation method, an implication method, a rule aggregation method, and a defuzzification method. Finally, the results of the model, based on actual data collected for the purpose of model validation, were illustrated, and sensitivity analysis was conducted to select the best fuzzy expert system configuration. This FES that has been developed provides an improvement over previous consensus-based aggregation approaches that assumed subjective importance weights of experts, as it incorporates the quality of each expert, using his or her relative attributes, in the decision-making process, and captures experts' knowledge and makes it available to non-knowledgeable individuals.

The next chapter explains the fuzzy consensus-based aggregation methods used to aggregate experts' opinions in the Fuzzy Consensus Building Framework (FCBF) described above, and explains how the importance weight factor of experts is incorporated in the decision-making process.

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5. Chapter Five - Fuzzy Consensus Building and Aggregation

5.1 Introduction

A Fuzzy Consensus Building Framework (FCBF) is developed to provide construction project owners and project contractor teams with a tool for early alignment of their project teams in deciding on the extent of their roles and responsibilities in any given project delivery system. This objective is achieved by developing a consensus building and aggregation model that involves project teams in the decision-making process. The model incorporates consensus of construction project teams in aggregating their opinions to decide on the party responsible for every standard task of a construction project, and it classifies the quality of experts in the decision-making process by weighting their responses during aggregation, based on their attributes.

In chapter 3, a template of project and construction management tasks was developed to help project teams determine the extent of their roles and responsibilities on a task-by-task basis using a fuzzy linguistic rating scale, which defined different extents of the roles and responsibilities of the project owner versus those of its contractors. In chapter 4, a standalone fuzzy expert system (FES) was developed to determine an importance weight factor of project teams, which classifies their quality in the aggregation process of project teams' opinions on the extent of their roles and responsibilities. The current chapter discusses the methods used in the FCBF to aggregate the opinion of project teams by combining their subjective opinions, and to build consensus by resolving disagreements in their opinions, which is a fundamental process in developing the Fuzzy Consensus Building Framework (FCBF).

Two different fuzzy consensus building and aggregation methods, which are applied in the FCBF, are discussed in this chapter: (1) the modified similarity aggregation method (SAM), which is proposed to incorporate consensus and quality of construction project teams in aggregating their opinions; and (2) the fuzzy preference relations consensus (FPRC) approach, which is proposed to resolve residual conflicts between project teams on their opinions using a consensus reaching process.

First, the modified similarity aggregation method (SAM) (Elbarkouky and Fayek 2010a) is applied to aggregate project teams' opinions on the party responsible for every standard task, previously classified in the standard template of project and construction management tasks in chapter 3. The modified SAM uses a flexible aggregation algorithm to aggregate project teams' linguistic assessments of the different parties' roles and responsibilities, based on the similarities between their different opinions. Thus, it ensures that the aggregated opinion is based on common agreement between the project teams. It also incorporates the importance weight factor of experts in the aggregation equation, which is computed using the standalone fuzzy expert system (FES) discussed in chapter 4. The project teams use the fuzzy linguistic rating scale, created in chapter 3, to determine the extent of the roles and responsibilities of the owner versus that of its contractors on a task-by-task basis using seven linguistic terms, with each defining a certain extent of responsibility of the owner versus that of its contractors. Then, the modified SAM aggregates project teams' linguistic assessments, and each task is classified under one of three responsibility task lists: the owner's, the contractors', or the shared responsibility task list. A detailed explanation of the algorithm used in the modified SAM is provided in section 5.2.

Second, the fuzzy preference relations consensus (FPRC) approach (Elbarkouky and Fayek 2010b and 2009) is applied in the FCBF to facilitate consensus building by identifying and reducing the conflicts between project teams that may exist when the algorithm used in the modified SAM determines tasks should be equally shared between the owner and its contractors. This step is required because when the modified SAM determines a task is equally shared, three possibilities may exist: (1) the project teams may have collectively agreed that the task is a valid shared task, with both parties having equally shared responsibility, which is a legitimate case; (2) the task was incorrectly classified by project teams as equally shared task because they were not able to decide on a party responsible for the task using the fuzzy linguistic rating scale; or (3) the algorithm used in the modified SAM failed to draw a reasonable conclusion based on the collective opinion of project teams due to an equal number of responses that may have existed on both sides of the fuzzy linguistic rating scale. Since there is no clear methodology to identify which of these possibilities resulted in a shared task using the modified SAM, all three possibilities are checked using the FPRC approach. The FPRC approach tests the possibility of transferring any of the shared tasks to either the owner or its contractors by introducing perceived shared tasks to project teams to make further responsibility assessments using fuzzy preference relations in a consensus reaching process. Then, a fuzzy linguistic consensus measure that identifies the degree of consensus among project teams on their preferences in a consensus reaching process is applied. Thereby, it reduces potential conflicts between project teams, and provides a means of alignment on their roles and responsibilities in a linguistic framework. A detailed explanation of the fuzzy preference relations consensus (FPRC) approach is provided in section 5.3. Figure 5.1 illustrates the modified SAM and the FPRC approach (highlighted) to demonstrate how they fit within the Fuzzy Consensus Building Framework (FCBF). Figure 5.1 also illustrates other components of the FCBF, which were discussed in chapters 3 and 4.

The next section discusses the algorithm used in the modified SAM, which is explained using a numerical example.

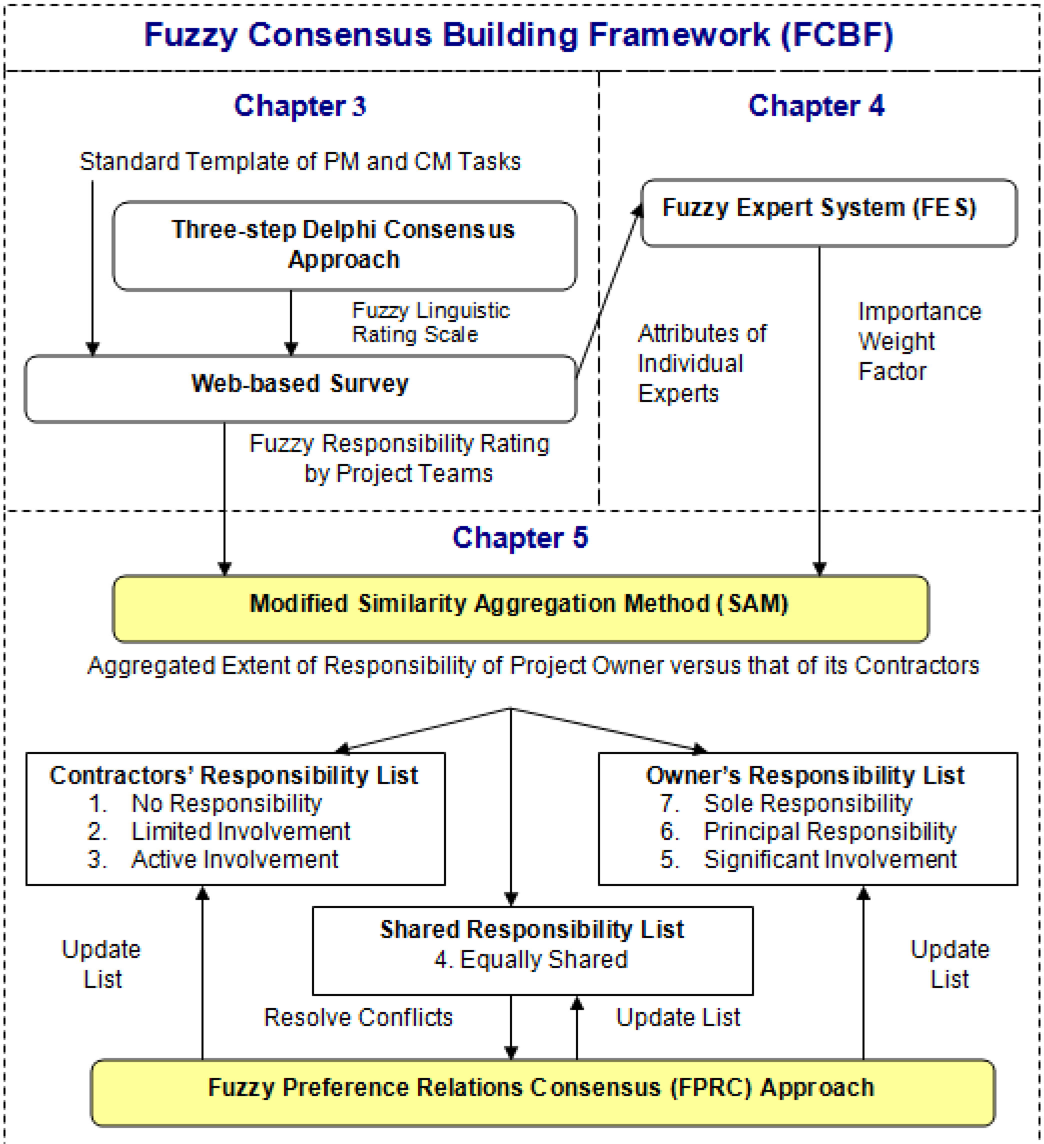

Figure 5.1. Fuzzy consensus building and aggregation methods in FCBF

5.2 Modified Similarity Aggregation Method (SAM)

The modified similarity aggregation method (SAM) (Elbarkouky and Fayek 2010a) is an aggregation algorithm applied in the Fuzzy Consensus Building Framework (FCBF) to aggregate project teams' opinions on the party responsible (owner versus contractor) for every standard task of the selected project delivery system by the project owner organization. The modified SAM aggregates project teams' opinions based on the similarity between their linguistic assessments using a modified algorithm that addresses the gaps of the original SAM (Hsu and Chen 1996), as previously explained in chapter 2.

The original SAM used a simple algorithm based on fuzzy arithmetic and similarity agreement. This algorithm can aggregate numerical forecasts provided by experts using fuzzy numbers by computing a consensus weight factor for each expert, based on the similarity of their opinions. A similarity measure function (Zwick et al. 1987) was used to calculate the degrees of similarity between experts' opinions, based on areas of overlap of their fuzzy numbers. As previously discussed in chapter 2, in order to address the limitations of SAM, the similarity aggregation method (Hsu and Chen 1996) is modified (Elbarkouky and Fayek 2010a) in the FCBF to be applied in a linguistic framework, and the modifications are summarized as follows:

- A standard fuzzy linguistic rating scale is created (chapter 3), on which project teams define different extents of the roles and responsibilities of the project owner versus those of its contractors, using linguistic terms that are represented by membership functions instead of fuzzy numbers (as in the case of the original SAM).

- A standalone fuzzy expert system (FES) is created (chapter 4) to determine an importance weight factor for each expert in the decision-making process, rather than subjectively assuming expert weights (Hsu and Chen 1996). Then, the importance weight factor of each expert (output of FES) is combined with his or her consensus weight factor in a modified SAM, and this produces an aggregated fuzzy number, depicted on the fuzzy linguistic scale.
- The Euclidean distance measure function (Heilpern 1997) is used to determine the best linguistic term for the aggregated fuzzy number (output of the SAM algorithm) to derive a meaningful linguistic output of the modified SAM. The linguistic term whose MF has the minimum Euclidean distance to the aggregated fuzzy number describes the final extent of the roles and responsibilities of the project owner versus its contractors for a given task.

The modified SAM is applied in four steps (listed below) after determining experts' linguistic assessments for every task using the seven linguistic terms previously explained in chapter 3 (Table 5.1):

- Step 1: Assign relevant membership functions to experts' linguistic assessments.
- Step 2: Determine experts' consensus weight factor.
- Step 3: Aggregate experts' opinions into a single fuzzy number.

- Step 4: Determine final extent of responsibility using appropriate linguistic terms.

Table 5.1. Description of linguistic terms forming a fuzzy linguistic rating scale

Rating	Linguistic term	Description
1	No responsibility	The project owner is not responsible for carrying out the task. The owner may be consulted based on the contractor's sole discretion.
2	Limited involvement	The project owner is not responsible for carrying out the task. Minor input is required from the owner to enable the contractor to perform the task.
3	Active involvement	The project owner is not responsible for carrying out the task. The owner must be involved in all task-related discussions and provide considerable input.
4	Shared equally	Both parties carry out the task with equal levels of involvement.
5	Significant involvement	The project owner is responsible for carrying out the task. The contracor must be involved in all task-related discussions and provide considerable input.
6	Principal responsibility	The project owner is responsible for carrying out the task. Minor input is required from the contractor to enable the owner to perform the task.
7	Sole responsibility	The project owner is fully responsible for carrying out the task. The contractor may be consulted based on the owner's sole discretion.

The following subsections explain the four steps of developing the modified SAM using a numerical example.

5.2.1 Step 1: Assign relevant membership functions to experts' linguistic assessments

In this step the linguistic assessments made by experts, regarding the extent of the roles and responsibilities of project owner versus that of its contractors, are depicted on the fuzzy linguistic rating scale. As a result, relevant membership functions are assigned to the individual linguistic assessments made by experts, which is a key step to enable applying the algorithm used in the modified SAM in a linguistic framework.

In order to explain this step, assume, for a given task, such as "prepare the design basis memorandum (DBM)," that three experts—E_1, E_2, and E_3—selected their fuzzy ratings, which determined the extent of responsibility of a project owner organization, as: R_1 *"Principal Responsibility,"* R_2 *"Principal Responsibility,"* and R_3 *"No Responsibility"* using the fuzzy linguistic rating scale (Figure 5.2), as illustrated in Table 5.2.

The fuzzy triplets (r_1, r_2, r_3) that define the membership function representing the experts' fuzzy ratings are determined based on the shapes and supports of the standard membership functions that describe the seven fuzzy ratings Y_k on the scale, where k ranges from 1 to 7 (Figure 5.2). The standard fuzzy ratings Y_k help the experts to determine the extent of the roles and responsibilities for each task according to the experts' respective linguistic terms.

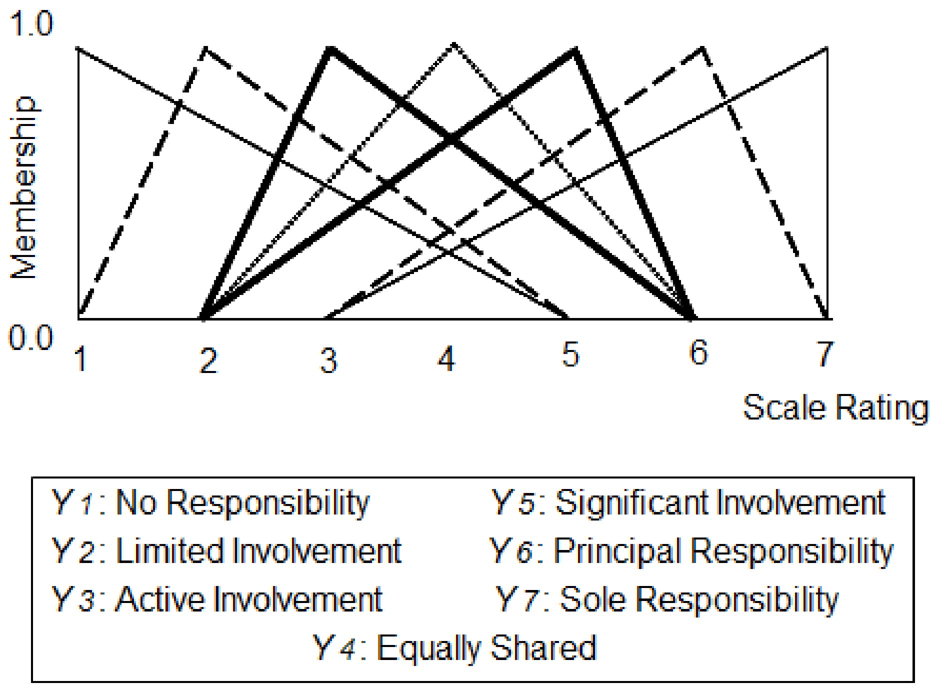

Figure 5.2. Fuzzy linguistic rating scale

Table 5.2 illustrates the fuzzy triplets that represent the linguistic assessments made by the three experts in the above example. The next step determines the consensus weight factor of each expert, which is used to weight his or her opinion in the aggregation algorithm.

Table 5.2. Numerical calculations of modified SAM

		Expert 1	Expert 2	Expert 3
(a) Rating		Principal responsibility	Principal responsibility	No responsibility
(b) Fuzzy triplets	r_1	3	3	1
	r_2	6	6	1
	r_3	7	7	5
(c) Agreement matrix	**Expert 1**	1.00	1.00	0.08
	Expert 2	1.00	1.00	0.08
	Expert 3	0.08	0.08	1.00
(d) Consensus calculation	$A(E_i)$	0.54	0.54	0.08
	CWF_i	0.47	0.47	0.06
	$RIWF_i$	0.400	0.400	0.200
	CDC_i	0.435	0.435	0.130
		R = (2.74 5.35 6.74) Owner's principal responsibility		

5.2.2 Step 2: Determine experts' consensus weight factor

This step involves calculating the agreement degrees between experts based on their relative fuzzy ratings, which enables determining the consensus weight factor of each expert. The consensus weight factor of experts is a key aspect in aggregating their linguistic assessments into a collective decision based on their common agreement. For example, if the consensus weight factor of an expert is high, then his or her opinion is close to the opinions that entail common agreement between experts, based on their relative fuzzy ratings. Hence, his or her opinion will have greater impact, or weight, than other experts in the aggregation process, and vice-versa.

First, the algorithm of the modified SAM calculates the agreement degree $S(R_i, R_j)$ between the fuzzy ratings selected by each expert pair. The agreement degree is determined using the similarity measure function, which was developed by Zwick et al. (1987). It is computed by dividing the intersection area of the ratings by the bounding area, as shown in Equation 5.1, where μ_{Ri} and μ_{Rj} are the relevant membership degrees of every element (x) of the fuzzy ratings selected by the two experts on the scale.

$$S(R_i, R_j) = \frac{\int_x (\min\{\mu_{Ri}(x), \mu_{Rj}(x)\})\,\mathrm{d}x}{\int_x (\max\{\mu_{Ri}(x), \mu_{Rj}(x)\})\,\mathrm{d}x} \qquad [5.1]$$

For example, based on the membership functions' shapes (Figure 5.2), the intersecting area between the fuzzy ratings of experts 1 and 2 is calculated as 1.0 because they selected the same fuzzy ratings from the fuzzy scale (both selected the linguistic term "Principal Responsibility"). The total bounded area is also equal to 1.0, so their agreement degree is $S(R_1, R_2)$ = 1.0. However, the area of intersection of the triangular shapes of the fuzzy ratings selected by experts 1 and 3 is calculated as 0.29, while the total area bounded by their fuzzy ratings on the fuzzy linguistic rating scale is 3.71 (Figure 5.3). This means that the agreement degrees between the pairs of experts, based on their relative fuzzy ratings, $S(R_1,$

R_3) = (0.29)/(3.71) = 0.08 and $S(R_2, R_3)$ = 0.08. An agreement matrix (AM) (Table 5.2) is constructed, which stores the calculated agreement degrees between expert pairs.

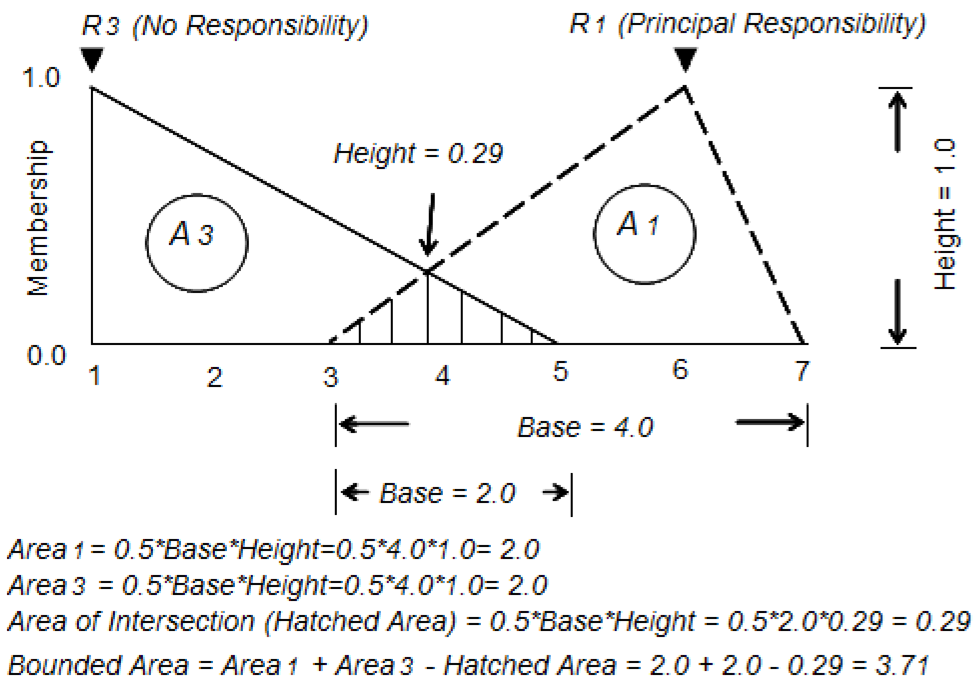

Figure 5.3. Area calculation of the shapes of the fuzzy ratings of experts 1 and 3

From the previous calculations, it is concluded that the agreement degree between the fuzzy ratings selected by expert *E1* and expert *E2*, which is equal to 1.0, is higher than the agreement degree between expert *E1* and expert *E3* and that between expert *E2* and expert *E3,* both equal to 0.08. This is valid because experts *E1* and *E2* selected the same linguistic term—“Principal Responsibility”—while expert *E3* made an opposing opinion by selecting the linguistic term “No Responsibility.”

The modified SAM algorithm then computes a consensus weight factor (CWF_i) for every expert (Equation 5.2), which determines how close or far an individual expert’s assessment is from the opinions that entail common agreement of the group. The consensus weight factor of every expert will weight his or her response during aggregation.

$$\mathrm{C}WF_i = \frac{A(E_i)}{\sum_{i=1}^{n} A(E_i)} \qquad [5.2]$$

where, $A(E_i)$ is the average level of agreement of an expert with other experts, and is calculated by dividing the sum of his or her agreement degrees with other experts by (n-1) number of experts. In the above example, $A(E_1) = A(E_2) = (1+0.08)/2 = 0.54$, $A(E_3) = (0.08 + 0.08)/2 = 0.08$. Thus, $CWF_1 = CWF_2 = (0.54)/(0.54+0.54+0.08) = 0.47$. Using the same equation, $CWF_3 = (0.08)/(0.54+0.54+0.08) = 0.06$, which means that the fuzzy rating of expert 3 has a smaller weight in the final aggregation stage compared to the fuzzy ratings of experts 1 and expert 2, as explained in the next step.

5.2.3 Step 3: Aggregate experts’ opinions into a single fuzzy number

This step involves aggregating experts’ fuzzy ratings into a single fuzzy number, which describes the extent of responsibility of each party that represents the collective opinion of the experts involved in the decision-making process.

First, the modified SAM algorithm computes a consensus degree coefficient (CDC_i), combining the relative importance weight factor ($RIWF_i$) of every expert with his or her consensus weight factor (CWF_i) in a single equation to reflect both the quality of experts and their level of agreement in the aggregation process. The relative importance weight factor ($RIWF_i$) of every expert is computed by normalizing his or her importance weight factor (w_i), which represents his or her quality based on his or her attributes (refer to the fuzzy expert system discussed in chapter 4). As illustrated in Equation 5.3, where n is the number of experts involved in the decision-making process, the relative importance weight factor ($RIWF_i$) of a given expert is computed by dividing his or her importance weight factor (w_i) (output of the FES) by the sum of the importance weight factor of the experts involved in the decision-making process. The sum of the relative importance weights of the experts involved in the decision-making process, therefore, is equal to the unity.

$$RIWF_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad [5.3]$$

In order to combine the consensus weight factor (CWF_i) of experts (which represents their level of agreement) with their relative importance weight factor ($RIWF_i$) (which represents their quality), a modifier (β) is used to either emphasize $RIWF_i$, if β is set to 1, or CWF_i, if β is set to 0 (Equation 5.4). This process is conducted before aggregating experts' opinions into a single fuzzy number (R).

$$CDC_i = \beta * RIWF_i + (1 - \beta) * CWF_i \qquad [5.4]$$

It is to be noted that there is no optimum value recommended for the modifier (β), which is selected based on the sole discretion of the user. If β is 0.5, there is equal emphasis of the quality of experts and their level of agreement in the aggregation process. In the case that a user is confident that the experts involved in the decision-making process are of equal importance weight values, or that the variations in their importance weights do not have an impact on their decision, β can be set to a value less than 0.5, and vice-versa.

For the CDC_i calculation of experts 1, 2, and 3, assume that their relative importance weight factors $RIWF_i$ are determined, after normalizing the output of the FES, to be 0.40, 0.40, and 0.20, respectively. By assuming equal emphasis of the three experts' consensus weight factor and their importance weight factor, a modifier β = 0.5 is selected. Thus, $CDC_1 = CDC_2$ = (0.50 × 0.40) + (0.50 × 0.47) = 0.435 and CDC_3 = (0.50 × 0.20) + (0.50 × 0.06) = 0.130. Note that the total CDC sums to 1.000.

Finally, the aggregated fuzzy number R for each task is the sum of the multiplication of the CDC_i of each expert by the fuzzy number R_i that represents his or her fuzzy rating (Equation 5.5).

$$R = \sum_{i=1}^{n} (CDC_i * R_i) \qquad [5.5]$$

Using the same example, R = [0.435 × (3, 6, 7)] + [0.435 × (3, 6, 7)] + [0.130 × (1, 1, 5)] = (2.74, 5.35, 6.74). The next step is to determine the final extent of the roles and responsibilities for every task by defining the relevant linguistic term that best matches the aggregated fuzzy number R, which is explained in the next step.

5.2.4 Step 4: Determine final extent of responsibility using appropriate linguistic term

Step 4 is the last step of the modified SAM that defines the aggregated fuzzy number with an appropriate linguistic term using the seven standard linguistic terms of the fuzzy linguistic rating scale. This step ensures that the aggregation algorithm is fully supported in a linguistic framework. The Euclidean distance measure, illustrated in its generic form (Heilpern 1997) in Equation 5.6, is used to determine the final extent of responsibility for each task by measuring the Euclidean distance between the triplets (r_1, r_2, r_3) of the aggregated fuzzy number R and those of the seven standard fuzzy ratings Y_k on the scale. For the Euclidean distance measure function, p = 2, n = 3 because each fuzzy rating is represented by a triplet, r_i is each number forming the triplet of the aggregated fuzzy number R, and y_i is the corresponding number forming the triplet of each of the seven standard fuzzy ratings (Y_k) on the scale.

$$d_g(R, Y_k) = (1/n\sum_{i=1}^{n}\left|r_i - y_i\right|^p)^{1/p} \qquad [5.6]$$

The linguistic term that best describes the aggregated fuzzy number (*R*) is the one defined by the standard fuzzy rating (Y_k) with the minimum distance to the aggregated fuzzy number *R* on the scale. This linguistic term determines the final responsibility for the task, as illustrated in Table 5.1.

After applying this step to the fuzzy ratings made by experts for every standard task, tasks are categorized into one of three responsibility task lists: owner's responsibility, contractors' responsibility, or a shared responsibility task list. The aggregated fuzzy rating resulting from the modified SAM determines the responsibility task list, in which the task should be classified. From Figure 5.1, the aggregated fuzzy ratings (Y_k) with peaks corresponding to the elements 5 ("significant involvement"), 6 ("principal responsibility"), and 7 ("Sole Responsibility" of the owner) indicate that the owner is responsible for the task. The fuzzy ratings (Y_k) with peaks corresponding to the elements 1 ("no responsibility"), 2 ("limited involvement"), and 3 ("active involvement") of the owner indicate that the contractor is the responsible party, because the scale is reciprocal. The fuzzy rating with a peak of 4 indicates an "equally shared" responsibility.

To demonstrate the applicability of the Euclidean distance measure function in the given example, the Euclidean distance measure function calculates the distance of the aggregated fuzzy number R(2.74, 5.35, 6.74) to each of the seven standard fuzzy ratings Y_k. Equation 5.7 illustrates a sample calculation of the Euclidean distance between the fuzzy number R(2.74, 5.35, 6.74) and the standard fuzzy rating Y_7(3, 7, 7) representing the linguistic term “sole responsibility”:

$$d_g\,(R,\,Y_7) = ((1/3 \times ((2.74 - 3)^2 + (5.35 - 7)^2 + (6.74 - 7)^2)))^{1/2} = 0.98 \quad [5.7]$$

Using the same method of calculation, the measure of the Euclidean distances of the fuzzy number R(2.74, 5.35, 6.74) to the standard fuzzy ratings, Y_1 (“no responsibility”), Y_2 (“limited involvement”), Y_3 (“active involvement”), Y_4 (“equally shared”), Y_5 (“significant involvement”), and Y_6 (“principal responsibility”) are 2.89, 2.40, 1.74, 0.99, 0.64, and 0.43, respectively. From the previous calculations, the owner organization’s final responsibility on the task “prepare the design basis memorandum (DBM)” can be defined by the linguistic term Y_6 (“principal responsibility”) because it has the minimum Euclidean distance (0.43) to the aggregated fuzzy number R(2.74, 5.35, 6.74) and the task is classified in the owner’s responsibility task list. Note that the linguistic term “principal responsibility” defines the same responsibility originally selected by experts 1 and 2 to represent their opinion. The outputs of the modified SAM will be illustrated based on the results of a case study in chapter 6, using actual data collected from experts.

The modified SAM, therefore, yields an appropriate aggregated decision entailing common agreement between experts in the above example, as the impact of expert 3's inconsistent opinion was minimized in the aggregation algorithm because of his or her low consensus weight factor of 0.06, compared to the relatively high consensus weight factors—0.47—of experts 1 and 2 (step 2). Also, the relative importance weight factor of expert 3, which is equal to 0.20 (step 3), is lower than that of expert 1 and expert 2. Thus, the relative importance weight factor of expert 3 did not increase his or her consensus degree coefficient (CDC_i), which was still lower than the consensus degree coefficients (CDC_i) of experts 1 and 2 due to their relatively high relative importance weight factor of 0.40 (step 3). In conclusion, the fuzzy rating "no responsibility" given by expert 3 did not have a significant impact on the aggregated decision "principal responsibility" of the modified SAM, which was based on the opinion of the other two experts of higher quality and level of agreement.

From the above, the modified similarity aggregation method (SAM) reduces inconsistency in the aggregated decision by incorporating lower consensus degree coefficients in the aggregation algorithm of the experts who are of lower quality and whose opinions are not consistent with the opinion that entails common agreement between experts. However, as previously discussed in section 5.1, the modified SAM may fail to derive an undisputed aggregated decision if a task is determined to be "equally shared." One possible scenario of this problem is that the task may have been incorrectly classified by project teams as a shared task because experts were not able to decide on a party responsible for the task using the fuzzy linguistic scale. Another possible scenario, in which the modified SAM may fail to draw a reasonable conclusion, may occur if experts provide symmetrically distributed fuzzy ratings on both sides of the fuzzy linguistic scale; this may lead to a flawed aggregated decision of an "equally shared" responsibility by the modified SAM algorithm. This problem mainly occurs because the calculated consensus weight values will be the same for all experts and the aggregation algorithm will determine the middle value on the scale, which is the "equally shared" responsibility as an aggregated decision. However, there is a third—and legitimate—possible scenario, wherein project teams may collectively agree that the task is a valid shared task, for which both parties have equally shared responsibility. Since there is no clear methodology to predict the prevalence of the latter scenario in the aggregation process when the task is determined as "equally shared," all the cases in which the tasks are determined as shared will be dealt with as potential conflicts between project teams, which need to be resolved.

The literature review conducted in chapter 2 recommends solving the problem of disagreement between experts on "equally shared" responsibilities by means of a consensus reaching process that helps identify and reduce the conflicts between experts during the aggregation of their opinions (Tanino 1984, Carlsson et al. 1992, Kacprzyk et al. 1992, Mich et al. 1993, Herrera and Verdegay 1993, Herrera and Herrera-Viedma 2000). As previously explained in chapter 2, Herrera et al. (1996) and Herrera and Herrera-Viedma (2000) proposed a relevant model of consensus building in group decision-making under linguistic assessments using fuzzy preference relations, which is modified in the Fuzzy Consensus Building Framework (FCBF) to solve the problem at hand. This method tests the possibility of transferring any of the shared tasks to either the owner or its contractors, or keeping them as shared, by introducing perceived shared tasks to project teams to make further responsibility assessments using fuzzy preference relations in a consensus reaching process.

The next section explains the Fuzzy Preference Relations Consensus (FPRC) approach, which modifies the consensus building model of Herrera et al. (1996) and Herrera and Herrera-Viedma (2000).

5.3 Fuzzy Preference Relations Consensus (FPRC) Approach

The application of Fuzzy Preference Relations Consensus (FPRC) approach (Elbarkouky and Fayek 2010b and 2009) in the FCBF is discussed in this section. The FPRC approach facilitates consensus reaching by identifying and reducing the conflicts between project teams that may exist when the modified SAM determines tasks should be "equally shared" between the owner and its contractors, and tests the possibility of transferring any of the shared tasks to either the owner or its contractors. In the FPRC approach, shared tasks are introduced to project teams to make further responsibility assessments using fuzzy preference relations in a consensus reaching process. In the case that the consensus reaching process indicates that the task under question must be shared, then the aggregation result of the modified SAM for this task is valid, and the task will remain in the shared responsibility task list, which is the possibility of having a legitimate shared task.

First, a fuzzy preference scale, which is constructed using expert judgement and the modified horizontal approach and interpolation technique (previously discussed in chapter 4), is introduced to project teams to determine their preferences on a finite set of responsibility alternatives (owner's responsibility, contractors' responsibility, and shared responsibility) for every perceived shared task. Project teams compare the three responsibility alternatives in pairs using linguistic preferences, which are defined on the fuzzy preference scale, to select a preferred responsibility alternative for each task. Then, a fuzzy linguistic consensus measure is applied, which identifies the degree of consensus among project teams on their preferences in a consensus reaching process. If the desired consensus level is not reached on an aggregated responsibility decision in the first round of the consensus reaching process, a second round is conducted to help experts reach consensus by exchanging information on the existing degree of consensus within the group. In this round, experts are allowed to discuss the reasons behind their opinions. As a result, some experts may either revise their decision so that it matches that of the largest number of experts in the group, or convince the other experts to modify their decision. Consensus rounds are repeated until the desired consensus level is reached, thus reducing or eliminating conflicting responsibilities. The next subsection explains the steps of applying the FPRC approach, which is followed by a numerical example for illustration purposes.

5.3.1 Steps of the Fuzzy Preference Relations Consensus (FPRC) Approach

This subsection explains the detailed steps that are followed to apply the Fuzzy Preference Relations Consensus (FPRC) approach in the FCBF. First, the basic modifications that were introduced to Herrera's et al. (1996) consensus model are discussed, and then the detailed steps of the FPRC are explained.

The basic modifications introduced by the FPRC to the consensus model put forth by Herrera et al. (1996) pertain to the generation of the fuzzy preference scale, the calculation of experts' importance weight factor, and the method of incorporation of the importance weight factor of experts in the calculation of the consensus degrees.

First, the fuzzy preference scale is created in the FPRC approach, using the perception of experts to generate its MFs. This is different from the approach of Herrera et al. (1996), which assumed that MFs have symmetrical or predetermined shapes. The FPRC approach also incorporates experts' importance weights in calculating consensus degrees using the standalone fuzzy expert system (chapter 4), instead of making subjective assessments of the importance weight factor of experts. The latter was the case in previous consensus reaching approaches, including the consensus model created by Herrera et al. (1996).

Experts' importance weights are incorporated in the calculation of the consensus degrees for each pair of responsibility alternatives using a modifier (λ), which can be changed to emphasize the average importance weight of experts, their frequency of responses on a certain preference relative to the total numbers of experts, or both. The use of the modifier (λ) in the FPRC approach improves on Herrera et al.'s (1996) approach that incorporated the importance weight factor of experts in the calculation of the consensus degrees using the minimum operator.

Figure 5.4 illustrates the steps involved in applying the Fuzzy Preference Relations Consensus (FPRC) approach, and is followed by a detailed explanation of each step.

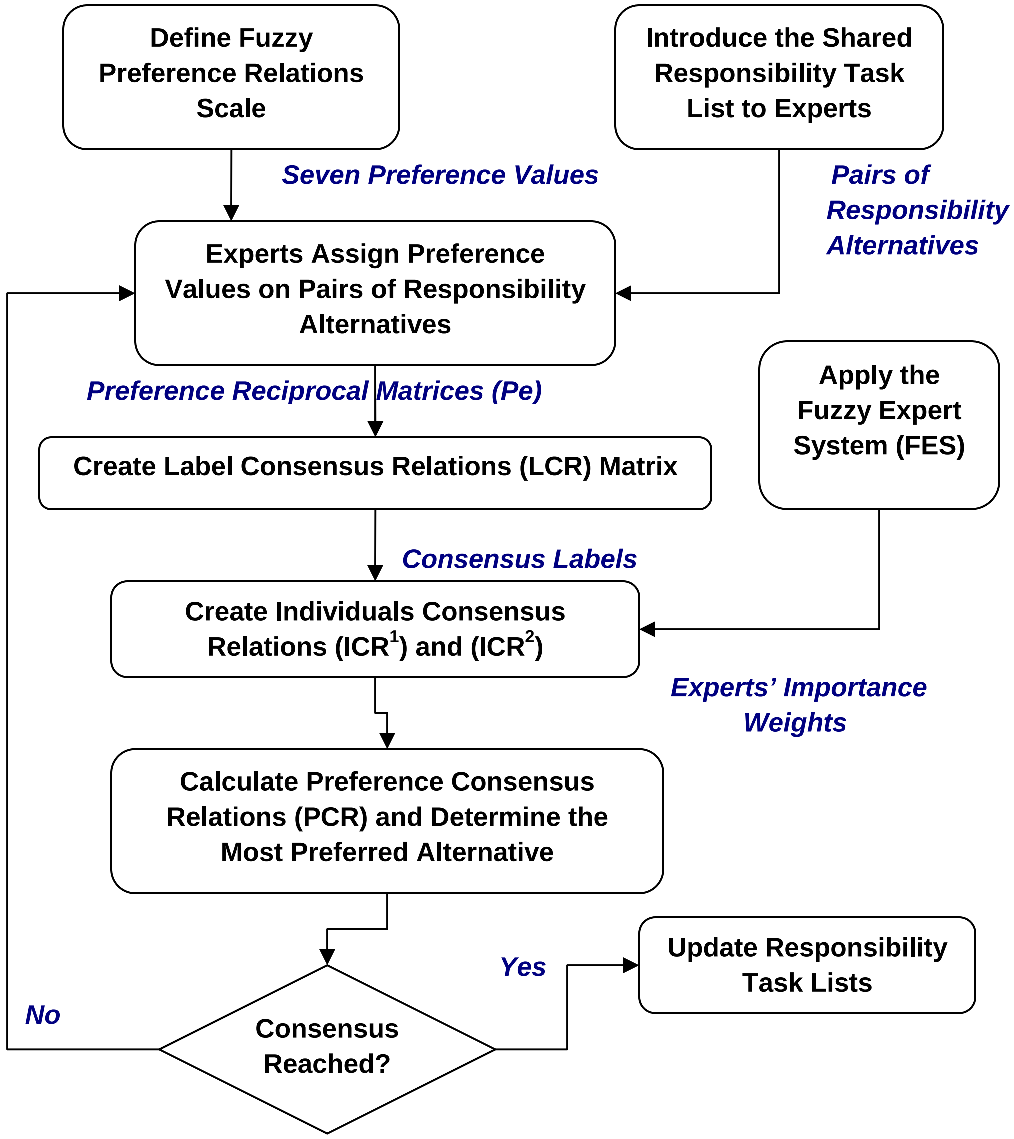

Figure 5.4. Steps of applying the Fuzzy Preference Relations Consensus approach

5.3.1.1 Step 1: Determining Fuzzy Preference Scale

A fuzzy preference scale is used by experts to determine their preferences on a finite set of responsibility alternatives, X = {x_1: owner responsibility, x_2: contractors' responsibility, x_3: shared responsibility}, that are introduced to experts in pairs for each perceived shared task. The preference scale, which ranges from 0 to 1, is composed of seven linguistic preference values in the finite set of labels (S), each of which is described by a linguistic label (l_i). Each linguistic label, as illustrated in Table 5.3, represents a certainty expression that describes a degree of certainty of an expert in preferring one responsibility alternative over another.

Table 5.3. Linguistic labels determining the preference values on the scale

Symbol	**Linguistic label**	**4-tuple describing the MF**
C	Certain	(1, 1, 0, 0)
EL	Extremely likely	(0.8, 0.9, 0.1, 0.1)
ML	Most likely	(0.7, 0.9, 0.2, 0.1)
IM	It may	(0.5, 0.7, 0.3, 0.1)
SC	Small chance	(0.20, 0.40, 0.20, 0.15)
EU	Extremely unlikely	(0.1, 0.2, 0.1, 0.15)
I	Impossible	(0, 0, 0, 0)

These labels range from *impossible,* which is the label of the minimum degree of preference (l_o) in S, to *certain*, which is the label of the maximum degree of preference (l_u). For example, if an expert prefers a given responsibility alternative (e.g., x_1: owner's responsibility) over another (e.g., x_2: contractors' responsibility) for a given task, then he or she may select the linguistic label *certain* from the scale. However, the same expert would choose the linguistic label *it may* if he or she does not prefer one alternative over another. The same fuzzy linguistic scale is also used to compute the consensus degrees linguistically. The linguistic labels describing the scale are used to define the consensus degree of experts on each preference using the linguistic meaning of these labels and the shapes of their membership functions. Thus, each of the seven linguistic labels defines a certain level of consensus that ranges from *impossible* (i.e., reaching consensus is impossible) to *certain* (i.e., reaching consensus is certain).

The membership functions (MFs) of the linguistic labels are constructed based on the modified horizontal approach combined with an interpolation technique, similar to those discussed in chapter 4. Each membership function is represented by the 4-tuple (g, h, α, β). The first two parameters indicate the interval in which the membership value is 1, while the third and fourth parameters indicate the left and right width (i.e., membership value of 0). The MFs are transformed to fit either triangular or trapezoidal shapes. A simple questionnaire (Appendix D) was used in an interview that solicited the opinions of six project managers of a large oil and gas project owner organization in Canada, each with more than 15 years of experience in the construction industry, and two of its contractors to determine the supports and shapes of each linguistic label. Questions were posed regarding the ranges of elements that experts think are appropriate to represent the MF of each term on a scale from 0 to 1. One question was posed regarding each linguistic term: "*What are the range of elements (x_i) that may represent this linguistic label on the scale from 0 to 1? Please circle as many answers as applicable.*" The replies of the experts were counted in terms of frequencies of responses ($P(x_i)$) to the total number (N) of responses for every element x_i in order to calculate its membership value ($A(x_i)$). This process resulted in the preliminary non-uniform shapes of each MF. The standard shapes of the membership functions (MFs) that best fit the non-uniform shapes were determined subjectively based on visual inspection of the preliminary non-standard shapes, or by calculating the least sum of errors for the cases that could not be determined using visual inspection. The elements of the standard shape with the least sum of errors to those of the non-uniform shape were considered the best fit for the data. Based on the above steps, only trapezoidal shapes fit all the non-uniform shapes. Figure 5.5 illustrates the final MFs of the seven linguistic labels that form the preference scale.

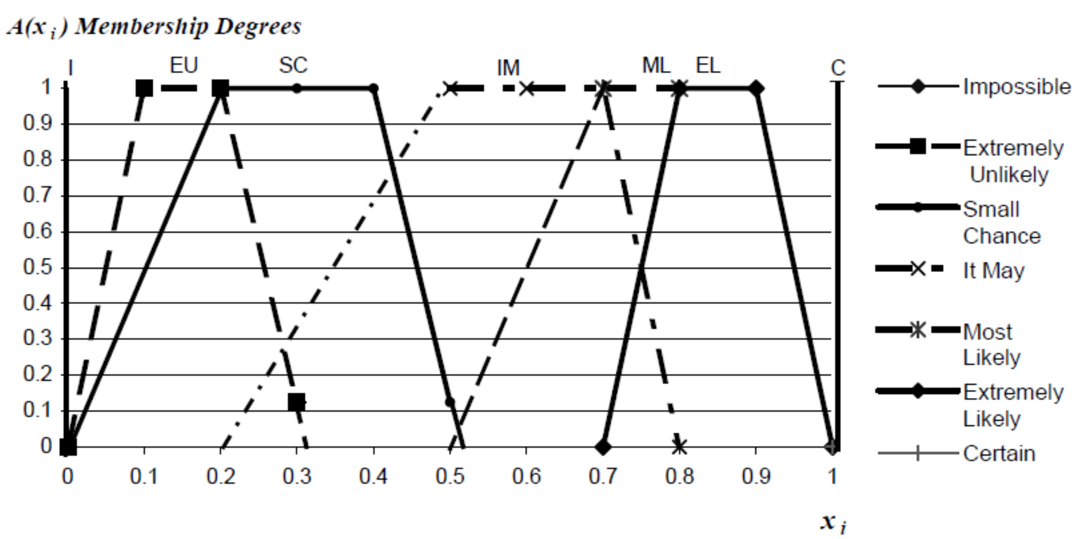

Figure 5.5. Final membership functions of the fuzzy preference scale

Table 5.3 illustrates the numerical values of the 4-tuple that represents the values of each membership function on the scale. The next step explains how individual experts can provide their preferences on pairs of responsibility alternatives using preference reciprocal matrices.

5.3.1.2 Step 2: Determining Preference Reciprocal Matrices

The pairs of responsibility alternatives are introduced to experts, using a preference reciprocal matrix (P_e) that is prepared for every task. Experts are then asked to assign their preferences on pairs of responsibility alternatives (x_i over x_j) for each task. The elements of the preference reciprocal matrix store the preferences of experts on the pairs of responsibility alternatives. Table 5.4 illustrates the preference reciprocal matrix (P_e) whose elements refer to the linguistic labels that are assigned by a sample expert for the pairs of responsibility alternatives. The elements of the matrix account for the reciprocal nature of the fuzzy preference scale. The next step illustrates the aggregation method of experts' preferences on pairs of responsibility alternatives.

Table 5.4. Preference reciprocal matrix used to collect an expert's preferences

	Owners' responsibility	**Contractors' responsibility**	**Shared responsibility**
Owners' responsibility	-	EL	IM
Contractors' responsibility	EU	-	IM
Shared responsibility	IM	IM	-

5.3.1.3 Step 3: Aggregating Experts' Preferences to Determine the Consensus Labels

After the experts specify their preference reciprocal matrices for each task, the frequency of experts' opinions is calculated for each selected linguistic label for each pair of responsibility alternatives. The linguistic label selected by the largest number in the group of experts for each pair of responsibility alternatives is considered the collective opinion of experts for that pair, and is called the "consensus label." Consensus labels are then inserted in the relevant location in a final aggregation matrix, called the label consensus relation (LCR) (Herrera et al. 1996), which is created for each task. For example, for a given pair of responsibility alternatives (e.g., x_1: owner's over x_3: shared responsibility), if three experts out of eight selected the preference value *certain*, while five experts selected the preference value *small chance*, then the consensus label that would represent this pair is *small chance* because the largest number in the group of experts (i.e., five) made that preference. This means that there is a *small chance* that the owner would handle this task over having it as a shared task. However, if four experts out of eight selected the preference value *certain*, while four experts selected the preference value *small chance*, then a collective opinion cannot be determined in this consensus round, and the steps of the FPRC approach will not proceed further, as consensus reaching is *impossible* (Table 5.3). A second consensus round, therefore, should be conducted before proceeding to the next steps of the FPRC approach, to help the experts reach a common agreement. In this second round, a moderator would reveal more information to the experts regarding the existing level of consensus amongst the group, and each expert would discuss the reason behind his or her opinion. The moderator would facilitate open discussion and sharing of opinions until the largest number of experts agrees to one of the given preference values.

5.3.1.4 Step 4: Calculating Importance Weights of Experts Using Fuzzy Expert System (FES)

The FPRC approach incorporates the qualifications of experts in measuring experts' consensus degrees based on their attributes: years and diversity of experience, role and years in role in the company, and enthusiasm and willingness to participate. The same standalone fuzzy expert system (FES), developed in chapter 4, is used to determine the importance weight factor of experts, which represent the quality of their opinions. The details of developing the FES, which is applied to both the modified SAM and the FPRC approach, are included in chapter 4.

5.3.1.5 Step 5: Creating Individual Consensus Relations (ICR) Matrix

Prior to calculating the consensus degrees on the pairs of responsibility alternatives, individual consensus relations matrices (ICR^1 and ICR^2) (Herrera et al. 1996) are created for every task. The elements of the ICR^1 contain the proportion of the number of experts who chose each consensus label in the LCR matrix, relative to the total numbers of experts. The elements of the ICR^2 matrix contain the values of the experts' respective importance weights, as calculated from the FES in step 4. A modifier (λ) is used to combine the values of the respective elements of the ICR^1 and ICR^2 matrices, which are stored in a combined ICR matrix. The elements of the ICR matrix either emphasize the values of the elements of the ICR^1, if λ is set to 0, or those of the ICR^2, if λ is set to 1. Equation 5.8 illustrates the calculation of a single element (ICR_{ij}) of the ICR matrix, where i and j refer to every element of the ICR matrix.

$$ICR_{ij} = \lambda \times ICR^1_{ij} + (1-\lambda) \times ICR^2_{ij} \qquad [5.8]$$

5.3.1.6 Step 6: Determining Consensus Degrees for Consensus Labels

Step 6 involves measuring experts' consensus degrees for the consensus labels that represent the experts' aggregated preferences on each pair of responsibility alternatives, using the values of the elements of the ICR matrix that are determined in step 5. The relative linguistic quantifiers (Q), as described by Zadeh (1983), are used for this purpose. Some examples of quantifiers are *as most, at least half,* and *all,* which are represented by fuzzy membership functions defined on the range between 0 and 1. The choice of the linguistic quantifier is based on the desired level of consensus between experts that the user would like to achieve for the consensus labels before making the final responsibility decision.

Before determining the consensus degrees for every consensus label, the ICR value of each consensus label in the LCR matrix should be determined. The ICR value of the consensus label represents the proportion of experts who assigned that label combined with their importance weights, as explained in step 5, and it ranges from 0 to 1. The ICR value indicates the value of the level of agreement of the largest number of experts in the group for that label.

The relative quantifier (*Q)* is applied to each ICR value to determine the linguistic consensus degree of the group of experts for every consensus label, using one of the seven linguistic labels (l_i) in the set of labels (*S*). These linguistic labels may determine that the existing level of consensus between experts for a certain consensus label is, for example, *impossible, most likely*, or *certain.* The method of determining the linguistic label that best describes the existing level of consensus between experts on each consensus label is determined by the relative linguistic quantifier *Q*(ICR), which indicates the degree to which the ICR value of each consensus label (l_i) satisfies the concept represented by *Q* (e.g., *at least half*). A conservative user may choose the quantifier *all* to calculate the consensus degrees. This means that consensus may not be reached for a given consensus label of a given pair of responsibility alternatives unless *all* the experts have agreed on the same consensus label for that pair. If the user is less conservative in terms of the required level of consensus between experts, the selected quantifier may be *at least half.* The linguistic label that determines the consensus degree for each consensus label of each pair of responsibility alternatives is determined using Equation 5.9.

$$\mathrm{Q}(\mathrm{ICR}) = \begin{cases} l_0 & \text{if } \mathrm{ICR} < a \\ l_\mathrm{i} & \text{if } a \le \mathrm{ICR} \le b \\ l_\mathrm{u} & \text{if } \mathrm{ICR} > b \end{cases} \qquad [5.9]$$

where, l_0 is the minimum linguistic label in S (i.e., *impossible*), l_u is the maximum linguistic label in S (i.e., *certain*), and l_i is the linguistic label of the maximum membership value on the fuzzy linguistic scale that corresponds to the element whose value is calculated by (ICR-*a*)/(*b*-*a*). Note that *a* and *b* are the parameters that determine the supports of the MF of the linguistic quantifier.

In order to explain how Equation 5.9 can be applied using different linguistic quantifiers, consider the following example. The ICR value of a group of experts who assigned a preference value *extremely likely* for a pair of responsibility alternatives (e.g., x_1: owner's over x_3: shared responsibility) for the sample task "prepare preliminary work breakdown structure" was calculated as 0.55. Now consider two scenarios: scenario 1 is the case of a conservative user who selected the relative quantifier *as many as possible* (a = 0.5 and b = 1.0) to calculate the linguistic consensus degree of the experts, and scenario 2 is the case of a less conservative user who selected the relative quantifier *at least half* (a = 0.0 and b = 0.5) to calculate the linguistic consensus degree of the experts. By applying Equation 5.9 in scenario 1, case a < ICR < b, Equation 5.10 calculates Q(ICR) as follows:

$Q(\text{ICR}) = l_i = (\text{ICR}-a)/(b-a) = (0.55-0.50)/(1-0.5) = 0.10$ [5.10]

In this case, the fuzzy linguistic scale should be used to determine the linguistic consensus degree that describes the current level of consensus between experts on their preference value (Figure 5.6). From Figure 5.6, the linguistic label of the maximum membership value on the fuzzy linguistic scale that corresponds to the element whose value is calculated by l_i = 0.10 is *extremely unlikely*. This means the level of consensus is *extremely unlikely* in scenario 1.

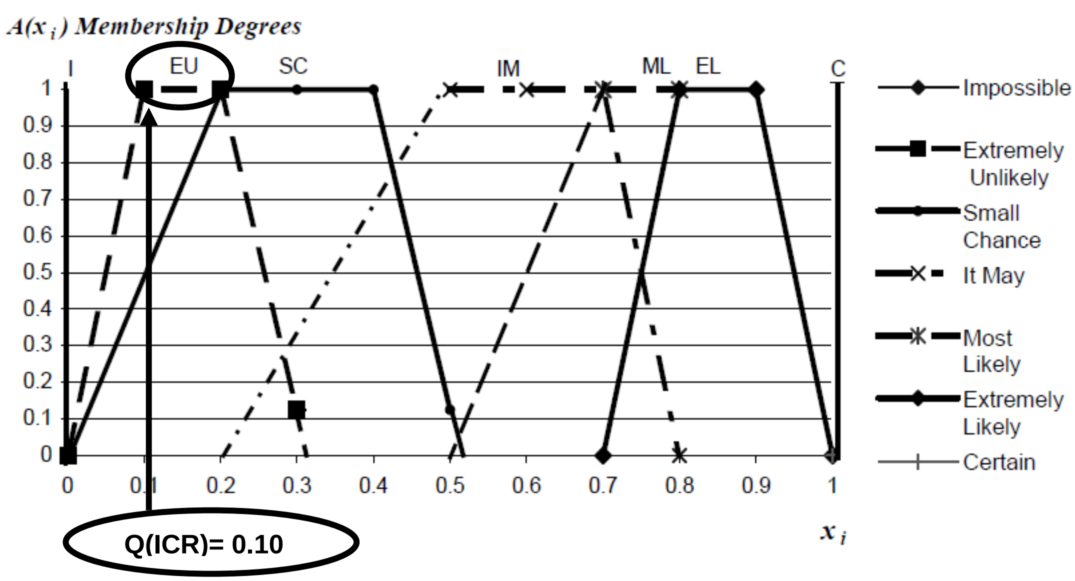

Figure 5.6. Example to determine the linguistic consensus degree of experts

As for scenario 2, by applying Equation 5.9, case ICR > b, Equation 5.11 calculates Q(ICR) as follows:

$Q(\text{ICR}) = l_u$ = maximum linguistic label in S = *certain* [5.11]

Thus, Equation 5.11 determines that the level of consensus between experts is *certain* in scenario 2.

After calculating the consensus degrees over the consensus labels for each pair of responsibility alternatives in step 6, a preference consensus relations (PCR) matrix is created for every task to store the calculated consensus degrees over the consensus labels for each pair of responsibility alternatives. The elements of the PCR matrix determine whether or not the required consensus level is reached for each consensus label in the current stage of the consensus reaching process. If the desired level of consensus, based on the selected quantifier, is not reached at this stage on every consensus label, then a second round is conducted with experts until the desired linguistic consensus degree is reached, as described earlier.

5.3.1.7 Step 7: Determining Final Responsibility for Each Task

The last step is conducted after reaching the required linguistic consensus degree for the consensus labels of each pair of responsibility alternatives. The final responsibility for each task is determined based on a simple linguistic choice function (Herrera and Herrera-Viedma 2000) (Equation 5.12) that determines the responsibility alternative (x_i) of the maximum linguistic choice degree (i.e., maximum consensus label in the LCR matrix) amongst the three responsibility alternatives in the set X of the responsibility alternatives {x_1: owner's responsibility, x_2: contractors' responsibility, x_2: shared responsibility}.

$$X^c = \{\underset{x_i \in X}{\mathrm{Max}}\, \mathrm{LCR}(x_i)\} \qquad [5.12]$$

where, X^c is the set of responsibility alternatives ordered by the value of their maximum consensus labels $\mathrm{LCR}^{max}(x_i)$ on the fuzzy preference scale. Table 5.5 illustrates the maximum consensus label $\mathrm{LCR}^{max}(x_i)$ for each responsibility alternative for a sample task "prepare preliminary work breakdown structure." From Table 5.5, the final responsibility for each task is determined based on the responsibility alternative of the greatest $\mathrm{LCR}^{max}(x_i)$ in X^c. In this example, X^c = [(x_1: owner's responsibility, EL), (x_2: contractors' responsibility, IM), (x_3: shared responsibility, IM)], and the responsibility alternative of the maximum consensus label $\mathrm{LCR}^{max}(x_i)$ is x_1: owner's responsibility of $\mathrm{LCR}^{max}(x_i)$ = "*EL: extremely likely*."

Table 5.5. Example of determining maximum consensus labels $\mathrm{LCR}^{max}(x_i)$

	Owners' responsibility	**Contractors' responsibility**	**Shared responsibility**	**$\mathrm{LCR}^{max}(x_i)$**
Owners' responsibility	-	**EL**	IM	**EL**
Contractors' responsibility	EU	-	**IM**	IM
Shared responsibility	**IM**	**IM**	-	IM

After determining the final responsibility for each task, the responsibility task lists are updated by classifying each task in its appropriate task list. The next subsection demonstrates an example to illustrate the FPRC approach.

5.3.2 Example of the Fuzzy Preference Relations Consensus (FPRC) Approach

The following example illustrates the steps of the FPRC approach:

Step 1: Determining Fuzzy Preference Scale

The fuzzy preference scale that was previously discussed in section 5.3.1 is used in this numerical example (Figure 5.5) in order to determine the preference values of experts and calculate their consensus degrees on their preferences.

Step 2: Determining Preference Reciprocal Matrices

Eight experts (e_i) were asked to indicate their preference reciprocal matrices (P_e) (Figure 5.7) for the sample task “providing benchmarking data and comparable projects' costs” using the linguistic labels illustrated in Table 5.3.

Step 3: Aggregating Experts' Preferences to Determine the Consensus Labels

In order to aggregate experts' opinions, the frequency of experts' opinions in selecting each linguistic label for each pair of responsibility alternatives is determined using the eight reciprocal matrices illustrated in Figure 5.7.

For example, for the pair of responsibility alternatives (x_3: shared over x_1: owner's responsibility), five experts (e_1, e_3, e_6, e_7, and e_8) out of eight selected the preference value *ML: most likely*. For the same pair of responsibility alternatives, the preference values *EL: extremely likely*, *IM: it may*, and *EU: extremely unlikely* were selected by experts e_2, e_4, and e_5, respectively. Therefore, the linguistic label selected by the largest number in the group of experts for the pair of responsibility alternatives (x_3: shared over x_1: owner's responsibility) was *ML: most likely*. This linguistic label was selected by five experts out of eight, and is considered the consensus label for this pair of responsibility alternatives. This consensus label is stored in the label consensus relations (LCR) matrix, and is denoted by the element LCR_{31} in the LCR matrix.

Expert (e_1)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	IM	SC
x_2:Cont.	IM	-	SC
x_3:Shared	ML	ML	-

Expert (e_2)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	SC	EU
x_2:Cont.	ML	-	ML
x_3:Shared	EL	SC	-

Expert (e_3)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	SC	SC
x_2:Cont.	ML	-	SC
x_3:Shared	ML	ML	-

Expert (e_4)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	ML	IM
x_2:Cont.	SC	-	IM
x_3:Shared	IM	IM	-

Expert (e_5)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	EL	EL
x_2:Cont.	EU	-	EL
x_3:Shared	EU	EU	-

Expert (e_6)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	EU	SC
x_2:Cont.	EL	-	ML
x_3:Shared	ML	SC	-

Expert (e_7)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	IM	SC
x_2:Cont.	IM	-	SC
x_3:Shared	ML	ML	-

Expert (e_8)

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	IM	SC
x_2:Cont.	IM	-	SC
x_3:Shared	ML	ML	-

Figure 5.7. Experts' preference reciprocal matrices

After conducting similar computations for the other pairs of responsibility alternatives, the elements of the LCR matrix are updated with the relevant consensus labels of the different pairs of responsibility alternatives. Figure 5.8 illustrates the elements of the LCR matrix, which contains the consensus labels that were selected by the largest number of experts for the different pairs of responsibility alternatives.

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	IM	SC
x_2:Cont.	IM	-	SC
x_3:Shared	ML	ML	-

Figure 5.8. Label consensus relations (LCR) matrix of the task "providing benchmarking data and comparable projects' costs"

Step 4: Calculating Importance Weights of Experts Using Fuzzy Expert System (FES)

In order to incorporate the quality of the experts in this decision-making process, the standalone fuzzy expert system (FES), which was developed in chapter 4, was used to determine the importance weights of the eight experts based on their attributes: years and diversity of experience, role and years in role in the company, and enthusiasm and willingness to participate. Figure 5.9 illustrates the outputs of the FES based on the different attributes of experts, which are used in the next step to create the individual consensus relations matrix (ICR).

Step 5: Creating Individual Consensus Relations (ICR) Matrix

In this step, the individual consensus relations matrices ICR^1 and ICR^2 are created for the task "providing benchmarking data and comparable projects' costs." The elements of the ICR^1 matrix contain the proportion of the number of experts who chose each consensus label in the LCR matrix, relative to the total numbers of experts. The elements of the ICR^2 matrix contain the values of the average importance weights of the experts who chose each consensus label in the LCR matrix.

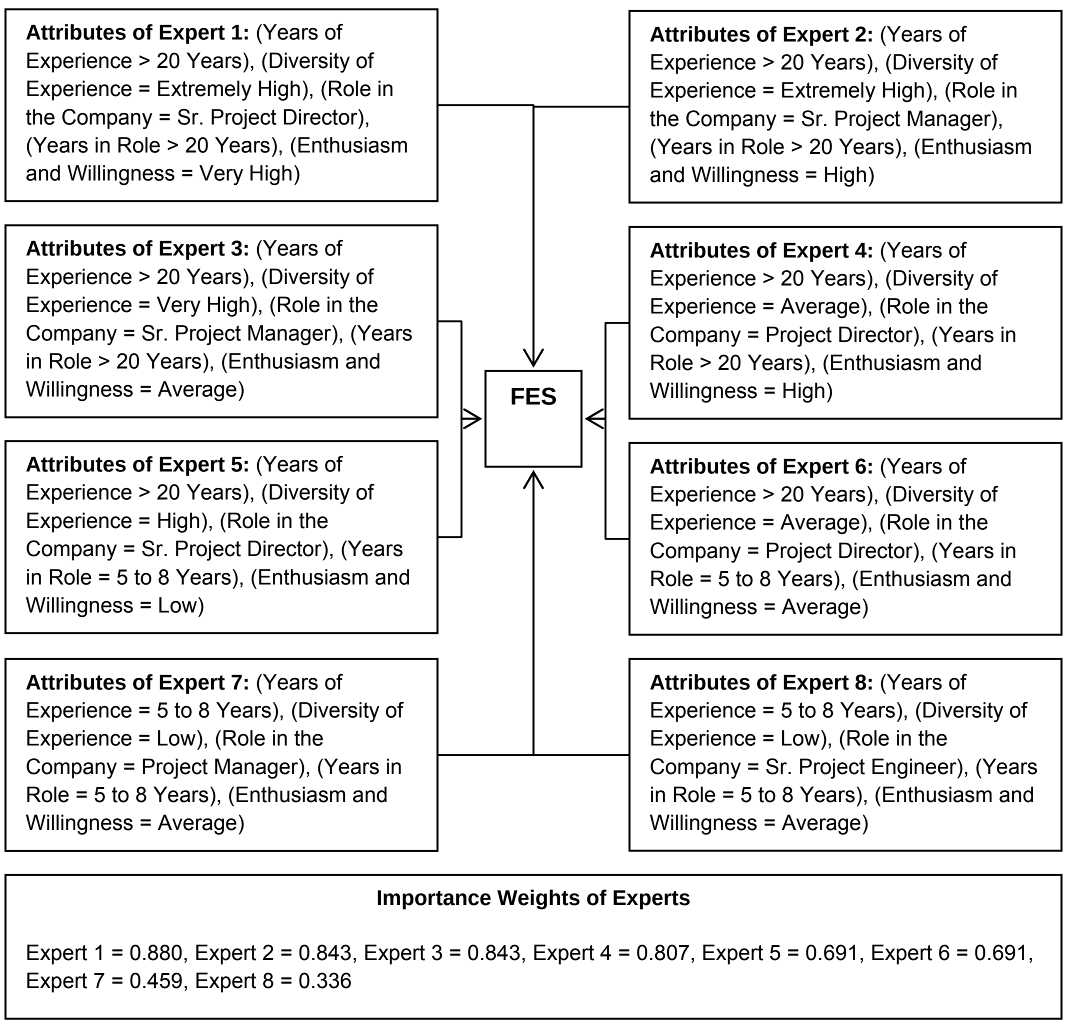

Figure 5.9. Importance weights of the eight experts as determined by the FES

Figures 5.10a and 5.10b illustrate the elements of the ICR^1 and ICR^2 matrices. In order to explain how the elements of the two matrices were determined, the same example used in step 3 is adopted. In this example, five experts agreed on the linguistic label *ML: most likely* for the alternatives pair x_3, x_1. The element ICR^1_{31} is calculated by dividing the proportion of the number of experts who chose the consensus label *ML: most likely* in the LCR matrix, by the total numbers of experts, i.e., ICR^1_{31} = 5/8 = 0.625. On the other hand, to calculate the element ICR^2_{31}, the average importance weight of the five experts (e_1, e_3, e_6, e_7, and e_8) that selected the consensus label *ML: most likely* in the LCR matrix is calculated, which is illustrated by Equation 5.13.

$$ICR^2_{31} = (0.880 + 0.843 + 0.691 + 0.459 + 0.336) / 5 = 0.642 \qquad [5.13]$$

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	0.375	0.625
x_2:Cont.	0.375	-	0.500
x_3:Shared	0.625	0.500	-

(a) ICR^1 Matrix

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	0.558	0.642
x_2:Cont.	0.558	-	0.630
x_3:Shared	0.642	0.630	-

(b) ICR^2 Matrix

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	0.467	0.633
x_2:Cont.	0.467	-	0.565
x_3:Shared	0.633	0.565	-

(c) ICR Matrix, λ=0.5

Figure 5.10. Individual consensus relations matrix (ICR) of the task "providing benchmarking data and comparable projects' costs"

In order to combine the values of the respective elements of the ICR^1 and ICR^2 matrices, which are stored in an ICR matrix, assume the modifier (λ) = 0.500. The element ICR_{31} is calculated as illustrated in Equation 5.14.

$$ICR_{31} = \lambda \times ICR^1_{31} + (1-\lambda) \times ICR^2_{31} = 0.500 \text{ X } 0.625 + 0.500 \text{ X } 0.642 = 0.633 \qquad [5.14]$$

Figure 5.10c illustrates the elements of the ICR matrix of the task "providing benchmarking data and comparable projects' costs." The next step involves calculating the consensus degrees of the experts based on the values of the elements of the ICR matrix.

Step 6: Determining Consensus Degrees for Consensus Labels

In this step, the consensus degrees of experts are measured to determine the level of consensus between experts on their selected consensus labels that were determined for the pairs of responsibility alternatives. Using the same previous example, assuming that the linguistic quantifier *at least half* is used with parameters a = 0 and b = 0.5, and applying Equation 5.9, the linguistic consensus degree PCR_{31} is the maximum linguistic label (l_u) in S, because $ICR_{31} > b$ (i.e., 0.633 > 0.5). The maximum linguistic label (l_u) in S is the linguistic label *certain* in this case. As for the linguistic consensus degree PCR_{12}, it is calculated according to case 2 of Equation 5.9, as *a<ICR<b* (i.e., 0<*0.467<0.5*), using the formula l_i = *(ICR-a)/(b-a)* = (0.467-0)/(0.5-0) = 0.934. From Figure 5.11, the linguistic label of the maximum membership value on the fuzzy preference scale that corresponds to 0.934 is the linguistic label *EL: extremely likely*.

Figure 5.12 illustrates the final consensus degrees calculated for the consensus labels of each pair of responsibility alternatives.

	x_1:Owner	x_2:Cont.	x_3:Shared
x_1:Owner	-	EL	C
x_2:Cont.	EL	-	C
x_3:Shared	C	C	-

Figure 5.11. Calculation of the consensus degree PCR_{12}

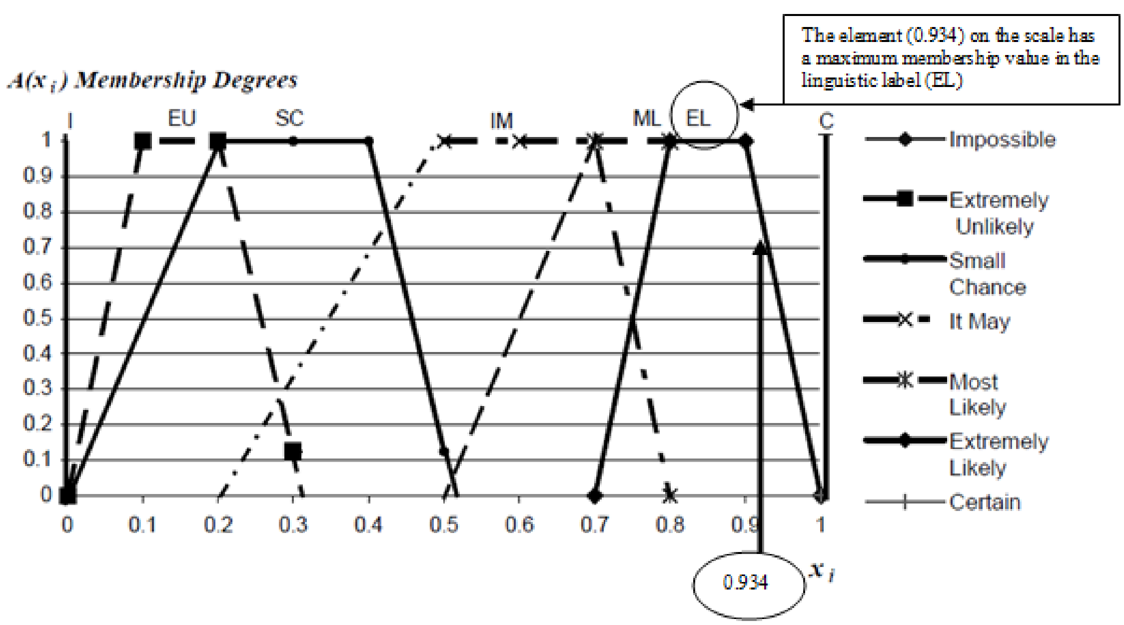

Figure 5.12. Final consensus degrees calculated for the consensus labels of the task “providing benchmarking data and comparable projects' costs”

Step 7: Determining Final Responsibility for Each Task

The last step is to determine the set X^c that ranks the three responsibility alternatives {x_1: owner's responsibility, x_2: contractors' responsibility, x_2: shared responsibility} in the order of their maximum consensus labels, and to determine the responsibility alternative of the greatest $LCR^{max}(x_i)$. From Equation 5.12 and as illustrated in Figure 5.13, the three alternatives are ranked as X^c = [(x_3: shared responsibility, *ML: most likely*), (x_1: owner's responsibility, IM: *it may*), (x_2: contractors' responsibility, *IM: it may*)].

	x_1:Owner	x_2:Cont.	x_3:Shared	$LCR^{max}(x_i)$
x_1:Owner	-	IM	SC	**IM**
x_2:Cont.	IM	-	SC	**IM**
x_3:Shared	ML	ML	-	**ML**

Figure 5.13. Determining $LCR^{max}(x_i)$ for the task "providing benchmarking data and comparable projects' costs"

Thus, the task "providing benchmarking data and comparable projects' costs" remains in the shared task list, as the experts agreed that the task can be "most likely (ML)" described as equally shared task (x_3). This means that consensus between experts was reached from the first round and that the original aggregated decision, the output of the modified SAM, was valid for this task.

5.3.3 General Discussion of the Fuzzy Preference Relations Consensus (FPRC) Approach

As previously discussed in this chapter, FPRC is a systematic approach that is applied in a consensus reaching process to help project teams resolve conflicts and be aligned on their proper roles and responsibilities in a given project delivery system. In this thesis, FPRC approach is only applied—as a final step of project team alignment—to project tasks that are perceived by experts as “Equally Shared”: an extent of responsibility determined by experts using the modified similarity aggregation method (SAM). Note that an “Equally Shared” extent of responsibility is only one possible outcome (out of seven) of the modified SAM in determining the extent of the roles and responsibilities of project teams on an initial set of PM and CM tasks. Arguable, FPRC approach can be applied to the original set of PM and CM tasks in order to avoid or reduce conflicts between the project team members during data collection stage, which may eliminate the need to use the modified SAM.

Although the previous argument may sound plausible because FPRC approach is more efficient than the modified SAM in reducing or eliminating conflicts during the data collection stage, use of a consensus reaching process in applying FPRC approach may not be practical if the (1) number of tasks is relatively large, (2) experts involved in the consensus reaching process are too many, or (3) alternatives set is relatively large. In the previous cases, use of a consensus reaching process may not be efficient (Predd et al. 2008) and may be very time-consuming. On the other hand, the modified SAM does not incorporate a consensus reaching process, which may require conducting several rounds to reach consensus between experts, in its algorithm. Thus, the modified SAM (1) can be applied to determine the roles and responsibilities of project teams for a large number of tasks, using one survey round; (2) can aggregate opinions collected from unlimited number of experts in one step; and (3) can incorporate different extents of responsibilities of project teams in the decision-making process. As such, the modified SAM is used—as an initial step of project teams' alignment—to aggregate experts' opinions, based on their consensus and importance weight factors, and it incorporates common agreement and quality of experts in the aggregated decision. Notwithstanding these advantages, the modified SAM is only efficient if its output aggregated decision for a given task is a non-shared responsibility, i.e., owner's or contractors' responsibility, due to the reasons previously discussed in subsection 5.2.4. Also, although the modified SAM can identify the tasks that may involve responsibility conflicts between experts, it can not be used to resolve these conflicts in a consensus reaching process. Thus, the FPRC approach is used as a final step of project teams' alignment in the Fuzzy Consensus Building Framework (FCBF), as the benefits of the FRPC approach complement those of the modified SAM.

Noting the advantages of using FPRC approach in resolving conflicts between project teams and promoting consensus reaching, a limitation of this approach is required to be addressed.

The FPRC approach uses fuzzy preference relations in collecting data from individual experts to express their level of preference in selecting one responsibility alternative over another. This approach is close to the pairwise comparison method (Saaty 1980) in that the matrix used to collect data from experts is a reciprocal matrix similar to that used by Saaty (1980) in comparing pairs of alternatives. However, the elements of the reciprocal matrix of Saaty (1980) contained ordinary numbers that measure the weight or priority of an object or a belief compared to another using a numerical measuring scale. This numerical method is slightly different from that of using a linguistic preference reciprocal matrix in comparing alternatives, as promoted by the FPRC appraoch. As opposed to the pairwise comparison method, the FPRC approach uses linguistic preference relations in demonstrating experts' preferences, which incorporates more human-consistency in the decision-making process by using natural language. However, the limitation of the FPRC approach is that it does not provide a method that measures the consistency of experts on their linguistic preferences. Note that if inconsistency of experts exists on their linguistic preferences, it may be carried throughout the consensus reaching process in the FPRC approach.

In order to deal with the problem of inconsistent opinions of individual experts, Saaty (1980) proposed a numerical method for measuring consistency using a consistency index (CI). The consistency index (CI) is calculated by applying simple mathematical operations to the elements of the reciprocal matrices—those representing individual experts' opinions—and the result should be a consistency ratio (CR) of (0.1) or less (Saaty 1980). Consistency (CR) ratio is calculated by dividing the consistency index (CI) by a random index (RI). The random index (RI) is a consistency index (CI) of a randomly generated reciprocal matrix, which is equal to an average of 0.58 for a (3 x 3) randomly generated reciprocal matrix (Saaty 1980). In his method, Saaty (1980) used an approximated number, called the maximum or principal eigenvalue (λ_{max}), to measure the consistency of experts opinions, which is calculated by applying simple mathematical operations to the elements of the reciprocal matrix. For an opinion of maximum consistency, the principal eigenvalue (λ_{max}) should be equal to the total number of alternatives in the reciprocal matrix. Thus, in theory, a consistency index (CI) of 0 represents the opinion of the maximum consistency.

On the other hand, the elements of the preference reciprocal matrix used in the FPRC approach are formed of linguistic preferences, which make it difficult to use Saaty (1980)'s numerical method in measuring consistency. One way of dealing with this problem is to replace each linguistic label by a crisp modal value (or an alpha-cut value) and calculate the eigenvalue, numerically, using Saaty (1980)'s method. A simpler way of dealing with this problem is to check the transitivity of the elements of the reciprocal matrix of each expert (Saaty 1980). For example, if the linguistic label "extremely likely (EL)" was selected by an expert to prefer the responsibility alternative "x_1:owner" over "x_3:shared", while the linguistic label "most likely (ML)" was selected by the same expert to prefer the responsibility alternative "$x_{3:}$:shared" over "$x_{2:}$:contractor", then the concept of transitivity holds if the same expert selected the linguistic preference "most likely (ML)" or more to prefer the responsibility alternative "x_1:owner" over "$x_{3:}$:contractor," or else the overall opinion of the expert will lead to an inconsistent conclusion. Not withstanding all the above limitations, perfect consistency in measurement is difficult to attain in practice, which is why the previous methods only provide a way of evaluating "how strongly consistency is violated" (Saaty 1980).

5.4 Conclusion

This chapter described the steps of applying two different fuzzy consensus building and aggregation methods in the FCBF that incorporated consensus and quality of construction project teams in aggregating their opinions. First, the modified similarity aggregation method (SAM) was applied to aggregate project teams' opinions to determine the extent of their roles and responsibilities for a predetermined set of standard tasks. The modified SAM addressed the limitations of a previous fuzzy similarity aggregation method by modifying it to be applied in a linguistic framework. The modified SAM provides construction project owners and project contractor teams with a tool for early alignment of their project teams on the extent of their roles and responsibilities in any project delivery system, as it ensures that the aggregated opinion of project teams is a result of their common agreement. Based on the aggregation results of the modified SAM, each standard task is classified under one of three responsibility task lists: the owner's, contractors', or shared responsibility task list.

The fuzzy preference relations consensus (FPRC) approach is then applied, as a second step, which complements the modified SAM to align project teams on their roles and responsibilities. The FPRC approach confirms shared tasks, or else resolves residual conflicts between experts on shared responsibilities by ensuring that the required level of consensus is reached between experts. The FPRC approach allows for the vagueness and imprecision that are inherent in the problem of resolving responsibility conflicts, as it measures the linguistic consensus degree that exists among project teams' opinions using a simple consensus measure. It allows project teams to compare their linguistic information on pairs of responsibility alternatives, which is an efficient and practical approach in resolving conflicts between experts' opinions on a set of similar alternatives. The FPRC approach also takes into account the quality of experts' opinions in decision-making by integrating the importance weight factor for each expert based on his or her individual characteristics using the standalone fuzzy expert system (chapter 4), which is incorporated into the calculation of the consensus degrees.

This chapter explained the final stage of applying the Fuzzy Consensus Building Framework (FCBF). The next chapter presents the validation stage of the FCBF model, using an actual case study of three projects in the field of oil and gas: an oil refinery plant, a waste control and reduction plant, and an extension construction project to a group of existing oil wells.

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6. Chapter Six - Case Study: Determining the Project Teams' Responsibilities in the Owner Managing Contractor (OMC) Project Delivery System

6.1 Introduction

A case study is presented in this chapter to show how the Fuzzy Consensus Building Framework (FCBF) was utilized by a group of project owner organizations in the field of oil and gas to involve their project teams in deciding on the extent of their new roles and responsibilities in an owner-customized project delivery system (PDS), namely owner managing contractor (OMC). The framework was applied as a tool for early alignment of the different project teams on the extent of their new roles and responsibilities, by building consensus and resolving conflicts that may arise between them in the decision-making process. In order to validate the outputs of the FCBF model, in terms of the proposed roles and responsibilities of the group of owner organizations versus those of their engineering, procurement, and construction (EPC) contractors, the output roles and responsibilities of the FCBF model are compared to project teams' actual roles and responsibilities in three actual projects. In these projects, the owner organizations implemented initial OMC project delivery systems, based on the preset objectives of the group of owner organizations.

This chapter is organized as follows: first, a necessary background of the case study—the OMC project delivery system—is presented; then the implementation stage of the different components of the FCBF is explained in detail; and finally, the analysis of implementation results and model validation is demonstrated.

The next section provides necessary background of the owner managing contractor (OMC) project delivery system (PDS).

6.2 Background of the Owner Managing Contractor (OMC) project delivery system

The Fuzzy Consensus Building Framework (FCBF) was implemented to assist a joint venture (JV) that was formed by a group of owner organizations in the oil and gas field. The FCBF assists the JV in defining and refining its roles and responsibilities versus those of its engineering, procurement, and construction (EPC) contractors in an owner-customized project delivery system, the owner managing contractor (OMC).

Before assembling the JV, three project owner organizations used engineering, procurement, and construction management (EPCM) contractors (Figure 6.1) to manage the construction of their individual projects from the design phase up to the project turnover phase. In the

EPCM project delivery system, each owner organization handled traditional supervision roles; the EPCM contractor executed all contracts and procurement, and was compensated on a cost reimbursable basis to perform engineering and management services and to manage the EPC and Engineering and Procurement (EP) companies, general contractors, and subcontractors. The major advantage of this system was that the EPCM contractor had the flexibility to deal with project problems and scope changes by deploying additional resources, without the need to negotiate cost and schedule impacts with the owners, although project owners were involved to a limited extent in equipment selection and commercial arrangements with major vendors and subcontractors. However, the EPCM project delivery system had one major disadvantage: each project owner had to assign its major project management (PM) and construction management (CM) functions to the EPCM contractor, which led to conflicts between project teams due to uncontrolled project interfaces. In addition, relying on the EPCM contractors for project management reduced the required PM and CM competencies of the owner organizations, reducing their ability to make project decisions in a timely manner. More about the advantages and disadvantages of using the EPCM project delivery systems can be found in a paper by Agnitsch et al. (2001).

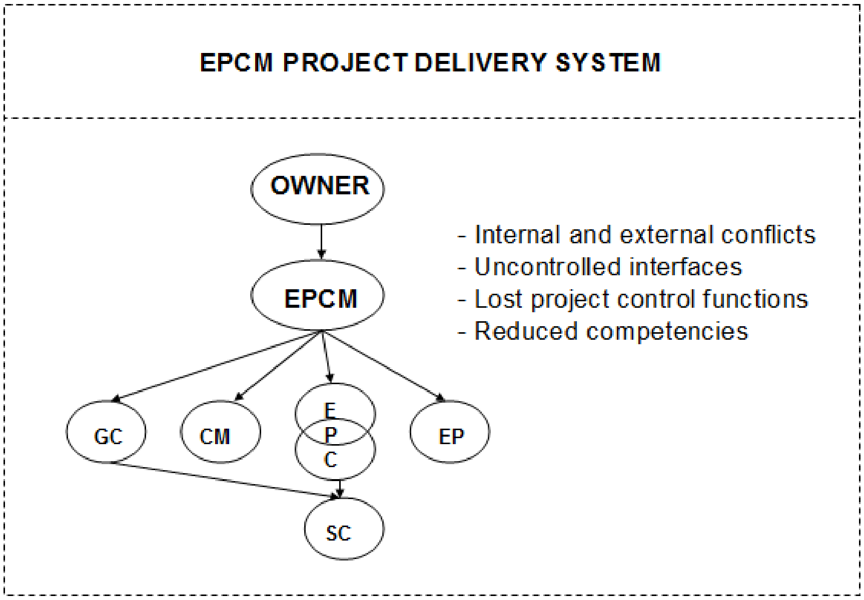


Figure 6.1. Engineering, procurement, and construction management PDS

To correct the problem, the three owner organizations undertook a joint venture (JV) to deliver their oil and gas construction projects more efficiently using a customized project delivery system, named owner managing contractor (OMC). In addition to assuming the roles of a traditional project owner organization, one of the three companies took over the PM and CM roles previously handled by the EPCM contractor. Thus, the traditional "owner" was assigned the title of "owner managing contractor (OMC)," which is how the project delivery system got its name (Figure 6.2).

Also, some of the roles of the EPC and EP contractors, such as setting up contracts for bulk purchasing of long lead equipment, were transferred to the OMC. This resulted in an OMC project delivery system that is a hybrid of the EPC and CM systems, because of the dual role of the OMC as a project and construction manager as well as an EPC contractor. The OMC differs from the CM PDS, as it encourages the owner to rely less on the use of external expertise, such as CM consultants or EPCM contractors, and it allows the sharing of the owner's resources with the EPC contractors in executing the project tasks. The OMC differs from partnering (Chan et al. 2003), as it allows the owner to manage its projects using internal resources for most project functions.

The intentions of the JV-owner organization in creating the OMC project delivery system were to better control project activities, reduce complex interfaces between project teams, enhance its PM and CM competencies, and benefit from economies of scale in procuring long lead items on behalf of the EPC and EP companies. Those intentions conform with the concept of "value interests" of the Construction Industry Institute (CII) (2010), which incorporates a set of project attributes defined by the owner organization prior to the project start that adds value to the owner organization (CII 2010). According to the JV-owner organization, four main project attributes were required by the owner to add value to the organization: (1) maximize JV's control function; (2) minimize projects' interfaces and conflicts; (3) maximize JV's in-house competencies, and (4) maximize JV's involvement in procurement. Those project attributes were communicated to the EPC contractors and the JV's in-house project teams in line with their early alignment process. These unique requirements created a complex environment for construction projects, causing confusion and misunderstanding in the roles and responsibilities of the project team in both the JV-owner organization and its EPC contractors. Thus, the JV-owner organization required a tool to help ensure the early alignment of its project teams on the extent of the its new roles and responsibilities, versus that of its EPC contractors, in the customized OMC project delivery system for a standard set of PM and CM tasks. The next section describes the implementation of the FCBF to solve this problem for the JV-owner organization.

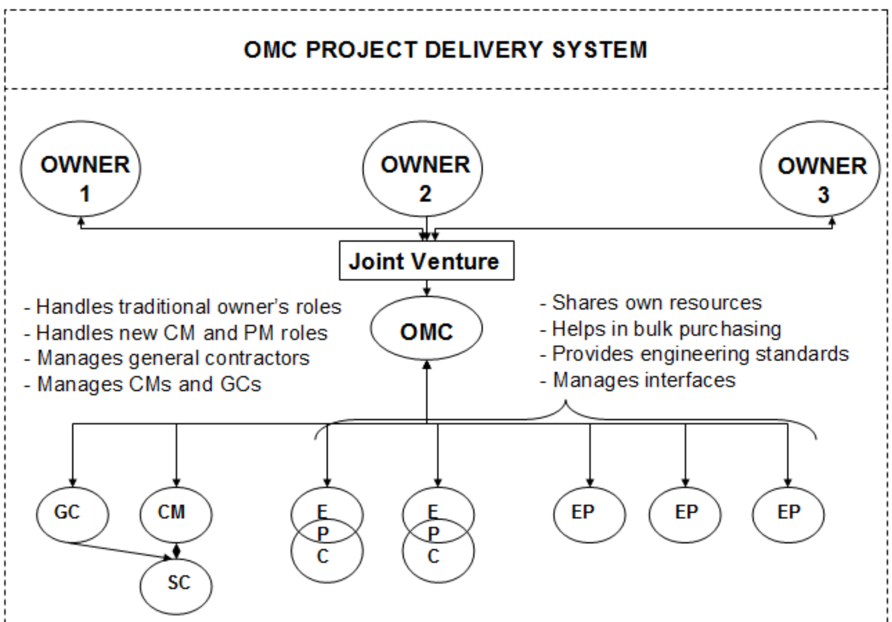


Figure 6.2. Owner managing contractor (OMC) PDS

6.3 Fuzzy Consensus Building Framework (FCBF) Implementation

This section demonstrates the implementation of the Fuzzy Consensus Building Framework (FCBF) to help the JV-owner organization ensure the early alignment of its project teams on the extent of their roles and responsibilities in the customized OMC project delivery system, using a standard set of PM and CM tasks (Appendix A). In order to achieve this objective, the following stages were implemented:

- Stage 1: Conducting a web-based survey to solicit project teams' opinions
- Stage 2: Applying the fuzzy expert system (FES) to determine the quality of the participating project teams
- Stage 3: Applying the modified similarity aggregation method (SAM) to aggregate project teams' opinions and create preliminary responsibility task lists
- Stage 4: Applying the Fuzzy Preference Relations Consensus (FPRC) approach to resolve conflicts on shared responsibilities, and to update final responsibility task lists

The following subsections explain the above stages in detail.

6.3.1 Stage 1: Conducting a web-based survey to solicit project teams' opinions

A web-based survey questionnaire (Appendix E) was developed to collect the opinions of the project teams of the JV-owner organization and its EPCs regarding the extent of the new roles and responsibilities of the JV-owner organization versus that of its EPC contractors' project teams in the OMC project delivery system. The survey allowed the project teams to decide on the extent of their new roles and responsibilities in the OMC project delivery system, using the seven linguistic terms that were created in chapter 3 (Table 6.1).

The web-based questionnaire was developed using a commercially available web-based survey tool—SurveyMonkey™—that introduced the standard template of the PM and CM tasks (Appendix A) to designated experts from the project teams of both the JV-owner and the EPC organizations, in order to define the extent of their roles and responsibilities in the OMC project delivery system on a task-by-task basis.

Table 6.1. Description of linguistic terms forming a fuzzy linguistic rating scale

Rating	Linguistic term	Description
1	No responsibility	The party (i.e., JV-owner) is not responsible at all for carrying out the task, yet it may be consulted based on the sole discretion of the sole responsible party (i.e., EPC contractor).
2	Limited involvement	The party is not responsible for carrying out the task, yet it is required to provide minor input to the other party to enable the other party to perform the task.
3	Active involvement	The party is not responsible for carrying out the task, yet it must be involved in all task-related discussions and must provide considerable input.
4	Shared equally	Both parties (i.e., JV-owner and the EPC contractor) perform the task with equal levels of involvement.
5	Significant involvement	The party is responsible for carrying out the task, yet it must involve the other party in all task-related discussions and must receive considerable input from the other party.
6	Principal responsibility	The party is responsible for carrying out the task, yet it will require minor input from the other party.
7	Sole responsibility	The party (i.e., JV-owner) is fully responsible for performing the task, yet it may choose to involve the other party (i.e., EPC contractor), if needed to.

The questionnaire was composed of four sections as follows:

- **Section 1 – Welcome to the survey:** This section introduced the objectives of the survey to the experts, and explained the meaning of the linguistic terms that were used to rate the different extents of the roles and responsibilities of the JV-owner organization versus those of its EPC contractors (Figure 6.3).

1. Welcome To The Survey

Dear user(s), welcome to the survey prepared by the Hole School of Construction Engineering, University of Alberta. As **the Owner** is trying to continuously improve and develop its understanding on how to execute its role as a **Managing Contractor**, the intent of the survey is to collect your responses with regard to the **extent** to which you perceive each of the included tasks as the responsibility of the **Owner** or the **Silo Contractor** in accordance with your role, as an owner or contractor, in a managing contractor (OMC) delivery system model.

The tasks are categorised into 18 work processes.

You are allowed to add **up to a maximum of 4 new tasks per each work process** should you feel the need to do so. **For these additional tasks, please provide an appropriate rating for each task you list, and describe each task in the free-form box, in the order in which you have rated it.**.

The rating scale is from 1 to 7, and indicates the extent to which you believe the task is the responsibility of the Owner or the Silo Contractor in terms of **performing the task. Note that decision making responsibility is not part of the rating you provide.**

A rating of **1** means **No Responsibility** (The party is not responsible at all for carrying out the task, yet he may be consulted based on the sole discretion of the sole responsible party).
A rating of **2** means **Limited Involvement** (The party is not responsible for carrying out the task, yet he is required to provide minor input to the other party to enable him to perform the task).
A rating of 3 means **Active Involvement** (The party is not responsible for carrying out the task, yet he must be involved in all task-related discussions and must provide considerable input).
A rating of **4** means **Shared Equally** (Both parties perform the task with equal levels of involvement).
A rating of 5 means **Significant Involvement** (The party is responsible for carrying out the task, yet he must involve the other party in all task-related discussions and nust receive considerable input from him).
A rating of 6 means **Principal Responsibility** (The party is responsible for carrying out the task, yet he will require minor input from the other party).
A rating of 7 means **Sole Responsibility** (The party is fully responsible for performing the task, yet he may choose to involve the other party if needed).

Alternatively, if the task is **Not Applicable** to your project then tick the **Last** column.

The next page of the survey is intended for collecting your information and general project related information, while page 3 is intended for collecting specific project related characteristics. Subsequently, you may proceed with rating the tasks as per the above described rating scale.

The approximate time to fill in the questionnaire is 90-120 minutes. You can save your responses and resume later; however, once you have completed the survey, you will not be able to modify your responses.

If you have any inquiry or request during filling in the questionnaire, contact **Mohamed El-Barkouky (elbarkou@ualberta.ca)**.

Figure 6.3. Web-based survey: Section 1 – Welcome to the survey

- **Section 2 – Users and project related information:** This section included multiple choice and open-ended type questions that addressed the characteristics of the participating experts and the general description of their projects (Figure 6.4), which also provided information on the attributes of individual experts, such as years of experience and role in the company. Information collected in this section was used as input values to apply the fuzzy expert system (FES) (chapter 4), which calculated the experts' importance weight factor, as will be discussed in stage 2 in section 6.3.2.

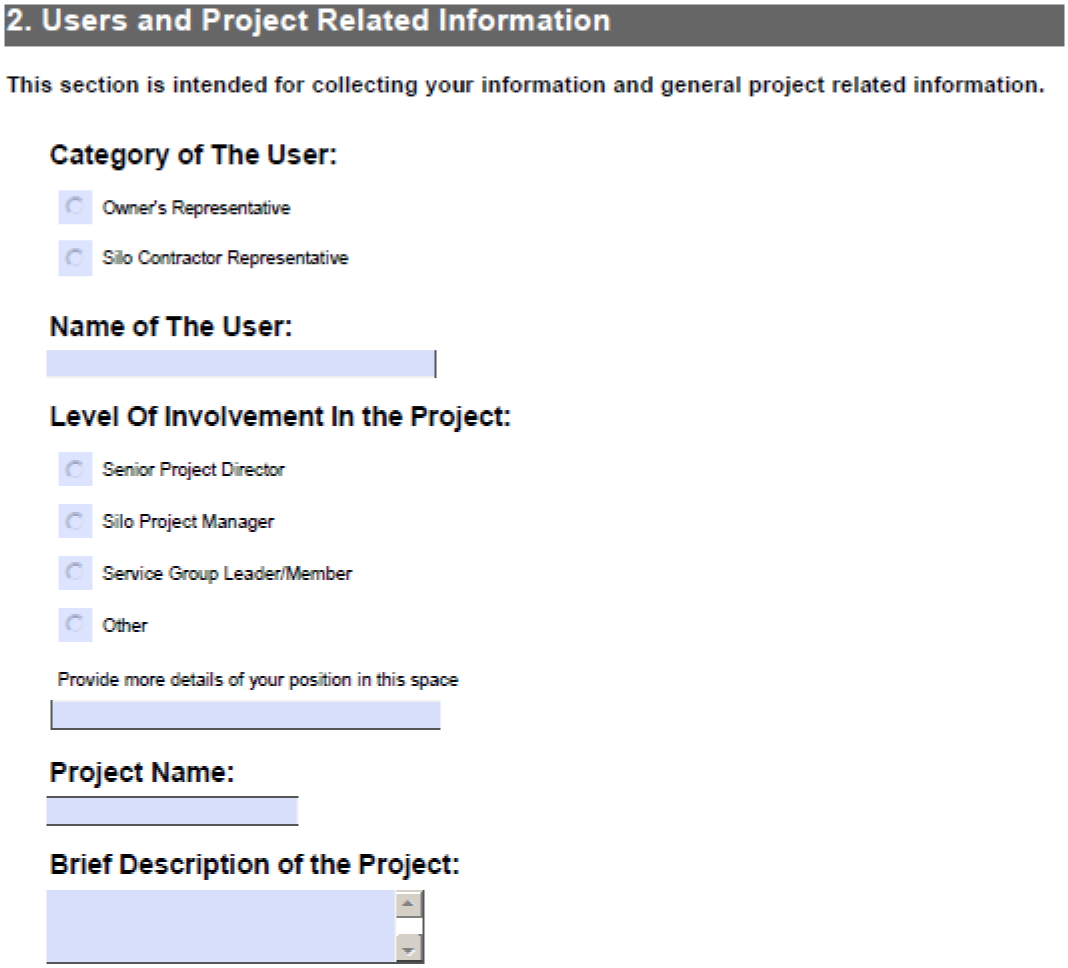
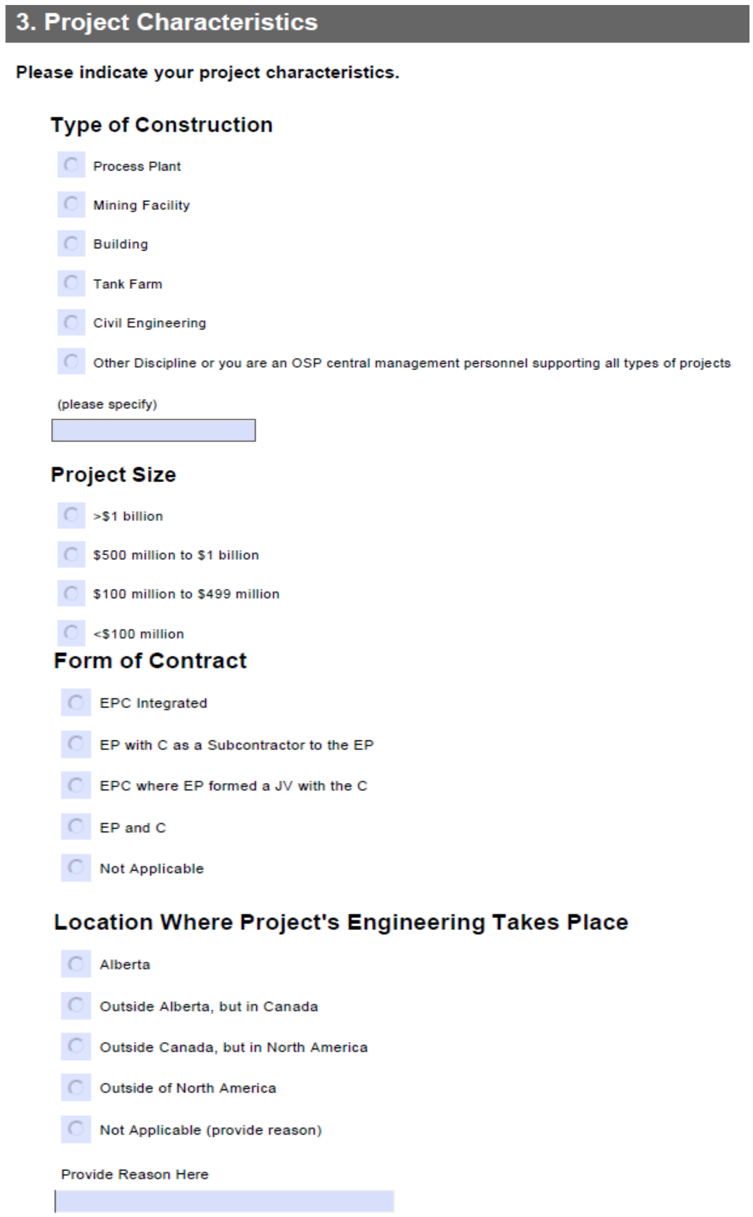


Figure 6.4. Web-based survey: Section 2 – Users and project related information

- **Section 3 – Project Characteristics:** This section included multiple choice and open-ended type questions that addressed the characteristics of the projects in which the participating experts were involved. Questions addressing projects' types, sizes, contract forms, and locations were included in this section (Figure 6.5).



3. Project Characteristics

Please indicate your project characteristics.

Type of Construction

- Process Plant
- Mining Facility
- Building
- Tank Farm
- Civil Engineering
- Other Discipline or you are an OSP central management personnel supporting all types of projects

(please specify)

Project Size

- >$1 billion
- $500 million to $1 billion
- $100 million to $499 million
- <$100 million

Form of Contract

- EPC Integrated
- EP with C as a Subcontractor to the EP
- EPC where EP formed a JV with the C
- EP and C
- Not Applicable

Location Where Project's Engineering Takes Place

- Alberta
- Outside Alberta, but in Canada
- Outside Canada, but in North America
- Outside of North America
- Not Applicable (provide reason)

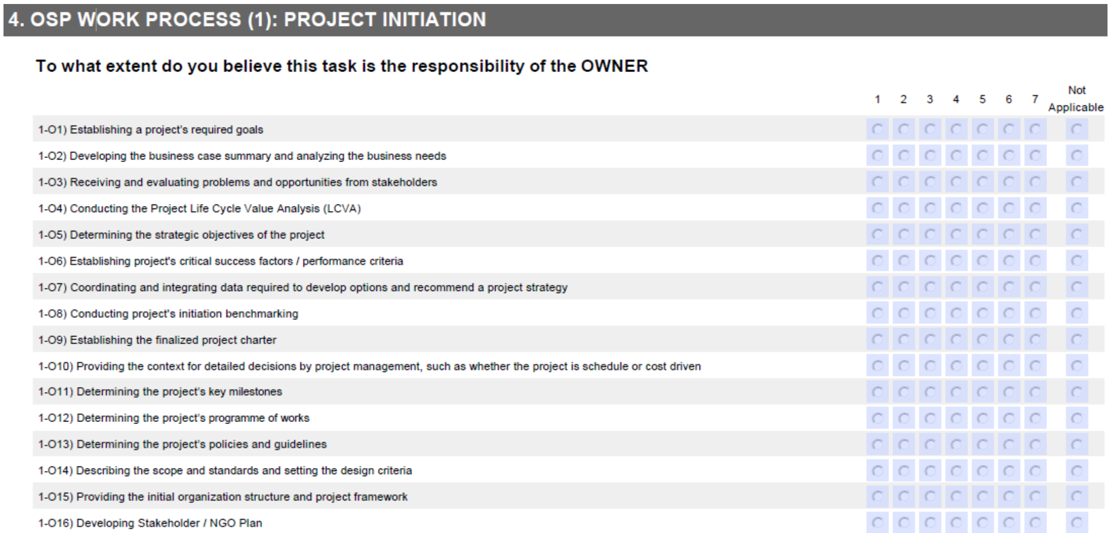
Provide Reason Here

Figure 6.5. Web-based survey: Section 3 – Project characteristics

- **Section 4 – Core of the survey**: This was the main section of the survey, as it classified the 324 standard project and construction management tasks (Appendix A), developed in chapter 2, into 18 standard work processes in the survey questionnaire, based on the JV's internal work structure (Table 6.2). Then, one question was posed for each task: "To what extent would you rate the roles and responsibilities of the owner versus that of its contractors?" For each task, each participating expert was asked to choose the linguistic term that represented his or her choice based on the linguistic terms described in Section 1 of the web-based survey. For those tasks that did not apply to an OMC project delivery system, a "not applicable" option was included in the survey for each task. Figure 6.6 illustrates a sample of the questions posed to experts for some of the tasks classified in the project initiation work process.

Table 6.2. Eighteen standard work processes used to classify the PM and CM tasks

1- Initiation	10- Engineering
2- Organization	11- Procurement
3- Project Management	12- Contracting
4- Safety Management	13- Construction Management
5- Regulation Compliance	14- Ready for Operation
6- Quality Management	15- Administration
7- Document Management	16- Change Management
8- Financial Controls	17- Information Systems
9- Project Controls	18- Operation and Maintenance



4. OSP WORK PROCESS (1): PROJECT INITIATION

To what extent do you believe this task is the responsibility of the OWNER

	1	2	3	4	5	6	7	Not Applicable
1-O1) Establishing a project's required goals								
1-O2) Developing the business case summary and analyzing the business needs								
1-O3) Receiving and evaluating problems and opportunities from stakeholders								
1-O4) Conducting the Project Life Cycle Value Analysis (LCVA)								
1-O5) Determining the strategic objectives of the project								
1-O6) Establishing project's critical success factors / performance criteria								
1-O7) Coordinating and integrating data required to develop options and recommend a project strategy								
1-O8) Conducting project's initiation benchmarking								
1-O9) Establishing the finalized project charter								
1-O10) Providing the context for detailed decisions by project management, such as whether the project is schedule or cost driven								
1-O11) Determining the project's key milestones								
1-O12) Determining the project's programme of works								
1-O13) Determining the project's policies and guidelines								
1-O14) Describing the scope and standards and setting the design criteria								
1-O15) Providing the initial organization structure and project framework								
1-O16) Developing Stakeholder / NGO Plan								

Figure 6.6. Web-based survey: Section 4 – Core of the survey

The web-based survey was conducted in two stages:

- **Stage 1: Conduct pilot survey**

A pilot survey was conducted across the key managers of the participating organizations, to ensure that the level of detail of the survey was appropriate for the study, the role of the experts was well-defined, and survey instructions were easy to follow (Hallowell and Gambates 2010). This stage followed the recommendations of Col Debella and Ries (2006), who conducted a survey regarding the performance of project delivery methods and, as a first step in their study, conducted a pilot survey with several respondents to ensure the survey effectiveness.

The pilot survey conducted in stage 1 involved three key directors of the JV-owner organization and one project director of one of its EPC contractors. The selected experts had more than 20 years of experience in construction projects in the field of oil and gas. This stage confirmed the wording of the standard tasks and the format of the survey, and assisted in collecting feedback on the effectiveness of the linguistic terms in rating each task. As a result of this stage, minor changes were introduced to the wordings of the tasks, either to increase their level of details or to clarify their meanings. Also, the experts advised that the average time taken to complete the pilot survey was 45 minutes, which was considered in stage 2 of the survey by allowing enough time for the participating experts to provide their feedback.

- **Stage 2: Conduct the final survey to solicit project teams' opinions**

After implementing the results of the pilot survey, the final survey, which adopted oil sands projects as pilot projects, was conducted to collect experts' linguistic assessments. The web-based questionnaire solicited the opinions of 52 experts of the JV-owner and EPC organizations. Before conducting the survey, key project managers of the JV-owner organization contacted the 52 experts to explain their objectives of applying the OMC project delivery system, and the level of control that the JV required to maintain in its projects using the OMC project delivery system. This was a key step to ensure that the participating project teams were aligned on the intentions of the survey and their roles.

Twenty-six project managers of the JV-owner organization and 11 of its EPC contractor organizations, all with 5 to 20 years of experience in the construction industry, responded to the survey (a 71% response rate). The results of the survey helped project teams define the responsibilities of the owner versus those of its EPC contractors in the new OMC project delivery system using the previously discussed seven linguistic terms, and it helped in collecting the 5 key attributes of the participating experts that represent the input factors to the fuzzy expert system.

Figure 6.7 illustrates the characteristics of the 37 participating experts and those of their projects. Table 6.3 illustrates the values of the 5 attributes representing the qualifications of the 37 experts who participated in the survey, while Appendix F illustrates the results of the survey. The next subsection demonstrates the results of the fuzzy expert system (FES) that determined the importance weights of the 37 experts involved in the decision-making process.

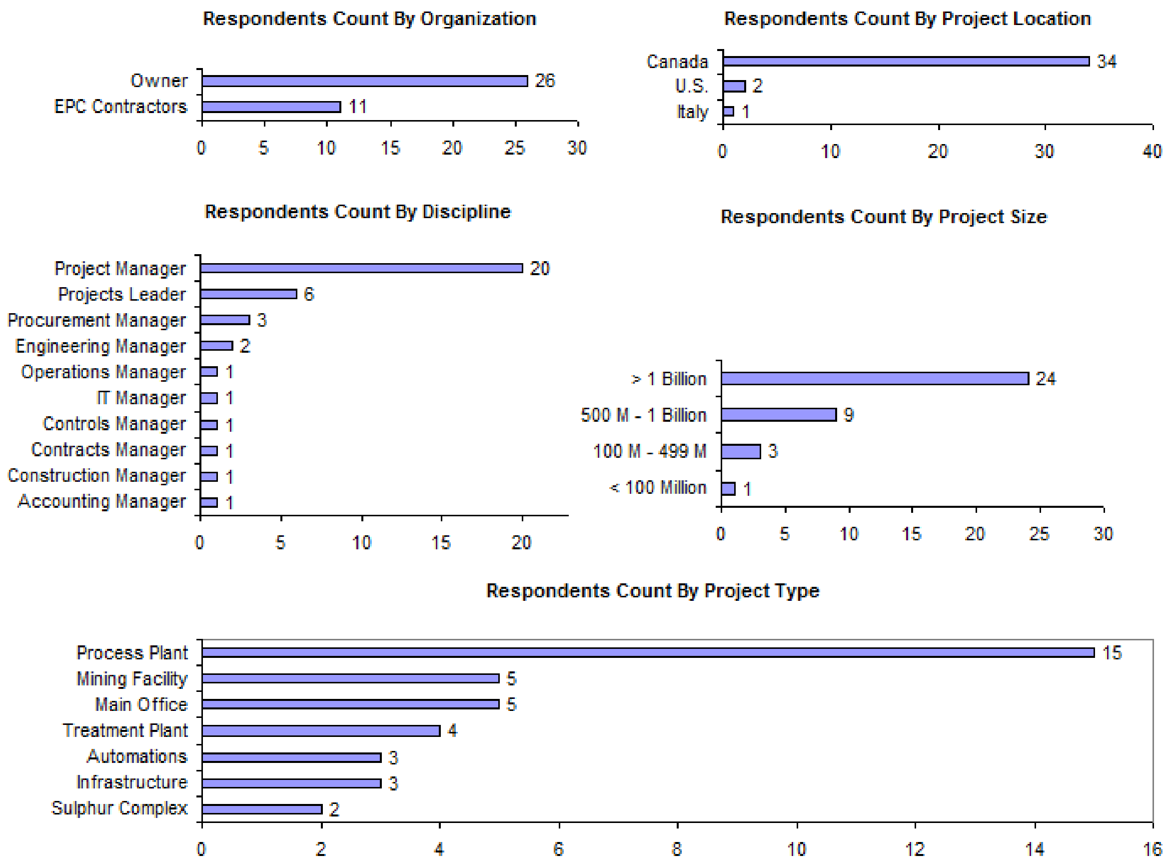


Figure 6.7. Characteristics of the projects of the participating experts and those of their projects

Table 6.3. Attributes of the experts who participated in the survey

Experts	Years of experience	Diversity of experience	Years in role	Enthusiasm and willingness	Role in the company
Expert 1	>20	Extremely high	>20	High	Sr. Project Manager
Expert 2	>20	High	>20	Very high	Sr. Project Manager
Expert 3	>20	Very high	>20	Average	Sr. Project Manager
Expert 4	>20	Average	>20	High	Project Director
Expert 5	>20	Average	9 to 12	High	Sr. Project Manager
Expert 6	>20	High	5 to 8	Low	General Manager
Expert 7	>20	Average	5 to 8	Average	Project Director
Expert 8	9 to 12	Extremely high	9 to 12	Low	Project Director
Expert 9	13 to 16	Very high	13 to 16	High	Sr. Project Engineer
Expert 10	9 to 12	High	9 to 12	Very high	Project Manager
Expert 11	9 to 12	High	9 to 12	Average	Sr. Project Manager
Expert 12	9 to 12	High	9 to 12	High	Project Manager
Expert 13	9 to 12	Average	9 to 12	Very high	Sr. Project Manager
Expert 14	9 to 12	High	9 to 12	High	Project Manager
Expert 15	13 to 16	Average	5 to 8	High	Sr. Project Engineer
Expert 16	5 to 8	High	5 to 8	High	Sr. Project Manager
Expert 17	5 to 8	High	5 to 8	Low	Sr. Project Manager
Expert 18	9 to 12	Low	5 to 8	Average	Project Director
Expert 19	5 to 8	Very high	5 to 8	Average	Project Manager
Expert 20	>20	Very low	1 to 4	High	Project Manager
Expert 21	5 to 8	Average	5 to 8	High	Project Engineer
Expert 22	5 to 8	High	5 to 8	Very low	Project Director
Expert 23	1 to 4	High	1 to 4	High	Project Director

Table 6.3. Attributes of the experts participated in the survey (continued)

Experts	Years of experience	Diversity of experience	Years in role	Enthusiasm and willingness	Role in the company
Expert 24	5 to 8	Low	5 to 8	High	Project Manager
Expert 25	5 to 8	Low	5 to 8	Average	Project Manager
Expert 26	5 to 8	Low	5 to 8	Average	Project Manager
Expert 27	5 to 8	Low	5 to 8	Average	Project Manager
Expert 28	5 to 8	Low	5 to 8	Average	Project Manager
Expert 29	5 to 8	Average	5 to 8	Average	Project Engineer
Expert 30	5 to 8	Low	5 to 8	Average	Project Manager
Expert 31	5 to 8	Low	5 to 8	Average	Project Manager
Expert 32	5 to 8	Low	5 to 8	Average	Project Manager
Expert 33	1 to 4	High	1 to 4	Average	Project Engineer
Expert 34	1 to 4	High	1 to 4	High	Leader
Expert 35	1 to 4	Average	1 to 4	Average	Project Engineer
Expert 36	5 to 8	Low	5 to 8	Average	Sr. Project Engineer
Expert 37	5 to 8	Low	5 to 8	Average	Sr. Project Engineer

6.3.2 Stage 2: Applying fuzzy expert system (FES) to determine the quality of the participating project teams

This stage involved applying the fuzzy expert system (FES), which was developed in chapter 4, using the base case FES configuration that determined the importance weight factors of the 37 experts involved in the decision-making process. Then, the importance weight factors of the experts were normalized to obtain their relative importance weight factors. Table 6.4 (same as Table 4.4) illustrates the relative importance weight factors of experts as determined by the FES, using its base case system configuration (chapter 4).

In the next stage, the relative importance weight factors (*RIWF*) of experts were combined with their consensus weight factors (*CWF*) in the modified similarity aggregation method (SAM) to aggregate experts' opinions based on the quality of their opinion and their consensus to decide on their roles and responsibilities in the new OMC project delivery system.

Table 6.4. Relative importance weight factors of experts as calculated by the FES

Experts	Importance weight factor	Relative importance weight factor	Experts	Importance weight factor	Relative importance weight factor
E1	0.336	0.016	*E20*	0.608	0.029
E2	0.459	0.022	*E21*	0.459	0.022
E3	0.414	0.020	*E22*	0.336	0.016
E4	0.690	0.033	*E23*	0.500	0.024
E5	0.500	0.024	*E24*	0.618	0.030
E6	0.608	0.029	*E25*	0.633	0.031
E7	0.459	0.022	*E26*	0.481	0.023
E8	0.618	0.030	*E27*	0.420	0.020
E9	0.460	0.022	*E28*	0.459	0.022
E10	0.477	0.023	*E29*	0.459	0.022
E11	0.380	0.018	*E30*	0.670	0.032
E12	0.608	0.029	*E31*	0.807	0.039
E13	0.517	0.025	*E32*	0.459	0.022
E14	0.476	0.023	*E33*	0.517	0.025
E15	0.459	0.022	*E34*	0.842	0.041
E16	0.842	0.041	*E35*	0.715	0.035
E17	0.842	0.041	*E36*	0.690	0.033
E18	0.500	0.024	*E37*	0.600	0.029
E19	0.459	0.022			

6.3.3 Stage 3: Applying the modified similarity aggregation method (SAM) to aggregate project teams' opinions and create preliminary responsibility task lists

The linguistic assessments collected from experts in stage 1, regarding the extent of the roles and responsibilities of the JV-owner organization versus that of its EPC contractors, were aggregated in this stage using the modified similarity aggregation method (SAM) for each of the 324 tasks.

The following four steps were applied in the modified SAM to aggregate experts' linguistic assessments to determine the project teams' extent of responsibility for the 324 tasks using the appropriate linguistic term.

- Step 1: Assign relevant membership functions to experts' linguistic assessments
- Step 2: Determine experts' consensus weight factor
- Step 3: Aggregate experts' opinions into a single fuzzy number
- Step 4: Determine the final extent of responsibility using the appropriate linguistic term

This subsection shows how the steps of the modified SAM were applied to aggregate experts' assessments for one of the 324 tasks, named "establishing project's critical success factors and performance criteria."

6.3.3.1 Step 1: Assign relevant membership functions to experts' linguistic assessments

For every task, the fuzzy triplets (r_1, r_2, r_3) of the membership functions describing the seven standard fuzzy ratings Y_k on the scale, where k ranged from 1 to 7, were assigned to corresponding linguistic assessments made by the 37 experts E_i, where i ranged from 1 to 37, using the fuzzy linguistic rating scale (Figure 6.8)

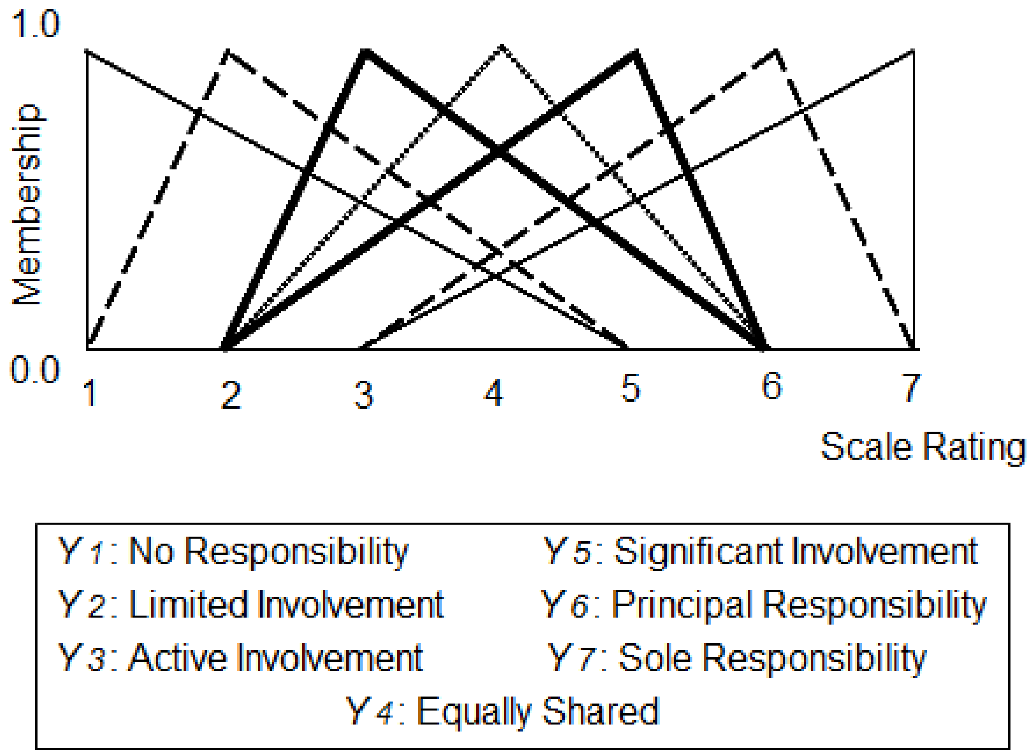


Figure 6.8. Fuzzy linguistic rating scale

Table 6.5 illustrates the standard fuzzy ratings Y_k, and the corresponding linguistic assessments made by experts, as well as the fuzzy triplets (r_1, r_2, r_3) that represent their relative fuzzy ratings R_i, where i ranges from 1 to 37, for the task “establishing project's critical success factors and performance criteria.”

Table 6.5. Assigning fuzzy triplets to experts' linguistic assessments

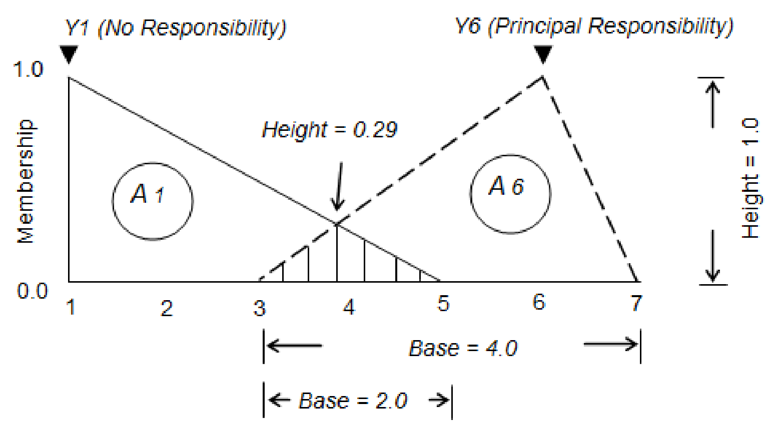
Experts	Yk	Linguistic term	Fuzzy triplet			Experts	Yk	Linguistic term	Fuzzy triplet		
E1	*Y6*	Principal responsibility	3	6	7	*E20*	*Y5*	Significant involvement	2	5	6
E2	*Y6*	Principal responsibility	3	6	7	*E21*	*Y7*	Sole responsibility	3	7	7
E3	*Y6*	Principal responsibility	3	6	7	*E22*	*Y7*	Sole responsibility	3	7	7
E4	*Y7*	Sole responsibility	3	7	7	*E23*	*Y7*	Sole responsibility	3	7	7
E5	*Y1*	No responsibility	1	1	5	*E24*	*Y7*	Sole responsibility	3	7	7
E6	*Y7*	Sole responsibility	3	7	7	*E25*	*Y7*	Sole responsibility	3	7	7
E7	*Y6*	Principal responsibility	3	6	7	*E26*	*Y7*	Sole responsibility	3	7	7
E8	*Y6*	Principal responsibility	3	6	7	*E27*	*Y6*	Principal responsibility	3	6	7
E9	*Y4*	Equally shared	2	4	6	*E28*	*Y5*	Significant involvement	2	5	6
E10	*Y7*	Sole responsibility	3	7	7	*E29*	*Y4*	Equally shared	2	4	6
E11	*Y6*	Principal responsibility	3	6	7	*E30*	*Y6*	Principal responsibility	3	6	7
E12	*Y2*	Limited involvement	1	2	5	*E31*	*Y7*	Sole responsibility	3	7	7
E13	*Y7*	Sole responsibility	3	7	7	*E32*	*Y5*	Significant involvement	2	5	6
E14	*Y6*	Principal responsibility	3	6	7	*E33*	*Y6*	Principal responsibility	3	6	7
E15	*Y6*	Principal responsibility	3	6	7	*E34*	*Y7*	Sole responsibility	3	7	7
E16	*Y6*	Principal responsibility	3	6	7	*E35*	*Y7*	Sole responsibility	3	7	7
E17	*Y1*	No responsibility	1	1	5	*E36*	*Y6*	Principal responsibility	3	6	7
E18	*Y6*	Principal responsibility	3	6	7	*E37*	*Y7*	Sole responsibility	3	7	7
E19	*Y7*	Sole responsibility	3	7	7						

6.3.3.2 Step 2: Determine experts' consensus weight factor

As a first step to calculate the consensus weight factor of experts, for each task of the 324 tasks, the agreement degrees $S(R_i, R_j)$ were calculated between pairs of experts, based on their relative fuzzy ratings (R_i). The agreement degrees were computed by dividing the intersection area of their fuzzy ratings by the bounding area, as shown in Equation 6.1, where μ_{Ri} and μ_{Rj} are the relevant membership degrees of every element (x) of the fuzzy ratings selected by the expert pairs on the scale.

$$S(R_i, R_j) = \frac{\int_x (\min\{\mu_{R_i}(x), \mu_{R_j}(x)\})\,dx}{\int_x (\max\{\mu_{R_i}(x), \mu_{R_j}(x)\})\,dx} \qquad [6.1]$$

Before calculating the agreement degrees between expert pairs, the areas of intersection and the bounding areas between the seven standard fuzzy ratings Y_k on the scale were calculated. Sample calculations of the area of intersection and bounding area between the standard fuzzy ratings Y_1 and Y_6 are shown in Figure 6.9. The results of the area calculations for the seven standard fuzzy ratings are illustrated in Table 6.6.



*Area 1 = 0.5*Base*Height=0.5*4.0*1.0= 2.0*
*Area 3 = 0.5*Base*Height=0.5*4.0*1.0= 2.0*
*Area of Intersection (Hatched Area) = 0.5*Base*Height = 0.5*2.0*0.29 = 0.29*
Bounding Area = Area 1 + Area 3 - Hatched Area = 2.0 + 2.0 - 0.29 = 3.71

Figure 6.9. Area calculations between standard fuzzy ratings Y_1 and Y_6

Table 6.6. Results of area calculations between the standard fuzzy ratings

Areas of intersection							
Fuzzy rating	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*
Y1	2.00	1.60	0.90	0.75	0.64	0.29	0.25
Y2	1.60	2.00	1.13	0.90	0.75	0.33	0.29
Y3	0.90	1.13	2.00	1.60	1.33	0.75	0.64
Y4	0.75	0.90	1.60	2.00	1.60	0.90	0.75
Y5	0.64	0.75	1.33	1.60	2.00	1.13	0.90
Y6	0.29	0.33	0.75	0.90	1.13	2.00	1.60
Y7	0.25	0.29	0.64	0.75	0.90	1.60	2.00
Bounding areas							
Fuzzy rating	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*
Y1	2.00	2.40	3.10	3.25	3.36	3.71	3.75
Y2	2.40	2.00	2.88	3.10	3.25	3.67	3.71
Y3	3.10	2.88	2.00	2.40	2.67	3.25	3.36
Y4	3.25	3.10	2.40	2.00	2.40	3.10	3.25
Y5	3.36	3.25	2.67	2.40	2.00	2.88	3.10
Y6	3.71	3.67	3.25	3.10	2.88	2.00	2.40
Y7	3.75	3.71	3.36	3.25	3.10	2.40	2.00

After calculating the areas of intersection and bounding areas between all the seven standard fuzzy ratings Y_k, the agreement degree $S(R_i, R_j)$ between the relative fuzzy ratings R_i of experts pairs was calculated—using Equation 6.1—by dividing the area of intersection between their fuzzy ratings R_i by the bounding area. For example, as shown in Table 6.5, for the task "establishing project's critical success factors and performance criteria," the fuzzy rating R_i of Expert E_1 was Y_6 "principal responsibility," while that of expert E_5 was Y_1 "no responsibility." Thus, from Equation 6.1, their agreement degree $S(R_1, R_5)$ is the area of intersection between their fuzzy ratings (R_1 *and* R_5) divided by the bounding area (i.e., the area of intersection between the standard fuzzy ratings Y_1 and Y_6 divided by the bounding area). From Table 6.6, the area of intersection between the standard fuzzy ratings Y_1 and Y_6 equals 0.290, while the bounding area is 3.710; thus, the agreement degree $S(R_1, R_5)$ = 0.290/3.710 = 0.078. Figure 6.10 illustrates the agreement matrix, which stores the agreement degrees between the experts in rating the task “establishing project's critical success factors and performance criteria.”

After calculating the agreement degrees, the modified SAM algorithm computed the consensus weight factor (CWF_i) for every expert (Equation 6.2), which determined how close or far an individual expert’s assessment is from the opinions that entailed common agreement of the group. The consensus weight factor of every expert weighted his or her response during aggregation.

$$\mathrm{C}WF_i = \frac{A(E_i)}{\sum_{i=1}^{n} A(E_i)} \qquad [6.2]$$

where, $A(E_i)$ is the average level of agreement of an expert with other experts, and is calculated by dividing the sum of his or her agreement degrees with other experts by (n-1) number of experts.

From Figure 6.10, Equation 6.3 calculates the average level of agreement of expert E_1 in rating the task “establishing project's critical success factors and performance criteria.”

$A(E_1)$ = (1.000 + 1.000 + 0.667 + 0.077 + 0.667 + 1.000 + 1.000 + 0.290 + 0.667 + 1.000 + 0.091 + 0.667 + 1.000 + 1.000 + 1.000 + 0.07 7 + 1.000 + 0.667 + 0.391 + 0.667 + 0.667 + 0.667 + 0.667 + 0.667 + 0.667 + 1.600 +

0.391 + 0.290 + 1.000 + 0.667 + 0.391 + 1.00 + 0.667 + 0.667 + 1.000 + 0.667) / 36 = 0.694 [6.3]

Table 6.7 illustrates the average level of agreement $A(E_i)$ of the 37 experts in rating the task "establishing project's critical success factors and performance criteria."

Table 6.7. Average level of agreement of experts for the task "establishing project's critical success factors and performance criteria"

Experts	$A(E_i)$	Experts	$A(E_i)$
E1	0.694	*E20*	0.383
E2	0.694	*E21*	0.691
E3	0.694	*E22*	0.691
E4	0.691	*E23*	0.691
E5	0.133	*E24*	0.691
E6	0.691	*E25*	0.691
E7	0.694	*E26*	0.691
E8	0.694	*E27*	0.694
E9	0.313	*E28*	0.383
E10	0.691	*E29*	0.313
E11	0.694	*E30*	0.694
E12	0.140	*E31*	0.691
E13	0.691	*E32*	0.383
E14	0.694	*E33*	0.694
E15	0.694	*E34*	0.691
E16	0.694	*E35*	0.691
E17	0.133	*E36*	0.694
E18	0.694	*E37*	0.691
E19	0.691	$\sum_{i=1}^{n} A(Ei)$ = 22.267	

From Table 6.7, the sum of the level of agreement of the 37 experts: $\sum_{i=1}^{37} A(Ei)$ = 22.267. Thus, from Equation 6.2, the consensus weight factor of expert E_1 is calculated as 0.031 (Equation 6.4).

Experts		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35	E36	E37
	Y_k	6	6	6	7	1	7	6	6	4	7	6	2	7	6	6	6	1	6	7	5	7	7	7	7	7	7	6	5	4	6	7	5	6	7	7	6	7
E1	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E2	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E3	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E4	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E5	1	0.077	0.077	0.077	0.067	1.000	0.067	0.077	0.077	0.231	0.067	0.077	0.667	0.067	0.077	0.077	0.077	1.000	0.077	0.067	0.191	0.067	0.067	0.067	0.067	0.067	0.067	0.077	0.191	0.231	0.077	0.067	0.191	0.077	0.067	0.067	0.077	0.067
E6	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E7	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E8	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E9	4	0.290	0.290	0.290	0.231	0.231	0.231	0.290	0.290	1.000	0.231	0.290	0.290	0.231	0.290	0.290	0.290	0.231	0.290	0.231	0.667	0.231	0.231	0.231	0.231	0.231	0.231	0.290	0.667	1.000	0.290	0.231	0.667	0.290	0.231	0.231	0.290	0.231
E10	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E11	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E12	2	0.091	0.091	0.091	0.077	0.667	0.077	0.091	0.091	0.290	0.077	0.091	1.000	0.077	0.091	0.091	0.091	0.667	0.091	0.077	0.231	0.077	0.077	0.077	0.077	0.077	0.077	0.091	0.231	0.290	0.091	0.077	0.231	0.091	0.077	0.077	0.091	0.077
E13	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E14	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E15	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E16	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E17	1	0.077	0.077	0.077	0.067	1.000	0.067	0.077	0.077	0.231	0.067	0.077	0.667	0.067	0.077	0.077	0.077	1.000	0.077	0.067	0.191	0.067	0.067	0.067	0.067	0.067	0.067	0.077	0.191	0.231	0.077	0.067	0.191	0.077	0.067	0.067	0.077	0.067
E18	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E19	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E20	5	0.391	0.391	0.391	0.290	0.191	0.290	0.391	0.391	0.667	0.290	0.391	0.231	0.290	0.391	0.391	0.391	0.191	0.391	0.290	1.000	0.290	0.290	0.290	0.290	0.290	0.290	0.391	1.000	0.667	0.391	0.290	1.000	0.391	0.290	0.290	0.391	0.290
E21	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E22	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E23	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E24	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E25	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E26	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E27	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E28	5	0.391	0.391	0.391	0.290	0.191	0.290	0.391	0.391	0.667	0.290	0.391	0.231	0.290	0.391	0.391	0.391	0.191	0.391	0.290	1.000	0.290	0.290	0.290	0.290	0.290	0.290	0.391	1.000	0.667	0.391	0.290	1.000	0.391	0.290	0.290	0.391	0.290
E29	4	0.290	0.290	0.290	0.231	0.231	0.231	0.290	0.290	1.000	0.231	0.290	0.290	0.231	0.290	0.290	0.290	0.231	0.290	0.231	0.667	0.231	0.231	0.231	0.231	0.231	0.231	0.290	0.667	1.000	0.290	0.231	0.667	0.290	0.231	0.231	0.290	0.231
E30	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E31	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E32	5	0.391	0.391	0.391	0.290	0.191	0.290	0.391	0.391	0.667	0.290	0.391	0.231	0.290	0.391	0.391	0.391	0.191	0.391	0.290	1.000	0.290	0.290	0.290	0.290	0.290	0.290	0.391	1.000	0.667	0.391	0.290	1.000	0.391	0.290	0.290	0.391	0.290
E33	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E34	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E35	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000
E36	6	1.000	1.000	1.000	0.667	0.077	0.667	1.000	1.000	0.290	0.667	1.000	0.091	0.667	1.000	1.000	1.000	0.077	1.000	0.667	0.391	0.667	0.667	0.667	0.667	0.667	0.667	1.000	0.391	0.290	1.000	0.667	0.391	1.000	0.667	0.667	1.000	0.667
E37	7	0.667	0.667	0.667	1.000	0.067	1.000	0.667	0.667	0.231	1.000	0.667	0.077	1.000	0.667	0.667	0.667	0.067	0.667	1.000	0.290	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.290	0.231	0.667	1.000	0.290	0.667	1.000	1.000	0.667	1.000

Figure 6.10. Agreement matrix for the task "establishing project's critical success factors and performance criteria"

$$CWF_1 = \frac{A(E_1)}{\sum_{i=1}^{37} A(Ei)} = \frac{0.694}{22.267} = 0.031 \qquad [6.4]$$

Table 6.8 illustrates the results of calculating the consensus weight factor of the 37 experts in rating the task “establishing project's critical success factors and performance criteria.”

Table 6.8. Consensus weight factor of experts for the task “establishing project's critical success factors and performance criteria”

Experts	*CWFi*	Experts	*CWFi*
E1	0.031	*E20*	0.017
E2	0.031	*E21*	0.031
E3	0.031	*E22*	0.031
E4	0.031	*E23*	0.031
E5	0.006	*E24*	0.031
E6	0.031	*E25*	0.031
E7	0.031	*E26*	0.031
E8	0.031	*E27*	0.031
E9	0.014	*E28*	0.017
E10	0.031	*E29*	0.014
E11	0.031	*E30*	0.031
E12	0.006	*E31*	0.031
E13	0.031	*E32*	0.017
E14	0.031	*E33*	0.031
E15	0.031	*E34*	0.031
E16	0.031	*E35*	0.031
E17	0.006	*E36*	0.031
E18	0.031	*E37*	0.031
E19	0.031		

In the next step of the modified SAM, the consensus weight factor (CWF_i) of each expert is combined with his or her relative importance weight factor ($RIWF_i$) to aggregate their fuzzy ratings into one single fuzzy number.

6.3.3.3 Step 3: Aggregate experts' opinions into a single fuzzy number

This step involved aggregating experts' fuzzy ratings into a single fuzzy number, which described the extent of responsibility of each party that represented the collective opinion of the experts involved in the decision-making process. First, in order to take account of both the quality of experts and their level of agreement in the aggregation process for every task, the consensus degree coefficient (CDC_i), combining the relative importance weight factor ($RIWF_i$) of every expert with his or her consensus weight factor (CWF_i) in a single equation, was calculated for each expert (Equation 6.5).

$$CDC_i = \beta * RIWF_i + (1 - \beta) * CWF_i \qquad [6.5]$$

In order to incorporate equal emphasis of the quality of experts and their level of agreement in the aggregation process, the JV-owner organization requested that the modifier β should be set to 0.5 in aggregating experts' linguistic assessments for all the tasks. Table 6.9 illustrates the results of calculating the consensus degree coefficient of the 37 experts in rating the task "establishing project's critical success factors and performance criteria” based on the *$RIWF_i$ and CWF_i* of experts, which were illustrated in Tables 6.4 and 6.8, respectively.

Table 6.9. Consensus degree coefficient of experts for the task “establishing project's critical success factors and performance criteria”

Experts	*CWFi*	*RIWFi*	*CDCi*	Experts	*CWFi*	*RIWFi*	*CDCi*
E1	0.031	0.016	0.024	*E20*	0.017	0.030	0.024
E2	0.031	0.022	0.027	*E21*	0.031	0.022	0.027
E3	0.031	0.020	0.026	*E22*	0.031	0.016	0.024
E4	0.031	0.033	0.032	*E23*	0.031	0.024	0.028
E5	0.006	0.024	0.015	*E24*	0.031	0.030	0.031
E6	0.031	0.029	0.030	*E25*	0.031	0.031	0.031
E7	0.031	0.022	0.027	*E26*	0.031	0.023	0.027
E8	0.031	0.030	0.031	*E27*	0.031	0.020	0.026
E9	0.014	0.022	0.018	*E28*	0.017	0.022	0.020
E10	0.031	0.023	0.027	*E29*	0.014	0.022	0.018
E11	0.031	0.018	0.025	*E30*	0.031	0.033	0.032
E12	0.006	0.029	0.018	*E31*	0.031	0.039	0.035
E13	0.031	0.025	0.028	*E32*	0.017	0.022	0.020
E14	0.031	0.023	0.027	*E33*	0.031	0.025	0.028
E15	0.031	0.022	0.027	*E34*	0.031	0.041	0.036
E16	0.031	0.041	0.036	*E35*	0.031	0.035	0.033
E17	0.006	0.041	0.024	*E36*	0.031	0.034	0.033
E18	0.031	0.024	0.028	*E37*	0.031	0.029	0.030
E19	0.031	0.022	0.027				

After calculating the CDC_i of every expert for every task, the aggregated fuzzy number R for each task was calculated (Equation 6.6) based on the sum of the multiplication of the CDC_i of each expert by the fuzzy number R_i that represented his or her fuzzy rating.

$$R = \sum_{i=1}^{n} (CDC_i * R_i) \qquad [6.6]$$

Table 6.10 illustrates the result of calculating the aggregated fuzzy number *R* that represented the extent of responsibility for the task “establishing project's critical success factors and performance criteria,” which was calculated as *R* = (2.79 6.04 6.79).

Table 6.10. Aggregated fuzzy number for the task “establishing project's critical success factors and performance criteria”

Experts	*CDCi*	Fuzzy triplets			*CDCi * Ri*			Experts	*Yk*	Fuzzy triplets			*CDCi * Ri*		
E1	0.024	3	6	7	0.072	0.143	0.167	*E20*	0.024	2	5	6	0.047	0.118	0.141
E2	0.027	3	6	7	0.081	0.161	0.188	*E21*	0.027	3	7	7	0.080	0.188	0.188
E3	0.026	3	6	7	0.077	0.154	0.180	*E22*	0.024	3	7	7	0.071	0.166	0.166
E4	0.032	3	7	7	0.097	0.227	0.227	*E23*	0.028	3	7	7	0.083	0.194	0.194
E5	0.015	1	1	5	0.015	0.015	0.076	*E24*	0.031	3	7	7	0.092	0.215	0.215
E6	0.030	3	7	7	0.091	0.213	0.213	*E25*	0.031	3	7	7	0.093	0.217	0.217
E7	0.027	3	6	7	0.081	0.161	0.188	*E26*	0.027	3	7	7	0.082	0.191	0.191
E8	0.031	3	6	7	0.092	0.184	0.215	*E27*	0.026	3	6	7	0.078	0.155	0.181
E9	0.018	2	4	6	0.037	0.073	0.110	*E28*	0.020	2	5	6	0.040	0.099	0.119
E10	0.027	3	7	7	0.082	0.191	0.191	*E29*	0.018	2	4	6	0.037	0.073	0.110
E11	0.025	3	6	7	0.075	0.149	0.174	*E30*	0.032	3	6	7	0.096	0.192	0.224
E12	0.018	1	2	5	0.018	0.036	0.090	*E31*	0.035	3	7	7	0.106	0.247	0.247
E13	0.028	3	7	7	0.085	0.197	0.197	*E32*	0.020	2	5	6	0.040	0.099	0.119
E14	0.027	3	6	7	0.082	0.164	0.191	*E33*	0.028	3	6	7	0.085	0.170	0.198
E15	0.027	3	6	7	0.081	0.161	0.188	*E34*	0.036	3	7	7	0.109	0.253	0.253
E16	0.036	3	6	7	0.109	0.218	0.254	*E35*	0.033	3	7	7	0.099	0.231	0.231
E17	0.024	1	1	5	0.024	0.024	0.118	*E36*	0.033	3	6	7	0.098	0.195	0.228
E18	0.028	3	6	7	0.084	0.167	0.195	*E37*	0.030	3	7	7	0.091	0.212	0.212
E19	0.027	3	7	7	0.080	0.188	0.188	*R* = (2.79 6.04 6.79)							

The final step in applying the modified SAM was to determine the extent of the roles and responsibilities for every task by defining the relevant linguistic term that best matched the aggregated fuzzy number *R*, and creating the preliminary responsibility tasks lists.

6.3.3.4 Step 4: Determine final extent of responsibility using appropriate linguistic term

In this step, the modified SAM defined each aggregated fuzzy number for each of the 324 tasks with an appropriate linguistic term using the seven standard linguistic terms of the fuzzy linguistic rating scale. The Euclidean distance measure (Equation 6.7) was applied to determine the final extent of responsibility for each task by measuring the Euclidean distance between the triplets (r_1, r_2, r_3) of the aggregated fuzzy number R and those of the seven standard fuzzy ratings Y_k on the scale, where p = 2 for the Euclidean distance measure function, n = 3 because each fuzzy rating is represented by a triplet, r_i is each number forming the triplet of the aggregated fuzzy number R, and y_i is the corresponding number forming the triplet of each of the seven standard fuzzy ratings (Y_k) on the scale.

$$d_g(R, Y_k) = (1/n \sum_{i=1}^{n} \left| r_i - y_i \right|^{p})^{1/p} \qquad [6.7]$$

Table 6.11 illustrates the result of measuring the Euclidean distance between the seven standard fuzzy ratings Y_k on the scale and the aggregated fuzzy number R that represented the extent of responsibility for the task “establishing project's critical success factors and performance criteria,” which was calculated as R = (2.79 6.04 6.79), as illustrated in Table 6.10.

From Table 6.11, the standard fuzzy ratings Y_k of the minimum Euclidean distance to the aggregated fuzzy number *R* was Y_6 “principal responsibility.”

Table 6.11. Euclidean distance measure for the task “establishing project's critical success factors and performance criteria”

Fuzzy rating	*Linguistic term*	*Euclidean distance*
Y1	No responsibility	3.26
Y2	Limited involvement	2.75
Y3	Active involvement	2.09
Y4	Equally shared	1.34
Y5	Significant involvement	0.88
Y6	**Principal responsibility**	**0.18**
Y7	Sole responsibility	0.58

After determining the linguistic terms that represented the different extents of the roles and responsibilities for each task of the standard 324 tasks, three preliminary responsibility task lists were created: owner’s responsibility, EPC contractors’ responsibility, and shared responsibility task list. The aggregated fuzzy ratings (Y_k) with peaks corresponding to the elements 5 “significant involvement,” 6 “principal responsibility,” and 7 “sole responsibility” of the owner indicated that the owner was responsible for the task. The fuzzy ratings (Y_k) with peaks corresponding to the elements 1 “no responsibility,” 2 “limited involvement,” and 3 “active involvement” of the owner indicated that the contractor was the responsible party, because the scale was reciprocal. The fuzzy rating with a peak of 4 indicates an “equally shared” responsibility.

Figure 6.11 illustrates the preliminary responsibility results for the work process safety management, based on the calculations of the modified SAM. Sixteen tasks were introduced to the 37 experts, and the modified SAM categorized the tasks in three responsibility task lists based on the aggregated responses of the experts. As illustrated in Figure 6.11, not only did the model categorize the tasks under the three task lists, but it also determined the extent of responsibility of each party for his or her own tasks. For example, out of a sample 16 tasks classified in the safety management work process, 8 tasks were categorized as owner’s tasks. The owner was found to have “principle responsibility” on five of them and “significant involvement” in conducting the other three tasks.

After applying the modified SAM to the 324 standard tasks and analyzing experts’ aggregated opinions, 168 tasks were determined as owner’s tasks, 110 were EPC contractors’ tasks, and 46 were equally shared tasks. The preliminary responsibly tasks lists of each category are illustrated in Appendix G.

The next subsection discusses the application of the fuzzy preference relations consensus (FPRC) approach to resolve any perceived conflicts on the 46 tasks with shared responsibilities.

Project Safety Management Standard Task List

1. Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL).
2. Administering the development and maintenance of safety programs.
3. Holding sessions for identifying hazards and eliminating them to reduce to lowest acceptable levels.
4. Communicating safety risks to projects' stakeholders.
5. Communicating safety expectations to projects' participants.
6. Establishing and managing a safety reporting and investigation system.
7. Administering training in health and safety.
8. Receiving and commenting on individual subcontractors' safety plans based on the projects' guidelines and standards.
9. Updating the emergency response plan and testing its efficiency.
10. Developing and maintaining a safety program that meets legal, regulatory, corporate, and local requirements.
11. Identifying hazards and reducing them to the lowest acceptable levels.
12. Conducting training in health and safety.
13. Providing support to interpret legislative and regulatory requirements.
14. Assisting the subcontractors in safe work practices.
15. Keeping all working and storage areas clean and secure.
16. Monitoring and coordinating safety, environment, and labour relations requirements.

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Safety Management Equally Shared Responsibility Task List

1. Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL).

Safety Management Owner's Responsibility Task List

(a) Tasks of Principal Responsibility:

2. Administering the development and maintenance of safety programs.

4. Communicating safety risks to projects' stakeholders.

5. Communicating safety expectations to projects' participants.

8. Receiving and commenting on individual subcontractors' safety plans based on the projects' guidelines and standards.

9. Updating the emergency response plan and testing its efficiency.

(b) Tasks of Significant Involvement:

3. Holding sessions for identifying hazards and eliminating them to reduce to lowest acceptable levels.

6. Establishing and managing a safety reporting and investigation system.

7. Administering training in health and safety.

Safety Management EPC Contractors' Responsibility Task List

(a) Tasks of Principal Responsibility:

10. Developing and maintaining a safety program that meets legal, regulatory, corporate, and local requirements.

11. Identifying hazards and reducing them to the lowest acceptable levels.

12. Conducting training in health and safety.

14. Assisting the subcontractors in safe work practices.

15. Keeping all working and storage areas clean and secure.

16. Monitoring and coordinating safety, environment, and labour relations requirements.

(b) Tasks of Significant Involvement:

13. Providing support to interpret legislative and regulatory requirements.

Figure 6.11. Preliminary responsibility results for the work process "safety management"

6.3.4 Stage 4: Applying the fuzzy preference relations consensus (FPRC) approach to resolve conflicts on shared responsibilities

In stage 4 of the FCBF, the fuzzy preference relations consensus (FPRC) approach (Elbarkouky and Fayek 2010b and 2009) was applied to the 46 tasks that were determined by the modified SAM as "equally shared." This step was required because in the cases where the modified SAM determined a task to be equally shared, three possibilities may have existed: (1) the project teams may have collectively agreed that some of these tasks were valid shared tasks, for which both parties were intended to have equally shared responsibility, which was a legitimate case; (2) some of the tasks may have been incorrectly classified by project teams as equally shared tasks because experts were not able to decide on a party responsible for the task using the fuzzy linguistic rating scale; or (3) the algorithm used in the modified SAM failed to draw a reasonable conclusion based on the collective opinion of project teams, due to an equal number of responses that may have existed on both sides of the fuzzy linguistic rating scale. Since there was no clear methodology to predict the prevalence of the first scenario in the aggregation process when the tasks were determined as "equally shared," all the 46 cases in which the tasks were determined as shared were dealt with as conflicts between project teams, which needed to be resolved. For those 46 tasks, the FPRC approach tested the possibility of transferring any of the shared tasks to either the owner or its EPC contractors.

Forty-six preliminary shared tasks (Table 6.12) were introduced to eight experts of the project teams to make further responsibility assessments for the tasks. Six of these experts were key decision makers of the JV-owner organization, two were project managers of its EPC contractors, and all had more than 20 years of experience in the construction industry. Those experts were the only available experts of the original 37 experts who previously rated the 324 tasks using the fuzzy linguistic rating scale.

The following steps were followed in the FPRC approach to determine the final responsibility decisions on the 46 tasks:

- Step 1: Determine preference reciprocal matrices for every task
- Step 2: Aggregate experts' preferences to determine the consensus labels
- Step 3: Create individual consensus relations (ICR) matrix
- Step 4: Determine experts' linguistic consensus degrees for consensus labels
- Step 5: Determine final responsibilities for the tasks and update responsibility task lists

Table 6.12. Preliminary shared responsibility task list

Task description	Work process
1. Providing benchmarking data and comparable projects' costs	Initiation
2. Preparing the design basis memorandum (DBM)	Initiation
3. Preparing the project's organizational chart as a part of the execution plan	Organization
4. Making project staff reassignments	Organization
5. Submitting a proposed organizational chart for final approvals	Organization
6. Preparing the project's detailed work breakdown structure	Project management
7. Implementing a value improvement practice (VIP) for process design improvement	Project management
8. Identifying, analyzing, mitigating, and controlling project risks	Project management
9. Developing risk mitigation plans and updating them as the project progresses	Project management
10. Participating in suppliers negotiations and providing approvals thereof	Project management
11. Developing a plan to address interface issues	Project management
12. Infusing new advances into the business planning process	Project management
13. Delivering best in class project execution	Project management
14. Conducting process hazard analysis (PHA) and setting safety integrity levels (SIL)	Safety management
15. Participating in the preparation of design from the preliminary release to the final release	Quality management
16. Recommending remedial works for defects	Quality management
17. Collecting, analyzing, and recording lessons learned in each project phase	Quality management
18. Maintaining vendor document control system	Document management
19. Developing the execution schedule and providing continuous updates	Project control
20. Integrating the execution schedule with the cost estimating and cost control functions	Project control
21. Identifying scheduling alternatives and improvements	Project control
22. Revising the subcontractors' time schedules and recommending changes	Project control
23. Recommending mitigating methods for schedule variances	Project control
24. Conducting full progress monitoring of the project activities	Project control
25. Determining estimate basis for facility components	Project control
26. Determining historical cost basis for facility components	Project control
27. Converting estimate basis to costs	Project control
28. Reviewing estimates with the project team	Project control
29. Preparing a cost break down structure and chart of accounts	Project control
30. Recommending mitigating methods for cost variances	Project control
31. Keeping records of the summary of charges as reflected by the job cost accounts	Project control
32. Forecasting project costs for activity cost control and providing budget updates	Project control
33. Creating and monitoring project reporting processes	Project control
34. Collecting cost data and reporting on the established metrics	Project control
35. Finalizing the front-end engineering design (FEED)	Engineering
36. Conducting design reviews and liaison with design	Engineering
37. Preparing the design requirements standards	Engineering
38. Liaison with design	Engineering
39. Evaluating and making recommendations on submitted bid packages	Procurement
40. Developing and maintaining a process for contracting work, equipment, and services	Procurement
41. Preparing construction method statements and alternatives	Construction
42. Inspecting and testing the construction work in accordance with the contract	Construction
43. Arranging, coordinating, and conducting training on the equipment /system requirements	Operations
44. Providing administrative support for meeting set up and coordination	Administration
45. Providing administrative support for teleconferences	Administration
46. Providing administrative support for office suppliers	Administration

The next subsections discuss how the above steps were implemented to determine the final responsibilities for the 46 shared tasks using the case of the preliminary shared task "preparing the project's detailed work breakdown structure."

6.3.4.1 Step 1: Determine preference reciprocal matrices for every task

In this step, the fuzzy preference scale (Figure 6.12), which was created in chapter 5, was presented to experts in a meeting in order to determine their preferences regarding the party responsible for every task using the seven linguistic preference labels of the scale in a consensus reaching process. Three responsibility alternatives were presented to experts: x_1*:* owner's responsibility*,* x_2*:* contractors' responsibility*,* and x_3*:* shared responsibility.

Experts were asked to assign their preferences on pairs of responsibility alternatives (x_i over x_j) for each task, using a preference reciprocal matrix (P_e). The elements of the preference reciprocal matrix stored the preferences of experts on pairs of responsibility alternatives. Also, the elements of the preference reciprocal matrix accounted for the reciprocal nature of the fuzzy preference scale. Thus, experts only had to determine half the elements of the matrix, while the other half was automatically determined using relevant reciprocal linguistic labels from the scale. For example, if an expert determined his or her preference for a pair of responsibility alternatives (e.g., x_1*:* owner's responsibility over x_2*:* EPC contractors' responsibility) as *EL: extremely likely*, then the reciprocal term *EU: extremely unlikely* is automatically stored in the relevant element of the matrix that corresponds to the pair (x_2*:* EPC contractors' responsibility over x_1*:* owner's responsibility).

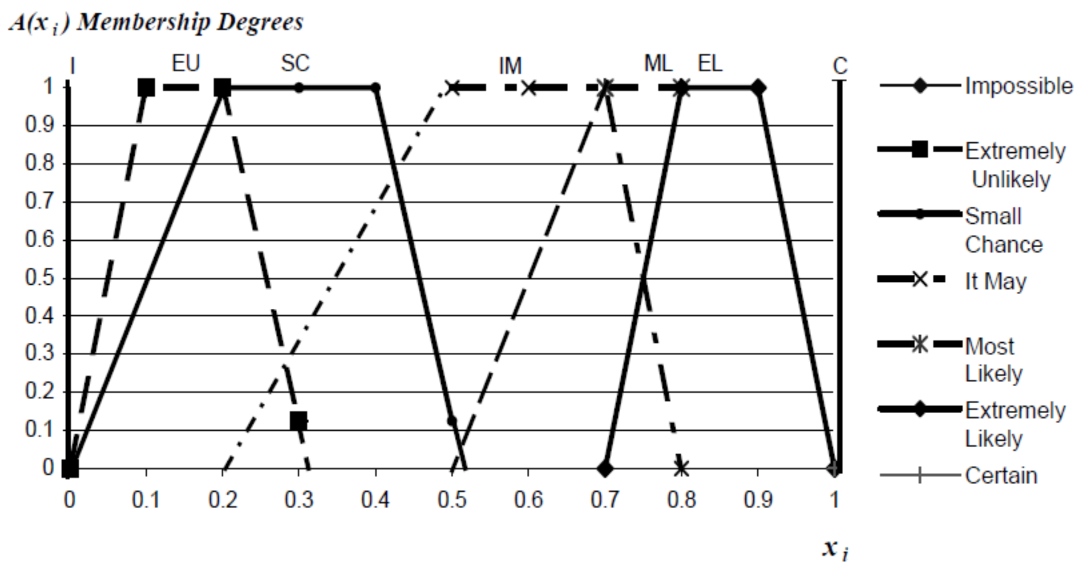

Figure 6.12. Fuzzy preference scale

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Figure 6.13 illustrates the preference reciprocal matrix (P_e) whose elements refer to the linguistic labels that were assigned by the 8 experts (e_i) for the task “preparing the project’s detailed work breakdown structure.” Figure 6.13 also illustrates the importance weights of the 8 experts, as calculated by the fuzzy experts system (FES).

The next step illustrates the aggregation process of experts’ preferences for responsibility alternatives pairs of every shared task.

Expert (e_1)
Importance Weight=0.880

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	EL	EL
x_2:EPC	EU	-	IM
x_3:Shared	EU	IM	-

Expert (e_2)
Importance Weight=0.843

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	IM	SC
x_2:EPC	IM	-	SC
x_3:Shared	ML	ML	-

Expert (e_3)
Importance Weight=0.843

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	IM	EU
x_2:EPC	IM	-	EU
x_3:Shared	EL	EL	-

Expert (e_4)
Importance Weight=0.807

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	EL	IM
x_2:EPC	EU	-	IM
x_3:Shared	IM	IM	-

Expert (e_5)
Importance Weight=0.691

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	EU	SC
x_2:EPC	EL	-	ML
x_3:Shared	ML	SC	-

Expert (e_6)
Importance Weight=0.691

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	IM	EU
x_2:EPC	IM	-	EU
x_3:Shared	EL	EL	-

Expert (e_7)
Importance Weight=0.459

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	EL	EL
x_2:EPC	EU	-	IM
x_3:Shared	EU	IM	-

Expert (e_8)
Importance Weight=0.336

	x_1:Owner	x_2:EPC	x_3:Shared
x_1:Owner	-	EL	EL
x_2:EPC	EU	-	IM
x_3:Shared	EU	IM	-

Figure 6.13. Preference reciprocal matrices for the task "preparing the project's detailed work breakdown structure”

6.3.4.2 Step 2: Aggregate experts' preferences to determine the consensus labels

In order to aggregate experts' opinions for every task, the frequency of experts' opinions in selecting each linguistic label for each pair of responsibility alternatives was determined using the 8 reciprocal matrices determined by the experts. For example, as illustrated in Figure 6.13, for the task "preparing the project's detailed work breakdown structure," for the pair of responsibility alternatives (x_1: owner's over x_2: EPC contractors' responsibility), four experts (e_1, e_4, e_7, and e_8) out of eight selected the preference value *EL: extremely likely*. For the same pair of responsibility alternatives, the preference value *IM: it may*, was selected by three experts (e_2, e_3, and e_6), and the preference value *EU: extremely unlikely* was selected by one expert (e_5). The linguistic label selected by the largest number in the group of experts determined their collective opinion for the pair of responsibility alternatives (x_1: owner's over x_2: EPC contractors' responsibility), which was *EL: extremely likely*. This linguistic label was selected by four experts out of eight, and was considered the consensus label for this pair of responsibility alternatives. This consensus label was stored in the label consensus relations (LCR) matrix, and was denoted by the element LCR_{12}.

After conducting similar computations for the other pairs of responsibility alternatives, the elements of the LCR matrix was updated with the relevant consensus labels of the different pairs of responsibility alternatives. Figure 6.14 illustrates the elements of the LCR matrix, which contains the consensus labels that were selected by the largest number of experts for the different pairs of responsibility alternatives.

The next subsection discusses the creation of individual consensus relations (ICR) matrices for the tasks that enabled calculating the consensus degrees between experts on their preferences.

	x1 :Owner	*x2 :EPC*	*x3 :Shared*
x1 :Owner	-	EL	EL
x2 :EPC	EU	-	IM
x3 :Shared	EU	IM	-

Figure 6.14. Label consensus relations (LCR) matrix for the task "preparing the project's detailed work breakdown structure"

6.3.4.3 Step 3: Create Individual Consensus Relations (ICR) Matrix

In this step, the individual consensus relations matrices (ICR^1) and (ICR^2) were determined for the 46 tasks, which was a fundamental step in computing the consensus degrees between experts on their preferences for each task. For example, for the task “preparing the project’s detailed work breakdown structure,” elements of the ICR^1 matrix contained the proportion of the number of experts who chose each consensus label in the LCR matrix, relative to the total numbers of experts. On the other hand, elements of the ICR^2 matrix contained the values of the average importance weights of the experts who chose each consensus label in the LCR matrix. Figures 6.15a and 6.15b illustrate the elements of the ICR^1 and ICR^2 matrices for this task. For example, four experts agreed on the linguistic label *EL: Extremely likely* for the alternatives pair (x_1, x_2). The element ICR^1_{12} was calculated by dividing the proportion of the number of experts who chose the consensus label *EL: Extremely likely* in the LCR matrix, by the total numbers of experts, i.e., $ICR^1_{12} = 4/8 = 0.500$. On the other hand, to calculate the element ICR^2_{12}, the average importance weight of the four experts (e_1, e_4, e_7, and e_8) who selected the consensus label *EL: Extremely likely* in the LCR matrix was calculated, and is illustrated by Equation 6.8.

$$ICR^2_{12} = (0.880 + 0.807 + 0.459 + 0.336) / 4 = 0.621 \quad [6.8]$$

	x_1:*Owner*	x_2:*EPC*	x_3:*Shared*
x_1:*Owner*	-	0.500	0.375
x_2:*EPC*	0.500	-	0.500
x_3:*Shared*	0.375	0.500	-

(a) ICR^1 Matrix

	x_1:*Owner*	x_2:*EPC*	x_3:*Shared*
x_1:*Owner*	-	0.621	0.558
x_2:*EPC*	0.621	-	0.621
x_3:*Shared*	0.558	0.621	-

(b) ICR^2 Matrix

Figure 6.15. Individual consensus relations ICR^1 and ICR^2 matrix for the task "preparing the project's detailed work breakdown structure"

In order to combine the values of the respective elements of the ICR^1 and ICR^2 matrices, which were stored in a combined ICR matrix that was created for each task, the modifier $\lambda = 0.500$ was selected by the JV-owner organization to incorporate equal weight of emphasis of both the average importance weight of experts (i.e., ICR^2) and their consensus relations (i.e., ICR^1) in determining their consensus degrees. For example, for the task "preparing the project's detailed work breakdown structure," the element ICR_{12} was calculated as illustrated in Equation 6.9.

$$ICR_{12} = \lambda \times ICR^1_{12} + (1- \lambda)\times ICR^2_{12} = 0.500 \text{ X } 0.621 + 0.500 \text{ X } 0.642 = 0.560 \quad [6.9]$$

Figure 6.16 illustrates the elements of the ICR matrix of the task "preparing the project's detailed work breakdown structure."

	x 1 :Owner	*x 2 :EPC*	*x 3 :Shared*
x 1 :Owner	-	0.560	0.467
x 2 :EPC	0.560	-	0.560
x 3 :Shared	0.467	0.560	-

Figure 6.16. Combined ICR matrix for the task "preparing the project's detailed work breakdown structure"

The next step involves determining the linguistic consensus degrees of the experts for their selected consensus labels, based on the values of the elements of the ICR matrix.

6.3.4.4 Step 4: Determine experts' linguistic consensus degrees for consensus labels

In this step, the linguistic consensus degrees of the 8 experts were determined to decide their level of consensus on their selected consensus labels (aggregated opinion) for each pair of responsibility alternatives. Hence, the preference consensus relations (PCR) matrix was created for every task to store the determined linguistic consensus degrees over the consensus labels for each pair of responsibility alternatives. This step was implemented for each of the 46 tasks.

Key managers of the JV-owner organization determined that their target level of consensus for the participating experts would be achieved if at least half of the experts agreed to the same consensus label for any of the pairs of responsibility alternatives. Thus, the linguistic quantifier *at least half* was used with parameters a = 0 and b = 0.5 (Zadeh 1983) to determine the linguistic consensus degrees of experts for every consensus label in the LCR matrix.

For example, for the task "preparing the project's detailed work breakdown structure," by applying Equation 6.10, the linguistic consensus degree $Q(ICR_{12})$ (which was stored in the element PCR_{12} of the preference consensus relations matrix) was determined as the maximum linguistic label (l_u) of the fuzzy preference scale, because $ICR_{12} > b$ (i.e., 0.560> 0.5). The maximum linguistic label (l_u) of the fuzzy preference scale is the linguistic label *certain* in this case, which means that consensus between the 8 experts was certain for the consensus label stored in the element LCR_{12} for this task. As for the linguistic consensus degree $Q(ICR_{13})$, it was determined according to case 2 of Equation 6.10, as

$a<ICR<b$ (i.e., $0<0.467<0.5$), using the formula $l_i = (ICR-a)/(b-a)$ = (0.467-0)/(0.5-0) = 0.934.

$$\mathrm{Q}(\mathrm{ICR}) = \begin{cases} l_0 & \text{if } \mathrm{ICR} < a \\ l_i & \text{if } a \le \mathrm{ICR} \le b \\ l_u & \text{if } \mathrm{ICR} > b \end{cases} \qquad [6.10]$$

From Figure 6.17, the linguistic label of the maximum membership value on the fuzzy preference scale that corresponds to 0.934 is the linguistic label *EL: extremely likely*, i.e., consensus was extremely likely.

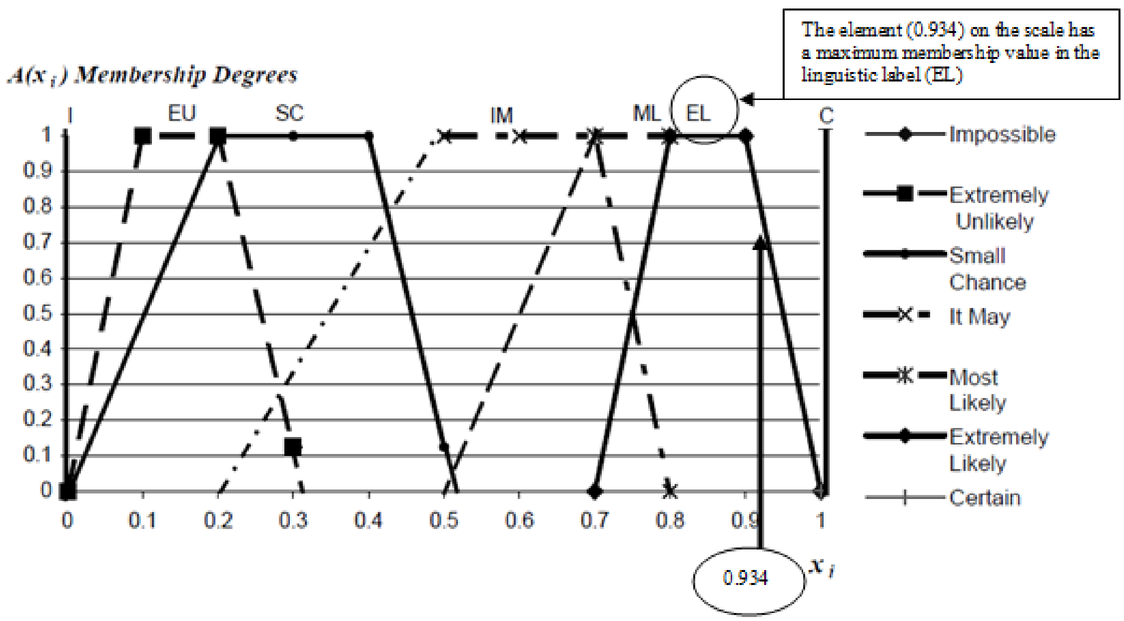

Figure 6.17. Calculation of the consensus degree PCR_{13} for the task "preparing the project's detailed work breakdown structure"

Figure 6.18 illustrates the PCR matrix that stored the final consensus degrees calculated for the consensus labels in the LCR matrix for the task “preparing the project’s detailed work breakdown structure.”

	x_1:*Owner*	x_2:*EPC*	x_3:*Shared*
x_1:*Owner*	-	*C*	*EL*
x_2:*EPC*	*C*	-	*C*
x_3:*Shared*	*EL*	*C*	-

Figure 6.18. Preference consensus relations (PCR) matrix for the task “preparing the project’s detailed work breakdown structure”

The next step was the final step in applying the FCPR approach to determine the final responsibility for each of the 46 tasks, which determined the tasks that remained as shared and those transferred to the owner’s or EPC contractors’ responsibility task lists.

6.3.4.5 Step 5: Determine final responsibilities for the tasks and update responsibility task lists

The last step in the FPRC approach was to determine the set X^c that ranks the three responsibility alternatives {x_1: owner’s responsibility, x_2: contractors’ responsibility, x_2: shared responsibility} for every task in the order of their maximum consensus labels, and to determine the responsibility alternative of the greatest $LCR^{max}(x_i)$. For example, for the task “preparing the project’s detailed work breakdown structure,” from Equation 6.11, and as illustrated in Figure 6.19, the three alternatives were ranked as X^c = [(x_1: owner's responsibility, *EL: extremely likely*), (x_2: EPC contractors' responsibility, IM: *it may*), (x_2: shared responsibility, *IM: it may*)].

$$X^c = \{\underset{x_i \in X}{\mathrm{Max}}\, \mathrm{LCR}(x_i)\} \qquad [6.11]$$

	x_1:*Owner*	x_2:*EPC*	x_3:*Shared*	$LCR^{max}x_i$
x_1:*Owner*	-	EL	EL	**EL**
x_2:*EPC*	EU	-	IM	IM
x_3:*Shared*	EU	IM	-	IM

Figure 6.19. Determining the final responsibility for the task "preparing the project's detailed work breakdown structure"

In conclusion, based on the target level of consensus set by the JV-owner organization, the experts agreed that the task "preparing the project's detailed work breakdown structure" was "extremely likely" to be classified into the owner's responsibility task list and not in the shared responsibility task list. The responsibility task lists were updated accordingly by transferring this task from the shared responsibility task list to that of the owner's. Note that if the target consensus level was not reached between the participating experts regarding the final responsibility for any of the tasks in this first round of the consensus reaching process, then a second round was conducted with experts to explain the existing consensus situation and reassess the preferences of experts after discussing the reasons behind the divergence in their opinions. This process helps in building consensus between project teams by resolving any residual conflicts on the roles and responsibilities for the tasks in the OMC project delivery system.

After implementing the FPRC approach, and determining final responsibilities for the 46 perceived shared tasks, the following updates were made to the preliminary responsibility task lists, as illustrated in Table 6.13:

- Eleven tasks were transferred to the EPC contractors' responsibility task list.
- Eleven tasks were transferred to the owner's responsibility task list.
- Eighteen tasks remained in the shared responsibility task list.
- Six tasks (shown in bold in Table 6.13) were impossible to determine the party responsible for them, because the participating experts did not achieve the target level of consensus that was set by the JV-owner organization's key decision-makers. A second consensus round was required to resolve conflicts on those tasks, but was not conducted because the experts who participated in the first round did not exist in the company to conduct a second round of the consensus reaching process.

Table 6.13. Results of the FPRC approach

Task description	Work process	FPRC output	Consensus degree
1. Providing benchmarking data and comparable projects' costs	Initiation	Shared	Certain
2. Preparing the Design Basis Memorandum (DBM)	Initiation	Shared	Certain
3. Preparing the project's organizational chart as a part of the execution plan	**Organization**	**None**	**Impossible**
4. Making project staff reassignments	Organization	Shared	Certain
5. Submitting a proposed organizational chart for final approvals	Organization	Contractor	Certain
6. Preparing the project's detailed work breakdown structure	Project management	Owner	Certain
7. Implementing a value improvement practice (VIP) for process design improvement	Project management	Shared	Certain
8. Identifying, analyzing, mitigating, and controlling project risks	Project management	Owner	Certain
9. Developing risk mitigation plans and updating them as the project progresses	Project management	Shared	Certain
10. Participating in suppliers negotiations and providing approvals thereof	Project management	Owner	Certain
11. Developing a plan to address interface issues	Project management	Shared	Certain
12. Infusing new advances into the business planning process	Project management	Owner	Certain
13. Delivering best in class project execution	Project management	Shared	Certain
14. Conducting process hazard analysis (PHA) and setting safety integrity levels (SIL)	Safety management	Shared	Certain
15. Participating in the preparation of design from the preliminary release to the final release	Quality management	Contractor	Certain
16. Recommending remedial works for defects	Quality management	Contractor	Certain
17. Collecting, analyzing, and recording lessons learned in each project phase	Quality management	Shared	Certain
18. Maintaining vendor document control system	Document management	Owner	Extremely likely
19. Developing the execution schedule and providing continuous updates	Project control	Contractor	Certain
20. Integrating the execution schedule with the cost estimating and cost control functions	**Project control**	**None**	**Impossible**
21. Identifying scheduling alternatives and improvements	Project control	Shared	Certain
22. Revising the subcontractors' time schedules and recommending changes	Project control	Contractor	Extremely likely
23. Recommending mitigating methods for schedule variances	Project control	Shared	Certain
24. Conducting full progress monitoring of the project activities	Project control	Shared	Certain
25. Determining estimate basis for facility components	**Project control**	**None**	**Impossible**
26. Determining historical cost basis for facility components	Project control	Owner	Certain
27. Converting estimate basis to costs	Project control	Shared	Certain
28. Reviewing estimates with the project team	Project control	Shared	Certain
29. Preparing a cost break down structure and chart of accounts	Project control	Contractor	Certain
30. Recommending mitigating methods for cost variances	Project control	Shared	Certain
31. Keeping records of the summary of charges as reflected by the job cost accounts	**Project control**	**None**	**Impossible**
32. Forecasting project costs for activity cost control and providing budget updates	Project control	Contractor	Certain
33. Creating and monitoring project reporting processes	Project control	Shared	Certain
34. Collecting cost data and reporting on the established metrics	Project control	Shared	Certain

Table 6.13. Results of the FPRC approach (continued)

Task description	Work process	FPRC output	Consensus degree
35. Finalizing the front-end engineering design (FEED)	**Engineering**	**None**	**Impossible**
36. Conducting design reviews	Engineering	Shared	Certain
37. Preparing the design requirements standards	**Engineering**	**None**	**Impossible**
38. Liaison with design	Engineering	Owner	Certain
39. Evaluating and making recommendations on submitted bid packages	Procurement	Contractor	Certain
40. Developing and maintaining a process for contracting work, equipment, materials, and services	Procurement	Contractor	Certain
41. Preparing construction method statements and alternatives	Construction	Contractor	Certain
42. Inspecting and testing the construction work in accordance with the requirements and the contract	Construction	Contractor	Certain
43. Arranging, coordinating, and conducting training on the equipment and system requirements	Ready for operations	Owner	Certain
44. Providing administrative support for meeting set up and coordination	Administration	Owner	Certain
45. Providing administrative support for teleconferences	Administration	Owner	Certain
46. Providing administrative support for office suppliers	Administration	Owner	Certain

The next section discusses how the Fuzzy Consensus Building Framework output was validated using three actual projects' data that applied an initial owner managing contractor (OMC) project delivery system, based on preset objectives of the JV-owner organization before implementing the FCBF.

6.4 Fuzzy Consensus Building Framework (FCBF) Model Validation

After applying the FCBF model to the 324 standard tasks and analyzing experts' aggregated opinions, 179 tasks were determined as owner's tasks, 121 were EPC contractors' tasks, and 18 were equally shared tasks, while the roles and responsibilities for 6 tasks could not be determined due to the unavailability of experts to participate in the second round of the consensus reaching process, as discussed in the previous subsection. These 6 tasks have been excluded from the analysis section of the model validation.

To test the validity of the FCBF model in providing an output that satisfies the JV-owner organization's determined requirements in an OMC project delivery system, the output responsibility results of the model were compared, on a work process basis, to the actual responsibilities for relevant tasks in three oil and gas construction projects, of sizes ranging from 30 million to over a billion dollars.

Project A was an oil refinery plant that followed a pure OMC project delivery system that satisfied the initial requirements of the JV in most of its work processes, and therefore was the most relevant to validate the FCBF model. This project was the largest in size—over a billion dollars—amongst the three projects. In this project, the JV-owner organization acted as the owner managing contractor (OMC) of the project, engaging an engineering and procurement (EP) contractor for detailed design and procurement, while a group of EPC contractors handled most of the project's construction works (e.g., mechanical installations, electrical works, piling, insulation, etc.).

Project B, an extension construction project to a group of existing oil wells sizing 30 million dollars, initially used an EPCM project delivery system, which changed during the construction phase to an OMC project delivery system. The owner initially used an EPCM contractor to handle the various project phases, and then the owner took over the CM function later on during the project. Some administration and project control issues took place in this project due to major inconsistencies in handling the project throughout its phases.

Project C, a waste control and reduction plant sizing 45 million dollars, implemented a hybrid project delivery system (OMC and partnering), where the owner organization formed an integrated team with its EPC contractors. This hybrid project delivery system was implemented in an effort to help strengthen the project teams in areas where the EPC contractors were weak, yet this project followed the initial requirements of the JV-owner organization the least, amongst the three projects.

The objective of comparing the output responsibility results of the FCBF model to the actual responsibilities for relevant tasks in the three projects was to determine whether the model's recommendations, which were based on the collective decision of the project teams, were aligned with the JV-determined requirements in each of the three actual OMC projects. This comparison also provided the JV with insights as to whether its various projects' teams were aligned on their roles and responsibilities in the individual projects. For each work process in each project, the degree of matching of the output responsibilities of the FCBF model to the actual responsibilities in the project was calculated as a percentage by dividing the number of tasks with matching (similar) responsibilities by the total number of tasks in this work process. The calculation of the degree of matching aimed for checking the content validity of the FCBF model, which is a non-statistical approach that focuses on determining if the content of a study fairly represents reality (Lucko and Rojas 2010).

First, the project managers of the three projects were asked via questionnaire to indicate whether each of the 318 tasks (after excluding 6 tasks with conflicting responsibilities from the 324) on their individual projects was the responsibility of the owner, the EPC contractors, or if it was equally shared; the output responsibility results of the FCBF model to those of the actual OMC projects were compared on a work process basis. This step determined whether project teams in each OMC project were aligned on the JV-determined requirements of the projects for each work process. In addition, to determine whether the recommendations of the FCBF model contribute to the success of each work process of the three OMC projects if followed, subjective assessments were solicited from the project managers via questionnaire (Appendix H) regarding their individual level of satisfaction for each work process in terms of its success in achieving the JV's desired objectives of the OMC project delivery system. A scale from 1 to 7, ranging from "extremely unsatisfactory" to "extremely satisfactory," was used to collect the level of satisfaction of the individual project managers for each work process on their individual projects, which aimed at checking the face validity of the FCBF model. Face validity is "a subjective judgment of non-statistical nature that seeks the opinion of non-researchers (e.g., industry practitioners) regarding the validity of a particular study" (Lucko and Rojas 2010).

For each work process that had a level of satisfaction lower than "average" and a degree of matching less than 65% (this cut-off percentage was decided by the JV's key managers), the project managers were asked, individually, to subjectively determine if the misalignment of the project teams (a degree of matching less than 65%) had an impact on the level of satisfaction of that work process in their relative projects. The project managers were asked to make their assessments on a scale from 1 to 5. A rating of 1 meant that misalignment had a "very low impact" on the level of satisfaction of a work process. A rating of 5 represented a “very high impact,” meaning that the low level of satisfaction for a work process was due to possible conflicts or gaps in responsibility assignments of its tasks because of misalignment of project teams. Tables 6.14, 6.15, and 6.16 illustrate the degree of matching and the level of satisfaction on a work process basis in Projects A, B, and C, respectively.

For Project A, five processes—regulation compliance, procurement, construction management, contracting, and operations and maintenance—showed a high degree of matching (85% to 100%) and had “satisfactory” or “very satisfactory” levels of satisfaction. Five processes—initiation, project management, financial controls, engineering, and ready for operations—showed an average degree of matching (65% to 75%). Most of these work processes had a “satisfactory” level of satisfaction, except for project management and initiation work processes, which had “average” and “very satisfactory” levels of satisfaction, respectively. The project manager of Project A indicated that no or minor responsibility conflicts took place between the project teams in the execution of all of these work processes. He also mentioned that these work processes were aligned with the JV-determined requirements of the OMC project delivery system, except for the project management work process, which had considerable conflicts and gaps in responsibilities of the PM teams and suffered from the unavailability of skilled resources.

Table 6.14. Comparison of the FCBF model's output responsibilities to those of Project A

(a) Process	(b) # of Tasks	(c) Matching %	(d) Satisfaction
Operation and maintenance	3	100%	Very satisfactory
Regulation compliance	9	90%	Satisfactory
Procurement	16	95%	Very satisfactory
Contracting	9	90%	Very satisfactory
Construction management	18	85%	Satisfactory
Initiation	28	70%	Very satisfactory
Financial controls	11	75%	Satisfactory
Engineering	25	75%	Satisfactory
Ready for operations	24	75%	Satisfactory
Project management	58	65%	Average
Quality	20	60%	Average
Change management	8	60%	Average
Organization	4	50%	Unsatisfactory
Project controls	45	45%	Unsatisfactory
Safety management	23	35%	Average
Document management	9	20%	Average
Information systems	4	25%	Average
Administration	4	0%	Satisfactory

Table 6.15. Comparison of the FCBF model's output responsibilities to those of Project B

(a) Process	(b) # of Tasks	(c) Matching %	(d) Satisfaction
Operation and maintenance	3	100%	Satisfactory
Regulation compliance	9	100%	Very satisfactory
Contracting	9	90%	Very satisfactory
Engineering	25	85%	Satisfactory
Project management	58	80%	Satisfactory
Change management	8	75%	Satisfactory
Information systems	4	75%	Satisfactory
Procurement	16	70%	Satisfactory
Initiation	28	70%	Satisfactory
Construction management	18	65%	Average
Financial controls	11	90%	Average
Organization	4	75%	Average
Ready for operations	24	65%	Average
Quality	20	55%	Average
Safety management	23	50%	Average
Document management	9	35%	Average
Project controls	45	55%	Unsatisfactory
Administration	4	0%	Unsatisfactory

Table 6.16. Comparison of the FCBF model's output responsibilities to those of Project C

(a) Process	(b) # of Tasks	(c) Matching %	(d) Satisfaction
Operation and maintenance	3	100%	Satisfactory
Administration	4	100%	Satisfactory
Initiation	28	90%	Very satisfactory
Financial controls	11	80%	Satisfactory
Regulation compliance	9	80%	Satisfactory
Document management	9	75%	Average
Ready for operations	24	60%	Average
Engineering	25	55%	Average
Procurement	16	50%	Average
Construction management	18	30%	Average
Contracting	9	25%	Average
Project controls	45	20%	Unsatisfactory
Project management	58	15%	Unsatisfactory
Quality	20	10%	Average
Safety management	23	5%	Average
Change management	8	0%	Unsatisfactory
Information systems	4	0%	Unsatisfactory
Organization	4	0%	Average

Three processes—information system, document management, and safety management—showed low degrees of matching, at 25%, 20%, and 35%, respectively, all rated as "average" in terms of level of satisfaction. The project manager indicated that no specific requirements were discussed by the JV prior to the execution stage of the OMC project regarding these three processes, which could have been a potential cause of misalignment (i.e., low degree of matching). However, there were different EPC contracts in the project with different requirements for these specific processes that were met to an “average” level of satisfaction.

In the same project, project controls and organization work processes had “unsatisfactory” levels of satisfaction and below average (45% and 50%) degrees of matching, respectively. The project manager stated the misalignment of project teams had a “very high impact” on these processes because of the gaps in responsibilities that were found between the owner and its EPC contractors during the project execution phase. The administration work process demonstrated the lowest degree of matching amongst the 18 process (0%), yet it was rated as “satisfactory” in terms of its level of satisfaction. When asked about this discrepancy, the project manager clarified that the tasks included in this process were all related to providing administrative support for meetings, teleconferencing, and office supplies, which the project manager decided to share with the EPC contractors, as opposed to keeping it as a sole responsibility of the owner. The latter was the decision that entailed the maximum consensus by the project teams in the consensus reaching process, based on the requirements of the OMC project delivery system (Table 6.13). The reason for this divergence was a decision made by the project manager during the project execution phase to cut down the project budget by sharing these tasks with the EPC contractors.

As for Project B, seven work processes—operations and maintenance, regulation compliance, contracting, engineering, project management, change management, and information system—showed a high degree of matching (75% to 100%) and had “satisfactory” or “very satisfactory” levels of satisfaction. Two processes—procurement and initiation—showed an average degree of matching of 70% and had a “satisfactory” level of satisfaction. Although financial controls and organization work processes showed relatively high degree of matching (90% and 75%, respectively), they only had an “average” level of satisfaction. The project manager of Project B clarified that there were minimal conflicts between the project teams on these two processes, which had “low impact” on their level of satisfaction. This fact proved that the responsibility outputs of the FCBF model were valid (the degree of matching was 95 and 75% for these two processes). However, the project manager stated that late application of the OMC project delivery system in Project B impacted the overall satisfaction level of these two processes, which resulted in project cost overrun and project financing problems. The rest of the work processes of Project B, such as project controls, administration, and document management, suffered from conflicts in responsibilities between the project teams, and their satisfaction levels were either “unsatisfactory” or “average.” The responsibility outputs of the FCBF model compared to those in Project B confirmed this fact, as for most of these processes, the degree of alignment ranged from 0% to 65%.

Project C was the project that least matched the responsibility outputs of the FCBF model, because this project did not perfectly follow an OMC project delivery system that the FCBF model was originally intended to align the project teams on. The actual responsibilities for most of the tasks executed in this project in at least 10 work processes were “equally shared,” such as project controls, engineering, and project management, due to the partnering agreement signed between the EPC contractors and the JV-owner organization, which did not match the responsibility outputs of the FCBF model. Note that only 18 tasks out of the 318 were determined as “equally shared” by the FCBF model, while in Project C had 179 tasks that were “equally shared.” For example, the degree of matching for the work processes, change management, information systems, organization, project management, and project controls ranged from 0% to 20%. In Project C, actual responsibilities for the tasks in only five work processes—operation and maintenance, administration, initiation, financial controls, and regulation compliance—had a high degree of matching that ranged from 80% to 100%, and their levels of satisfaction were either “satisfactory” or “very satisfactory.” Those tasks were not shared with the EPC contractors, and they followed similar responsibility outputs to those of the FCBF model.

In general, the above analysis indicates that most of the work processes that showed a considerably high degree of matching (75% or more) of the output responsibilities of the FCBF model to the actual responsibilities were satisfactory or very satisfactory in terms of satisfying the JV-owner organization's determined requirements in an OMC project delivery system. This result indicated that the model's recommendations, which were based on the collective decision of the project teams, were aligned with the JV-determined requirements of the OMC projects. The analysis also indicated that the processes that did not follow the recommendations of the FCBF model, such as project controls, did not satisfy the JV-determined requirements of the OMC project. Thus, the FCBF model's recommendations are valid. The FCBF model also provided the JV with insights on whether its project teams were aligned on their roles and responsibilities in an OMC project, and showed the impact of not aligning the project teams in the form of a low level of satisfaction of work processes.

The FCBF provides the JV-owner organization with a structured approach that helps in determining the extent of its roles and responsibilities in the new OMC project delivery system. It can also help the JV-owner organization in aligning its different project teams on the extent of their roles and responsibilities by involving them in the decision-making process, and by resolving potential conflicts that may arise between project teams in a consensus reaching process.

6.5 Conclusion

The Fuzzy Consensus Building Framework (FCBF) was demonstrated using a case study in this chapter to show how the different components of the FCBF can be implemented using actual data, and to validate the model proposed by the FCBF. The background of the case study was presented, which involved a group of project owner organizations who formed a Joint-Venture owner organization that applied a new project delivery system, known as owner managing contractor (OMC), to gain more control over its projects.

The FCBF was implemented by the JV-owner organization and its EPC contractors as a tool for early alignment of their different project teams on the extent of their new roles and responsibilities in the OMC project delivery system, by building consensus and resolving conflicts between the teams using a consensus-reaching process. The implementation stage of the different components of the FCBF was explained in detail, and the analysis of implementation results and model validation were demonstrated.

For validation purposes, the output roles and responsibilities of the FCBF model were compared, on a work-process basis, to project teams' responsibilities in three actual projects, in which the JV-owner organization implemented an initial OMC project delivery system based on predetermined objectives set by the JV. The output roles and responsibilities of the FCBF model matched those of the OMC projects for most of their work processes (content validity). The validation analysis also indicated that the processes that did not follow the recommendations of the FCBF model did not satisfy the JV-determined requirements of the OMC project (face validity).

In conclusion, the FCBF provides a structure and guidelines towards successful roles and responsibilities task assignment, according to the requirements of the OMC project delivery system that entailed common agreement between project teams. It can be used in aligning different project teams on their roles and responsibilities, and can define and refine these roles in any given project delivery system and in any phase of the construction project.

6.6 References

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7. Chapter Seven - Summary and Future Work

This chapter provides a summary of the work conducted in this research, and summarizes the contributions. Limitations of the proposed framework and recommendations for future research are also outlined.

7.1 Summary

Construction project owners are continuously changing and adapting their approaches to handling construction projects. These approaches have evolved over time due to the complexity and capital-intensiveness of the construction projects. Increased project risks, cost overruns, and schedule delays are considered potential problems that may arise in construction projects due to high levels of competition and the push for technology advancement. This trend has prompted the introduction of innovative project delivery systems, which impacted owners' organization structures, as owners outsource various project functions in order to reduce their own risks in exceeding project costs and to minimize project delays. Outsourcing resulted in project owners having less control over their projects with the downsizing of their in-house qualified personnel.

The problem of the lost project control encourages construction project owners to pay closer attention to managing projects in-house, by selecting an innovative standard or customized project delivery system that may help regain their lost control. Due to the presence of various project teams in complex construction projects, the decision to shift from one project delivery system to another standard or owner-customized project delivery system may come at an expense, as it may cause a problem of misalignment of various project teams on their new roles and responsibilities. Eventually this difficulty of misalignment creates more need for establishing a flexible framework that can allow project teams to participate in determining the extent of their roles and responsibilities in the selected project delivery system, based on the owner's preset objectives.

The framework should help in discovering and reducing inconsistencies amongst the opinions of individual project team members by incorporating common agreement and building consensus in aggregating their opinions at an early stage of the project. This, in turn, will minimize the problem of having unnecessary duplication or gaps in the allocation of project tasks, if teams' roles and responsibilities are not clearly outlined. Such a framework has to deal with the decision-making problem in a fully supported linguistic environment in terms of knowledge elicitation and aggregation. Aggregating opinions in a linguistic environment is a fundamental objective due to the vagueness and imprecise nature of using natural language in describing different overlapping extents of the roles and responsibilities of project teams, which can neither be assessed using numerical numbers, nor aggregated using statistical-based aggregation approaches. Finally, the framework should be capable of dealing with the qualitative aspects in defining the level of expertise and knowledge of the experts in order to determine and incorporate their credibility in decision-making.

This research has established a comprehensive consensus building and aggregation framework, called the Fuzzy Consensus Building Framework (FCBF), that incorporates consensus and the quality of project teams in determining the fundamental roles and responsibilities of the project owner versus those of its contractors in a given project delivery system. The framework created in this thesis is based upon using the significant capability of fuzzy logic to support linguistic assessments made by experts in determining the different extents of their roles and responsibilities in a given project delivery system, which addresses the limitations of the commonly used statistical approaches for aggregating opinions. Fuzzy logic also deals with the problem of experts who are inconsistent on their respective domains, and provides solutions to the inability of statistical approaches to aggregate opinions in a linguistic environment or create a proper consensus measure that deals with linguistic assessments.

The framework consists of a data collection strategy and methods to collect project teams' linguistic assessments that determine the extent of their roles and responsibilities in a given project delivery system; a standalone fuzzy expert system (FES) to incorporate the quality of project teams' members in the decision-making process; a modified similarity aggregation method (SAM) to aggregate project teams' linguistic assessment and ensure that the aggregated opinion is a result of their common agreement; and a fuzzy preference relations consensus (FPRC) approach that deals with linguistic assessments to resolve residual conflicts between project teams on their perceived shared responsibilities by building consensus and measuring their level of agreement on their aggregated opinion.

The first component of the FCBF is the data collection strategy and methods, in which an integrated standardized template of project management (PM) and construction management (CM) tasks was developed based on reviewing different project and construction management standard guidelines, and interviewing industry peers to document the fundamental generic CM and PM tasks that are incorporated in different standard project delivery systems of construction projects. This template provides project owner organizations and their contractors with guidelines that enable their project teams to classify and determine the extent of their roles and responsibilities in a given project delivery system, based on predefined competencies determined by project owner. Also, in the data collection strategy, a fuzzy linguistic scale that determines the appropriate linguistic terms defining different extents of the roles and responsibilities of the owner versus those of its contractors was created. The method used to create the fuzzy linguistic rating scale was the three-step Delphi approach, which involved experts of the construction industry in deciding on the appropriate linguistic terms that can be used to define different extents of the roles and responsibilities of their project teams in any construction project. The three-step Delphi approach is conducted in a consensus reaching process to help project teams develop common understanding and reach agreement on the extent of overlap between the meanings of the linguistic terms of the scale, which is an important step in project teams' alignment. The third component of the data collection strategy involves the preparation of a questionnaire using a web-based tool to enable the collection of the linguistic assessments of project teams on every task in the standard template, using the fuzzy linguistic rating scale. The data collection strategy is the first step of the FCBF that involves different project teams in the decision-making process to determine the extent of their roles and responsibilities, which satisfies the objectives of the participating organization in the selected project delivery system, based on their common agreement.

The second component of the FCBF is a standalone fuzzy expert system (FES), which was developed, using FuzzyTECH®, to incorporate the quality of experts in the decision-making process. FES determines an output importance weight factor for each expert, based on his or her specific attributes: years of experience, diversity of experience, role in the company, years in role, and enthusiasm and willingness. Two hundred forty-three (3^5) fuzzy IF-Then rules were implemented in FES, based on determining the influence of the input variables (experts' attributes) on the output variable and by considering all available combinations of the linguistic terms comprising the five input variables. The results of the FES were illustrated, based on actual data collected for the purpose of validation, and sensitivity analysis was conducted to select the best fuzzy expert system configuration. The fuzzy expert system provides an improvement over previous consensus-based aggregation approaches, which assumed subjective importance weights of experts. FES incorporates the quality of each expert, using his or her relative attributes, in the decision-making process, and captures experts' knowledge and makes it available to non-knowledgeable individuals.

The third component of the FCBF is the modified similarity aggregation method (SAM), which is applied to aggregate project teams' opinions on the party responsible for every standard task, previously classified in the standard template of project and construction management tasks. The modified SAM uses a flexible aggregation algorithm to aggregate project teams' linguistic assessments of the different parties' roles and responsibilities, based on the similarities between their different opinions. The modified SAM ensures that the aggregated opinion is based on common agreement between the project teams. It also incorporates the importance weight factor of experts in the aggregation equation, which is computed using the standalone fuzzy expert system (FES). The project teams use the fuzzy linguistic rating scale to determine the extent of the roles and responsibilities of the owner versus that of its contractors on a task-by-task basis. Then, the modified SAM aggregates project teams' linguistic assessments, and each task is classified under one of three responsibility task lists: the owner's, contractors', or shared responsibility task list. The modified SAM addressed the limitations of a previous fuzzy similarity aggregation method by modifying it to be applied in a linguistic framework. It provides construction project owners and project contractor teams with a tool for early alignment of their project teams on the extent of their roles and responsibilities in any project delivery system, as it ensures that the aggregated opinion of project teams is a result of their common agreement.

There are also other some advantages of applying the modified SAM, as an efficient step in project teams' alignment: (1) it can be applied to determine the roles and responsibilities of project teams for a large number of tasks, using one survey round only; (2) it enables involving unlimited number of experts in the decision making process; and (3) it incorporates different extents of responsibilities of project teams in the decision making process. Notwithstanding the above advantages, although the modified SAM can identify the tasks that may involve responsibility conflicts between experts (i.e., shared tasks), it can not be used to resolve these conflicts in a consensus reaching process. This is the main reason why FPRC approach is used as a final step of project teams' alignment in the Fuzzy Consensus Building Framework (FCBF).

The last component of the FCBF is the fuzzy preference relations consensus (FPRC) approach, which complements the modified SAM to align project teams on their roles and responsibilities. The FPRC approach confirms shared tasks, or else resolves residual conflicts between experts on shared responsibilities by ensuring that the required level of consensus is reached between experts. The FPRC approach allows for the vagueness and imprecision that are inherent in the problem of resolving responsibility conflicts, as it measures the linguistic consensus degree that exists among project teams' opinions using a linguistic consensus measure. It allows project teams to compare their linguistic information on pairs of responsibility alternatives, which is an efficient and practical approach in resolving conflicts between experts' opinions on a set of alternatives. The FPRC approach also takes into account the quality of experts' opinions in calculating their level of consensus by incorporating the importance weight factor for each expert, based on his or her individual characteristics. This importance weight factor was determined using the standalone fuzzy expert system (FES). Although FPRC approach is successful in resolving conflicts between experts, using a consensus reaching process, it is only used in the FCBF to complement the aggregation process of the modified SAM due to the impracticability of applying FPRC approach when: (1) number of tasks is relatively large; (2)

experts involved in the consensus reaching process are too many; or (3) alternatives set is relatively large. In the previous cases, use of a consensus reaching process may not be efficient and may be very time-consuming, which motivate using the modified SAM as an initial step for project teams' alignment, which determine the tasks that may cause responsibility conflicts between experts, prior to the application of the FPRC approach.

The Fuzzy Consensus Building Framework (FCBF) was used by a JV-project owner organization in the field of oil and gas to involve its project teams in deciding on the extent of its roles and responsibilities versus that of its EPC contractors in the owner managing contractor (OMC) project delivery system. The framework was applied as a tool for early alignment of the different project teams by building consensus and resolving conflicts in the decision-making process. In order to validate the FCBF model, its output roles and responsibilities were compared to project teams' responsibilities in three actual projects in the field of oil and gas: an oil refinery plant, a waste control and reduction plant, and an extension construction project to a group of existing oil wells. In these projects, the JV-owner organization implemented an initial OMC project delivery system, based on its preset objectives. The percentage of matching responsibilities was calculated for relevant tasks in each work process of the actual projects, which demonstrated the content validity of the FCBF model. In addition, face validation was conducted with project managers of the oil and gas projects using the data collected from their relative projects to validate the findings from this study. Analysis of the validation results was carried out, and the project managers noted their acceptance with the findings and noted the advantage of using the proposed FCBF to align project teams on their roles and responsibilities in the owner managing contractor (OMC) project delivery system.

7.2 Contributions

This thesis extends the fuzzy set application in the construction domain by providing a Fuzzy Consensus Building Framework (FCBF) that incorporates several fuzzy logic techniques (the modified similarity aggregation method (SAM), the fuzzy preference relations consensus (FPRC) approach, and the fuzzy expert system (FES)) to solve a construction industry problem: alignment of project teams in determining the extent of the roles and responsibilities of project owners versus that of its contractors in any project delivery system. This research is practical and unique in that it integrates fuzzy consensus approaches in a comprehensive framework to establish a roles and responsibilities structure of project teams in any project delivery system—a framework that has not been previously attempted. The FCBF creates a more powerful modeling tool capable of aligning project teams and reducing conflicts in the assignment of the responsibility of tasks between the owner and its contractors as early as the project initiation phase. Thus, the project teams can concentrate on the work to be done, rather than dealing with responsibility conflicts during project execution. The FCBF introduces a model that is relevant to researchers, and makes various academic contributions and industrial contributions to the construction industry. Described below the key academic contributions offered by this research:

- The FCBF improves on previous fuzzy consensus approaches by incorporating fuzzy logic to aggregate experts' opinions in the decision-making process in order to overcome the limitations of the commonly used statistical approaches for aggregating opinions.
- The FCBF modifies the similarity aggregation method (SAM), an aggregation algorithm previously used to aggregate opinions about fuzzy numerical assessments, by adapting it to aggregate experts' linguistic assessments instead.
- The FCBF incorporates the concept of fuzzy preference relations in the decision-making process; it modifies a previous fuzzy preference aggregation approach by incorporating a method for creating membership functions and implementing a modifier that weights the quality of experts and their consensus preference relations in measuring their consensus level.
- The FCBF incorporates the subjective quality aspects of experts in decision-making using a fuzzy expert system, which improves on previous approaches that rely on subjective assessments for experts' weights in aggregating their opinions.

- The FCBF incorporates a fuzzy consensus measure that supports consistency in decision-making by allowing experts to measure and reach an adequate level of consensus linguistically, which guides the experts on their level of consensus in every round of the consensus reaching process.

In addition to the academic contributions, the FCBF also offers several industrial contributions, which can be summarized as follows:

- The FCBF contributes to the construction industry by combining fuzzy logic, the Delphi approach, and expert systems in a comprehensive framework, which involves project teams in the decision-making process to ensure early alignment of the project teams on their proper roles and responsibilities in any project delivery system.
- The FCBF supports decision-making in a linguistic environment that allows project teams to express themselves linguistically, which naturally suits how experts make assessments or evaluations in the construction industry.
- The FCBF accounts for the subjective opinions of multiple experts in classifying project roles and responsibilities, as well as the quality of experts, to develop a valuable decision support tool for construction project owners and their contractors for determining their roles and responsibilities in any project delivery system.

- The FCBF introduces a standardized template of project and construction management tasks, which can help the owner and its contractors in determining their roles and responsibilities in a given project delivery system.
- The FCBF supports the creation of membership functions to represent the extent of the roles and responsibilities of project owners versus their contractors, using a three-step Delphi consensus approach.
- The concept of fuzzy preference relations is applied in the FCBF, which provides the owner with an additional tool that measures the degree of consensus of its experts on any perceived shared responsibilities, and thereby reduces potential conflicts between project teams.

7.3 Recommendations for Future Work

The methodology presented in this research and the findings obtained have created more interest for future research that may further develop the fuzzy logic-based consensus approaches and fuzzy expert system used in the FCBF to facilitate early alignment of project teams on specific objectives set by project owner organizations. Future work can be conducted by building upon the findings from this study, and can be summarized as follows:

- The modified horizontal approach, coupled with an interpolation technique, was used with multiple experts to elicit the membership functions for the input and output variables of the FES and to create the fuzzy preference relations scale. Only five experts and eight experts were made available by the participating owner organization to derive the membership functions of the FES and the fuzzy preference scale, respectively. The modified horizontal approach usually provides better results when larger numbers of experts are involved in the decision-making process. As a future development of the FES, more experts are required to derive the membership functions until no significant variations exist in the final shapes of the MFs. Furthermore, only linear shapes (triangular and trapezoidal) were used to derive the membership functions of the input and output variables of the FES. As a future development, other shapes can be derived using data-driven techniques, which need further investigations that may involve collection of historical data regarding the shapes of the MFs, if available, and the results can be compared.

- Five attributes that represent the quality of experts were used as independent input variables of the FES: years of experience, diversity of experience, role in the company, years in role, and enthusiasm and willingness. As a future development to this research, the assumption that the input variables were independent needs to be further investigated, which can be done using expert judgment and correlation analysis between the input variables.

Also, interaction and relative significance of the five input factors on experts' importance weight could be explored, and sensitivity analysis could be conducted to verify the results. Another future development could be to test the significance of using additional subjective input variables, such as loyalty to the company, years with the company, level of education, experience in multi-cultural environments, and ethics and professionalism on the experts' importance weight, by conducting sensitivity analysis.

- Experts' importance weights (outputs of the FES) were defuzzified as crisp values that were used in the aggregation algorithm of the modified SAM to incorporate the quality of experts in the decision-making process. The same crisp values were used to weight the experts' importance weights in determining their linguistic consensus degrees in the fuzzy preference relations consensus (FPRC) approach. A future development may consider determining a fuzzy output value of the FES, instead of its crisp output value, which can describe experts' importance weights using a linguistic label. This linguistic label can be selected from the seven linguistic labels of the fuzzy preference scale. In this case, the membership functions of the output variable of the FES would be those defined by the fuzzy preference scale, whose linguistic labels could describe the linguistic importance weights of experts. Then, these linguistic labels can be combined, in the FPRC approach, with the linguistic labels representing experts' consensus relations using an appropriate fuzzy operator to calculate the consensus degrees of experts in a fully supported linguistic environment. This advancement would incorporate more human-consistency in the decision-making process by using natural language.

- In the FPRC approach, seven linguistic labels were used to develop the fuzzy preference scale. In order to construct the membership functions of these linguistic labels, an assumption was made that the experts who were involved in the decision-making process perceived the meanings of the seven linguistic labels in the same manner. This assumption needs to be further investigated in a future work, as it is recommended that those linguistic labels are to be calibrated prior to using them in determining experts' preferences on the pairs of responsibility alternatives.
- In the FPRC approach, a fuzzy linguistic consensus measure was created using linguistic quantifiers to guide experts on their "overall" level of consensus (consensus degree) in choosing one responsibility alternative over the other in the consensus reaching process. A future development may consider computing the linguistic distance between the linguistic label selected by each individual expert and the consensus label determined by the largest number of the group of experts (i.e., the aggregated opinion of experts). The output of this process is a linguistic label, which is

determined using the fuzzy preference scale, that helps in measuring the individual consensus degree of each expert. This individual consensus degree can support the original finding of the "overall" consensus degree of the group of experts, which has been determined by the existing FPRC approach. This additional step can guide the moderator of the consensus reaching process to determine how far the opinion of each individual expert is from the collective opinion of experts using a linguistic label, e.g., *most likely*, *extremely likely*, *it may*, etc. This simple, yet interesting step helps the moderator in determining which expert(s) has the most inconsistent opinion amongst the group, which may help in identifying the reasons of conflicts between experts in order to be able to reduce conflicts in the second round of the consensus reaching process.

- Further to the consensus measure used in the existing FPRC approach, a future work is needed to develop a numerical or a linguistic consistency measure of individual experts' opinions, prior to measuring consensus between their opinions. Such consistency measure shall indicate the consistency degree of each expert (i.e., coherence in his or her judgements about the alternatives set) in the consensus reaching process. This consistency measure can be used, together with the existing consensus measure, to control the consensus reaching process, and thus reach a more rational consensus solution, i.e., less distorted consensus solutions due to inconsistencies in the experts' opinions.

- In the FCBF, a standard template of generic project and construction management tasks was developed to enable the project teams to decide on the extent of their roles and responsibilities using appropriate linguistic terms. The template was limited only to 324 generic PM and CM tasks. A future development to the FCBF may involve customizing or detailing some of its generic tasks to be used in various applications, which may provide project teams in different disciplines of the construction project with relevant tasks to decide on the extent of their roles and responsibilities relative to their discipline. For example, project teams can use a detailed set of customized tasks to determine their relative departmental responsibilities using FCBF.
- A future development that may help enhancing the robustness of the FCBF is to implement some or all of its various steps using an automated tool that may facilitate applying those steps in a more efficient manner.
- The fuzzy preference relations consensus (FPRC) approach introduced three responsibility alternatives (owner’s responsibility, contractors’ responsibility, and shared responsibility) to experts to reassess their roles and responsibilities for perceived shared tasks. A future development of the FPRC approach is to increase the

number of responsibility alternatives to seven, which define different extents of the roles and responsibilities of project teams, similar to those used in the modified SAM, to better classify shared tasks.

- The FCBF was initially tested and validated by comparing its output results, in terms of proposed roles and responsibilities of project teams in the OMC project delivery systems, to those of three actual OMC projects in the field of oil and gas. This comparison is considered an initial step in validating the FCBF, which needs a more comprehensive approach in order to fully validate its model components. In general, in order to generalize the applicability of the FCBF, more cases should be used, while the outputs of the FCBF model should be implemented in an actual project to observe how the recommended roles and responsibilities (i.e., output of the FCBF model) may contribute to the success of an actual OMC project instead of conducting "after the fact" comparisons. Also, the FCBF model should be tested out for different project delivery systems, and for applications determining departmental responsibilities. The following steps are recommended to be applied in a future research work to incorporate a more comprehensive validation strategy of the FCBF:

1- Establish owner's value interests prior to using the FCBF to align project teams on their roles and responsibilities, e.g., maximize control function, minimize project interfaces, etc.

2- Communicate those value interests to the project teams and ensure that they fully understand the meanings and the implications of these value interests on project goals, and the roles and responsibilities of the owner organization versus those of its contractors.

3- Apply the FCBF to ensure early alignment of the project teams on the extent of their roles and responsibilities, based on the value interests set by the owner organization.

4- Incorporate the alignment results of the FCBF in actual project(s) and ensure that allocation of the project teams' roles and responsibilities is based on the recommendations of the FCBF model.

5- Measure the project manager(s) levels of satisfaction, after the completion of each phase of the project(s), in terms of satisfying every value interest and every goal set by the project owner organization, and record any case of responsibility conflicts in each work process of the project.

6- Analyze the results in terms of the level of satisfaction and occurrence of responsibility conflicts or gaps in each work process and during every phase of the project.

7- Repeat the above steps in different projects and in different project delivery systems in order to ensure the applicability of the FCBF in satisfying the needs of different owners' and contractors' organizations.

APPENDIX A

LISTS OF STANDARD TASKS

Table A.1. Project Initiation task list

Task Description
1. Establishing a project’s required goals
2. Developing the business case summary and analyzing the business needs
3. Receiving and evaluating problems and opportunities from stakeholders
4. Conducting the Project Life Cycle Value Analysis (LCVA)
5. Determining the strategic objectives of the project
6. Establishing project's critical success factors / performance criteria
7. Coordinating and integrating data required to develop options and recommend a project strategy
8. Conducting project's initiation benchmarking
9. Establishing the finalized project charter
10. Providing the context for detailed decisions by project management, such as whether the project is schedule or cost driven
11. Determining the project’s key milestones
12. Determining the project’s program of works
13. Determining the project’s policies and guidelines
14. Describing the scope and standards and setting the design criteria
15. Providing the initial organization structure and project framework
16. Developing Stakeholder / NGO Plan
17. Preparing the Design Basis Memorandum(DBM)
18. Determining the project execution strategy
19. Preparing the project’s preliminary work breakdown structure
20. Deciding on the full project sanctioning
21. Obtaining regulatory approvals
22. Setting the operational philosophy
23. Creating conceptual drawings
24. Finalizing the feasibility analysis study of the project
25. Performing project's financial and investment risk assessment
26. Conducting stage gate reviews
27. Conducting preliminary feasibility studies
28. Providing benchmarking data and comparable projects' costs

Table A.2. Project Organization task list

Task Description
1. Conducting team-building exercises
2. Preparing the project organization chart as a part of the execution plan
3. Making project staff reassignments
4. Supporting team members on methods and implications
5. Approving the project organization chart prior to execution

Table A.3. Project Management task list

Task Description
1. Preparing the project’s detailed work breakdown structure
2. Approving detailed scope statements of work for all contractors
3. Preparing the Preliminary Project Execution Plan (PEP)
4. Implementing a value improvement practice (VIP) for process design improvement
5. Conducting coordination meetings with project planners and estimators
6. Incorporating start/finish milestone dates in a project's integrated schedule
7. Determining the overall project’s duration
8. Setting up a monitoring team to watch over the schedule performance
9. Applying liquidated damages or incentives based on contract performance
10. Submitting the overall schedule status reports to key stakeholders
11. Identifying, analyzing, mitigating, and controlling project risks
12. Adopting an active risk-management approach that includes the assignment of mitigation responsibilities to the appropriate project participants
13. Developing risk mitigation plans and updating them as the project progresses and following through with mitigation actions until risks are acceptable
14. Communicating project progress to key stakeholders and introducing changes to the project risk management plan
15. Participating in suppliers negotiations and providing approvals thereof
16. Networking, coordinating, and collaborating with project team members and support teams (e.g., specialist estimators, site operations, and design engineers)
17. Developing an effective and efficient project teams
18. Developing open communications and trust
19. Establishing clear accountabilities
20. Identifying and resolving gaps, overlaps, and duplications in roles, responsibilities, positions, and eliminating the dysfunctional elements from the team
21. Accepting key personnel of the project parties and advising on non-accepted personnel
22. Initiating the development of the project execution plan and monitoring its implementation
23. Establishing project organization and accountabilities
24. Interpreting and communicating the project goals to team members
25. Communicating the project monitoring and control system
26. Assembling project teams’ representatives
27. Monitoring and approving the scope, conceptual design, and risk analysis
28. Approving and monitoring the project reporting processes
29. Making sure that project’s critical result areas are met
30. Recruiting operating or ready for operations organization
31. Monitoring adherence to safety plans and receiving periodical reports on performance
32. Setting initial partnering strategy, if any
33. Establishing legally and financially tenable alliances
34. Managing alliances
35. Acquiring available skills and knowledge from all involved partners

Table A.3. Project Management task list (continued)

Task Description
36. Establishing decision-making authority levels and sources
37. Establishing communication systems with partners
38. Setting alliance performance measurement and reward systems
39. Developing communication networks with the industry peers
40. Reporting activities and status to senior management
41. Identifying critical interfaces and critical issues
42. Preparing an interface management plan
43. Assigning roles and responsibilities to address interface issues
44. Providing an interface management enabling tool
45. Delivering best in class project execution
46. Providing preliminary cost estimation and scheduling
47. Providing input into the preparation of the preliminary project execution plan
48. Advising on the contracting strategy, and subcontractors
49. Infusing new advances into the business planning process
50. Developing the own-works execution plan and providing continuous updates to the plan
51. Preparing reports and holding progress meetings with key stakeholders
52. Submitting the overall schedule status reports
53. Administering team-building exercises to develop open communications and trust
54. Developing the project execution plan and monitoring its implementation
55. Managing assigned resources to achieve the project objectives
56. Assembling contractors’ project team
57. Ensuring the contractor team has access to resources, tools, and equipment
58. Reporting the project status to relevant stakeholders

Table A.4. Safety Management task list

Task Description
1. Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL)
2. Administering the development and maintenance of a safety programs that meets legal, regulatory, corporate, and local requirements
3. Holding preliminary sessions for identifying project hazards
4. Communicating safety risks to project stakeholders
5. Communicating safety expectations to project participants
6. Establishing a safety reporting and investigation system
7. Administering training in health and safety
8. Receiving and commenting on individual subcontractors' safety plans
9. Having the highest regard for safety, emergency procedures, and loss management
10. Updating the emergency response plan and testing its efficiency
11. Developing and maintaining project safety program
12. Monitoring adherence to the safety plan and reporting subcontractors’ compliance results
13. Reducing hazards during the project to the lowest acceptable levels

Table A.4. Safety Management task list (continued)

Task Description
14. Communicating safety risks to subcontractors
15. Managing the safety reporting and investigation system during project execution
16. Conducting training in health and safety
17. Providing support to interpret legislative and regulatory requirements
18. Assisting the subcontractors in safe work practices
19. Performing the work in a manner which will cause minimum inconvenience, injury, and damage to others
20. Protecting the work site, the owner’s property, and the property of third parties
21. Complying with all safety requirements specified in the contract
22. Keeping all working and storage areas clean, orderly, and secure
23. Monitoring and coordinating safety, environment, and labor relations requirements

Table A.5. Regulation Compliance task list

Task Description
1. Conducting regulatory reviews
2. Defining external permitting strategy (which, how and when)
3. Identifying the regulatory agencies
4. Establishing and maintaining communication links with regulators and facilities
5. Acquiring and maintaining knowledge of the environmental requirements
6. Coordinating and conducting environmental assessments
7. Applying for environmental permits
8. Preparing the environmental management plan of the project
9. Monitoring the environmental management plan of the project

Table A.6. Quality Management task list

Task Description
1. Participating in the preparation of design from the preliminary release to the final release
2. Conducting independent project review
3. Maintaining past contractors and suppliers experience system
4. Reviewing work processes to ensure best practices are being used
5. Ensuring integration of all processes to avoid duplication and gaps
6. Defining the quality requirements as clearly as possible at the project outset
7. Determining the project’s quality standards and testing requirements
8. Setting up performance guarantees (required tests, audits, frequency of inspections, types, and methods of inspections)
9. Recommending remedial works for defects
10. Conducting comprehensive quality audits
11. Preparing the inspection and testing plans
12. Collecting, analyzing, and recording lessons learned in each project phase

Table A.6. Quality Management task list (continued)

Task Description
13. Developing and maintaining a process to transfer lessons learned information to future projects
14. Integrating maintenance and operability with the lessons learned process
15. Receiving inspection requests from the subcontractors and handling testing
16. Inspecting and approving all installations of subcontractors
17. Identifying deficiencies and ensuring remedies are in place
18. Following the quality requirements as set by the owner
19. Inspecting and testing the construction work in accordance with the requirements of the construction contract
20. Documenting the lessons learned

Table A.7. Document Management task list

Task Description
1. Maintaining vendor document control system
2. Maintaining a document control facility
3. Developing and managing a system to collect the project data
4. Managing the information in databases and retrieval systems
5. Archiving project close-out documentation and communicating lessons learned
6. Developing and maintaining a process to transfer operations and maintenance knowledge throughout the projects
7. Coordinating data flow and documents between project components and parties
8. Incorporating maintenance and operability into standards where appropriate
9. Preparing and submitting the operation and maintenance manuals prior to testing

Table A.8. Financial Controls task list

Task Description
1. Approving project funding
2. Providing timely payment to the contractors based on the work done
3. Providing the payment of invoices for procured goods
4. Setting the financial plans
5. Finalizing the Authorization for Expenditures (AFE)
6. Preparing the asset management plan
7. Setting the financial audit methodology
8. Reporting to financial systems
9. Recording payables and receivables
10. Monitoring and updating integrated project cash position
11. Reporting to the financial systems of the owner

Table A.9. Project Controls task list

Task Description
1. Developing the execution schedule and providing continuous updates
2. Integrating the execution schedule with the cost estimating and control functions
3. Identifying scheduling alternatives and improvements
4. Revising the contractors' time schedules and recommending changes
5. Linking both the engineering and procurement tasks to the construction time schedule and determining appropriate lead and lag times
6. Determining the schedule-driven activities to ensure the work will be performed in a coordinated manner
7. Selecting the most appropriate planning and monitoring tools to the project
8. Incorporating various contracts' works in one integrated time schedule and determining who works when
9. Producing the overall schedule status reports
10. Recommending mitigating methods for schedule variances
11. Conducting full progress monitoring of the project activities
12. Providing cost and schedule estimated contingencies
13. Tracking and monitoring of the risks and risk allowance/contingency
14. Reporting the outcome from risk management planning to the project execution plan- e.g. adding a contingency budget or time to the plan
15. Determining estimate basis for facility components
16. Determining historical cost basis for facility components
17. Converting estimate basis to costs
18. Comparing the estimate of individual items with the previous costs of similar items
19. Reviewing estimates with the project team
20. Preparing detailed estimates for cost and schedule
21. Preparing forecasts and costs to completion estimates based on current project status
22. Preparing cost break down structures and chart of accounts
23. Preparing integrated project cash flow
24. Developing a system to forecast overall project costs at completion
25. Recommending mitigating methods for cost variances
26. Monitoring project's individual cost items
27. Keeping records of the summary of charges as reflected by the job cost accounts, including expenditures and estimated costs
28. Comparing the planned budget to the actual budget based on the overall planned versus actual expenditures of the combined contracts
29. Forecasting for activity cost control and providing budget updates
30. Relating Cost and Schedule Information and producing an earned value analysis
31. Creating and monitoring project reporting processes
32. Managing the network of benchmark partners
33. Assessing and implementing the best monitoring practices
34. Monitoring internal performance against the established standards
35. Collecting data and reporting on the established metrics
36. Collecting data and involving all project participants in schedule preparation

Table A.9. Project Controls task list (continued)

Task Description
37. Integrating cost estimating and control and providing necessary input
38. Communicating scheduling conflicts with the contractors' systems
39. Implementing alternatives and improvements in the schedule
40. Scheduling, work monitoring, and reporting on the progress of the work relative to the project's milestones
41. Maintaining project planning and monitoring tools
42. Producing the overall schedule status reports
43. Progress monitoring of the project activities
44. Gathering all the required detailed information for estimating
45. Preparing the detailed estimates
46. Preparing the forecasts and costs to completion estimates
47. Supporting project teams on cost and risk direction
48. Producing regular status reports on costs, scope, and risk

Table A.10. Engineering task list

Task Description
1. Defining the Front-End Engineering Design (FEED)
2. Finalizing the Front-End Engineering Design (FEED)
3. Participating in performing calculations and detailed design
4. Participating in producing drawings, material lists, and specifications
5. Issuing construction and fabrication work packages
6. Providing technical coordination with suppliers
7. Conducting design reviews
8. Preparing a detailed quantity take off of the project's items
9. Incorporating maintenance and operability into standards where appropriate
10. Administering the constructability process
11. Negotiating constructability plans with contractors
12. Providing constructability input to the lessons learned
13. Liaison with design
14. Preparing design from the preliminary release to final release
15. Preparing the design requirements standards
16. Converting and implementing new technologies
17. Performing calculations and detailed design
18. Producing drawings, material lists, and specifications
19. Adhering to standards, codes, laws, and corporate practices
20. Providing technical coordination with the suppliers
21. preparing the final installation details
22. Performing coordination works and design reviews
23. Providing the owner with the as-built drawings upon completion of the works
24. Establishing a constructability plan
25. Evaluating constructability information with the owner
26. Incorporating the proposed improvements into the project plan

Table A.11. Procurement task list

Task Description
1. Evaluating and making recommendations on submitted bid packages
2. Developing and maintaining a process for contracting work, resources, and services
3. Issuing material purchase orders (POs)
4. Providing expediting service
5. Providing instructions and guidelines that identify the levels of review and approvals required by the owner in relation to the procured goods
6. Determining the procurement strategies and owner’s specified materials
7. Inspecting partially or fully the delivered materials to site
8. Preparing transportation and logistics plan for supply
9. Liaison with equipment and material suppliers
10. Procuring long lead items and bulk equipment
11. Providing timely coordination and management of transportation
12. Assembling the required information including site investigations and inspection
13. Developing and maintaining a process for subcontracting work, equipment, materials, and services
14. Providing supply inspection services
15. Establishing and implementing purchasing standards
16. Submitting any required material samples for approval

Table A.12. Contracting task list

Task Description
1. Developing the contracting procedure
2. Developing and implementing a dispute resolution mechanism to manage claims
3. Ensuring corporate and legal requirements are met
4. Interpreting contract conditions including matters dealing with legal, financial, technical, and taxation
5. Preparing RFPs and negotiating the final contract conditions prior to award
6. Preparing the insurance plan
7. Providing copies of the insurance policies before signing the contract with the other party
8. Setting up the contract delivery method(s) (DB, D-Bid-B, CM, etc.) and format (fixed, variable, cost-plus, etc)
9. Preparing and submitting invoices for the work performed under the contract

Table A.13. Construction Management task list

Task Description
1. Preparing construction method statements and alternatives
2. Selecting and implementing the optimum construction strategy for the project
3. Coordinating the installation of equipment amongst contractors
4. Coordinating multi-trade and multi-site activities amongst contractors
5. Receiving and evaluating problems and opportunities from concerned contractors
6. Administering, supervising, managing, and monitoring the contractors
7. Inspecting and testing the construction work in accordance with the contract
8. Maintaining and keeping the as-built drawings on the work site
9. Installing all equipment and structures
10. Providing required information during construction and installation
11. Providing tools, construction equipment, and consumables
12. Maintaining site cleanup and restoration
13. Receiving, storing, and handling of material and equipment at site
14. Managing the project site
15. Coordinating multi-trade and multi-site activities amongst subcontractors
16. Receiving and evaluating problems and opportunities from subcontractors
17. Coordinating the installation of equipment
18. Coordinating subcontractors' works

Table A.14. Ready for Operation task list

Task Description
1. Providing input on operability, and maintainability processes as well as providing supplementary technical support
2. Producing and/or approving individual commissioning
3. Providing design sign-offs plans
4. Providing the final inspections and signing-off on the project installations
5. Inspecting and approving all installations
6. Developing a teamwork/ownership environment during the commissioning stage
7. Coordinating commissioning plans for the manufacturers, suppliers, and contractors
8. Collecting turnover documentation
9. Coordinating the transition from construction to operation
10. Recommending operation strategies
11. Arranging, coordinating, and ensuring training on equipment and system requirements
12. Issuing completion certificates upon taking over work for functional use
13. Coordinating start-up activities
14. Finalizing handing over and start-up systems
15. Obtaining license to operate
16. Performing spares and warranty management
17. Comparing the performance requirements with the project's performance outcome
18. Executing the commissioning plan
19. Providing proper turnover documentation

Table A.14. Ready for Operation task list (continued)

Task Description
20. Arranging, coordinating, and conducting training on the equipment and system requirements
21. Conducting performance testing based on the performance standards.
22. Obtaining the work sign-off
23. Coordinating the start-up activities within subcontractors and suppliers
24. Coordinating and working in liaison with production units

Table A.15. Operations and Maintenance task list

Task Description
1. Developing and implementing operating procedures including shutdown/start-up and emergency procedures
2. Developing and implementing maintenance and inspection programs
3. Developing and implementing turnaround plan including safe making procedure

Table A.16. Administration task list

Task Description
1. Providing administrative support for travel
2. Providing administrative support for meeting set up and coordination
3. Providing administrative support for teleconferences
4. Providing administrative support for office suppliers

Table 17. Change Management task list

Task Description
1. Managing project changes
2. Developing team responses and strategies to deal with changes
3. Providing required approvals for design changes after revising designs
4. Developing and implementing an integrated contract change control process for all contractors
5. Evaluating preliminary cost of change orders and providing necessary approvals
6. Evaluating contractor's feedback on change requests and deciding on whether the changes are to be executed or not
7. Getting the necessary approvals on design changes
8. Submitting requests for change orders and reporting to the owner

Table A.18. Information System task list

Task Description
1. Providing a mechanism for monitoring and assessing the options to upgrade existing technologies
2. Scoping, developing and providing business systems and application requirements
3. Scoping, developing and providing project IT hardware requirements
4. Providing the required support in the required areas of equipment, systems, and processes

APPENDIX B

QUESTIONNAIRE TO CONSTRUCT MEMBERSHIP FUNCTIONS AND DETERMINE INFLUENCE OF INPUTS ON OUTPUT IN FES

QUESTIONNAIRE TO CONSTRUCT MEMBERSHIP FUNCTIONS AND DETERMINE INFLUENCE OF INPUTS ON OUTPUT IN FES

INTRODUCTION

The University of Alberta, Hole School of Construction Engineering would like to ask for your help in creating a decision-making model to assist in determining a weight factor for each participant/expert filling the OMC survey. The variable is called the **Importance Weight Factor** of experts participating in rating the tasks of the owner in a managing contractor model. The determined importance weight of each expert helps in calculating the weighted average of a group of experts' ratings of a certain task, i.e., the importance weight factor of each expert will be included in the formulae. The model will account for five main factors that the company uses when evaluating its experts/employees. The following questionnaire will help us determining the importance weight of experts using the five input factors:

1- **Years of Experience** indicates the years of experience an expert has in the construction industry. This factor affects experts' understanding of the managing contractor model and awareness of its importance.
2- **Role in the Company** indicates the managerial skill level of an expert. This factor affects the judgment capability of expert with regard to the managing contractor model and ability to interpret and categorize the tasks to be rated under each work process.
3- **Years in Role** determines the years of experience of an expert in his role of his managerial position. This factor compliments the factor "position in the company" so that the rating provided by a more senior manager in his role has significance reliability.
4- **Enthusiasm/Willingness** indicates an expert's potential to contribute to the survey and determines the validity of his response.
5- **Diversity of Experience** determines the experts experience in an owner organization and in an EPC organization.

First, you will need to rank the five variables in terms of their influence on the output variable (Importance Weight Factor) on a scale of 1 to 7. Following that you will be asked to quantify certain linguistic terms that are used to describe each input variable and the output variable. For each of the three questions soliciting information on each linguistic term (e.g., Low, Average, and High) please select **MORE THAN ONE** answer for each question unless you feel that only one answer is applicable.

Thank you very much for your time and cooperation.

PART I: RANKING THE INPUT VARIABLES

Please rank the following input variables in terms of their influence on the output variable (Importance Weight Factor) on a scale of 1 to 7?

Years of Experience	1	2	3	4	5	6	7	1 = No Influence 2 = Very Low 3 = Low 4 = Medium 5 = High 6 = Very High 7 = Extremely High
Role in the Company	1	2	3	4	5	6	7	
Years in Role	1	2	3	4	5	6	7	
Enthusiasm/ Willingness	1	2	3	4	5	6	7	
Diversity of experience	1	2	3	4	5	6	7	

PART II: CONSTRUCTION OF MEMBERSHIP FUNCTIONS

INPUT VARIABLE 1: YEARS OF EXPERIENCE

How many **YEARS** of Experience would classify an expert as having **SMALL** number of years of experience in project and construction management? Please check all applicable circles.

< 1 Year ◯ **1-4** ◯ **5-8** ◯ **9-12** ◯ **13-16** ◯ **17-20** ◯ **>20** ◯

How many **YEARS** of Experience would classify an expert as having **MEDIUM** number of years of experience in project and construction management? Please check all applicable circles.

< 1 Year ◯ **1-4** ◯ **5-8** ◯ **9-12** ◯ **13-16** ◯ **17-20** ◯ **>20** ◯

How many **YEARS** of Experience would classify an expert as having **LARGE** number of years of experience in project and construction management? Please check all applicable circles.

< 1 Year ◯ **1-4** ◯ **5-8** ◯ **9-12** ◯ **13-16** ◯ **17-20** ◯ **>20** ◯

INPUT VARIABLE 2: ROLE IN THE COMPANY

Which **ROLES** in the company would be classified as **LOW** level of managerial positions? Please check all applicable circles.

Lead ◯ **Project Engineer** ◯ **Sr. Project Engineer** ◯ **Project Manager** ◯

Sr. Project Manager ◯ **Project Director** ◯ **Sr. Director/General Manager** ◯

Which **ROLES** in the company would be classified as **MEDIUM** level of managerial positions? Please check all applicable circles.

Lead ◯ **Project Engineer** ◯ **Sr. Project Engineer** ◯ **Project Manager** ◯

Sr. Project Manager ◯ **Project Director** ◯ **Sr. Director/General Manager** ◯

Which **ROLES** in the company would be classified as **HIGH** level of managerial positions? Please check all applicable circles.

Lead ◯ **Project Engineer** ◯ **Sr. Project Engineer** ◯ **Project Manager** ◯

Sr. Project Manager ◯ **Project Director** ◯ **Sr. Director/General Manager** ◯

INPUT VARIABLE 3: YEARS IN ROLE

How many **YEARS** of Experience **IN ROLE** would classify an expert as having **SMALL** number of years in role? Please check all applicable circles.

< 1 Year	**1-4**	**5-8**	**9-12**	**13-16**	**17-20**	**>20**
◯	◯	◯	◯	◯	◯	◯

How many **YEARS** of Experience **IN ROLE** would classify an expert as having **MEDIUM** number of years in role? Please check all applicable circles.

< 1 Year	**1-4**	**5-8**	**9-12**	**13-16**	**17-20**	**>20**
◯	◯	◯	◯	◯	◯	◯

How many **YEARS** of Experience **IN ROLE** would classify an expert as having **LARGE** number of years in role? Please check all applicable circles.

< 1 Year	**1-4**	**5-8**	**9-12**	**13-16**	**17-20**	**>20**
◯	◯	◯	◯	◯	◯	◯

INPUT VARIABLE 4: ENTHUSIASM AND WILLINGNESS

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having a **LOW** level of enthusiasm and willingness to complete a survey? Please check all applicable circles.

1	**2**	**3**	**4**	**5**	**6**	**7**
◯	◯	◯	◯	◯	◯	◯

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having a **MEDIUM** level of enthusiasm and willingness to complete a survey? Please check all applicable circles.

1	**2**	**3**	**4**	**5**	**6**	**7**
◯	◯	◯	◯	◯	◯	◯

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having a **HIGH** level of enthusiasm and willingness to complete a survey? Please check all applicable circles.

1	2	3	4	5	6	7
⬭	⬭	⬭	⬭	⬭	⬭	⬭

INPUT VARIABLE 5: DIVERSITY OF EXPERIENCE

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having **LOW DIVERSITY** level of experience (OWNER / EPC) to complete a survey? Please check all applicable circles.

1	2	3	4	5	6	7
⬭	⬭	⬭	⬭	⬭	⬭	⬭

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having **MEDIUM DIVERSITY** level of experience (OWNER / EPC) to complete a survey? Please check all applicable circles.

1	2	3	4	5	6	7
⬭	⬭	⬭	⬭	⬭	⬭	⬭

On a scale of 1 to 7, what are the numbers on the scale that may rank the expert as having **HIGH DIVERSITY** level of experience (OWNER / EPC) to complete a survey? Please check all applicable circles.

1	2	3	4	5	6	7
⬭	⬭	⬭	⬭	⬭	⬭	⬭

COMMENTS ON INPUT VARIABLES

OUTPUT VARIABLE: IMPORTANCE WEIGHT FACTOR

On a scale of 0 to 1, what are the numbers on the scale that may rank the expert as having **VERY SMALL** importance weight factor? Please check all applicable circles.

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

On a scale of 0 to 1, what are the numbers on the scale that may rank the expert as having **SMALL** importance weight factor? Please check all applicable circles.

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

On a scale of 0 to 1, what are the numbers on the scale that may rank the expert as having **MEDIUM** importance weight factor? Please check all applicable circles.

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

On a scale of 0 to 1, what are the numbers on the scale that may rank the expert as having **LARGE** importance weight factor? Please check all applicable circles.

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

On a scale of 0 to 1, what are the numbers on the scale that may rank the expert as having **VERY LARGE** importance weight factor? Please check all applicable circles.

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

COMMENTS ON OUTPUT VARIABLE

APPENDIX C

FUZZY IF-THEN RULES OF FUZZY EXPERT SYSTEM (FES)

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
1	small	small	low	low	low	1.00	very small
2	small	small	low	low	medium	1.00	small
3	small	small	low	low	high	1.00	small
4	small	small	low	medium	low	1.00	small
5	small	small	low	medium	medium	1.00	small
6	small	small	low	medium	high	1.00	small
7	small	small	low	high	low	1.00	medium
8	small	small	low	high	medium	1.00	medium
9	small	small	low	high	high	1.00	medium
10	small	small	medium	low	low	1.00	small
11	small	small	medium	low	medium	1.00	small
12	small	small	medium	low	high	1.00	small
13	small	small	medium	medium	low	1.00	small
14	small	small	medium	medium	medium	1.00	small
15	small	small	medium	medium	high	1.00	small
16	small	small	medium	high	low	1.00	small
17	small	small	medium	high	medium	1.00	medium
18	small	small	medium	high	high	1.00	medium
19	small	small	high	low	low	1.00	small
20	small	small	high	low	medium	1.00	small
21	small	small	high	low	high	1.00	small
22	small	small	high	medium	low	1.00	small
23	small	small	high	medium	medium	1.00	small
24	small	small	high	medium	high	1.00	medium
25	small	small	high	high	low	1.00	medium
26	small	small	high	high	medium	1.00	medium
27	small	small	high	high	high	1.00	medium
28	small	medium	low	low	low	1.00	small
29	small	medium	low	low	medium	1.00	small
30	small	medium	low	low	high	1.00	small
31	small	medium	low	medium	low	1.00	small
32	small	medium	low	medium	medium	1.00	small
33	small	medium	low	medium	high	1.00	medium
34	small	medium	low	high	low	1.00	medium
35	small	medium	low	high	medium	1.00	medium
36	small	medium	low	high	high	1.00	medium
37	small	medium	medium	low	low	1.00	small
38	small	medium	medium	low	medium	1.00	small
39	small	medium	medium	low	high	1.00	small
40	small	medium	medium	medium	low	1.00	small

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
41	small	medium	medium	medium	medium	1.00	small
42	small	medium	medium	medium	high	1.00	medium
43	small	medium	medium	high	low	1.00	medium
44	small	medium	medium	high	medium	1.00	medium
45	small	medium	medium	high	high	1.00	medium
46	small	medium	high	low	low	1.00	small
47	small	medium	high	low	medium	1.00	small
48	small	medium	high	low	high	1.00	small
49	small	medium	high	medium	low	1.00	small
50	small	medium	high	medium	medium	1.00	medium
51	small	medium	high	medium	high	1.00	medium
52	small	medium	high	high	low	1.00	medium
53	small	medium	high	high	medium	1.00	medium
54	small	medium	high	high	high	1.00	medium
55	small	large	low	low	low	1.00	small
56	small	large	low	low	medium	1.00	small
57	small	large	low	low	high	1.00	small
58	small	large	low	medium	low	1.00	small
59	small	large	low	medium	medium	1.00	medium
60	small	large	low	medium	high	1.00	medium
61	small	large	low	high	low	1.00	medium
62	small	large	low	high	medium	1.00	medium
63	small	large	low	high	high	1.00	medium
64	small	large	medium	low	low	1.00	small
65	small	large	medium	low	medium	1.00	small
66	small	large	medium	low	high	1.00	medium
67	small	large	medium	medium	low	1.00	medium
68	small	large	medium	medium	medium	1.00	medium
69	small	large	medium	medium	high	1.00	medium
70	small	large	medium	high	low	1.00	medium
71	small	large	medium	high	medium	1.00	medium
72	small	large	medium	high	high	1.00	medium
73	small	large	high	low	low	1.00	small
74	small	large	high	low	medium	1.00	small
75	small	large	high	low	high	1.00	medium
76	small	large	high	medium	low	1.00	medium
77	small	large	high	medium	medium	1.00	medium
78	small	large	high	medium	high	1.00	medium
79	small	large	high	high	low	1.00	medium
80	small	large	high	high	medium	1.00	medium

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
81	small	large	high	high	high	1.00	medium
82	medium	small	low	low	low	1.00	small
83	medium	small	low	low	medium	1.00	small
84	medium	small	low	low	high	1.00	small
85	medium	small	low	medium	low	1.00	small
86	medium	small	low	medium	medium	1.00	medium
87	medium	small	low	medium	high	1.00	medium
88	medium	small	low	high	low	1.00	medium
89	medium	small	low	high	medium	1.00	medium
90	medium	small	low	high	high	1.00	medium
91	medium	small	medium	low	low	1.00	small
92	medium	small	medium	low	medium	1.00	small
93	medium	small	medium	low	high	1.00	medium
94	medium	small	medium	medium	low	1.00	medium
95	medium	small	medium	medium	medium	1.00	medium
96	medium	small	medium	medium	high	1.00	medium
97	medium	small	medium	high	low	1.00	medium
98	medium	small	medium	high	medium	1.00	medium
99	medium	small	medium	high	high	1.00	medium
100	medium	small	high	low	low	1.00	small
101	medium	small	high	low	medium	1.00	small
102	medium	small	high	low	high	1.00	medium
103	medium	small	high	medium	low	1.00	medium
104	medium	small	high	medium	medium	1.00	medium
105	medium	small	high	medium	high	1.00	medium
106	medium	small	high	high	low	1.00	medium
107	medium	small	high	high	medium	1.00	medium
108	medium	small	high	high	high	1.00	medium
109	medium	medium	low	low	low	1.00	small
110	medium	medium	low	low	medium	1.00	small
111	medium	medium	low	low	high	1.00	medium
112	medium	medium	low	medium	low	1.00	medium
113	medium	medium	low	medium	medium	1.00	medium
114	medium	medium	low	medium	high	1.00	medium
115	medium	medium	low	high	low	1.00	medium
116	medium	medium	low	high	medium	1.00	medium
117	medium	medium	low	high	high	1.00	medium
118	medium	medium	medium	low	low	1.00	small
119	medium	medium	medium	low	medium	1.00	medium
120	medium	medium	medium	low	high	1.00	medium

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
121	medium	medium	medium	medium	low	1.00	medium
122	medium	medium	medium	medium	medium	1.00	medium
123	medium	medium	medium	medium	high	1.00	medium
124	medium	medium	medium	high	low	1.00	medium
125	medium	medium	medium	high	medium	1.00	medium
126	medium	medium	medium	high	high	1.00	large
127	medium	medium	high	low	low	1.00	medium
128	medium	medium	high	low	medium	1.00	medium
129	medium	medium	high	low	high	1.00	medium
130	medium	medium	high	medium	low	1.00	medium
131	medium	medium	high	medium	medium	1.00	medium
132	medium	medium	high	medium	high	1.00	medium
133	medium	medium	high	high	low	1.00	medium
134	medium	medium	high	high	medium	1.00	large
135	medium	medium	high	high	high	1.00	large
136	medium	large	low	low	low	1.00	medium
137	medium	large	low	low	medium	1.00	medium
138	medium	large	low	low	high	1.00	medium
139	medium	large	low	medium	low	1.00	medium
140	medium	large	low	medium	medium	1.00	medium
141	medium	large	low	medium	high	1.00	medium
142	medium	large	low	high	low	1.00	medium
143	medium	large	low	high	medium	1.00	large
144	medium	large	low	high	high	1.00	large
145	medium	large	medium	low	low	1.00	medium
146	medium	large	medium	low	medium	1.00	medium
147	medium	large	medium	low	high	1.00	medium
148	medium	large	medium	medium	low	1.00	medium
149	medium	large	medium	medium	medium	1.00	medium
150	medium	large	medium	medium	high	1.00	medium
151	medium	large	medium	high	low	1.00	medium
152	medium	large	medium	high	medium	1.00	large
153	medium	large	medium	high	high	1.00	large
154	medium	large	high	low	low	1.00	medium
155	medium	large	high	low	medium	1.00	medium
156	medium	large	high	low	high	1.00	medium
157	medium	large	high	medium	low	1.00	medium
158	medium	large	high	medium	medium	1.00	medium
159	medium	large	high	medium	high	1.00	large
160	medium	large	high	high	low	1.00	large

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
161	medium	large	high	high	medium	1.00	large
162	medium	large	high	high	high	1.00	large
163	large	small	low	low	low	1.00	medium
164	large	small	low	low	medium	1.00	medium
165	large	small	low	low	high	1.00	medium
166	large	small	low	medium	low	1.00	medium
167	large	small	low	medium	medium	1.00	medium
168	large	small	low	medium	high	1.00	medium
169	large	small	low	high	low	1.00	medium
170	large	small	low	high	medium	1.00	large
171	large	small	low	high	high	1.00	large
172	large	small	medium	low	low	1.00	medium
173	large	small	medium	low	medium	1.00	medium
174	large	small	medium	low	high	1.00	medium
175	large	small	medium	medium	low	1.00	medium
176	large	small	medium	medium	medium	1.00	medium
177	large	small	medium	medium	high	1.00	medium
178	large	small	medium	high	low	1.00	medium
179	large	small	medium	high	medium	1.00	large
180	large	small	medium	high	high	1.00	large
181	large	small	high	low	low	1.00	medium
182	large	small	high	low	medium	1.00	medium
183	large	small	high	low	high	1.00	medium
184	large	small	high	medium	low	1.00	medium
185	large	small	high	medium	medium	1.00	medium
186	large	small	high	medium	high	1.00	large
187	large	small	high	high	low	1.00	large
188	large	small	high	high	medium	1.00	large
189	large	small	high	high	high	1.00	large
190	large	medium	low	low	low	1.00	medium
191	large	medium	low	low	medium	1.00	medium
192	large	medium	low	low	high	1.00	medium
193	large	medium	low	medium	low	1.00	medium
194	large	medium	low	medium	medium	1.00	medium
195	large	medium	low	medium	high	1.00	large
196	large	medium	low	high	low	1.00	large
197	large	medium	low	high	medium	1.00	large
198	large	medium	low	high	high	1.00	large
199	large	medium	medium	low	low	1.00	medium
200	large	medium	medium	low	medium	1.00	medium

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
201	large	medium	medium	low	high	1.00	medium
202	large	medium	medium	medium	low	1.00	medium
203	large	medium	medium	medium	medium	1.00	medium
204	large	medium	medium	medium	high	1.00	large
205	large	medium	medium	high	low	1.00	large
206	large	medium	medium	high	medium	1.00	large
207	large	medium	medium	high	high	1.00	large
208	large	medium	high	low	low	1.00	medium
209	large	medium	high	low	medium	1.00	medium
210	large	medium	high	low	high	1.00	medium
211	large	medium	high	medium	low	1.00	medium
212	large	medium	high	medium	medium	1.00	large
213	large	medium	high	medium	high	1.00	large
214	large	medium	high	high	low	1.00	large
215	large	medium	high	high	medium	1.00	large
216	large	medium	high	high	high	1.00	large
217	large	large	low	low	low	1.00	medium
218	large	large	low	low	medium	1.00	medium
219	large	large	low	low	high	1.00	medium
220	large	large	low	medium	low	1.00	medium
221	large	large	low	medium	medium	1.00	large
222	large	large	low	medium	high	1.00	large
223	large	large	low	high	low	1.00	large
224	large	large	low	high	medium	1.00	large
225	large	large	low	high	high	1.00	large
226	large	large	medium	low	low	1.00	medium
227	large	large	medium	low	medium	1.00	medium
228	large	large	medium	low	high	1.00	large
229	large	large	medium	medium	low	1.00	large
230	large	large	medium	medium	medium	1.00	large
231	large	large	medium	medium	high	1.00	large
232	large	large	medium	high	low	1.00	large
233	large	large	medium	high	medium	1.00	large
234	large	large	medium	high	high	1.00	large
235	large	large	high	low	low	1.00	medium
236	large	large	high	low	medium	1.00	medium
237	large	large	high	low	high	1.00	large
238	large	large	high	medium	low	1.00	large
239	large	large	high	medium	medium	1.00	large
240	large	large	high	medium	high	1.00	large

IF						THEN	
#	Years of Experience	Years in Role	Role in the Company	Diversity of Experience	Enthusiasm	DoS	Importance Weight
241	large	large	high	high	low	1.00	large
242	large	large	high	high	medium	1.00	very large
243	large	large	high	high	high	1.00	very large

APPENDIX D

QUESTIONNAIRE TO CONSTRUCT MEMBERSHIP FUNCTIONS OF FUZZY PREFERENCE RELATIONS SCALE

QUESTIONNAIRE

CONSTRUCTION OF MEMBERSHIP FUNCTIONS OF FUZZY PREFERENCE RELATIONS SCALE

INTRODUCTION

The University of Alberta, Hole School of Construction Engineering would like to ask for your help in creating the fuzzy preference scale, which will be used later to determine your preferences on pairs of responsibility alternatives, as well as your consensus degrees.

The following questionnaire will help us determining the shape of each membership function representing each linguistic label on scale based on your input. The following are the fuzzy preference linguistic labels that we would like to draw their membership functions:

Fuzzy Preference	Symbol
7: Certain	C
6: Extremely Likely	EL
5: Most Likely	ML
4: It May	IM
3: Small Chance	SC
2: Extremely Unlikely	EU
1: Impossible	I

Note: for the linguistic labels “Certain” and “Impossible” you are not going to be asked to provide an input, as they are only represented on the scale by the elements 1 and 0, respectively.

Thank you very much for your time and cooperation.

1. What are the values on the scale that may represent the linguistic label **Extremely Unlikely (EU)?** Please circle all applicable values.

   0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

2. What are the values on the scale that may represent the linguistic label **Small Chance (SC)?** Please circle all applicable values.

   0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

3. What are the values on the scale that may represent the linguistic label **It May (IM)?** Please circle all applicable values.

   0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

4. What are the values on the scale that may represent the linguistic label **Most Likely (ML)?** Please circle all applicable values.

   0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

5. What are the values on the scale that may represent the linguistic label **Extremely Likely (EL)?** Please circle all applicable values.

   0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Thank You!

APPENDIX E

WEB-BASED SURVEY QUESTIONNAIRE TO RATE THE EXTENT OF THE ROLES AND RESPONSIBILITIES OF THE PROJECT OWNER VERSUS ITS CONTRACTORS IN THE OMC PROJECT DELIVERY SYSTEM

1. Welcome To The Survey

Dear user(s), welcome to the survey prepared by the Hole School of Construction Engineering, University of Alberta. As **the Owner** is trying to continuously improve and develop its understanding on how to execute its role as a **Managing Contractor**, the intent of the survey is to collect your responses with regard to the **extent** to which you perceive each of the included tasks as the responsibility of the **Owner** or the **Silo Contractor** in accordance with your role, as an owner or contractor, in a managing contractor **(OMC)** delivery system model.

The tasks are categorised into 18 work processes.

You are allowed to add **up to a maximum of 4 new tasks per each work process** should you feel the need to do so. **For these additional tasks, please provide an appropriate rating for each task you list, and describe each task in the free-form box, in the order in which you have rated it.**.

The rating scale is from 1 to 7, and indicates the extent to which you believe the task is the responsibility of the Owner or the Silo Contractor in terms of **performing the task. Note that decision making responsibility is not part of the rating you provide.**

A rating of **1** means **No Responsibility** (The party is not responsible at all for carrying out the task, yet he may be consulted based on the sole discretion of the sole responsible party).
A rating of **2** means **Limited Involvement** (The party is not responsible for carrying out the task, yet he is required to provide minor input to the other party to enable him to perform the task).
A rating of **3** means **Active Involvement** (The party is not responsible for carrying out the task, yet he must be involved in all task-related discussions and must provide considerable input).
A rating of **4** means **Shared Equally** (Both parties perform the task with equal levels of involvement).
A rating of **5** means **Significant Involvement** (The party is responsible for carrying out the task, yet he must involve the other party in all task-related discussions and nust receive considerable input from him).
A rating of **6** means **Principal Responsibility** (The party is responsible for carrying out the task, yet he will require minor input from the other party).
A rating of **7** means **Sole Responsibility** (The party is fully responsible for performing the task, yet he may choose to involve the other party if needed).

Alternatively, if the task is **Not Applicable** to your project then tick the **Last** column.

The next page of the survey is intended for collecting your information and general project related information, while page 3 is intended for collecting specific project related characteristics. Subsequently, you may proceed with rating the tasks as per the above described rating scale.

The approximate time to fill in the questionnaire is 90-120 minutes. You can save your responses and resume later; however, once you have completed the survey, you will not be able to modify your responses.

If you have any inquiry or request during filling in the questionnaire, contact **Mohamed El-Barkouky (elbarkou@ualberta.ca)**.

2. Users and Project Related Information

This section is intended for collecting your information and general project related information.

Category of The User:

- ◯ Owner's Representative
- ◯ Silo Contractor Representative

Name of The User:

Level Of Involvement In the Project:

- ◯ Senior Project Director
- ◯ Silo Project Manager
- ◯ Service Group Leader/Member
- ◯ Other

Provide more details of your position in this space

Project Name:

Brief Description of the Project:

3. Project Characteristics

Please indicate your project characteristics.

Type of Construction

- ◯ Process Plant
- ◯ Mining Facility
- ◯ Building
- ◯ Tank Farm
- ◯ Civil Engineering
- ◯ Other Discipline or you are an OSP central management personnel supporting all types of projects

(please specify)

Project Size

- ◯ >$1 billion
- ◯ $500 million to $1 billion
- ◯ $100 million to $499 million
- ◯ <$100 million

Form of Contract

- ◯ EPC Integrated
- ◯ EP with C as a Subcontractor to the EP
- ◯ EPC where EP formed a JV with the C
- ◯ EP and C as separate entities contracted with owner
- ◯ Not Applicable

Location Where Project's Engineering Takes Place

- ◯ Alberta
- ◯ Outside Alberta, but in Canada
- ◯ Outside Canada, but in North America
- ◯ Outside of North America
- ◯ Not Applicable (provide reason)

Provide Reason Here

4. WORK PROCESS (1): PROJECT INITIATION

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
1-O1) Establishing a project's required goals								
1-O2) Developing the business case summary and analyzing the business needs								
1-O3) Receiving and evaluating problems and opportunities from stakeholders								
1-O4) Conducting the Project Life Cycle Value Analysis (LCVA)								
1-O5) Determining the strategic objectives of the project								
1-O6) Establishing project's critical success factors / performance criteria								
1-O7) Coordinating and integrating data required to develop options and recommend a project strategy								
1-O8) Conducting project's initiation benchmarking								
1-O9) Establishing the finalized project charter								
1-O10) Providing the context for detailed decisions by project management, such as whether the project is schedule or cost driven								
1-O11) Determining the project's key milestones								
1-O12) Determining the project's programme of works								
1-O13) Determining the project's policies and guidelines								
1-O14) Describing the scope and standards and setting the design criteria								
1-O15) Providing the initial organization structure and project framework								
1-O16) Developing Stakeholder / NGO Plan								
1-O17) Preparing the Design Basis Memorandum(DBM)								
1-O18) Determining the project execution strategy								
1-O19) Preparing the project's preliminary work breakdown structure								
1-O20) Deciding on the full project sanctioning								
1-O21) Obtaining regulatory approvals								
1-O22) Setting the operational philosophy								
1-O23) Participating in creating conceptual drawings								

	1	2	3	4	5	6	7	Not Applicable
1-O24) Finalizing the feasibility analysis study of the project								
1-O25) Performing project's financial and investment risk assessment								
1-O26) Conducting stage gate reviews								
1-O27) Additional Task 1:								
1-O28) Additional Task 2:								
1-O29) Additional Task 3:								
1-O30) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
1-C1) Aiding the owner in conducting feasibility studies								
1-C2) Providing benchmarking data and comparable projects' costs								
1-C3) Additional Task 1:								
1-C4) Additional Task 2:								
1-C5) Additional Task 3:								
1-C6) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

5. WORK PROCESS (2): ORGANIZATION

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
2-O1) Conducting team-building exercises	◯	◯	◯	◯	◯	◯	◯	◯
2-O2) Preparing the project's organisational chart as a part of the execution plan	◯	◯	◯	◯	◯	◯	◯	◯
2-O3) Making project staff reassignments	◯	◯	◯	◯	◯	◯	◯	◯
2-O4) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
2-O5) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
2-O6) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
2-O7) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
2-C1) Supporting team members on methods and implications	◯	◯	◯	◯	◯	◯	◯	◯
2-C2) Submitting a proposed organisational chart, for the owner's approval, as part of the execution plan	◯	◯	◯	◯	◯	◯	◯	◯
2-C3) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
2-C4) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
2-C5) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
2-C6) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

6. WORK PROCESS (3): PROJECT MANAGEMENT

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
3-O1) Preparing the project's detailed work breakdown structure	○	○	○	○	○	○	○	○
3-O2) Approving detailed scope statements of work for all EPC contractors	○	○	○	○	○	○	○	○
3-O3) Preparing the Preliminary Project Execution Plan (PEP)	○	○	○	○	○	○	○	○
3-O4) Implementing a value improvement practice (VIP) for process design improvement	○	○	○	○	○	○	○	○
3-O5) Conducting coordination meetings with EPC contractors' planners and estimators	○	○	○	○	○	○	○	○
3-O6) Incorporating start/finish milestone dates in the project's integrated schedule to emphasize on project's physical interfaces between contractors and between suppliers	○	○	○	○	○	○	○	○
3-O7) Determining the overall Project's duration	○	○	○	○	○	○	○	○
3-O8) Setting up a monitoring team to watch over the schedule performance of various EPC contractors when the execution stage starts	○	○	○	○	○	○	○	○
3-O9) Applying liquidated damages or incentives based on contract performance	○	○	○	○	○	○	○	○
3-O10) Submitting the overall schedule status reports to key management	○	○	○	○	○	○	○	○
3-O11) Identifying, analyzing, mitigating, and controlling project risks	○	○	○	○	○	○	○	○
3-O12) Adopting an active risk-management approach that includes the assignment of mitigation responsibilities to the appropriate project participants and the oversight of follow-through regarding every risk factor	○	○	○	○	○	○	○	○
3-O13) Developing risk mitigation plans and updating them as the project progresses and following through with mitigation actions until risks are acceptable	○	○	○	○	○	○	○	○
3-O14) Effectively communicating the progress to all key stakeholders, as well as changes to the project risks and mitigation plans	○	○	○	○	○	○	○	○
3-O15) Participating in suppliers negotiations and providing approvals thereof	○	○	○	○	○	○	○	○
3-O16) Networking, coordinating, and collaborating with other project team members and support teams, including specialist estimators, site operations, and design function engineers	○	○	○	○	○	○	○	○
3-O17) Developing an effective and efficient owner team that coordinates with the EPC team(s)	○	○	○	○	○	○	○	○
3-O18) Developing open communications and trust	○	○	○	○	○	○	○	○
3-O19) Establishing clear accountabilities	○	○	○	○	○	○	○	○
3-O20) Identifying and resolving gaps, overlaps, and duplications in roles, responsibilities, positions, and eliminating the dysfunctional elements from the team, while updating the HR plan	○	○	○	○	○	○	○	○
3-O21) Accepting key personnel of the EPCs and advising on non-accepted personnel	○	○	○	○	○	○	○	○
3-O22) Initiating the development of the project execution plan and monitoring its implementation	○	○	○	○	○	○	○	○

3-O23) Establishing project organization and accountabilities
3-O24) Interpreting and communicating the project goals to team members
3-O25) Communicating the project monitoring and control system
3-O26) Assembling the owner representatives on the project team
3-O27) Monitoring and approving the scope, conceptual design, and risk analysis
3-O28) Approving and monitoring the project reporting processes
3-O29) Making sure that project's critical result areas are met
3-O30) Recruiting operating or ready for operations organization
3-O31) Monitoring adherence to safety plans and receiving periodical reports on performance
3-O32) Setting Initial Partnering Strategy
3-O33) Establishing legally and financially tenable alliances
3-O34) Managing alliances
3-O35) Acquiring available skills and knowledge from all involved partners
3-O36) Establishing decision-making authority levels and sources
3-O37) Establishing communication systems with partners
3-O38) Setting alliance performance measurement and reward systems
3-O39) Developing communication networks with the industry peers
3-O40) Reporting activities and status to senior management
3-O41) Identifying critical interfaces and any issues
3-O42) Developing a plan to address interface issues
3-O43) Assigning roles & responsibilities to address interface issues
3-O44) Providing an interface management tool
3-O45) Delivering best in class project execution
3-O46) Additional Task 1:
3-O47) Additional Task 2:
3-O48) Additional Task 3:
3-O49) Additional Task 4:

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
3-C1) Providing preliminary cost estimation and scheduling	○	○	○	○	○	○	○	○
3-C2) Providing input into the preparation of the Preliminary Project Execution Plan	○	○	○	○	○	○	○	○
3-C3) Advising on the contracting strategy, and subcontractors	○	○	○	○	○	○	○	○
3-C4) Infusing new advances into the business planning process	○	○	○	○	○	○	○	○
3-C5) Developing the own-works execution plan and providing continuous updates to the plan	○	○	○	○	○	○	○	○
3-C6) Preparing reports and attendance at meetings with the owner	○	○	○	○	○	○	○	○
3-C7) Submitting the overall schedule status reports to the owner	○	○	○	○	○	○	○	○
3-C8) Conducting team-building exercises and developing open communications and trust	○	○	○	○	○	○	○	○
3-C9) Initiating the development of the project execution plan and monitoring its implementation	○	○	○	○	○	○	○	○
3-C10) Managing assigned resources to achieve the project objectives	○	○	○	○	○	○	○	○
3-C11) Assembling EPC's project team	○	○	○	○	○	○	○	○
3-C12) Ensuring the EPC team has access to resources, tools, and equipment	○	○	○	○	○	○	○	○
3-C13) Reporting the project status to the stakeholders	○	○	○	○	○	○	○	○
3-C14) Additional Task 1:	○	○	○	○	○	○	○	○
3-C15) Additional Task 2:	○	○	○	○	○	○	○	○
3-C16) Additional Task 3:	○	○	○	○	○	○	○	○
3-C17) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

7. WORK PROCESS (4): EHS&S MANAGEMENT

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
4-O1) Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL)	○	○	○	○	○	○	○	○
4-O2) Making sure that individual EPCs develop and maintain a safety program that meets legal, regulatory, corporate, and local requirements	○	○	○	○	○	○	○	○
4-O3) Holding sessions with EPC contractors for identifying hazards and eliminating them to reduce to lowest acceptable levels	○	○	○	○	○	○	○	○
4-O4) Communicating safety risks to stakeholders	○	○	○	○	○	○	○	○
4-O5) Communicating safety expectations to all participants	○	○	○	○	○	○	○	○
4-O6) Establishing and managing a safety reporting and investigation system	○	○	○	○	○	○	○	○
4-O7) Organizing training in health and safety	○	○	○	○	○	○	○	○
4-O8) Receiving and commenting on individual EPC contractor’s safety plans based on the project’s guidelines and standards	○	○	○	○	○	○	○	○
4-O9) Having the highest regard for safety, emergency procedures, and loss management at all times	○	○	○	○	○	○	○	○
4-O10) Updating the emergency response plan and testing its efficiency	○	○	○	○	○	○	○	○
4-O11) Additional Task 1:	○	○	○	○	○	○	○	○
4-O12) Additional Task 2:	○	○	○	○	○	○	○	○
4-O13) Additional Task 3:	○	○	○	○	○	○	○	○
4-O14) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
4-C1) Developing and maintaining a safety program that meets legal, regulatory, corporate, and local requirements								
4-C2) Monitoring adherence to the safety plan and reporting on performance for all subcontractors								
4-C3) Identifying hazards and reducing them to the lowest acceptable levels								
4-C4) Communicating safety risks to stakeholders								
4-C5) Establishing and managing a safety reporting and investigation system								
4-C6) Conducting training in health and safety								
4-C7) Providing support to interpret legislative and regulatory requirements								
4-C8) Assisting the subcontractors in safe work practices								
4-C9) Performing the work in a manner which will cause minimum inconvenience, injury, and damage to others								
4-C10) Protecting the work site, the owner's property, and the property of third parties from loss or damage								
4-C11) Complying with all other safety requirements specified in the contract								
4-C12) Keeping all its working and storage areas clean, orderly, and secure								
4-C13) Monitoring and coordinating safety, environment, and labour relations requirements								
4-C14) Additional Task 1:								
4-C15) Additional Task 2:								
4-C16) Additional Task 3:								
4-C17) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

8. WORK PROCESS (5): REGULATIONS COMPLIANCE & STAKEHOLDER'S RELATIONS

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
5-O1) Conducting regulatory reviews	○	○	○	○	○	○	○	○
5-O2) Defining external permitting strategy (which, how and when)	○	○	○	○	○	○	○	○
5-O3) Identifying the regulatory agencies	○	○	○	○	○	○	○	○
5-O4) Establishing and maintaining communication links with regulators and facilities	○	○	○	○	○	○	○	○
5-O5) Acquiring and maintaining knowledge of the environmental requirements	○	○	○	○	○	○	○	○
5-O6) Coordinating and conducting environmental assessments	○	○	○	○	○	○	○	○
5-O7) Applying for environmental permits	○	○	○	○	○	○	○	○
5-O8) Preparing the environmental management plan of the project	○	○	○	○	○	○	○	○
5-O9) Additional Task 1:	○	○	○	○	○	○	○	○
5-O10) Additional Task 2:	○	○	○	○	○	○	○	○
5-O11) Additional Task 3:	○	○	○	○	○	○	○	○
5-O12) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
5-C1) Aiding the owner in preparing the environmental management plan of the project								
5-C2) Additional Task 1:								
5-C3) Additional Task 2:								
5-C4) Additional Task 3:								
5-C5) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

9. WORK PROCESS (6): QUALITY MANAGEMENT

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
6-O1) Participating in the preparation of design from the preliminary release to the final release								
6-O2) Conducting independent project review								
6-O3) Maintaining past contractors/suppliers experience system								
6-O4) Reviewing work processes to ensure best practices are being used								
6-O5) Ensuring integration of all processes to avoid duplication and gaps								
6-O6) Defining the quality requirements as clearly as possible at the project outset								
6-O7) Determining the project's quality standards and testing requirements								
6-O8) Setting up performance guarantees (required tests, audits, frequency of inspections, types, and methods of inspections)								
6-O9) Recommending remedial works for defects								
6-O10) Performing quality audits								
6-O11) Preparing the inspection and testing plans								
6-O12) Collecting, analyzing, and recording lessons learned in each project phase								
6-O13) Developing and maintaining a process to transfer Lessons Learned information to future projects								
6-O14) Integrating maintenance and operability with the lessons learned process								
6-O15) Additional Task 1:								
6-O16) Additional Task 2:								
6-O17) Additional Task 3:								
6-O18) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
6-C1) Receiving inspection requests from the subcontractors and handling testing	◯	◯	◯	◯	◯	◯	◯	◯
6-C2) Inspecting and approving all installations of subcontractors	◯	◯	◯	◯	◯	◯	◯	◯
6-C3) Identifying deficiencies and ensuring remedies are in place	◯	◯	◯	◯	◯	◯	◯	◯
6-C4) Following the quality requirements as set by the owner	◯	◯	◯	◯	◯	◯	◯	◯
6-C5) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	◯	◯	◯	◯	◯	◯	◯	◯
6-C6) Documenting the lessons learned	◯	◯	◯	◯	◯	◯	◯	◯
6-C7) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
6-C8) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
6-C9) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
6-C10) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

10. WORK PROCESS (7): TECHNICAL INFORMATION & DOCUMENT MANAGEMENT

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
7-O1) Maintaining vendor document control system	○	○	○	○	○	○	○	○
7-O2) Maintaining a document control facility	○	○	○	○	○	○	○	○
7-O3) Developing and managing a system to collect the project data	○	○	○	○	○	○	○	○
7-O4) Managing the information in databases and retrieval systems	○	○	○	○	○	○	○	○
7-O5) Archiving project close-out documentation and communicating lessons learned	○	○	○	○	○	○	○	○
7-O6) Developing and maintaining a process to transfer operations and maintenance knowledge throughout the projects	○	○	○	○	○	○	○	○
7-O7) Coordinating data flow and documents between projects	○	○	○	○	○	○	○	○
7-O8) Additional Task 1:	○	○	○	○	○	○	○	○
7-O9) Additional Task 2:	○	○	○	○	○	○	○	○
7-O10) Additional Task 3:	○	○	○	○	○	○	○	○
7-O11) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
7-C1) Incorporating maintenance and operability into standards where appropriate								
7-C2) Preparing and submitting the operation and maintenance manuals prior to testing								
7-C3) Additional Task 1:								
7-C4) Additional Task 2:								
7-C5) Additional Task 3:								
7-C6) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

11. WORK PROCESS (8): FINANCIAL CONTROLS

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
8-O1) Approving project funding	◯	◯	◯	◯	◯	◯	◯	◯
8-O2) Providing timely payment to the contractor based on the work done and the schedule of values	◯	◯	◯	◯	◯	◯	◯	◯
8-O3) Providing the payment of invoices for procured goods	◯	◯	◯	◯	◯	◯	◯	◯
8-O4) Setting the financial plans	◯	◯	◯	◯	◯	◯	◯	◯
8-O5) Finalizing the Authorisation for Expenditures (AFE)	◯	◯	◯	◯	◯	◯	◯	◯
8-O6) Preparing the asset management plan	◯	◯	◯	◯	◯	◯	◯	◯
8-O7) Setting the financial audit methodology	◯	◯	◯	◯	◯	◯	◯	◯
8-O8) Reporting to financial systems	◯	◯	◯	◯	◯	◯	◯	◯
8-O9) Recording payables and receivables	◯	◯	◯	◯	◯	◯	◯	◯
8-O10) Monitoring and updating the project's cash position	◯	◯	◯	◯	◯	◯	◯	◯
8-O11) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
8-O12) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
8-O13) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
8-O14) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
8-C1) Reporting to the financial systems of the owner								
8-C2) Additional Task 1:								
8-C3) Additional Task 2:								
8-C4) Additional Task 3:								
8-C5) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

12. WORK PROCESS (9): PROJECT CONTROLS

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
9-O1) Developing the execution schedule and providing continuous updates	◯	◯	◯	◯	◯	◯	◯	◯
9-O2) Integrating the execution schedule with the cost estimating and cost control functions and providing input for both	◯	◯	◯	◯	◯	◯	◯	◯
9-O3) Identifying scheduling alternatives and improvements	◯	◯	◯	◯	◯	◯	◯	◯
9-O4) Revising the EPC contractors' time schedules	◯	◯	◯	◯	◯	◯	◯	◯
9-O5) Linking both the engineering and procurement tasks to the construction time schedule and determining appropriate lead and lag times	◯	◯	◯	◯	◯	◯	◯	◯
9-O6) Determining the schedule-driven activities to ensure the work will be performed in a coordinated manner	◯	◯	◯	◯	◯	◯	◯	◯
9-O7) Incorporating various EPC contracts' works in one integrated time schedule and determining who works when	◯	◯	◯	◯	◯	◯	◯	◯
9-O8) Selecting and using the most appropriate planning and monitoring tools	◯	◯	◯	◯	◯	◯	◯	◯
9-O9) Producing the overall schedule status reports	◯	◯	◯	◯	◯	◯	◯	◯
9-O10) Recommending mitigating methods for schedule variances	◯	◯	◯	◯	◯	◯	◯	◯
9-O11) Progress monitoring of the project activities	◯	◯	◯	◯	◯	◯	◯	◯
9-O12) Providing cost and schedule estimated contingencies with the aid of the EPC	◯	◯	◯	◯	◯	◯	◯	◯
9-O13) Tracking and monitoring of the risks and risk allowance/contingency	◯	◯	◯	◯	◯	◯	◯	◯
9-O14) Reporting the outcome from risk management planning to the project execution plan- e.g. adding a contingency budget or time to the plan	◯	◯	◯	◯	◯	◯	◯	◯
9-O15) Determining estimate basis for facility components	◯	◯	◯	◯	◯	◯	◯	◯
9-O16) Determining historical cost basis for facility components	◯	◯	◯	◯	◯	◯	◯	◯
9-O17) Converting estimate basis to costs	◯	◯	◯	◯	◯	◯	◯	◯
9-O18) Comparing the estimate of individual items with the previous costs of similar items	◯	◯	◯	◯	◯	◯	◯	◯
9-O19) Reviewing estimates with the project team	◯	◯	◯	◯	◯	◯	◯	◯
9-O20) Preparing detailed estimate	◯	◯	◯	◯	◯	◯	◯	◯
9-O21) Preparing forecasts and costs to completion estimates based on the current project's status	◯	◯	◯	◯	◯	◯	◯	◯
9-O22) Preparing a cost break down structure and chart of accounts	◯	◯	◯	◯	◯	◯	◯	◯
9-O23) Preparing integrated project cash flow	◯	◯	◯	◯	◯	◯	◯	◯
	◯	◯	◯	◯	◯	◯	◯	◯

9-O24) Developing a system to forecast all project costs at completion

9-O25) Recommending mitigating methods for cost variances

9-O26) Monitoring project's individual cost items

9-O27) Keeping records of the summary of charges as reflected by the job cost accounts, including expenditures and estimated costs

9-O28) Comparing the planned budget to the actual budget based on the overall planned versus actual expenditures of the combined EPC contracts

9-O29) Forecasting for activity cost control and providing budget updates

9-O30) Relating Cost and Schedule Information and producing an earned value analysis

9-O31) Creating and monitoring project reporting processes

9-O32) Managing the network of benchmark partners

9-O33) Assessing and implementing the best practices

9-O34) Monitoring internal performance against the established standards

9-O35) Collecting data and reporting on the established metrics

9-O36) Additional Task 1:

9-O37) Additional Task 2:

9-O38) Additional Task 3:

9-O39) Additional Task 4:

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
9-C1) Collecting data and involving all project participants in schedule preparation	○	○	○	○	○	○	○	○
9-C2) Integrating with estimating and cost control, as well as providing input to estimating and cost control	○	○	○	○	○	○	○	○
9-C3) Communicating scheduling conflicts with other EPC contractors' systems	○	○	○	○	○	○	○	○
9-C4) Implementing alternatives and improvements in the schedule	○	○	○	○	○	○	○	○
9-C5) Scheduling, work monitoring, and reporting on the progress of the work relative to the milestones to the Owner	○	○	○	○	○	○	○	○
9-C6) Selecting and using the most appropriate planning and monitoring tools	○	○	○	○	○	○	○	○
9-C7) Producing the overall schedule status reports	○	○	○	○	○	○	○	○
9-C8) Progress monitoring of the project activities	○	○	○	○	○	○	○	○
9-C9) Gathering all the required detailed information for estimating	○	○	○	○	○	○	○	○
9-10) Preparing the detailed estimates	○	○	○	○	○	○	○	○
9-11) Preparing the forecasts and costs to completion estimates	○	○	○	○	○	○	○	○
9-12) Supporting the owner on cost and risk direction	○	○	○	○	○	○	○	○
9-13) Producing regular status reports on costs, scope, and risk	○	○	○	○	○	○	○	○
9-14) Additional Task 1:	○	○	○	○	○	○	○	○
9-15) Additional Task 2:	○	○	○	○	○	○	○	○
9-16) Additional Task 3:	○	○	○	○	○	○	○	○
9-17) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

13. WORK PROCESS (10): ENGINEERING

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
10-O1) Defining the Front-End Engineering Design (FEED)								
10-O2) Finalizing the Front-End Engineering Design (FEED)								
10-O3) Participating in performing calculations and detailed design								
10-O4) Participating in producing drawings, material lists, and specifications								
10-O5) Issuing construction and fabrication work packages								
10-O6) Providing technical coordination with suppliers								
10-O7) Conducting design reviews								
10-O8) Preparing a detailed quantity take off of the project's items								
10-O9) Incorporating maintenance and operability into standards where appropriate								
10-O10) Administering the constructability process								
10-O11) Negotiating constructability plans with EPCs contractors								
10-O12) Providing constructability input to the lessons learned								
10-O13) Liaison with design								
10-O14) Additional Task 1:								
10-O15) Additional Task 2:								
10-O16) Additional Task 3:								
10-O17) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
10-C1) Preparing design from the preliminary release to final release	◯	◯	◯	◯	◯	◯	◯	◯
10-C2) Preparing the design requirements standards	◯	◯	◯	◯	◯	◯	◯	◯
10-C3) Converting and implementing new technologies	◯	◯	◯	◯	◯	◯	◯	◯
10-C4) Performing calculations and detailed design	◯	◯	◯	◯	◯	◯	◯	◯
10-C5) Producing drawings, material lists, and specifications	◯	◯	◯	◯	◯	◯	◯	◯
10-C6) Adhering to standards, codes, laws, and corporate practices	◯	◯	◯	◯	◯	◯	◯	◯
10-C7) Providing technical coordination with the suppliers	◯	◯	◯	◯	◯	◯	◯	◯
10-C8) preparing the final installation details	◯	◯	◯	◯	◯	◯	◯	◯
10-C9) Performing coordination works and design reviews	◯	◯	◯	◯	◯	◯	◯	◯
10-C10) Providing the owner with the as-built drawings upon completion of the works	◯	◯	◯	◯	◯	◯	◯	◯
10-C11) Establishing a constructability plan	◯	◯	◯	◯	◯	◯	◯	◯
10-C12) Evaluating constructability information with the owner	◯	◯	◯	◯	◯	◯	◯	◯
10-C13) Incorporating the proposed improvements into the project plan	◯	◯	◯	◯	◯	◯	◯	◯
10-C14) Providing constructability input to the lessons learned	◯	◯	◯	◯	◯	◯	◯	◯
10-C15) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
10-C16) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
10-C17) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
10-C18) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

14. WORK PROCESS (11): SUPPLY CHAIN MANAGEMENT

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
11-O1) Evaluating and making recommendations on submitted bid packages	○	○	○	○	○	○	○	○
11-O2) Developing and maintaining a process for contracting work, equipment, materials, and services	○	○	○	○	○	○	○	○
11-O3) Issuing material purchase orders (POs)	○	○	○	○	○	○	○	○
11-O4) Providing expediting service	○	○	○	○	○	○	○	○
11-O5) Providing instructions and guidelines that identify the levels of review and approvals required by the owner in relation to the procured goods	○	○	○	○	○	○	○	○
11-O6) Determining the procurement strategies and owner's specified materials to the EPC contractors	○	○	○	○	○	○	○	○
11-O7) Inspecting partially or fully the delivered materials to site	○	○	○	○	○	○	○	○
11-O8) Preparing transportation and logistics plan for supply	○	○	○	○	○	○	○	○
11-O9) Liaison with equipment and material suppliers	○	○	○	○	○	○	○	○
11-O10) Procuring long lead items and bulk equipment	○	○	○	○	○	○	○	○
11-O11) Additional Task 1:	○	○	○	○	○	○	○	○
11-O12) Additional Task 2:	○	○	○	○	○	○	○	○
11-O13) Additional Task 3:	○	○	○	○	○	○	○	○
11-O14) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
11-C1) Providing timely coordination and management of transportation and related services for the work	○	○	○	○	○	○	○	○
11-C2) Assemblying the required information including site investigations and inspection requirements	○	○	○	○	○	○	○	○
11-C3) Developing and maintaining a process for subcontracting work, equipment, materials, and services	○	○	○	○	○	○	○	○
11-C4) Providing supply inspection services	○	○	○	○	○	○	○	○
11-C5) Establishing and implementing purchasing standards	○	○	○	○	○	○	○	○
11-C6) Submitting any required material samples for the owner's representative's approval, together with any relevant information	○	○	○	○	○	○	○	○
11-C7) Additional Task 1:	○	○	○	○	○	○	○	○
11-C8) Additional Task 2:	○	○	○	○	○	○	○	○
11-C9) Additional Task 3:	○	○	○	○	○	○	○	○
11-C10) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

15. WORK PROCESS (12): CONTRACTING

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
12-O1) Developing the contracting procedure	○	○	○	○	○	○	○	○
12-O2) Developing and implementing a dispute resolution mechanism to avoid or manage claims	○	○	○	○	○	○	○	○
12-O3) Ensuring corporate and legal requirements are met	○	○	○	○	○	○	○	○
12-O4) Interpreting contract conditions including matters dealing with legal, financial, technical, and taxation	○	○	○	○	○	○	○	○
12-O5) Preparing RFPs and negotiating the final contract conditions prior to awarding to EPCs	○	○	○	○	○	○	○	○
12-O6) Preparing the insurance plan	○	○	○	○	○	○	○	○
12-O7) Providing copies of the insurance policies before requiring the contractor to sign the EPC contract	○	○	○	○	○	○	○	○
12-O8) Setting up the contract delivery method(s) (DB, D-Bid-B, CM, etc.) and format (fixed, variable, cost-plus, etc)	○	○	○	○	○	○	○	○
12-O9) Additional Task 1:	○	○	○	○	○	○	○	○
12-O10) Additional Task 2:	○	○	○	○	○	○	○	○
12-O11) Additional Task 3:	○	○	○	○	○	○	○	○
12-O12) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
12-C1) Preparing and submitting invoices for all work performed in accordance with the contract	◯	◯	◯	◯	◯	◯	◯	◯
12-C2) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
12-C3) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
12-C4) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
12-C5) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

16. WORK PROCESS (13): CONSTRUCTION

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
13-O1) Preparing construction method statements and alternatives	○	○	○	○	○	○	○	○
13-O2) Selecting and implementing the optimum construction strategy for the project	○	○	○	○	○	○	○	○
13-O3) Coordinating the installation of equipment amongst EPC contractors	○	○	○	○	○	○	○	○
13-O4) Coordinating multi-trade and multi-site activities amongst EPC contractors	○	○	○	○	○	○	○	○
13-O5) Receiving and evaluating problems and opportunities from concerned EPCs	○	○	○	○	○	○	○	○
13-O6) Administering, supervising, managing, and monitoring the EPC contractors	○	○	○	○	○	○	○	○
13-O7) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	○	○	○	○	○	○	○	○
13-O8) Additional Task 1:	○	○	○	○	○	○	○	○
13-O9) Additional Task 2:	○	○	○	○	○	○	○	○
13-O10) Additional Task 3:	○	○	○	○	○	○	○	○
13-O11) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
13-C1) Maintaining and keeping the as-built drawings on the work site	◯	◯	◯	◯	◯	◯	◯	◯
13-C2) Installing all equipment and structures	◯	◯	◯	◯	◯	◯	◯	◯
13-C3) Providing required information during construction & installation	◯	◯	◯	◯	◯	◯	◯	◯
13-C4) Providing tools, construction equipment, and consumables	◯	◯	◯	◯	◯	◯	◯	◯
13-C5) Maintaining site cleanup and restoration	◯	◯	◯	◯	◯	◯	◯	◯
13-C6) Receiving, storing, and handling of material and equipment at site	◯	◯	◯	◯	◯	◯	◯	◯
13-C7) Managing the project site	◯	◯	◯	◯	◯	◯	◯	◯
13-C8) Coordinating multi-trade and multi-site activities amongst subcontractors and suppliers	◯	◯	◯	◯	◯	◯	◯	◯
13-C9) Receiving and evaluating problems and opportunities from concerned subcontractors	◯	◯	◯	◯	◯	◯	◯	◯
13-C10) Coordinating the installation of equipment	◯	◯	◯	◯	◯	◯	◯	◯
13-C11) Coordination of subcontractors work	◯	◯	◯	◯	◯	◯	◯	◯
13-C12) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
13-C13) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
13-C14) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
13-C15) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

17. WORK PROCESS (14): READY FOR OPERATIONS (RFO)

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
14-O1) Providing input on operability, and maintainability processes as well as providing supplementary technical support	○	○	○	○	○	○	○	○
14-O2) Producing and/or approving individual commissioning	○	○	○	○	○	○	○	○
14-O3) Providing design sign-offs plans	○	○	○	○	○	○	○	○
14-O4) Providing the final inspections and signing-off on the project installations	○	○	○	○	○	○	○	○
14-O5) Inspecting and approving all installations	○	○	○	○	○	○	○	○
14-O6) Developing a teamwork/ ownership environment during the commissioning stage	○	○	○	○	○	○	○	○
14-O7) Coordinating commissioning plans for the manufacturers, suppliers, and EPCs	○	○	○	○	○	○	○	○
14-O8) Collecting turnover documentation	○	○	○	○	○	○	○	○
14-O9) Coordinating the transition from construction to operation	○	○	○	○	○	○	○	○
14-O10) Recommending operation strategies	○	○	○	○	○	○	○	○
14-O11) Arranging, coordinating, and ensuring training on equipment and system requirements	○	○	○	○	○	○	○	○
14-O12) Issuing functional completion certificates upon taking over the work for functional use	○	○	○	○	○	○	○	○
14-O13) Coordinating start-up activities	○	○	○	○	○	○	○	○
14-O14) Finalizing handing over and start-up systems	○	○	○	○	○	○	○	○
14-O15) Obtaining license to operate	○	○	○	○	○	○	○	○
14-O16) Performing spares and warranty management	○	○	○	○	○	○	○	○
14-O17) Additional Task 1:	○	○	○	○	○	○	○	○
14-O18) Additional Task 2:	○	○	○	○	○	○	○	○
14-O19) Additional Task 3:	○	○	○	○	○	○	○	○
14-O20) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
14-C1) Comparing the performance requirements with the project's performance outcome								
14-C2) Executing the commissioning plan								
14-C3) Providing the owner with proper turnover documentation								
14-C4) Arranging, coordinating, and conducting training on the equipment and system requirements								
14-C5) Conducting performance testing based on the performance standards.								
14-C6) Obtaining the work sign-off from the owner								
14-C7) Coordinating the start-up activities within subcontractors and suppliers								
14-C8) Coordinating and working in liaison with production units								
14-C9) Additional Task 1:								
14-C10) Additional Task 2:								
14-C11) Additional Task 3:								
14-C12) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

18. WORK PROCESS (15): OPERATIONS & MAINTENANCE

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
15-O1) Developing and implementing operating procedures including shutdown/start-up and emergency procedures	◯	◯	◯	◯	◯	◯	◯	◯
15-O2) Developing and implementing maintenance and inspection programs	◯	◯	◯	◯	◯	◯	◯	◯
15-O3) Developing and implementing turnaround plan including safe making procedure	◯	◯	◯	◯	◯	◯	◯	◯
15-O4) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
15-O5) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
15-O6) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
15-O7) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
15-C1) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
15-C2) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
15-C3) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
15-C4) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

19. WORK PROCESS (16): ADMINISTRATION

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
16-O1) Providing administrative support for travel								
16-O2) Providing administrative support for meeting set up and coordination								
16-O3) Providing administrative support for teleconferences								
16-O4) Providing administrative support for office suppliers								
16-O5) Additional Task 1:								
16-O6) Additional Task 2:								
16-O7) Additional Task 3:								
16-O8) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
16-C1) Additional Task 1:								
16-C2) Additional Task 2:								
16-C3) Additional Task 3:								
16-C4) Additional Task 4:								

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

20. WORK PROCESS (17): MANAGEMENT OF CHANGE

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
17-O1) Managing project changes	○	○	○	○	○	○	○	○
17-O2) Developing team responses and strategies to deal with changes	○	○	○	○	○	○	○	○
17-O3) Providing required approvals for design changes after revising designs	○	○	○	○	○	○	○	○
17-O4) Developing and implementing a contract change control process	○	○	○	○	○	○	○	○
17-O5) Evaluating preliminary cost of change orders and providing necessary approvals	○	○	○	○	○	○	○	○
17-O6) Evaluating feedbacks of EPC on change requests and deciding on whether the changes are to be executed or not	○	○	○	○	○	○	○	○
17-O7) Additional Task 1:	○	○	○	○	○	○	○	○
17-O8) Additional Task 2:	○	○	○	○	○	○	○	○
17-O9) Additional Task 3:	○	○	○	○	○	○	○	○
17-O10) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
17-C1) Getting the necessary approvals on design changes	○	○	○	○	○	○	○	○
17-C2) Submitting requests for change orders and reporting to the owner	○	○	○	○	○	○	○	○
17-C3) Additional Task 1:	○	○	○	○	○	○	○	○
17-C4) Additional Task 2:	○	○	○	○	○	○	○	○
17-C5) Additional Task 3:	○	○	○	○	○	○	○	○
17-C6) Additional Task 4:	○	○	○	○	○	○	○	○

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

21. WORK PROCESS (18): INFORMATION SYSTEMS

To what extent do you believe this task is the responsibility of the OWNER on this project?

	1	2	3	4	5	6	7	Not Applicable
18-O1) Providing a mechanism for monitoring and assessing the options to upgrade existing technologies	◯	◯	◯	◯	◯	◯	◯	◯
18-O2) Scoping, developing and providing business systems and application requirements	◯	◯	◯	◯	◯	◯	◯	◯
18-O3) Scoping, developing and providing project IT hardware requirements	◯	◯	◯	◯	◯	◯	◯	◯
18-O4) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
18-O5) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
18-O6) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
18-O7) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

To what extent do you believe this task is the responsibility of the SILO CONTRACTOR on this project?

	1	2	3	4	5	6	7	Not Applicable
18-C1) Providing the required support in the required areas of equipment, systems, and processes	◯	◯	◯	◯	◯	◯	◯	◯
18-C2) Additional Task 1:	◯	◯	◯	◯	◯	◯	◯	◯
18-C3) Additional Task 2:	◯	◯	◯	◯	◯	◯	◯	◯
18-C4) Additional Task 3:	◯	◯	◯	◯	◯	◯	◯	◯
18-C5) Additional Task 4:	◯	◯	◯	◯	◯	◯	◯	◯

Please use the free-form box below to list the names of your additional tasks in the same order you added and rated them above (please use the corresponding number when naming them).

APPENDIX F

EXPERTS' RESPONSES TO WEB-BASED SURVEY

	Fuzzy Rating (Y_k)						
1- PROJECT INITIATION PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1-O1) Establishing a project's required goals	2	1	0	0	2	10	22
1-O2) Developing the business case summary and analyzing the business needs	3	0	0	0	1	4	29
1-O3) Receiving and evaluating problems and opportunities from stakeholders	1	1	1	2	6	11	15
1-O4) Conducting the Project Life Cycle Value Analysis (LCVA)	3	0	0	2	7	11	14
1-O5) Determining the strategic objectives of the project	3	0	0	1	1	4	28
1-O6) Establishing project's critical success factors / performance criteria	2	1	0	2	3	14	15
1-O7) Coordinating and integrating data required to develop options and recommend a project strategy	1	2	1	3	10	12	8
1-O8) Conducting project's initiation benchmarking	3	0	1	2	4	13	14
1-O9) Establishing the finalized project charter	3	0	0	1	4	12	17
1-O10) Providing the context for detailed decisions by project management, such as whether the project is schedule or cost driven	2	1	1	2	1	10	20
1-O11) Determining the project's key milestones	2	2	0	3	7	11	12
1-O12) Determining the project's programme of works	1	2	2	3	10	10	9
1-O13) Determining the project's policies and guidelines	3	1	0	2	3	13	15
1-O14) Describing the scope and standards and setting the design criteria	2	2	0	3	9	8	13
1-O15) Providing the initial organization structure and project framework	3	2	0	2	3	12	15
1-O16) Developing Stakeholder / NGO Plan	2	2	0	1	1	8	23
1-O17) Preparing the Design Basis Memorandum(DBM)	3	1	11	7	2	5	8
1-O18) Determining the project execution strategy	1	2	4	4	8	12	6
1-O19) Preparing the project's preliminary work breakdown structure	2	3	4	3	4	11	10
1-O20) Deciding on the full project sanctioning	3	0	0	0	1	6	27
1-O21) Obtaining regulatory approvals	2	2	0	1	5	6	21
1-O22) Setting the operational philosophy	2	0	1	1	3	10	20
1-O23) Participating in creating conceptual drawings	2	3	8	7	10	2	5
1-O24) Finalizing the feasibility analysis study of the project	2	0	3	5	9	7	11
1-O25) Performing project's financial and investment risk assessment	1	0	1	4	5	8	18
1-O26) Conducting stage gate reviews	0	2	0	6	9	11	9
1-C1) Aiding in conducting feasibility studies	2	3	6	5	11	3	7
1-C2) Providing benchmarking data and comparable projects' costs	1	5	5	7	8	7	4

	Fuzzy Rating (Y_k)						
2- ORGANIZATION PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2-O1) Conducting team-building exercises	1	3	2	25	1	4	1
2-O2) Preparing the owners project's organisational chart as a part of the execution plan	1	6	6	7	6	6	5
2-O3) Making project staff reassignments	4	7	3	5	6	3	9
2-C1) Supporting team members on methods and implications	1	1	2	5	7	13	8
2-C2) Submitting a proposed organisational chart, for the owner's approval, as part of the execution plan	1	2	1	1	4	8	20

	Fuzzy Rating (Y_k)						
3- PROJECT MANAGEMENT PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3-O1) Preparing the project's detailed work breakdown structure	2	7	8	5	7	4	4
3-O2) Approving detailed scope statements of work for all EPC contractors	2	7	8	5	7	4	4
3-O3) Preparing the Preliminary Project Execution Plan (PEP)	2	7	8	5	7	4	4
3-O4) Implementing a value improvement practice (VIP) for process design improvement	2	7	8	5	7	4	4
3-O5) Conducting coordination meetings with EPC contractors' planners and estimators	2	7	8	5	7	4	4
3-O6) Incorporating start/finish milestone dates in a project's integrated schedule to emphasize on project's physical interfaces between contractors and suppliers	2	7	8	5	7	4	4
3-O7) Determining the overall Project's duration	2	7	8	5	7	4	4
3-O8) Setting up a monitoring team to watch over the schedule performance of various EPC contractors when the execution stage starts	2	7	8	5	7	4	4
3-O9) Applying liquidated damages or incentives based on contract performance	2	7	8	5	7	4	4
3-O10) Submitting the overall schedule status reports to key management	2	7	8	5	7	4	4
3-O11) Identifying, analyzing, mitigating, and controlling project risks	2	7	8	5	7	4	4
3-O12) Adopting an active risk-management approach that includes the assignment of mitigation responsibilities to the appropriate project participants and the oversight of follow-through regarding every risk factor	2	7	8	5	7	4	4
3-O13) Developing risk mitigation plans and updating them as the project progresses and following through with mitigation actions until risks are acceptable	2	7	8	5	7	4	4
3-O14) Effectively communicating the progress to all key stakeholders, as well as changes to the project risks and mitigation plans	2	7	8	5	7	4	4
3-O15) Participating in suppliers negotiations and providing approvals thereof	2	7	8	5	7	4	4
3-O16) Networking, coordinating, and collaborating with other project team members and support teams, including specialist estimators, site operations, and design function engineers	2	7	8	5	7	4	4
3-O17) Developing an effective and efficient owner team that coordinates with the EPC team(s)	2	7	8	5	7	4	4
3-O18) Developing open communications and trust	2	7	8	5	7	4	4
3-O19) Establishing clear accountabilities	2	7	8	5	7	4	4
3-O20) Identifying and resolving gaps, overlaps, and duplications in roles, responsibilities, positions, and eliminating the dysfunctional elements from the team, while updating the HR plan	2	7	8	5	7	4	4
3-O21) Accepting key personnel of the EPCs and advising on non-accepted personnel	4	0	0	0	5	8	20
3-O22) Initiating the development of the project execution plan and monitoring its implementation	1	3	5	7	6	6	9
3-O23) Establishing project organization and accountabilities	2	2	3	7	4	8	11
3-O24) Interpreting and communicating the project goals to team members	2	3	1	9	2	8	12
3-O25) Communicating the project monitoring and control system	1	4	5	7	4	8	8
3-O26) Assembling the owner representatives on the project team	2	0	0	0	0	4	31
3-O27) Monitoring and approving the scope, conceptual design, and risk analysis	0	1	2	4	4	12	14
3-O28) Approving and monitoring the project reporting processes	2	1	1	3	6	11	13
3-O29) Making sure that project's critical result areas are met	2	0	1	12	7	6	9
3-O30) Recruiting operating or ready for operations organization	2	0	0	1	0	1	33
3-O31) Monitoring adherence to safety plans and receiving periodical reports on performance	3	2	2	9	6	4	11
3-O32) Setting Initial Partnering Strategy	2	1	0	3	2	6	23
3-O33) Establishing legally and financially tenable alliances	1	2	0	3	0	7	24
3-O34) Managing alliances	1	2	0	3	2	6	23
3-O35) Acquiring available skills and knowledge from all involved partners	1	2	0	4	4	8	18
3-O36) Establishing decision-making authority levels and sources	2	1	1	2	2	5	24
3-O37) Establishing communication systems with partners	4	1	0	6	2	3	21
3-O38) Setting alliance performance measurement and reward systems	1	1	0	5	4	7	19
3-O39) Developing communication networks with the industry peers	1	1	1	4	3	10	17
3-O40) Reporting activities and status to senior management	4	0	0	3	6	9	15
3-O41) Identifying critical interfaces and any issues	2	1	3	14	8	3	6
3-O42) Developing a plan to address interface issues	3	3	4	11	7	3	6
3-O43) Assigning roles & responsibilities to address interface issues	2	2	4	8	8	8	5
3-O44) Providing an interface management tool	1	2	2	3	6	11	12
3-O45) Delivering best in class project execution	1	4	1	17	5	5	4
3-C1) Providing preliminary cost estimation and scheduling	1	2	2	1	7	13	11
3-C2) Providing input into the preparation of the Preliminary Project Execution Plan	4	5	5	2	4	10	7
3-C3) Advising on the contracting strategy, and subcontractors	1	3	5	3	8	10	7
3-C4) Infusing new advances into the business planning process	3	9	3	6	6	5	5
3-C5) Developing the own-works execution plan and providing continuous updates to the plan	2	1	2	1	2	16	13
3-C6) Preparing reports and attendance at meetings with the owner	2	0	1	1	1	14	18
3-C7) Submitting the overall schedule status reports to the owner	2	0	1	0	1	13	20
3-C8) Conducting team-building exercises and developing open communications and trust	1	1	0	15	6	9	5
3-C9) Initiating the development of the project execution plan and monitoring its implementation	1	2	3	2	8	13	8
3-C10) Managing assigned resources to achieve the project objectives	2	1	0	1	0	13	20
3-C11) Assembling EPC's project team	2	2	0	0	0	12	21
3-C12) Ensuring the EPC team has access to resources, tools, and equipment	3	0	0	0	0	12	22
3-C13) Reporting the project status to the stakeholders	1	3	6	7	2	10	8

	Fuzzy Rating (Y_k)						
4- EHS&S MANAGEMENT PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4-O1) Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL)	2	1	9	7	8	5	5
4-O2) Administering the development and maintainence of a safety programs that meets legal, regulatory, corporate, and local requirements	0	3	2	4	6	11	11
4-O3) Holding sessions for identifying hazards and eliminating them to reduce to lowest acceptable levels	1	0	5	5	7	10	9
4-O4) Communicating safety risks to projects' stakeholders	1	0	0	7	4	13	12
4-O5) Communicating safety expectations to all projects' participants	1	0	0	8	3	10	15
4-O6) Establishing and managing a safety reporting and investigation system	1	3	2	5	8	6	12
4-O7) Administering training in health and safety	1	4	4	9	6	5	8
4-O8) Receiving and commenting on individual subcontractors' safety plans based on the projects' guidelines and standards	0	2	1	1	4	13	16
4-O9) Having the highest regard for safety, emergency procedures, and loss management at all times	1	0	0	19	2	3	12
4-O10) Updating the emergency response plan and testing its efficiency	2	1	1	5	4	12	12
4-C1) Developing and maintaining a safety program that meets legal, regulatory, corporate, and local requirements	1	0	1	5	5	12	13
4-C2) Monitoring adherence to the safety plan and reporting on performance for all subcontractors	1	0	1	3	3	11	18
4-C3) Identifying hazards and reducing them to the lowest acceptable levels	1	0	0	7	5	11	13
4-C4) Communicating safety risks to stakeholders	3	3	1	14	5	2	9
4-C5) Establishing and managing a safety reporting and investigation system	1	1	4	10	3	7	11
4-C6) Conducting training in health and safety	1	0	0	5	7	11	13
4-C7) Providing support to interpret legislative and regulatory requirements	1	2	6	5	7	7	9
4-C8) Assisting the subcontractors in safe work practices	1	0	1	1	7	11	16
4-C9) Performing the work in a manner which will cause minimum inconvenience, injury, and damage to others	1	0	0	4	3	12	17
4-C10) Protecting the work site, the owner's property, and the property of third parties from loss or damage	1	1	0	4	3	13	15
4-C11) Complying with all other safety requirements specified in the contract	1	1	0	2	2	7	24
4-C12) Keeping all working and storage areas clean, orderly, and secure	3	0	0	1	2	6	25
4-C13) Monitoring and coordinating safety, environment, and labour relations requirements	1	1	2	3	4	12	14

	Fuzzy Rating (Y_k)						
5- REGULATIONS COMPLIANCE & STAKEHOLDER'S RELATIONS PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5-O1) Conducting regulatory reviews	0	1	0	0	5	14	17
5-O2) Defining external permitting strategy (which, how and when)	1	0	1	0	5	10	20
5-O3) Identifying the regulatory agencies	0	1	0	3	3	10	20
5-O4) Establishing and maintaining communication links with regulators and facilities	0	0	1	2	2	12	20
5-O5) Acquiring and maintaining knowledge of the environmental requirements	1	0	0	3	2	17	14
5-O6) Coordinating and conducting environmental assessments	1	0	0	2	2	16	16
5-O7) Applying for environmental permits	1	0	0	0	3	7	26
5-O8) Preparing the environmental management plan of the project	1	0	0	1	3	10	22
5-C1) Aiding the owner in preparing the environmental management plan of the project	0	6	5	1	9	4	12

	Fuzzy Rating (Y_k)						
6- QUALITY MANAGEMENT PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
6-O1) Participating in the preparation of design from the preliminary release to the final release	1	4	17	0	5	1	9
6-O2) Conducting independent project review	1	2	1	4	9	9	11
6-O3) Maintaining past contractors/suppliers experience system	0	3	6	1	7	8	12
6-O4) Reviewing work processes to ensure best practices are being used	0	5	3	6	5	10	8
6-O5) Ensuring integration of all processes to avoid duplication and gaps	1	3	3	10	6	9	5
6-O6) Defining the quality requirements as clearly as possible at the project outset	1	0	2	1	4	13	16
6-O7) Determining the project's quality standards and testing requirements	1	1	6	1	7	11	10
6-O8) Setting up performance guarantees (required tests, audits, frequency of inspections, types, and methods of inspections)	2	1	5	4	6	13	6
6-O9) Recommending remedial works for defects	4	7	4	8	5	4	5
6-O10) Conducting comprehensive quality audits	0	5	4	8	5	5	10
6-O11) Preparing the inspection and testing plans	4	13	5	5	2	4	4
6-O12) Collecting, analyzing, and recording lessons learned in each project phase	1	3	8	13	5	4	3
6-O13) Developing and maintaining a process to transfer Lessons Learned information to future projects	1	3	4	8	6	5	10
6-O14) Integrating maintenance and operability with the lessons learned process	0	1	2	3	6	16	9
6-C1) Receiving inspection requests from the subcontractors and handling testing	0	1	0	1	0	19	16
6-C2) Inspecting and approving all installations of subcontractors	0	1	0	2	4	13	17
6-C3) Identifying deficiencies and ensuring remedies are in place	0	1	0	0	5	18	13
6-C4) Following the quality requirements as set by the owner	1	0	0	0	0	12	24
6-C5) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	0	0	1	0	1	15	20
6-C6) Documenting the lessons learned	0	0	1	7	5	11	13

	Fuzzy Rating (Y_k)						
7- TECHNICAL INFORMATION & DOCUMENT MANAGEMENT PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
7-O1) Maintaining vendor document control system	5	9	3	7	2	4	7
7-O2) Maintaining a document control facility	5	7	0	6	1	9	9
7-O3) Developing and managing a system to collect the project data	2	8	0	5	3	8	11
7-O4) Managing the information in databases and retrieval systems	2	6	2	6	2	11	8
7-O5) Archiving project close-out documentation and communicating lessons learned	2	4	2	5	3	12	9
7-O6) Developing and maintaining a process to transfer operations and maintenance knowledge throughout the projects	0	2	0	1	5	17	12
7-O7) Coordinating data flow and documents between project components and parties	1	2	0	2	3	14	15
7-C1) Incorporating maintenance and operability into standards where appropriate	1	5	3	5	3	11	9
7-C2) Preparing and submitting the operation and maintenance manuals prior to testing	0	3	2	0	1	15	16

	Fuzzy Rating (Y_k)						
8- FINANCIAL CONTROLS PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
8-O1) Approving project funding	2	0	0	0	0	1	34
8-O2) Providing timely payment to the contractor based on the work done and the schedule of values	2	0	0	2	1	8	24
8-O3) Providing the payment of invoices for procured goods	2	0	0	4	3	10	18
8-O4) Setting the financial plans	2	0	1	3	0	7	24
8-O5) Finalizing the Authorisation for Expenditures (AFE)	1	1	0	0	0	3	32
8-O6) Preparing the asset management plan	0	2	0	1	2	7	25
8-O7) Setting the financial audit methodology	0	0	2	1	1	7	26
8-O8) Reporting to financial systems	1	3	0	2	2	9	20
8-O9) Recording payables and receivables	1	5	0	2	3	7	19
8-O10) Monitoring and updating integrated silos cash position	1	3	0	4	4	7	18
8-C1) Reporting to the financial systems of the owner	0	2	1	0	4	12	18

	Fuzzy Rating (Y_k)						
9- PROJECT CONTROLS PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
9-O1) Developing the execution schedule and providing continuous updates	4	5	7	5	5	7	4
9-O2) Integrating the execution schedule with the cost estimating and cost control functions and providing input for both	3	7	9	1	4	7	6
9-O3) Identifying scheduling alternatives and improvements	1	6	6	10	6	5	3
9-O4) Revising the EPC contractors' time schedules and recommending changes	3	7	5	9	3	3	7
9-O5) Linking both the engineering and procurement tasks to the construction time schedule and determining appropriate lead and lag times	4	17	4	1	7	2	2
9-O6) Determining the schedule-driven activities to ensure the work will be performed in a coordinated manner	3	14	6	2	7	1	4
9-O8) Selecting and using the most appropriate planning and monitoring tools	1	8	3	5	3	7	10
9-O7) Incorporating various EPC contracts' works in one integrated time schedule and determining who works when	2	0	3	2	9	10	11
9-O9) Producing the overall schedule status reports	4	6	1	1	7	8	10
9-O10) Recommending mitigating methods for schedule variances	3	9	7	10	3	3	2
9-O11) Conducting full progress monitoring of the project activities	4	9	7	4	4	5	4
9-O12) Providing cost and schedule estimated contingencies with the aid of the EPC	2	4	2	6	7	9	7
9-O13) Tracking and monitoring of the risks and risk allowance/contingency	1	5	6	5	4	10	6
9-O14) Reporting the outcome from risk management planning to the project execution plan- e.g. adding a contingency budget or time to the plan	1	5	3	3	7	10	8
9-O15) Determining estimate basis for facility components	2	6	9	4	4	8	4
9-O16) Determining historical cost basis for facility components	2	11	6	2	5	8	3
9-O17) Converting estimate basis to costs	6	9	6	3	2	6	5
9-O18) Comparing the estimate of individual items with the previous costs of similar items	5	13	6	4	2	4	3
9-O19) Reviewing estimates with the project team	2	5	4	10	5	4	7
9-O20) Preparing detailed estimates for cost and schedule	10	14	7	2	2	0	2
9-O21) Preparing forecasts and costs to completion estimates based on the current project's status	7	9	7	5	4	1	4
9-O22) Preparing a cost break down structure and chart of accounts	5	9	3	3	0	8	9
9-O23) Preparing integrated project cash flow	1	7	2	4	4	6	13
9-O24) Developing a system to forecast all project costs at completion	0	8	5	2	1	7	14
9-O25) Recommending mitigating methods for cost variances	1	7	6	10	3	3	7
9-O26) Monitoring project's individual cost items	7	13	3	7	1	2	4
9-O27) Keeping records of the summary of charges as reflected by the job cost accounts, including expenditures and estimated costs	3	11	2	8	2	2	9
9-O28) Comparing the planned budget to the actual budget based on the overall planned versus actual expenditures of the combined EPC contracts	1	3	6	6	1	8	12
9-O29) Forecasting for activity cost control and providing budget updates	4	8	6	5	2	5	7
9-O30) Relating Cost and Schedule Information and producing an earned value analysis	4	10	8	6	2	2	5
9-O31) Creating and monitoring project reporting processes	2	9	4	4	3	8	7
9-O32) Managing the network of benchmark partners	1	2	2	4	4	11	13
9-O33) Assessing and implementing the best monitoring practices	1	2	6	12	4	4	8
9-O34) Monitoring internal performance against the established standards	1	6	1	5	2	12	10
9-O35) Collecting data and reporting on the established metrics	3	6	5	5	4	7	7
9-C1) Collecting data and involving all project participants in schedule preparation	0	2	1	2	4	21	7
9-C2) Integrating with estimating and cost control, as well as providing input to estimating and cost control	1	0	1	3	7	16	9
9-C3) Communicating scheduling conflicts with other EPC contractors' systems	0	3	6	6	7	8	7
9-C4) Implementing alternatives and improvements in the schedule	0	0	1	3	4	20	9
9-C5) Scheduling, work monitoring, and reporting on the progress of the work relative to the milestones to the Owner	0	1	0	1	0	22	13
9-C6) Selecting and using the most appropriate planning and monitoring tools	1	2	2	5	7	15	5
9-C7) Producing the overall schedule status reports	2	3	1	4	5	10	12
9-C8) Progress monitoring of the project activities	1	0	1	2	4	13	16
9-C9) Gathering all the required detailed information for estimating	0	1	0	2	1	20	13
9-10) Preparing the detailed estimates	1	0	0	1	2	15	18
9-11) Preparing the forecasts and costs to completion estimates	1	0	0	1	3	17	15
9-12) Supporting the owner on cost and risk direction	0	1	0	3	7	13	13
9-13) Producing regular status reports on costs, scope, and risk	0	1	0	1	3	15	17

	Fuzzy Rating (Y_k)						
10- ENGINEERING PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10-O1) Defining the Front-End Engineering Design (FEED)	1	0	2	5	6	9	14
10-O2) Finalizing the Front-End Engineering Design (FEED)	1	10	12	2	4	1	7
10-O3) Participating in performing calculations and detailed design	12	17	2	1	1	0	4
10-O4) Participating in producing drawings, material lists, and specifications	12	12	5	1	1	1	5
10-O5) Issuing construction and fabrication work packages	19	10	0	3	1	0	4
10-O6) Providing technical coordination with suppliers	11	13	4	3	1	1	4
10-O7) Conducting design reviews	2	5	12	6	3	3	6
10-O8) Preparing a detailed quantity take off of the project's items	20	9	1	3	0	0	4
10-O9) Incorporating maintenance and operability into standards where appropriate	1	3	3	8	5	10	7
10-O10) Administering the constructability process	4	13	6	3	3	2	6
10-O11) Negotiating constructability plans with EPC contractors	1	5	5	6	3	5	12
10-O12) Providing constructability input to the lessons learned	0	3	10	9	2	5	8
10-O13) Liaison with design	3	8	8	1	6	2	9
10-C1) Preparing design from the preliminary release to final release	0	1	0	0	4	17	15
10-C2) Preparing the design requirements standards	2	5	6	5	7	7	5
10-C3) Converting and implementing new technologies	1	7	0	6	8	7	8
10-C4) Performing calculations and detailed design	1	0	0	0	1	4	31
10-C5) Producing drawings, material lists, and specifications	1	0	0	1	0	11	24
10-C6) Adhering to standards, codes, laws, and corporate practices	1	0	0	1	2	7	26
10-C7) Providing technical coordination with the suppliers	0	1	0	0	0	17	19
10-C8) preparing the final installation details	1	0	1	0	1	8	26
10-C9) Performing coordination works and design reviews	1	0	1	2	6	18	9
10-C10) Providing the owner with the as-built drawings upon completion of the works	1	0	0	0	3	8	25
10-C11) Establishing a constructability plan	0	1	0	3	4	19	10
10-C12) Evaluating constructability information with the owner	1	0	0	4	10	11	11
10-C13) Incorporating the proposed improvements into the project plan	1	0	0	3	4	16	13
10-C14) Providing constructability input to the lessons learned	1	0	2	7	8	9	10

	Fuzzy Rating (Y_k)						
11- SUPPLY CHAIN MANAGEMENT PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
11-O1) Evaluating and making recommendations on submitted bid packages	4	14	2	3	4	3	7
11-O2) Developing and maintaining a process for contracting work, equipment, materials, and services	3	12	5	2	4	2	9
11-O3) Issuing material purchase orders (POs)	13	12	4	1	0	3	4
11-O4) Providing expediting service	19	9	2	1	0	1	5
11-O5) Providing instructions and guidelines that identify the levels of review and approvals required by the owner in relation to the procured goods	4	2	0	1	2	12	16
11-O6) Determining the procurement strategies and owner's specified materials	1	1	4	3	3	12	13
11-O7) Inspecting partially or fully the delivered materials to site	8	13	4	4	2	1	5
11-O8) Preparing transportation and logistics plan for supply	9	12	3	5	1	2	5
11-O9) Liaison with equipment and material suppliers	14	11	3	2	1	2	4
11-O10) Procuring long lead items and bulk equipment	11	11	4	3	3	1	4
11-C1) Providing timely coordination and management of transportation and related services for the work	0	1	0	0	0	19	17
11-C2) Assemblying the required information including site investigations and inspection requirements	0	0	2	1	2	15	17
11-C3) Developing and maintaining a process for subcontracting work, equipment, materials, and services	0	1	0	1	2	20	13
11-C4) Providing supply inspection services	0	1	0	0	0	18	18
11-C5) Establishing and implementing purchasing standards	3	3	1	7	6	9	8
11-C6) Submitting any required material samples for the owner's representative's approval, together with any relevant information	2	0	0	0	3	12	20

	Fuzzy Rating (Y_k)						
12- CONTRACTING PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
12-O1) Developing the contracting procedure	2	3	1	3	3	7	18
12-O2) Developing and implementing a dispute resolution mechanism to avoid or manage claims	2	1	3	4	3	10	14
12-O3) Ensuring corporate and legal requirements are met	2	2	0	6	2	4	21
12-O4) Interpreting contract conditions including matters dealing with legal, financial, technical, and taxation	0	4	0	4	7	9	13
12-O5) Preparing RFPs and negotiating the final contract conditions prior to awarding to EPCs	1	2	1	3	2	5	23
12-O6) Preparing the insurance plan	0	1	0	2	1	8	25
12-O7) Providing copies of the insurance policies before requiring the contractor to sign the EPC contract	2	1	0	1	1	8	24
12-O8) Setting up the contract delivery method(s) (DB, D-Bid-B, CM, etc.) and format (fixed, variable, cost-plus, etc)	1	1	1	3	2	9	20
12-C1) Preparing and submitting invoices for all work performed in accordance with the contract	2	0	0	0	0	7	28

	Fuzzy Rating (Y_k)						
13-CONSTRUCTION PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
13-O1) Preparing construction method statements and alternatives	3	6	10	3	2	6	7
13-O2) Selecting and implementing the optimum construction strategy for the project	1	3	9	3	7	4	10
13-O3) Coordinating the installation of equipment amongst EPC contractors	1	4	1	7	10	5	9
13-O4) Coordinating multi-trade and multi-site activities amongst EPC contractors	0	3	3	7	8	6	10
13-O5) Receiving and evaluating problems and opportunities from concerned EPCs	1	2	2	3	8	8	13
13-O6) Administering, supervising, managing, and monitoring the EPC contractors	0	4	0	1	3	9	20
13-O7) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	4	12	7	1	2	2	9
13-C1) Maintaining and keeping the as-built drawings on the work site	1	0	0	1	1	8	26
13-C2) Installing all equipment and structures	1	0	0	0	0	6	30
13-C3) Providing required information during construction & installation	0	1	0	1	0	8	27
13-C4) Providing tools, construction equipment, and consumables	1	1	0	0	0	5	30
13-C5) Maintaining site cleanup and restoration	1	0	0	0	0	5	31
13-C6) Receiving, storing, and handling of material and equipment at site	0	1	0	1	0	8	27
13-C7) Managing the project site	0	1	4	2	2	9	19
13-C8) Coordinating multi-trade and multi-site activities amongst subcontractors and suppliers	0	3	2	4	1	10	17
13-C9) Receiving and evaluating problems and opportunities from concerned subcontractors	0	1	0	1	2	17	16
13-C10) Coordinating the installation of equipment	0	1	0	0	0	10	26
13-C11) Coordination of subcontractors work	0	1	0	0	0	10	26

	Fuzzy Rating (Y_k)						
14- READY FOR OPERATIONS (RFO) PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
14-O1) Providing input on operability, and maintainability processes as well as providing supplementary technical support	1	1	0	1	5	14	15
14-O2) Producing and/or approving individual commissioning	2	0	0	1	4	10	20
14-O3) Providing design sign-offs plans	3	5	3	2	4	12	8
14-O4) Providing the final inspections and signing-off on the project installations	1	2	2	3	4	10	15
14-O5) Inspecting and approving all installations	1	4	5	3	7	6	11
14-O6) Developing a teamwork/ ownership environment during the commissioning stage	1	0	0	4	7	9	16
14-O7) Coordinating commissioning plans for the manufacturers, suppliers, and EPCs	2	3	1	4	7	9	11
14-O8) Collecting turnover documentation	3	4	5	1	2	8	14
14-O9) Coordinating the transition from construction to operation	1	0	1	2	4	14	15
14-O10) Recommending operation strategies	2	1	1	0	1	15	17
14-O11) Arranging, coordinating, and ensuring training on equipment and system requirements	0	1	0	1	4	15	16
14-O12) Issuing functional completion certificates upon taking over the work for functional use	0	2	0	1	2	7	25
14-O13) Coordinating start-up activities	1	0	1	0	4	9	22
14-O14) Finalizing handing over and start-up systems	3	2	0	1	4	6	21
14-O15) Obtaining license to operate	1	0	0	0	1	2	32
14-O16) Performing spares and warranty management	0	1	0	1	6	9	20
14-C1) Comparing the performance requirements with the project's performance outcome	0	4	6	3	5	11	8
14-C2) Executing the commissioning plan	2	4	9	5	3	3	11
14-C3) Providing the owner with proper turnover documentation	1	0	1	0	4	9	22
14-C4) Arranging, coordinating, and conducting training on the equipment and system requirements	2	5	10	2	8	0	10
14-C5) Conducting performance testing based on the performance standards.	2	4	4	1	9	6	11
14-C6) Obtaining the work sign-off from the owner	2	1	1	2	2	10	19
14-C7) Coordinating the start-up activities within subcontractors and suppliers	3	3	4	5	4	7	11
14-C8) Coordinating and working in liaison with production units	5	7	1	5	3	5	11

	Fuzzy Rating (Y_k)						
15- OPERATIONS & MAINTENANCE PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
15-O1) Developing and implementing operating procedures including shutdown/start-up and emergency procedures	1	0	0	3	3	12	18
15-O2) Developing and implementing maintenance and inspection programs	1	0	0	1	1	14	20
15-O3) Developing and implementing turnaround plan including safe making procedure	1	0	0	2	0	12	22

	Fuzzy Rating (Y_k)						
16- ADMINISTRATION PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
16-O1) Providing administrative support for travel	5	4	1	8	5	6	8
16-O2) Providing administrative support for meeting set up and coordination	7	4	1	10	4	5	6
16-O3) Providing administrative support for teleconferences	6	4	2	9	5	4	7
16-O4) Providing administrative support for office suppliers	8	5	3	6	2	3	10

	Fuzzy Rating (Y_k)						
17-MANAGEMENT OF CHANGES PROCESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
17-O1) Managing project changes	1	1	2	9	2	8	14
17-O2) Developing team responses and strategies to deal with changes	2	0	2	7	2	9	15
17-O3) Providing required approvals for design changes after revising designs	1	1	0	3	2	11	19
17-O4) Developing and implementing An integrated contract change control process for all EPCs	1	0	0	7	4	6	19
17-O5) Evaluating preliminary cost of change orders and providing necessary approvals	1	1	2	6	4	10	13
17-O6) Evaluating feedbacks of EPC on change requests and deciding on whether the changes are to be executed or not	0	2	0	0	1	15	19
17-C1) Getting the necessary approvals on design changes	0	2	2	3	5	8	17
17-C2) Submitting requests for change orders and reporting to the owner	1	1	1	2	3	9	20

18-INFORMATION SYSTEMS PROCESS	Fuzzy Rating (Y_k) 1	2	3	4	5	6	7
18-O1) Providing a mechanism for monitoring and assessing the options to upgrade existing technologies	1	2	1	2	5	12	14
18-O2) Scoping, developing and providing business systems and application requirements	1	3	1	1	3	8	20
18-O3) Scoping, developing and providing project IT hardware requirements	2	3	2	4	1	8	17
18-C1) Providing the required support in the required areas of equipment, systems, and processes	0	2	0	3	5	10	17

APPENDIX G

RESPONSIBILITY TASK LISTS

1- PROJECT INITIATION PROCESS	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
1-O1) Establishing a project's required goals	OWNER	PRINCIPAL RESPONSIBILITY
1-O2) Developing the business case summary and analyzing the business needs	OWNER	SOLE RESPONSIBILITY
1-O3) Receiving and evaluating problems and opportunities from stakeholders	OWNER	PRINCIPAL RESPONSIBILITY
1-O4) Conducting the Project Life Cycle Value Analysis (LCVA)	OWNER	PRINCIPAL RESPONSIBILITY
1-O5) Determining the strategic objectives of the project	OWNER	PRINCIPAL RESPONSIBILITY
1-O6) Establishing project's critical success factors / performance criteria	OWNER	PRINCIPAL RESPONSIBILITY
1-O7) Coordinating and integrating data required to develop options and recommend a project strategy	OWNER	PRINCIPAL RESPONSIBILITY
1-O8) Conducting project's initiation benchmarking	OWNER	PRINCIPAL RESPONSIBILITY
1-O9) Establishing the finalized project charter	OWNER	PRINCIPAL RESPONSIBILITY
1-O10) Providing the context for detailed decisions by project management, such as whether the project is schedule or cost driven	OWNER	PRINCIPAL RESPONSIBILITY
1-O11) Determining the project's key milestones	OWNER	PRINCIPAL RESPONSIBILITY
1-O12) Determining the project's programme of works	OWNER	SIGNIFICANT INVOLVEMENT
1-O13) Determining the project's policies and guidelines	OWNER	PRINCIPAL RESPONSIBILITY
1-O14) Describing the scope and standards and setting the design criteria	OWNER	PRINCIPAL RESPONSIBILITY
1-O15) Providing the initial organization structure and project framework	OWNER	PRINCIPAL RESPONSIBILITY
1-O16) Developing Stakeholder / NGO Plan	OWNER	PRINCIPAL RESPONSIBILITY
1-O18) Determining the project execution strategy	OWNER	SIGNIFICANT INVOLVEMENT
1-O19) Preparing the project's preliminary work breakdown structure	OWNER	SIGNIFICANT INVOLVEMENT
1-O20) Deciding on the full project sanctioning	OWNER	PRINCIPAL RESPONSIBILITY
1-O21) Obtaining regulatory approvals	OWNER	PRINCIPAL RESPONSIBILITY
1-O22) Setting the operational philosophy	OWNER	PRINCIPAL RESPONSIBILITY
1-O23) Participating in creating conceptual drawings	OWNER	SIGNIFICANT INVOLVEMENT
1-O24) Finalizing the feasibility analysis study of the project	OWNER	SIGNIFICANT INVOLVEMENT
1-O25) Performing project's financial and investment risk assessment	OWNER	PRINCIPAL RESPONSIBILITY
1-O26) Conducting stage gate reviews	OWNER	PRINCIPAL RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
1-C1) Aiding in conducting feasibility studies	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
1-C2) Providing benchmarking data and comparable projects' costs	SHARED	SHARED EQUALLY
1-O17) Preparing the Design Basis Memorandum(DBM)	SHARED	SHARED EQUALLY

2- ORGANIZATION	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
2-O1) Conducting team-building exercises	OWNER	SIGNIFICANT INVOLVEMENT
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
2-C1) Supporting team members on methods and implications	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
2-O2) Preparing the owners project's organisational chart as a part of the execution plan	SHARED	SHARED EQUALLY
2-O3) Making project staff reassignments	SHARED	SHARED EQUALLY
2-C2) Submitting a proposed organisational chart, for the owner's approval, as part of the execution plan	SHARED	SHARED EQUALLY

3- PROJECT MANAGEMENT PROCESS	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
3-O2) Approving detailed scope statements of work for all EPC contractors	OWNER	PRINCIPLE RESPONSIBLITY
3-O3) Preparing the Preliminary Project Execution Plan (PEP)	OWNER	PRINCIPLE RESPONSIBLITY
3-O5) Conducting coordination meetings with EPC contractors' planners and estimators	OWNER	SIGNIFICANT INVOLVEMENT
3-O6) Incorporating start/finish milestone dates in a project's integrated schedule to emphasize on project's physical interfaces between contractors and suppliers	OWNER	SIGNIFICANT INVOLVEMENT
3-O7) Determining the overall Project's duration	OWNER	PRINCIPLE RESPONSIBLITY
3-O8) Setting up a monitoring team to watch over the schedule performance of various EPC contractors when the execution stage starts	OWNER	PRINCIPLE RESPONSIBLITY
3-O9) Applying liquidated damages or incentives based on contract performance	OWNER	PRINCIPLE RESPONSIBLITY
3-O10) Submitting the overall schedule status reports to key management	OWNER	PRINCIPLE RESPONSIBLITY
3-O12) Adopting an active risk-management approach that includes the assignment of mitigation responsibilities to the appropriate project participants and the oversight of follow-through for each task	OWNER	SIGNIFICANT INVOLVEMENT
3-O14) Effectively communicating the progress to all key stakeholders, as well as changes to the project risks and mitigation plans	OWNER	SIGNIFICANT INVOLVEMENT
3-O16) Networking, coordinating, and collaborating with other project team members and support teams, including specialist estimators, site operations, and design function engineers	OWNER	SIGNIFICANT INVOLVEMENT
3-O17) Developing an effective and efficient owner team that coordinates with the EPC team(s)	OWNER	SOLE RESPONSIBILITY
3-O18) Developing open communications and trust	OWNER	SIGNIFICANT INVOLVEMENT
3-O19) Establishing clear accountabilities	OWNER	SIGNIFICANT INVOLVEMENT
3-O20) Identifying and resolving gaps, overlaps, and duplications in roles, responsibilities, positions, and eliminating the dysfunctional elements from the team, while updating the HR plan	OWNER	SIGNIFICANT INVOLVEMENT
3-O21) Accepting key personnel of the EPCs and advising on non-accepted personnel	OWNER	PRINCIPLE RESPONSIBLITY
3-O22) Initiating the development of the project execution plan and monitoring its implementation	OWNER	SIGNIFICANT INVOLVEMENT
3-O23) Establishing project organization and accountabilities	OWNER	SIGNIFICANT INVOLVEMENT
3-O24) Interpreting and communicating the project goals to team members	OWNER	SIGNIFICANT INVOLVEMENT
3-O25) Communicating the project monitoring and control system	OWNER	SIGNIFICANT INVOLVEMENT
3-O26) Assembling the owner representatives on the project team	OWNER	SOLE RESPONSIBILITY
3-O27) Monitoring and approving the scope, conceptual design, and risk analysis	OWNER	PRINCIPLE RESPONSIBLITY
3-O28) Approving and monitoring the project reporting processes	OWNER	PRINCIPLE RESPONSIBLITY
3-O29) Making sure that project's critical result areas are met	OWNER	SIGNIFICANT INVOLVEMENT
3-O30) Recruiting operating or ready for operations organization	OWNER	SOLE RESPONSIBILITY
3-O31) Monitoring adherence to safety plans and receiving periodical reports on performance	OWNER	SIGNIFICANT INVOLVEMENT
3-O32) Setting Initial Partnering Strategy	OWNER	PRINCIPLE RESPONSIBLITY
3-O33) Establishing legally and financially tenable alliances	OWNER	PRINCIPLE RESPONSIBLITY
3-O34) Managing alliances	OWNER	PRINCIPLE RESPONSIBLITY
3-O35) Acquiring available skills and knowledge from all involved partners	OWNER	PRINCIPLE RESPONSIBLITY
3-O36) Establishing decision-making authority levels and sources	OWNER	PRINCIPLE RESPONSIBLITY
3-O37) Establishing communication systems with partners	OWNER	PRINCIPLE RESPONSIBLITY
3-O38) Setting alliance performance measurement and reward systems	OWNER	PRINCIPLE RESPONSIBLITY
3-O39) Developing communication networks with the industry peers	OWNER	PRINCIPLE RESPONSIBLITY
3-O40) Reporting activities and status to senior management	OWNER	PRINCIPLE RESPONSIBLITY
3-O41) Identifying critical interfaces and any issues	OWNER	SIGNIFICANT INVOLVEMENT
3-O43) Assigning roles & responsibilities to address interface issues	OWNER	SIGNIFICANT INVOLVEMENT
3-O44) Providing an interface management tool	OWNER	PRINCIPLE RESPONSIBLITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
3-C1) Providing preliminary cost estimation and scheduling	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C2) Providing input into the preparation of the Preliminary Project Execution Plan	CONTRACTOR	SIGNIFICANT INVOLVEMENT
3-C3) Advising on the contracting strategy, and subcontractors	CONTRACTOR	SIGNIFICANT INVOLVEMENT
3-C5) Developing the own-works execution plan and providing continuous updates to the plan	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C6) Preparing reports and attendance at meetings with the owner	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C7) Submitting the overall schedule status reports to the owner	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C8) Conducting team-building exercises and developing open communications and trust	CONTRACTOR	SIGNIFICANT INVOLVEMENT
3-C9) Initiating the development of the project execution plan and monitoring its implementation	CONTRACTOR	SIGNIFICANT INVOLVEMENT
3-C10) Managing assigned resources to achieve the project objectives	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C11) Assembling EPC's project team	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C12) Ensuring the EPC team has access to resources, tools, and equipment	CONTRACTOR	PRINCIPLE RESPONSIBLITY
3-C13) Reporting the project status to the stakeholders	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
3-O1) Preparing the project's detailed work breakdown structure	SHARED	SHARED EQUALLY
3-O4) Implementing a value improvement practice (VIP) for process design improvement	SHARED	SHARED EQUALLY
3-O11) Identifying, analyzing, mitigating, and controlling project risks	SHARED	SHARED EQUALLY
3-O13) Developing risk mitigation plans and updating them as the project progresses and following through with mitigation actions until risks are acceptable	SHARED	SHARED EQUALLY
3-O15) Participating in suppliers negotiations and providing approvals thereof	SHARED	SHARED EQUALLY
3-O42) Developing a plan to address interface issues	SHARED	SHARED EQUALLY
3-O45) Delivering best in class project execution	SHARED	SHARED EQUALLY
3-C4) Infusing new advances into the business planning process	SHARED	SHARED EQUALLY

4- SAFETY MANAGEMENT	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
4-O2) Administering the development and maintainence of a safety programs that meets legal, regulatory, corporate, and local requirements	OWNER	PRINCIPLE RESPONSIBILITY
4-O3) Holding sessions for identifying hazards and eliminating them to reduce to lowest acceptable levels	OWNER	SIGNIFICANT INVOLVEMENT
4-O4) Communicating safety risks to projects' stakeholders	OWNER	PRINCIPLE RESPONSIBILITY
4-O5) Communicating safety expectations to all projects' participants	OWNER	PRINCIPLE RESPONSIBILITY
4-O6) Establishing and managing a safety reporting and investigation system	OWNER	SIGNIFICANT INVOLVEMENT
4-O7) Administering training in health and safety	OWNER	SIGNIFICANT INVOLVEMENT
4-O8) Receiving and commenting on individual subcontractors' safety plans based on the projects' guidelines and standards	OWNER	PRINCIPLE RESPONSIBILITY
4-O9) Having the highest regard for safety, emergency procedures, and loss management at all times	OWNER	SIGNIFICANT INVOLVEMENT
4-O10) Updating the emergency response plan and testing its efficiency	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
4-C1) Developing and maintaining a safety program that meets legal, regulatory, corporate, and local requirements	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C2) Monitoring adherence to the safety plan and reporting on performance for all subcontractors	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C3) Identifying hazards and reducing them to the lowest acceptable levels	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C4) Communicating safety risks to stakeholders	CONTRACTOR	SIGNIFICANT INVOLVEMENT
4-C5) Establishing and managing a safety reporting and investigation system	CONTRACTOR	SIGNIFICANT INVOLVEMENT
4-C6) Conducting training in health and safety	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C7) Providing support to interpret legislative and regulatory requirements	CONTRACTOR	SIGNIFICANT INVOLVEMENT
4-C8) Assisting the subcontractors in safe work practices	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C9) Performing the work in a manner which will cause minimum inconvenience, injury, and damage to others	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C10) Protecting the work site, the owner's property, and the property of third parties from loss or damage	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C11) Complying with all other safety requirements specified in the contract	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C12) Keeping all working and storage areas clean, orderly, and secure	CONTRACTOR	PRINCIPLE RESPONSIBILITY
4-C13) Monitoring and coordinating safety, environment, and labour relations requirements	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
4-O1) Conducting Process Hazard Analysis (PHA) and setting Safety Integrity Levels (SIL)	SHARED	SHARED EQUALLY

5- REGULATIONS COMPLIANCE	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
5-O1) Conducting regulatory reviews	OWNER	PRINCIPAL RESPONSIBILITY
5-O2) Defining external permitting strategy (which, how and when)	OWNER	PRINCIPAL RESPONSIBILITY
5-O3) Identifying the regulatory agencies	OWNER	PRINCIPAL RESPONSIBILITY
5-O4) Establishing and maintaining communication links with regulators and facilities	OWNER	PRINCIPAL RESPONSIBILITY
5-O5) Acquiring and maintaining knowledge of the environmental requirements	OWNER	PRINCIPAL RESPONSIBILITY
5-O6) Coordinating and conducting environmental assessments	OWNER	PRINCIPAL RESPONSIBILITY
5-O7) Applying for environmental permits	OWNER	SOLE RESPONSIBILITY
5-O8) Preparing the environmental management plan of the project	OWNER	PRINCIPAL RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
5-C1) Aiding the owner in preparing the environmental management plan of the project	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
NA		

6- QUALITY MANAGEMENT	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
6-O2) Conducting independent project review	OWNER	PRINCIPLE RESPONSIBILITY
6-O3) Maintaining past contractors/suppliers experience system	OWNER	SIGNIFICANT INVOLVEMENT
6-O4) Reviewing work processes to ensure best practices are being used	OWNER	SIGNIFICANT INVOLVEMENT
6-O5) Ensuring integration of all processes to avoid duplication and gaps	OWNER	SIGNIFICANT INVOLVEMENT
6-O6) Defining the quality requirements as clearly as possible at the project outset	OWNER	PRINCIPLE RESPONSIBILITY
6-O7) Determining the project's quality standards and testing requirements	OWNER	SIGNIFICANT INVOLVEMENT
6-O8) Setting up performance guarantees (required tests, audits, frequency of inspections, types, and methods of inspections)	OWNER	SIGNIFICANT INVOLVEMENT
6-O10) Conducting comprehensive quality audits	OWNER	SIGNIFICANT INVOLVEMENT
6-O13) Developing and maintaining a process to transfer Lessons Learned information to future projects	OWNER	SIGNIFICANT INVOLVEMENT
6-O14) Integrating maintenance and operability with the lessons learned process	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
6-O11) Preparing the inspection and testing plans	CONTRACTOR	PRINCIPLE RESPONSIBILITY
6-C1) Receiving inspection requests from the subcontractors and handling testing	CONTRACTOR	PRINCIPLE RESPONSIBILITY
6-C2) Inspecting and approving all installations of subcontractors	CONTRACTOR	PRINCIPLE RESPONSIBILITY
6-C3) Identifying deficiencies and ensuring remedies are in place	CONTRACTOR	PRINCIPLE RESPONSIBILITY
6-C4) Following the quality requirements as set by the owner	CONTRACTOR	SOLE RESPONSIBILITY
6-C5) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	CONTRACTOR	SOLE RESPONSIBILITY
6-C6) Documenting the lessons learned	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
6-O1) Participating in the preparation of design from the preliminary release to the final release	SHARED	SHARED EQUALLY
6-O9) Recommending remedial works for defects	SHARED	SHARED EQUALLY
6-O12) Collecting, analyzing, and recording lessons learned in each project phase	SHARED	SHARED EQUALLY

7- DOCUMENT MANAGEMENT	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
7-O2) Maintaining a document control facility	OWNER	SIGNIFICANT INVOLVEMENT
7-O3) Developing and managing a system to collect the project data	OWNER	SIGNIFICANT INVOLVEMENT
7-O4) Managing the information in databases and retrieval systems	OWNER	SIGNIFICANT INVOLVEMENT
7-O5) Archiving project close-out documentation and communicating lessons learned	OWNER	SIGNIFICANT INVOLVEMENT
7-O6) Developing and maintaining a process to transfer operations and maintenance knowledge throughout the projects	OWNER	PRINCIPLE RESPONSIBILITY
7-O7) Coordinating data flow and documents between project components and parties	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
7-C1) Incorporating maintenance and operability into standards where appropriate	CONTRACTOR	SIGNIFICANT INVOLVEMENT
7-C2) Preparing and submitting the operation and maintenance manuals prior to testing	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
7-O1) Maintaining vendor document control system	SHARED	SHARED EQUALLY

8- FINANCIAL CONTROL	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
8-O1) Approving project funding	OWNER	SOLE RESPONSIBILITY
8-O2) Providing timely payment to the contractor based on the work done and the schedule of values	OWNER	PRINCIPLE RESPONSIBILITY
8-O3) Providing the payment of invoices for procured goods	OWNER	PRINCIPLE RESPONSIBILITY
8-O4) Setting the financial plans	OWNER	PRINCIPLE RESPONSIBILITY
8-O5) Finalizing the Authorisation for Expenditures (AFE)	OWNER	SOLE RESPONSIBILITY
8-O6) Preparing the asset management plan	OWNER	SOLE RESPONSIBILITY
8-O7) Setting the financial audit methodology	OWNER	SOLE RESPONSIBILITY
8-O8) Reporting to financial systems	OWNER	PRINCIPLE RESPONSIBILITY
8-O9) Recording payables and receivables	OWNER	PRINCIPLE RESPONSIBILITY
8-O10) Monitoring and updating integrated silos cash position	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
8-C1) Reporting to the financial systems of the owner	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
NA		

9- PROJECT CONTROL	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
9-O8) Selecting and using the most appropriate planning and monitoring tools	OWNER	SIGNIFICANT INVOLVEMENT
9-O7) Incorporating various EPC contracts' works in one integrated time schedule and determining who works when	OWNER	PRINCIPLE RESPONSIBILITY
9-O9) Producing the overall schedule status reports	OWNER	SIGNIFICANT INVOLVEMENT
9-O12) Providing cost and schedule estimated contingencies with the aid of the EPC	OWNER	SIGNIFICANT INVOLVEMENT
9-O13) Tracking and monitoring of the risks and risk allowance/contingency	OWNER	SIGNIFICANT INVOLVEMENT
9-O14) Reporting the outcome from risk management planning to the project execution plan- e.g. adding a contingency budget or time to the plan	OWNER	SIGNIFICANT INVOLVEMENT
9-O23) Preparing integrated project cash flow	OWNER	SIGNIFICANT INVOLVEMENT
9-O24) Developing a system to forecast all project costs at completion	OWNER	SIGNIFICANT INVOLVEMENT
9-O28) Comparing the planned budget to the actual budget based on the overall planned versus actual expenditures of the combined EPC contracts	OWNER	SIGNIFICANT INVOLVEMENT
9-O32) Managing the network of benchmark partners	OWNER	PRINCIPLE RESPONSIBILITY
9-O33) Assessing and implementing the best monitoring practices	OWNER	SIGNIFICANT INVOLVEMENT
9-O34) Monitoring internal performance against the established standards	OWNER	SIGNIFICANT INVOLVEMENT
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
9-O5) Linking both the engineering and procurement tasks to the construction time schedule and determining appropriate lead and lag times	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-O6) Determining the schedule-driven activities to ensure the work will be performed in a coordinated manner	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-O18) Comparing the estimate of individual items with the previous costs of similar items	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-O20) Preparing detailed estimates for cost and schedule	CONTRACTOR	PRINCIPAL RESPONSIBILITY
9-O21) Preparing forecasts and costs to completion estimates based on the current project's status	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-O26) Monitoring project's individual cost items	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-O30) Relating Cost and Schedule Information and producing an earned value analysis	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-C1) Collecting data and involving all project participants in schedule preparation	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C2) Integrating with estimating and cost control, as well as providing input to estimating and cost control	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C3) Communicating scheduling conflicts with other EPC contractors' systems	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-C4) Implementing alternatives and improvements in the schedule	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C5) Scheduling, work monitoring, and reporting on the progress of the work relative to the milestones to the Owner	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C6) Selecting and using the most appropriate planning and monitoring tools	CONTRACTOR	SIGNIFICANT INVOLVEMENT
9-C7) Producing the overall schedule status reports	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C8) Progress monitoring of the project activities	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-C9) Gathering all the required detailed information for estimating	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-10) Preparing the detailed estimates	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-11) Preparing the forecasts and costs to completion estimates	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-12) Supporting the owner on cost and risk direction	CONTRACTOR	PRINCIPLE RESPONSIBILITY
9-13) Producing regular status reports on costs, scope, and risk	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
9-O1) Developing the execution schedule and providing continuous updates	SHARED	SHARED EQUALLY
9-O2) Integrating the execution schedule with the cost estimating and cost control functions and providing input for both	SHARED	SHARED EQUALLY
9-O3) Identifying scheduling alternatives and improvements	SHARED	SHARED EQUALLY
9-O4) Revising the EPC contractors' time schedules and recommending changes	SHARED	SHARED EQUALLY
9-O10) Recommending mitigating methods for schedule variances	SHARED	SHARED EQUALLY
9-O11) Conducting full progress monitoring of the project activities	SHARED	SHARED EQUALLY
9-O15) Determining estimate basis for facility components	SHARED	SHARED EQUALLY
9-O16) Determining historical cost basis for facility components	SHARED	SHARED EQUALLY
9-O17) Converting estimate basis to costs	SHARED	SHARED EQUALLY
9-O19) Reviewing estimates with the project team	SHARED	SHARED EQUALLY
9-O22) Preparing a cost break down structure and chart of accounts	SHARED	SHARED EQUALLY
9-O25) Recommending mitigating methods for cost variances	SHARED	SHARED EQUALLY
9-O27) Keeping records of the summary of charges as reflected by the job cost accounts, including expenditures and estimated costs	SHARED	SHARED EQUALLY
9-O29) Forecasting for activity cost control and providing budget updates	SHARED	SHARED EQUALLY
9-O31) Creating and monitoring project reporting processes	SHARED	SHARED EQUALLY
9-O35) Collecting data and reporting on the established metrics	SHARED	SHARED EQUALLY

10- ENGINEERING	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
10-O1) Defining the Front-End Engineering Design (FEED)	OWNER	PRINCIPLE RESPONSIBILITY
10-O9) Incorporating maintenance and operability into standards where appropriate	OWNER	SIGNIFICANT INVOLVEMENT
10-O11) Negotiating constructability plans with EPC contractors	OWNER	SIGNIFICANT INVOLVEMENT
10-O12) Providing constructability input to the lessons learned	OWNER	SIGNIFICANT INVOLVEMENT
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
10-O3) Participating in performing calculations and detailed design	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-O4) Participating in producing drawings, material lists, and specifications	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-O5) Issuing construction and fabrication work packages	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-O6) Providing technical coordination with suppliers	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-O8) Preparing a detailed quantity take off of the project's items	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-O10) Administering the constructability process	CONTRACTOR	SIGNIFICANT INVOLVEMENT
10-C1) Preparing design from the preliminary release to final release	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C3) Converting and implementing new technologies	CONTRACTOR	SIGNIFICANT INVOLVEMENT
10-C4) Performing calculations and detailed design	CONTRACTOR	SOLE RESPONSIBILITY
10-C5) Producing drawings, material lists, and specifications	CONTRACTOR	SOLE RESPONSIBILITY
10-C6) Adhering to standards, codes, laws, and corporate practices	CONTRACTOR	SOLE RESPONSIBILITY
10-C7) Providing technical coordination with the suppliers	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C8) preparing the final installation details	CONTRACTOR	SOLE RESPONSIBILITY
10-C9) Performing coordination works and design reviews	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C10) Providing the owner with the as-built drawings upon completion of the works	CONTRACTOR	SOLE RESPONSIBILITY
10-C11) Establishing a constructability plan	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C12) Evaluating constructability information with the owner	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C13) Incorporating the proposed improvements into the project plan	CONTRACTOR	PRINCIPLE RESPONSIBILITY
10-C14) Providing constructability input to the lessons learned	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
10-O2) Finalizing the Front-End Engineering Design (FEED)	SHARED	SHARED EQUALLY
10-O7) Conducting design reviews	SHARED	SHARED EQUALLY
10-O13) Liaison with design	SHARED	SHARED EQUALLY
10-C2) Preparing the design requirements standards	SHARED	SHARED EQUALLY

11- PROCUREMENT (SUPPLY CHAIN)	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
11-O5) Providing instructions and guidelines that identify the levels of review and approvals required by the owner in relation to the procured goods	OWNER	PRINCIPLE RESPONSIBILITY
11-O6) Determining the procurement strategies and owner's specified materials	OWNER	PRINCIPLE RESPONSIBILITY
11-O10) Procuring long lead items and bulk equipment	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
11-O3) Issuing material purchase orders (POs)	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-O4) Providing expediting service	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-O7) Inspecting partially or fully the delivered materials to site	CONTRACTOR	SIGNIFICANT INVOLVEMENT
11-O8) Preparing transportation and logistics plan for supply	CONTRACTOR	SIGNIFICANT INVOLVEMENT
11-O9) Liaison with equipment and material suppliers	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-C1) Providing timely coordination and management of transportation and related services for the work	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-C2) Assemblying the required information including site investigations and inspection requirements	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-C3) Developing and maintaining a process for subcontracting work, equipment, materials, and services	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-C4) Providing supply inspection services	CONTRACTOR	PRINCIPLE RESPONSIBILITY
11-C5) Establishing and implementing purchasing standards	CONTRACTOR	SIGNIFICANT INVOLVEMENT
11-C6) Submitting any required material samples for the owner's representative's approval, together with any relevant information	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
11-O1) Evaluating and making recommendations on submitted bid packages	SHARED	SHARED EQUALLY
11-O2) Developing and maintaining a process for contracting work, equipment, materials, and services	SHARED	SHARED EQUALLY

12- CONTRACTING	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
12-O1) Developing the contracting procedure	OWNER	PRINCIPLE RESPONSIBILITY
12-O2) Developing and implementing a dispute resolution mechanism to avoid or manage claims	OWNER	PRINCIPLE RESPONSIBILITY
12-O3) Ensuring corporate and legal requirements are met	OWNER	PRINCIPLE RESPONSIBILITY
12-O4) Interpreting contract conditions including matters dealing with legal, financial, technical, and taxation	OWNER	PRINCIPLE RESPONSIBILITY
12-O5) Preparing RFPs and negotiating the final contract conditions prior to awarding to EPCs	OWNER	PRINCIPLE RESPONSIBILITY
12-O6) Preparing the insurance plan	OWNER	SOLE RESPONSIBILITY
12-O7) Providing copies of the insurance policies before requiring the contractor to sign the EPC contract	OWNER	PRINCIPLE RESPONSIBILITY
12-O8) Setting up the contract delivery method(s) (DB, D-Bid-B, CM, etc.) and format (fixed, variable, cost-plus, etc)	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
12-C1) Preparing and submitting invoices for all work performed in accordance with the contract	CONTRACTOR	SOLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
NA		

13- CONSTRUCTION MANAGEMENT	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
13-O2) Selecting and implementing the optimum construction strategy for the project	OWNER	SIGNIFICANT INVOLVEMENT
13-O3) Coordinating the installation of equipment amongst EPC contractors	OWNER	SIGNIFICANT INVOLVEMENT
13-O4) Coordinating multi-trade and multi-site activities amongst EPC contractors	OWNER	PRINCIPLE RESPONSIBILITY
13-O5) Receiving and evaluating problems and opportunities from concerned EPCs	OWNER	PRINCIPLE RESPONSIBILITY
13-O6) Administering, supervising, managing, and monitoring the EPC contractors	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
13-C1) Maintaining and keeping the as-built drawings on the work site	CONTRACTOR	SOLE RESPONSIBILITY
13-C2) Installing all equipment and structures	CONTRACTOR	SOLE RESPONSIBILITY
13-C3) Providing required information during construction & installation	CONTRACTOR	SOLE RESPONSIBILITY
13-C4) Providing tools, construction equipment, and consumables	CONTRACTOR	SOLE RESPONSIBILITY
13-C5) Maintaining site cleanup and restoration	CONTRACTOR	SOLE RESPONSIBILITY
13-C6) Receiving, storing, and handling of material and equipment at site	CONTRACTOR	SOLE RESPONSIBILITY
13-C7) Managing the project site	CONTRACTOR	PRINCIPLE RESPONSIBILITY
13-C8) Coordinating multi-trade and multi-site activities amongst subcontractors and suppliers	CONTRACTOR	PRINCIPLE RESPONSIBILITY
13-C9) Receiving and evaluating problems and opportunities from concerned subcontractors	CONTRACTOR	PRINCIPLE RESPONSIBILITY
13-C10) Coordinating the installation of equipment	CONTRACTOR	SOLE RESPONSIBILITY
13-C11) Coordination of subcontractors work	CONTRACTOR	SOLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
13-O1) Preparing construction method statements and alternatives	SHARED	SHARED EQUALLY
13-O7) Inspecting and testing the construction work in accordance with the owner's requirements and the construction contract	SHARED	SHARED EQUALLY

14- READY FOR OPERATION	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
14-O1) Providing input on operability, and maintainability processes as well as providing supplementary technical support	OWNER	PRINCIPLE RESPONSIBILITY
14-O2) Producing and/or approving individual commissioning	OWNER	PRINCIPLE RESPONSIBILITY
14-O3) Providing design sign-offs plans	OWNER	SIGNIFICANT INVOLVEMENT
14-O4) Providing the final inspections and signing-off on the project installations	OWNER	PRINCIPLE RESPONSIBILITY
14-O5) Inspecting and approving all installations	OWNER	SIGNIFICANT INVOLVEMENT
14-O6) Developing a teamwork/ ownership environment during the commissioning stage	OWNER	PRINCIPLE RESPONSIBILITY
14-O7) Coordinating commissioning plans for the manufacturers, suppliers, and EPCs	OWNER	SIGNIFICANT INVOLVEMENT
14-O8) Collecting turnover documentation	OWNER	SIGNIFICANT INVOLVEMENT
14-O9) Coordinating the transition from construction to operation	OWNER	PRINCIPLE RESPONSIBILITY
14-O10) Recommending operation strategies	OWNER	PRINCIPLE RESPONSIBILITY
14-O11) Arranging, coordinating, and ensuring training on equipment and system requirements	OWNER	PRINCIPLE RESPONSIBILITY
14-O12) Issuing functional completion certificates upon taking over the work for functional use	OWNER	SOLE RESPONSIBILITY
14-O13) Coordinating start-up activities	OWNER	PRINCIPLE RESPONSIBILITY
14-O14) Finalizing handing over and start-up systems	OWNER	PRINCIPLE RESPONSIBILITY
14-O15) Obtaining license to operate	OWNER	SOLE RESPONSIBILITY
14-O16) Performing spares and warranty management	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
14-C1) Comparing the performance requirements with the project's performance outcome	CONTRACTOR	SIGNIFICANT INVOLVEMENT
14-C2) Executing the commissioning plan	CONTRACTOR	SIGNIFICANT INVOLVEMENT
14-C3) Providing the owner with proper turnover documentation	CONTRACTOR	PRINCIPLE RESPONSIBILITY
14-C5) Conducting performance testing based on the performance standards.	CONTRACTOR	SIGNIFICANT INVOLVEMENT
14-C6) Obtaining the work sign-off from the owner	CONTRACTOR	PRINCIPLE RESPONSIBILITY
14-C7) Coordinating the start-up activities within subcontractors and suppliers	CONTRACTOR	SIGNIFICANT INVOLVEMENT
14-C8) Coordinating and working in liaison with production units	CONTRACTOR	SIGNIFICANT INVOLVEMENT
SHARED RESPONSIBILITY TASK LIST		
14-C4) Arranging, coordinating, and conducting training on the equipment and system requirements	SHARED	SHARED EQUALLY

15- OPERATIONS AND MAINTENANCE	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
15-O1) Developing and implementing operating procedures including shutdown/start-up and emergency procedures	OWNER	PRINCIPLE RESPONSIBILITY
15-O2) Developing and implementing maintenance and inspection programs	OWNER	PRINCIPLE RESPONSIBILITY
15-O3) Developing and implementing turnaround plan including safe making procedure	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
NA		
SHARED RESPONSIBILITY TASK LIST		
NA		

16- ADMINISTRATION	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
16-O1) Providing administrative support for travel	OWNER	SIGNIFICANT INVOLEMENT
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
NA		
SHARED RESPONSIBILITY TASK LIST		
16-O2) Providing administrative support for meeting set up and coordination	SHARED	SHARED EQUALLY
16-O3) Providing administrative support for teleconferences	SHARED	SHARED EQUALLY
16-O4) Providing administrative support for office suppliers	SHARED	SHARED EQUALLY

17- MANAGEMENT OF CHANGES	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
17-O1) Managing project changes	OWNER	PRINCIPLE RESPONSIBILITY
17-O2) Developing team responses and strategies to deal with changes	OWNER	PRINCIPLE RESPONSIBILITY
17-O3) Providing required approvals for design changes after revising designs	OWNER	PRINCIPLE RESPONSIBILITY
17-O4) Developing and implementing An integrated contract change control process for all EPCs	OWNER	PRINCIPLE RESPONSIBILITY
17-O5) Evaluating preliminary cost of change orders and providing necessary approvals	OWNER	PRINCIPLE RESPONSIBILITY
17-O6) Evaluating feedbacks of EPC on change requests and deciding on whether the changes are to be executed or not	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
17-C1) Getting the necessary approvals on design changes	CONTRACTOR	PRINCIPLE RESPONSIBILITY
17-C2) Submitting requests for change orders and reporting to the owner	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
NA		

18- INFORMATION SYSTEM	FCBF MODEL OUTPUT	EXTENT OF RESPONSIBILITY (SAM)
OWNER'S RESPONSIBILITY TASK LIST		
18-O1) Providing a mechanism for monitoring and assessing the options to upgrade existing technologies	OWNER	PRINCIPLE RESPONSIBILITY
18-O2) Scoping, developing and providing business systems and application requirements	OWNER	PRINCIPLE RESPONSIBILITY
18-O3) Scoping, developing and providing project IT hardware requirements	OWNER	PRINCIPLE RESPONSIBILITY
EPC CONTRACTORS' RESPONSIBILITY TASK LIST		
18-C1) Providing the required support in the required areas of equipment, systems, and processes	CONTRACTOR	PRINCIPLE RESPONSIBILITY
SHARED RESPONSIBILITY TASK LIST		
NA		

APPENDIX H

QUESTIONNAIRE TO VALIDATE FUZZY CONSENSUS BUILDING FRAMEWORK (FCBF)

QUESTIONNAIRE TO VALIDATE FUZZY CONSENSUS BUILDING FRAMEWORK (FCBF) MODEL

Project Manager Name:

Contact Number:

Email:

Project Name:

Number of EPC Contractors Involved:

Project Size in Canadian Dollars:

Method of Delivery of the Project:

General Description of the Project:

SECTION 1

Section 1 of this survey requires you to rank your satisfaction level with each work process in your project in terms of achieving the objectives of the Owner Managing Contractor (OMC) project delivery system, as set by the Owner.

Using the seven linguistic terms below, how would you rank your satisfaction level with each of the following 18 work processes in your project in terms of achieving the OMC objectives, as set by the Owner?

	Extremely Unsatisfactory	Very Unsatisfactory	Unsatisfactory	Average	Satisfactory	Very Satisfactory	Extremely Satisfactory
Initiation							
Organization							
Project Management							
Safety Management							
Regulation Compliance							
Quality							
Document Management							
Financial Controls							
Project Controls							
Engineering							
Supply Chain (Procurement)							
Contracting							
Construction Management							
Ready for Operation							
Administration (HR)							
Change Management							
Information System							
Operation and Maintenance							

SECTION 2

Section 2 of this survey requires you to rank the impact of misalignment between your project teams on the level of satisfaction of each work process that you previously ranked as “Average” or below in Section 1.

For any of the 18 processes that you rated in Section 1, if its level of satisfaction was ranked as “Average” or below, using the five linguistic terms below, what was the impact of responsibility misalignment between project teams on the satisfaction level of this process? If the reasons for dissatisfaction were due to factors other than misalignment, please discuss in the column titled “Reasons other than Responsibility Misalignment.”

	Very Low Impact	Low Impact	Average Impact	High Impact	Very High Impact	Reasons other than Responsibility Misalignment
Initiation						
Organization						
Project Management						
Safety Management						
Regulation Compliance						
Quality						
Document Management						
Financial Controls						
Project Controls						
Engineering						
Supply Chain (Procurement)						
Contracting						
Construction Management						
Ready for Operation						
Administration (HR)						
Change Management						
Information System						
Operation and Maintenance						