QATAR UNIVERSITY

COLLEGE OF ENGINEERING

A NOVEL FRAMEWORK FOR CONSTRUCTION CONTRACTOR SELECTION USING UNIQUE HYBRID MULTI-CRITERIA DECISION-MAKING TECHNIQUE

BY

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ABSTRACT

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Title: A Novel Framework for Construction Contractor Selection Using Unique Hybrid Multi-Criteria Decision-Making Technique

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The successful delivery of a construction project is highly dependent on the contractor allocated to the project and hence the proper selection of the contractor is of significant importance. In public sector, the procurement method is mostly competitive bidding in which the contractor with the lowest bid price is selected at the final selection stage after passing through the technical and commercial evaluations. However, it is evident that selecting the construction contractor at the final stage only based on the lowest price does not yield the best project delivery. This thesis proposes a novel framework for the selection of construction contractor by identifying non-price contractor selection criteria; and develops a unique hybrid multi-criteria decision-making technique of DEMATEL-AHP-FRM to solve the contractor selection problem. A case study from Qatar was conducted to verify the proposed model through a survey that was conducted by interviewing professionals from the construction industry. It was found that, according to the sample project data acquired, the proposed model selection yielded to the selection of a contractor with a balanced non-price and price score, neglecting the lowest price contractor. Indeed, by careful analysis, it was shown that the selection output of the model is predicted to eventually result in better project delivery aspects as the selected contractor

is more capable in terms of technical and other aspects, namely non-price criteria, than the lowest price contractor.

DEDICATION

I consider getting the master degree a great achievement in my life, and thus I dedicate this effort to:

My brother for his uncountable support

My parents for being patient

My friends for keeping me up

All entities who participated in the study through interviews

All faculty members who supported me

Qatar in which the study is done for to return some of its favors on me

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CHAPTER 1 : INTRODUCTION

This chapter presents overview about the thesis topic, followed by statement of problem, scope and methodology, aims and objectives and last but not least outline of this thesis paper.

1.1 Overview

Construction industry is considered to be one of the largest industries in the world, in terms of total worth, number of employees and number of projects. The global construction industry was reported to have a total worth of 8.5 trillion USD in 2015 and expected to grow to 10.3 trillion USD in 2020 (Global Construction Market Worth, 2015). One can find some sort of construction related work in almost everywhere, from small houses to as sophisticated projects as nuclear plants. Due to the versatility nature and size of this industry, complications and issues are always present. Some common issues are delays in delivery of projects, cost overrun and quality mismatch, in which they affect project success. According to PMBOK 5^{th}, project success is measured by meeting the criteria and baselines set by stakeholders in terms of time, cost, quality, scope, etc. However, as other industries are being improved day after day through research and development, construction industry is not an exception. One of the main factors resulting in projects' success or failure is the contractor selection process. This thesis studies the current contractor selection process and proposes a unique hybrid selection model for the contractor selection process, supported by a case study from Qatar.

1.2 Statement of Problem

One of the common observations from the construction industry is the persistent delays and cost overruns in addition to the quality disputes between the clients and contractors. A tremendous amount of money is wasted because of that and the contractor selection is highly repetitive procedure in which any new construction project will need to pass by this procedure of selection of the suitable contractor.

A large number of studies have been published in this area of research to investigate the reasons behind such phenomena. Researchers and professionals from the construction industry attribute these project delivery unsatisfactory outcomes to the contractor selection process.

Competitive bidding has been applied for decades as a method for awarding contracts in construction related projects, particularly in the public sector, as it is a lawful obligation to use competitive bidding to grant most contracts (Chen, 1989).

This is done to ensure the integrity of the contractor selection process and remove any chance for a conflict of interest. Since the public contracts procurement only is considered in this research paper, competitive bidding will be the center of focus for this study.

In the competitive bidding contract awarding mechanism, the process starts by calling for bidders either through open or closed tender for the construction project. Either way, the bidders submit two documents: technical proposal and financial proposal. A technical evaluation process takes place to verify the capability of the participating contractors to deliver the project as per requirement and according to the time, cost and quality expected. The client – in this case the public sector, such as government institutions – sets up some minimum criteria for the technical evaluation process, in which any contractor who passes all the minimum requirements for all evaluation criteria is considered to be a qualified contractor for this specific project. It is worthy to mention that until this stage, only the technical proposals are opened and investigated. Then, from the set of qualified contractors, the selection is made of the most suitable contractor to work of this specific project according to the price submitted. Here, the financial proposals envelops are opened and the contractor with lowest price is directly selected, as the decision makers (client) assume that all the candidates are already qualified for the work and they will get the most benefit by selecting the lowest price bidder. This is denoted as the final selection of contractor.

However, it is proven from practice and literature that basing the final selection on the price only does not result in the best project delivery aspect most of the time. This was already comprehensively discussed in chapter 2, section 2.1.

Thus, this research focuses essentially on the final selection of construction contractor. After expansively analyzing the current bidding process which is briefly summarized above, it was concluded that we cannot change the bidding process as it is a well-established contract award mechanism and it has legal background and support, but instead we can enhance the bidding process by suggesting a support mechanism for the decision makers to have a better, scientific-based judgment on the final contractor selection. Therefore, the proposed enhancement is re-implementation of the technical evaluation scores again in the final selection of the contractor (non-price criteria) to yield better selection with balanced price and non-price criteria.

Many techniques and mathematical models have been developed to solve the contractor selection problem, such as the implementation of decision making techniques for the contractor selection. However, no technique has been regarded as a solution to the contractor selection problem and the research in this field is still ongoing. By careful investigation of the literature, a new unique hybrid decision making technique of DEMATEL-AHP-FRM was developed in this thesis and applied to a real case scenario where contractor selection is performed using this selection model.

The thesis attempts to identify, develop and apply a new hybrid model of DEMATEL-AHP-FRM for the contractor selection problem; and the output and behavior of the model were investigated to evaluate the effectiveness of the model.

1.3 Scope and Methodology:

In this research, the problem of contractor selection was addressed by utilizing decision making techniques as the means to perform the final contractor selection. More specifically, a new unique hybrid DEMATEL-AHP-FRM model was developed and implemented in the proposed contractor selection framework, assuming to enhance the contractor selection process. Moreover, the proposed model was applied to a real case study from the construction field to evaluate the outcomes of the model.

The very first step in this research is to perform a comprehensive study on the effect of the selection of contractor on the project delivery aspects to justify the importance of this research. This was done by reviewing the literature and conducting interviews with the professionals in the construction industry. The next step was to characterize the current contractor selection process and the criteria that are being used to evaluate the contractors and make the selection accordingly. Indeed, identifying the selection criteria is of essential importance as it sets the basis for the study and the developed selection model. After identifying the contractor selection criteria from the literature, the unique hybrid DEMATEL-AHP-FRM model was developed based on these criteria and a novel contractor selection framework was proposed to serve this purpose.

A survey was conducted to acquire the necessary data to test out the proposed contractor selection model of hybrid DEMATEL-AHP-FRM through interviews with experts in the field of contract awarding and filling out questionnaires by them.

In this research, data from the survey were implemented in the proposed model of hybrid DEMATEL-AHP-FRM and the contractor selection was performed accordingly.

The research framework followed in this thesis is shown below in Figure 1:

Figure 1. Research Framework.

It is worthy to mention that the scope of this thesis covers the following aspects:

- Only main criteria are considered from the literature, as each region, country and institution have their own sub-criteria. So, to generalize the model, only the main criteria were considered since they are common for everyone.
- Qualitative and quantitative are combined together as a percentage score.
- Only competitive bidding is considered.
- Only public-sector procurement is considered.
- Only scenarios were prequalification is done prior to contractor selection are considered.
- Institutions that participated in the survey are confidential and neither their names nor any other data will be shared, only the data will be presented with no references. This is based on their demand to remain confidential.
- Only the contractor selection for construction projects is considered, not any maintenance, renovation or other type of projects are considered.

Moreover, for the case study carried out for this thesis, interviews with professionals from construction industry in the field of contract awarding were conducted to fill out questionnaires reflecting the data required to test the proposed contractor selection framework. However, any designation to this case study in this report (survey, questionnaire, interviews, case study) refers to the approach mentioned above.

1.4 Aims & Objectives

The objectives of this research are stated as follows:

- Identify the criteria used to evaluate the contractors and thus select the most suitable one based on these criteria.
- Develop a new hybrid model of DEMATEL-AHP-FRM to be used specifically for the construction contractor selection.
- Propose a unique framework for the construction contractor selection based on the developed hybrid model of DEMATEL-AHP-FRM and the design of a survey to support that framework.
- Validate the proposed framework for construction contractor selection and suggest improvements for future standardization.

1.5 Outline of the Thesis Paper

This research paper constitutes from the following chapters:

Chapter 1 is the introduction of this thesis. It includes an overview of the topic, problem statement, scope and methodology, aims and objectives as well as the outline of the thesis repot.

Chapter 2 provides a brief of the studies done in the field of contractor selection. Moreover, it demonstrates the AHP and DEMATEL models and their applications.

Chapter 3 explains in detail the methodology of research followed and implemented in this study. The proposed novel framework for contractor selection, characterized set of selection criteria, Pareto analysis, unique DEMATEL-AHP-FRM hybrid model, all set of equations generated as well as survey design and structure; all are provided in this chapter.

Chapter 4 shows the actual implementation of the proposed novel framework of contractor selection by applying the unique hybrid model of DEMATEL-AHP-FRM to a case study, step by step, to illustrate the model. It also demonstrates the calculations and required data analysis.

Chapter 5 delivers a comprehensive discussion of the results and findings. It also deliberates the viability of the proposed framework/new hybrid model and the best way to apply it is real world.

Chapter 6 is the last chapter and it includes the conclusion, recommendations and future works.

CHAPTER 2 : LITERATURE REVIEW

One of the major success or failure factors for construction projects is the contractor. As a result, a huge effort is spent by researchers to study in deep the factors in force for the contractor selection and which factors affects the most and have higher weights resulting in the final selection of the contractor. In addition, a lot of scientific techniques based on mathematical modeling and other methods were implemented to solve the contractor selection problem and yield the best outcomes. Yet, there is no agreed-on set of factors for the selection of contractors nor best solving technique for the contractor selection problem, since these are highly dependent on each country's laws and regulations and each solving technique has its own weaknesses. In this chapter, the literature was reviewed to cover the effects of contractor selection on project success, criteria for contractor selection and last but not least contractor selection techniques.

2.1 Effects of Contractor Selection on Projects' Success

The most common definition to project success is the iron triangle, in which a successful project is the one delivered on time, within budget as well as according to specifications (Jafari, 2013; Alzahrani and Emsley, 2013). In this case, the project success factors are time, cost and quality. However, some researchers believe that the success factors vary from project to project based on the size, complexity and uniqueness (Jafari, 2013). According to PMBOK 5th Edition, project success is measured by meeting the criteria and baselines set by stakeholders in terms of time, cost, quality, scope, etc.

Toor and Ogunlana (2010) mentioned that some studies reveal that the criteria for project success assessment are: technical performance, efficiency of execution, managerial and organizational implications, personal growth and manufacturer's ability and business performance.

Others have defined the project success factors as those which are set to support project stakeholders to complete projects with the most desirable results (Alzahrani and Emsley, 2013). Moreover, literature shows that construction projects is moving in the direction not to depend on the traditional measures – iron triangle – to a more practical approach of today's challenges mixing quantitative and qualitative measures (Toor and Ogunlana, 2010).

A summary of research done on project success factors is shown in Table 1 below:

Table 1

Summary of Research on Project Success Factors (Jafari, 2013)

Reference	Country	Subject	Main/Top Criteria
Ahmed and Kangari (1995)	United States	Client satisfaction factors	Time; cost; quality; client orientation; communication skills; response to complaints
Chan et al. (2001)	Hong Kong	Project success factors for design-build projects	Project team commitment; contractor's competencies; risk and liability assessment; client's competencies; end-users' needs; constraints imposed by end-users
Cooke-Davies (2002)	UK	Critical factors to project success	Project management success; success on an individual

			project; consistency in project success
Nguyen et al. (2004)	Vietnam	Success factors	Comfort; competence; commitment; communication
Collins and Baccarini (2004)	Australia	Project management success criteria	Time; cost; quality/meeting specification; cooperation; project management process; profit; high standard of work; achieving scope; team members satisfied; risks managed; change & change management; repeat work; meeting standards; safety; personal

			development; continuing relationships; environmental
Wang and Huang (2006)	China	Indicators of project success	Cost; time; quality; relation/guanxi; overall success
Gransberg and Barton (2007)	United states	Factors in federal design-build procurement	Rice; technical; qualifications; schedule; project management
Ahadzie et al. (2008)	Ghana	Potential success criteria	Project costs; project quality; customer/client satisfaction; project duration; health and safety measures; environmental impact; risk containment; technology transfer

Doloi (2009)	Australia	Project attributes	On-time project delivery; comply with the quality specifications; perform to safety requirements; site safety; flexibility in critical activities; personnel availability; similar work experience; overall experience; tender price and estimates; defects liability attribute
Toor and Ogumlana (2010)	Thailand	Key performance indicators	On time; under budget; efficiency (use of resources); safety; meets the specifications; free from defects (high quality of

			workmanship); conforms to stakeholder's expectations; doing the right thing (effectiveness); minimized construction aggravation, disputes, and conflicts
Alzahrani and Emsley (2013)	UK	Project success attributes	Financial attributes; management attributes; technical attributes; past experience attribute; past performance attributes; organization attributes; environmental attributes; health

	and safety attributes; quality attributes; resources attributes

Although there are different points of views from the literature on the factors that assess the project success, all the studies and research agree that the contractor is a major contributor to any construction project and has the power to either make the project a success or failure.

Because of the major role that contractor is bearing in a construction project, selection of these entities is crucial in management and owner decision making (Semaan and Salem, 2017). The requisite selection process of contractors is precisely impacting construction's project success and achievement of laid set of objectives, hence this selection process deemed critical part of the project life cycle for the owner and its project manager (Nieto-Morote and Ruz-Vila, 2012). Choosing contractor as main player of a project deems to be the most important perplexing mind in perspective of the owner. In this industry, choosing the right contractor who can provide the requirements and specifications needed by owner to an appropriate level is a major challenge of the client in the beginning of the project life cycle (Kog and Yaman, 2016).

The main objective of this selection process is to achieve all the specifications within acceptable tolerances, reduce risk and add value to the client, contractor and all stakeholder involve. Traditionally, public works are tendered publicly such as highways, MRT, ports, roads, dams, etc. Contractors play the major role in such projects and this is a good reason to be critical in selecting contractors. Selecting contractors can include investigation of a company of their previous projects, their successes, failures and any other aspects that will persuade owner to choose contractor (Kog and Yaman, 2016; Darvish, Yasaei and Saeedi, 2009). Subsequently, due to criticality of the selection of contractors, this proper selection of appropriate stakeholders including consultants is highly crucial factor in achieving good project performance and overall attainment of success in a project (Lam, Palaneeswaran and Yu, 2009). Searching for appropriate contractor for any project is crucial to attain assurance that the project will finished as expected, in terms of cost, time, quality and other related factors even safety and environmental matters. The right contractor then can be defined as company that has capability to achieve these set objectives and considering the factors mentioned previously (Afshar et al., 2017). As per Alhazmi and McCaffer, 2000, selection of proper contractors increases the chances that a project will be successful, fulfill owner's specifications, goals and objectives in the project and keep the factors of time, cost and quality within acceptable tolerances. It is therefore, indeed extremely crucial to sensibly choose a contractor (Huang, 2011). Again as stated above and in Plebankiewicz, 2010, one of the vital processes in the life cycle of construction project and most indispensable process is the selection of appropriate contractors. Selection of eligible and proper contractor increases the chances of success and reduces risk and uncertainties of a project.

However, several articles have shown in their study that even an established, experienced contractor might still experience high risks due to the nature of projects. Projects in nature are similar though unique. With these, the probability of failure is still high. It is a distinguished truth in construction that it contains a lot of uncertainties and risk and the success of the project highly depends on wisely use of resources. Further, construction projects are unique, fragmented and complicated compared to other industries; therefore stakeholders must deal with great care to achieve the goals. Accordingly, tight connection and strict procedures between contractor and client who are the key players of this industry are expected for the achievement of the projects objectives (Kog and Yaman, 2016). Consequently, it is absolutely necessary and extremely important that an owner has a strict mechanism in choosing a contractor that is competent and reliable to handle project to attain success objective. However, choosing contractors is not undemanding job. History of failures and delays in mega projects around the globe has underscored the importance of this practice (Semaan and Salem, 2017). Currently in the construction industry, owners consistently face several risks and unpredictability of contractor selection which affects the overall performance level of their selection process of contractors. This is a settled matter to achieved pre-specified objectives and projects success (Lam, Palaneeswaran, and Yu, 2009; Trivedi, Pandey, and Bhadoria, 2011). Soliciting to reduce failures and risks as a prequalification in the selection process is frequently executed to assess the capability of contractors prior to their inclusion in the bidding (Jaskowski, Biruk, and Bucon, 2010; Zavadskas and Vilutienė, 2006).

In order to ensure the hiring of eligible contractor and reduce risk of the project, both selection and evaluation processes are extremely important factors in any pre-qualification process. This is crucial process to concomitantly successfully attain time, cost and quality specifications of projects (Hosseini Nasab and Mirghani Ghamsarian, 2015). Other than stated above, irresponsible selection of incapable contractor increases the risk that a client will be dissatisfied; cost, time and quality will be out of acceptable threshold. In addition, bad legacy not only to the contractor who build a project, but also the client who will have a bad reputation of not choosing properly a contractor for their projects (Doloi, 2009).

Therefore, the vital process in the life cycle of construction project and most indispensable process is the selection of appropriate contractors. When it comes to influences in project success and goals, contractors in construction industry are the leaders. It is just right then to conclude that selecting these companies is crucial in the process and life cycle of a project (Huang, 2011).

2.2 Criteria for Contractor Selection

For public sector, the traditional way of procurement that has been used for a long time and still being used is the lowest bid award, or in other words competitive bidding (Waara and Bröchner, 2006). However, research is steps ahead of practice in the implementation of other criteria other than price in the final selection of contractors. The denotation of “non-price criteria” has been used to describe other criteria considered in addition to the price criterion (Zavadskas et al, 2008; Waara and Bröchner, 2006).

The nature of the contractor selection criteria is that they are described in two categories, qualitative and quantitative criteria. Even though qualitative criteria are not straightforward quantified by numerical values, they usually get combined with the quantitative ones and are given numerical representation based on the model used to extract data (Lam and Yu 2011).

These non-price criteria are considered main criteria and are constituted of sub-criteria in which the evaluation of these sub-criteria defines the attributes of the main criteria (Alzahrani and Emsley, 2013). However, some researchers only considered the main criteria in their analysis of the contractor selection process to ease the analysis (Idrus, Sodangi and Amran, 2011).

Importantly, a comprehensive review was performed by the author of this thesis on the non-price criteria used to be integrated with the price criterion for the lowest price bid type of contract awarding, and the summary of this comprehensive review is shown in Table 2. It should be noticed that only papers for the last ten years were considered and reviewed to obtain the set of non-price criteria.

Table 2

Summary of Construction Contractor Non-Price Selection Criteria

ID	Contractor Selection Criteria (CSC)	References
1	Experience	(Semaan and Salem, 2017), (Marzouk, 2008), (Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
2	Reputation	(Semaan and Salem, 2017), (Vahdani et al., 2013), (Wang et al., 2013), (Ibadov, 2015), (Nassar and Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Watt, Kayis and Willey, 2010)
3	Previous Projects	(Semaan and Salem, 2017), (Zavadskas, Turskis and Tamošaitiene, 2008), (Alzahrani and Emsley, 2013)

4	Financial Standing	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (Wang et al., 2013), (Ibadov, 2015), (San Cristóbal, 2012), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
5	Technical Ability	(Vahdani et al., 2013), (Huang, 2011), (Wang et al., 2013), (Ibadov, 2015), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010)
6	Management Capability	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (Wang et al., 2013), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010), (Doloi, 2009)
7	Health and Safety	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (San Cristóbal, 2012), (Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013),

		(YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013)
8	Experience of Personnel/Staff	(Marzouk, 2008), (Chou, Pham and Wang, 2013), (Bendaña, del Caño and Pilar de la Cruz, 2008)
9	Past Failed Contracts	(Marzouk, 2008), (Doloi, 2009)
10	Quality Management and Control	(Huang, 2011), (Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
11	Current Workload, Capacity & Progress	(Huang, 2011), (Idrus, Sodangi and Amran, 2011), (Idrus, Sodangi and Amran, 2011), (Doloi, Iyer and Sawhney, 2011), (Watt, Kayis and Willey, 2010)
12	Organizational Skills	(Wang et al., 2013), (Ibadov, 2015), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010)
13	Communication & Relationships	(Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (Idrus, Sodangi and Amran,

		2011), (Idrus, Sodangi and Amran, 2011), (Doloi, Iyer and Sawhney, 2011), (Watt, Kayis and Willey, 2010), (Doloi, 2009)
14	Construction Completion Time	(Chou, Pham and Wang, 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013)
15	Guarantees	(Zavadskas, Turskis and Tamošaitiene, 2008), (Zavadskas, Turskis and Tamošaitiene, 2008)
16	Resources	(Bendaña, del Caño and Pilar de la Cruz, 2008), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013)
17	Risks	(Bendaña, del Caño and Pilar de la Cruz, 2008)
18	Track/Past Performance	(Wang et al., 2013), (Idrus, Sodangi and Amran, 2011), (YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010)
19	Technology Implementation	(Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013), (Watt, Kayis and Willey, 2010)
20	Political Considerations	(Idrus, Sodangi and Amran, 2011)

21	Planning and Control Capability	(Nassar and Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015)
22	Equipment/Plant Capability	(Nassar and Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011)
23	Personnel/Staff	(Huang, 2011), (YILMAZ and ERGONUL, 2011)
24	Environmental Management/ Protection	(Nassar and Hosny, 2013), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013)
25	Project specific	(Doloi, 2009)
26	Flexibility	(Doloi, 2009)

However, for the full summary of contractor selection criteria including both main and sub criteria, refer to Appendix A.

2.3 Multi-Criteria Decision-Making Techniques

The decision-making techniques used to tackle the contractor selection problem are various in type and implementation. Nevertheless, research in the field of decision-making techniques for contractor selection is ongoing. An overview of decision-making techniques along with types and examples are presented in this section.

2.3.1 Single Decision-Making Techniques

2.3.1.1 Overview

Single decision-making techniques are extensively used in many areas of research such as supply chain management, construction management, etc. however, based on the application and desired analysis, the selection of the technique is make (Mardani et al, 2015).

2.3.1.1.1 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

In current years, numerous Multi-Criteria Decision Aid (MCDA) methods have been suggested to help in choosing the best compromise alternatives. The development of MCDA methods has been encouraged not only by a diversity of real-life problems of multiple criteria, but also by specialists' desire to suggest enhanced decision-making techniques (Wiecek et al., 2008). One of the most current MCDA methods that were developed is The Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method which was developed by Brans in 1982 (Vincke and Brans, 1985). PROMETHEE is an outranking method for a finite set of alternatives to be rated and selected among criteria, which are regularly conflicting. PROMETHEE is also a quite simple rating method in conception and application in comparison with the other multi-criteria methods (Brans et al., 1986). Thus, the use of PROMETHEE method is greatly increasing year by year as the number of specialists who are applying the PROMETHEE method to practical real-life problems, and researchers who are attentive to the

PROMETHEE method are increasing (Behzadian et al., 2010).

The PROMOTHEE method is applied in five main stages (Sabaei, Erkoyuncu and Roy, 2015). In the first stage, a preference function which presents the preference of decision-makers for an action with respect to another action is defined. The second stage deals with the comparison of the recommended alternative in pairs to the preference function. In the third stage, an evaluation matrix is established from the results of these comparisons as the predicted value of every criterion for every alternative. The ranking is accomplished in the two final stages: the fourth stage contains the PROMOTHEE I method application for partial ranking and then the fifth stage contains PROMOTHEE II method for complete ranking of the alternatives. The main benefit of this method is that normalization of scores is not needed. Instead, weight should be defined separately as the weighting techniques are not part of the method (Fülöp, 2005).

Environment Management is one of the most popular topics where PROMETHEE methods are being used in. There are several specific areas in the Environment Management which uses PROMETHEE methods such as: (1) Life Cycle Assessment, (2) Waste Management, (3) land-use planning and (4) Environmental Impact Assessment (Geldermann and Rentz, 2005; Queiruga et al., 2008; Diakoulaki and Karangelis, 2007; BEYNON and WELLS, 2008). In addition, PROMETHEE method was used in many published papers under the topic of Business and Financial Management. Most of these papers were focusing on the key aspects of investment analysis, performance measurement, general management and portfolio management (Albadvi, Chaharsooghi and Esfahanipour, 2007; Kalogeras et al., 2005; Bilsel, Büyüközkan and Ruan, 2006; Baourakis et al., 2002). Chemistry is a new and common topic in PROMETHEE applications and a significant number of publications have been published in this topic. The publications on the topic of Chemistry are regularly interested in the evaluation and ranking of chemical materials and specimens in the experimental fields (Zhang et al., 2006; NI et al., 2007). Last but not least, a considerable number of papers argued other application aspects of the PROMETHEE methods such as: Agriculture, Design, Medicine, Education, Sports, and Government (Özerol and Karasakal, 2007; Coelho and Bouillard, 2005).

2.3.1.1.2 Analytical Network Process (ANP)

One of the widely used multi-criteria decision-making techniques is the Analytical Network Process (ANP). The seven columns of the Analytical Hierarchy Process (AHP) play as the initial point for the Analytical Network Process (ANP). The ANP delivers a general framework to sort out decisions without taking into consideration any assumptions about the independence of higher-level components from lower-level components and about the independence of the components within a level (Cheng, Li and Yu, 2005). Actually, the ANP uses a network that does not need any level specifications as in the hierarchy. The ANP is a beneficial method for estimation and for representing a diversity of competitors with their interactions and relative strength to be applied in decision making (Cheng and Li, 2004).

The ANP is a pairing of two main parts. The first part consists of a network of criteria and sub-criteria which controls the interaction (Bayazit, 2006). The second part is a network of influences among the components (Saaty, 2001). The network differs from criterion to criterion and a different super-matrix is calculated for each control criterion. Lastly, each of these super-matrices is weighted by the importance of its control criterion and the outcomes are aggregated through addition of all control criteria (van Staden, 1999).

Construction is one of the most common topics where the ANP process is applied. For instance, an ANP system was developed to accurately assess the impact of the interdependences factors among the construction risk problems (Lu et al., 2007). Furthermore, a several underground construction technologies were executed using the ANP as a multi-criteria comparison method (Bobylev, 2011). Likewise, the ANP was applied in the construction bid evaluation in order to select the nearest bidder to the ideal (Wang, Xu and Li, 2009; Hong-yan, 2011). Although the ANP method was applied extensively in the construction fields, it also has been successfully applied in many other areas such as: (1) Supply Chain Improvement (2) Product Planning (3) Strategic Service Vision (4) R&D Project Selection (5) Quality Function Deployment (6) Transportation Projects (7) Machine Tool Selection (Agarwal and Shankar, 2002; Karsak, Sozer, and Alptekin, 2003; Lee and Kim, 2001; Meade and Presley, 2002; Partovi, 2001; Partovi and Corredoira, 2002; Shang, Tjader, and Ding, 2004; Yurdakul, 2004).

2.3.1.1.3 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was presented by Hwang and Yoon in 1981 (Chen and Hwang in 1992). TOPSIS is a multi-criteria decision-making method used for identifying solutions from a finite set of alternatives (Jahanshahloo, Lotfi and Izadikhah, 2006). As a recognized classical MCDM method, TOPSIS has gained much attention from researchers and specialists, and the global attention in the TOPSIS method has highly grown (Behzadian et al., 2012).

The key principle of TOPSIS method is that the selected alternative have to be in the ‘‘farthest distance’’ from the negative-ideal solution and the ‘‘shortest distance’’ from the positive-ideal solution (Taylan et al., 2014). In TOPSIS method, the ideal alternative is established out of the best characteristic values possible, and thus, it is usually a ‘created’ alternative. Likewise, the negative-ideal alternative is also a created alternative which is established out of the worst characteristic values possible. The relative closeness (similarity) of each alternative to the ideal alternative is evaluated on the basis of its distances from both the ideal and the negative-ideal alternatives (Baykasoglu et al., 2009). TOPSIS method introduces two main points as a reference; however, it does not consider the relative importance in the distances between these points (Opricovic and Tzeng, 2004).

There is wide range of real-world applications where the TOPSIS method is increasingly involved in for classifying across different fields and some specific areas. TOPSIS method was used in many areas such as: (1) Design, Engineering and Manufacturing Systems, (2) Chemical Engineering, (3) Energy Management, (4) Health, Safety and Environment Management, (5) Supply Chain Management and Logistics, (6) Business and Marketing Management, (7) Water Resources Management, (8) Human Resources Management, and (9) Other topics as well (Athanasopoulos, Riba and Athanasopoulou, 2009; Ramezani, Bashiri and Atkinson, 2011; Aalami, Moghaddam and Yousefi, 2010; Aiello et al., 2008; Alimoradi, Yussuf and Zulkifli, 2011; Amiri et al., 2009; Afshar et al., 2010; Boran, Genç and Akay, 2011; Albayrak and Erensal, 2009).

2.3.1.1.4 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a non-parametric productive efficiency measurement tool developed for applications which involve multiple inputs and multiple outputs. DEA was firstly developed by Charneset et al. in 1978, who proposed a novel method that couples and transforms multiple inputs and outputs into a single efficiency index (Seiford, 1996). This method first institutes an efficient frontier designed by a set of decision-making units (DMUs) that show best practices and afterwards assigns the efficiency level to another non-frontier units depending on their distances to the efficient frontier (Liu et al., 2013). The basic idea has then created a wide range of varieties in calculating efficiency.

Nowadays, several DEA efficiency models, such as: the Variable-Returns-to-Scale (VRS), the Constant Returns to Scale (CRS), the Slacks-Based measures and the Free Disposal Hull (FDH), the additive, etc. are available for various types of calculating requirement (Liu et al., 2013). It also has been applied to several industrial and non-industrial backgrounds, such as: banking, education, hospital, etc. (Emrouznejad, Parker and Tavares, 2008).

2.3.1.1.5 Other Decision-Making Techniques

Other decision-making methods can be shown in the following summary Table 3:

Table 3

Summary of Single Decision-Making Techniques (Jato-Espino et al, 2014)

Abbreviation	Method	Description
AHP	Analytical hierarchy process	Structured technique for analyzing MCDM problems according to a pairwise comparison scale
ANP	Analytical network process	Generalization of the AHP method which enables the existence of interdependencies among criteria
COPRAS	Complex proportional assessment	Stepwise method aimed to rank a set of alternatives according to their significance and utility degree
DEA	Data envelopment analysis	Non-parametric system for measuring the efficiency of a set of multiple decision making units

-	Delphi	Iterative method designed to obtain the most reliable consensus from a group of experts responding to a series of questionnaires
DRSA	Dominance-based rough set approach	Derivation of rough set theory which allows defining a MCDM problem through a series of inference rules of the type “if … then”
ELECTRE	Elimination et choix traduisant la realite	Group of techniques addressed to outrank a set of alternatives by determining their concordance and discordance indexes
FSs	Fuzzy sets	Extension of traditional concept of crisp sets which states that the belongingness of an

		element to a set may vary within the interval [0,1]
GST	Grey system theory	Philosophy of handling data according to the information contained in them, from black (no information) to white (complete information)
GT	Game theory	Area of applied mathematics that studies the interaction of formalized structures to make strategic decisions
HOQ	House of quality	House-shaped diagram that transforms user demands into quality design criteria through a relationship matrix and a correlation matrix
IFSs	Intuitionistic fuzzy sets	In addition to the belongingness grade of an element to a set proposed

		by FSs, IFSs also considers its non-belongingness grade (hesitancy)
MAUT	Multi-attribute utility theory	Methodology employed to make decisions by comparing the utility values of a series of attributes in terms of risk and uncertainty
MAVT	Multi-attribute value theory	Compensatory technique that converts the attributes forming a MCDM problem into one single value through the called value functions
MCS	Monte carlo simulations	Non-deterministic methods used to find approximate solutions to complex problems by experimenting with random numbers
MEW	Multiplicative exponential weighting	Aggregative scoring system in which alternatives are

		evaluated by the weighted product of their attributes
MIVES	Modelo integrado de valor para evaluaciones sostenibles	Nested methodology which combines two concepts as MCDA and Value Engineering to synthesize any type of criteria in a value index
PROMETHEE	Preference ranking organization method for enrichment of evaluations	Family of outranking methods based on the selection of a preference function for each criterion forming a MCDM problem
SAW	Simple additive weighting	Technique aimed to determine a weighted score for each alternative by adding the contributions of each attribute multiplied by their weights
SIR	Superiority and inferiority ranking	Method that uses six generalized criteria to establish the preferences of

		a decision maker by determining the superiority and inferiority flows
SMAA	Stochastic multiobjective acceptability analysis	Methodology that determines the acceptability index of an alternative as the variety of measurements making it the preferred one
TOPSIS	Technique for order of preference by similarity to ideal solution	Technique based on the concept that the best alternative to a MCDM problem is that which is closest to its ideal solution
UT	Utility theory	Method for measuring the degree of desirability provided by tangible and/or intangible criteria through their utility functions
UTA	Utilities additives	Methodology that uses linear programming to optimize the use of utility

		functions to properly reflect the preferences of decision makers
VIKOR	Visekriterijumska Optimizacija I kompromisno redenje	Method for determining the compromise ranking-list of a set of alternatives according to the measure of closeness to the ideal solution

2.3.1.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) method was firstly worked out by Thomas Saaty in 1971-1975 (Saaty and Tran, 2007). This method was presented as an effective tool to support the Multi-Criteria Decision-Making (MCDM) process in many areas. MCDM methods use a structured and logical approach to model complicated decision-making problems (Kalbar, Karmakar and Asolekar, 2012). Since its development and due to its simplicity and flexibility, AHP has been one of the most commonly used MCDM (Martin and Daim, 2012; Karasakal and Aker, 2017). AHP models depend on a comparative judgment of the alternatives and criteria (Grady, He and Peeta, 2015). Hence, AHP is a suitable tool for evaluating complex multiple criteria alternatives including subjective judgment (Huang, Chu and Chiang, 2008). As project selection problems commonly include numerous hierarchical criteria with numerous alternatives and a group of professionals with different judgments, AHP models have been used successfully to improve project selection in the research and development settings (Grady, He and Peeta, 2015).

The AHP procedure includes the following steps: (1) decay of the decision problem into a hierarchy of simpler sub-problems, (2) pairwise judgments of the criteria weights with regard to the objective with 9 degree scale, (3) arrangement of criteria weights (eigenvector matching with the maximal eigenvalue). Likewise, when the criteria are qualitative, pairwise judgments of alternatives in regard to a particular criterion is executed. This allows the decision maker to determine assessments depending on single criteria (alternatives' priorities) and synthetic global scores as a weighted sum of fractional assessments (Jaskowski, Biruk and Bucon, 2010).

One of the first applications of the AHP in construction was done by Skibniewski and Chao (1992), who argued the benefits in which this technique could provide to the technical and economical assessments. Later, a study was conducted in which the AHP was applied in a decision-making method to assess the problem of contractor prequalification (Al-Harbi, 2001). Similarly, another selection models executed to create a preference ranking for contractors' prequalification (Topcu, 2004; Abudayyeh et al., 2007). Later, a tremendous amount of effort was implemented on the contractor selection process with the use of AHP method as a mathematical tool to assist the selection process (Jaskowski, Biruk and Bucon, 2010; Wang et al., 2013; Mazaheri-Zadeh and Naji-Azimi, 2015; Chiang, F. Yu and Luarn, 2017).

Beside contractor prequalification and selection, there are other applications where AHP was used for selection and evaluation. For instance, contracting model development, evaluation of advanced construction technology, budget determination procedure for public building construction projects, construction method choice, risk assessment for construction joint ventures, equipment and building assembly selection, the best-value bid, development of a model for computing the system intelligence score of key building control systems in the intelligent buildings (Lin, Wang and Yu, 2008; Pan, 2008; Skibniewski and Chao, 1992; Abudayyeh et al., 2007; Goldenberg and Shapira, 2007; Nassar, Thabet and Beliveau, 2003; Lai, Wang and Wang, 2008; Hsueh et al., 2007; Wong, Li and Lai, 2008).

2.3.1.3 Decision Making Trial and Evaluation Laboratory (DEMATEL)

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was first developed by the Geneva Research Centre of the Battelle Memorial Institute between years 1972 and 1976 (Gabus and Fontela, 1972). It was designed to study and visualize the complex and intertwined problematic group (TZENG, CHIANG and LI, 2007; Wu, 2008). DEMATEL is applied to build and emphasize the Network Relations Map (NRM) among criteria and it can confirm interrelationships among a range of factors (Gabus and Fontela, 1974). In addition, it has the capability of transforming the qualitative designs to the quantitative analysis, and it can quantify related degrees and relationships between different factors in order to understand the relationship structure to solve the problem (Lee et al., 2010).

In DEMATEL, the criteria are divided into two main groups; the cause group and the effect group. The cause group influences on the effect group where such effect is used to measure the criteria weights (Dalalah et al., 2011). This technique not only converts the dependence between relationships into a cause and effect group, but also finds the critical factors of a complex structure system with the help of a causal diagram (Si et al., 2018). The causal diagram uses digraphs instead of directionless graphs to characterize the basic concept of dependent relationships and the strengths of influence among the factors (Wu, 2008).

The establishment for the DEMATEL is done in four main steps: (1) calculating the average matrix, (2) calculating the normalized initial direct-influence matrix, (3) deriving the total relation matrix, and (4) setting a threshold value and obtain the impact-relations map (Li and Tzeng, 2009). In the fourth step, an applicable threshold value is necessary to obtain a suitable impact relations map as well as conventional information for further analysis and decision-making. The method is tailed to set a threshold value is conducting argument with experts. This is done by illustrating a measuring scale, which can be used to express the relationship or strength of influence between the factors or variables (Shen, Lin and Tzeng, 2011; Lee et al., 2011). The typical range for this influence scale is as follows: 0, no influence; 1, low influence; 2, medium influence; 3, high influence; and 4, very high influence (Nilashi et al., 2014).

During the early stages of its development, DEMATEL was designed to identify complex problems in the world such as apartheid, starvation, environmental protection, and energy conservation. Later, the DEMATEL was occupied in three main research areas: (1) world problem structures; (2) analyzing and developing flexible methods for solving complex world problems and (3) reviewing research and methodology data pertaining to world problems (Lee et al., 2010). Because of its advantages and capabilities, the methodology of DEMATEL has received a great deal of attention in our time and many researchers have applied it for solving complicated system problems in numerous fields. Besides, the DEMATEL nowadays has been protracted for better decision-making in different real-world systems (Si et al., 2018).

2.3.2 Hybrid Decision-Making Techniques

2.3.2.1 Overview

When a single decision-making technique is not sufficient to solve a decision-making problem due to a weakness in the technique, complexity of the problem or any other reason, researchers have been investigating the combination of single decision-making techniques in order to develop hybrid decision-making techniques that overcome the weaknesses of the individual techniques. In this section, a brief of the hybrid decision-making techniques is presented.

2.3.2.2 Analytic Hierarchy Process (AHP) Combinations

In addition to what was mentioned previously about the AHP method in the literature, the first expansions of the AHP method was developed in 1983 by van Laarhoven and Pedrycz, in which they combined the fuzzy set theory with AHP. One of the common combinations with AHP method is the fuzzy set theory. The fuzzy set theory is a method that affords representing in numerical form the linguistic approximations used for describing the relationships between data items (Jaskowski, Biruk and Bucon, 2010).

Fuzzy set theory can efficiently model judgment and deal with uncertainties, and it could be applied to tackle the inaccurate and subjective nature of other models to accomplish a more reliable framework (Chou, Pham and Wang, 2013). Though, fuzzy set theory has a weakness in classifying relative weights of the decision criteria, alternatively one of the most accurate and simple method for classifying the relative weights is the AHP method (Hosny, Nassar and Esmail, 2013). Consequently, the combination between Fuzzy-AHP is a powerful methodology which takes all advantages of the fuzzy set theory and AHP. In the fuzzy expansion of the AHP method, the process of weights determination or vectors calculation of priorities on the basis of pairwise comparison matrices is a complicated computational problem (Arslan, 2008).

The Fuzzy-AHP method has been applied widely and in various areas. For example, Fuzzy-AHP method was applied in highway re-establishment to prioritize its activities according to the environmental validity (Filippo, Martins Ribeiro and Kahn Ribeiro, 2007). Also, a Fuzzy-AHP model was proposed to measure the suitability of several bridge construction methods (Pan, 2008). Additionally, a Fuzzy-AHP methodology was developed for contractor prequalification which is able of dealing with ambiguity and imprecision that linguistic judgments implicate (Jaskowski, Biruk and Bucon, 2010).

Though, there are several combinations between AHP and other MCDM methods. For instance, AHP-MIVES combination was proposed to assess the most sustainable design to construct schools in Catalonia (Pons and Aguado, 2012). Besides, a combination of AHP-Fuzzy-PROMETHEE was developed to calculate the critical path of construction projects (San Cristobal, 2013). Also, an AHP-VIKOR method was established to take in hand the bidding procedure of construction projects (Liu and Yan, 2007). Moreover, an assessment of the suitability of different rock tunnel excavation was completed using an AHP-Fuzzy-TOPSIS combination method (Golestanifar et al., 2011). Last but not least, a combination of AHP-ELECTRE-Fuzzy was implemented to study the location selection of dry port construction projects (Ka, 2011).

2.3.2.3 Decision Making Trial and Evaluation Laboratory (DEMATEL) Combinations

As for the AHP method, researchers have also combined the DEMATEL technique with other MCDM techniques to enhance the outputs and overcome the weaknesses/shortages of the DEMATEL technique. Basically, one of the famous and common combinations of DEMATEL is with ANP. The DEMATEL and ANP methods are combined in order to observe and study the importance level of the calculated factors and sub-factors (Gölcük and Baykasoğlu, 2016). In that direction, DEMATEL is used to build interrelations between main factors and between sub-factors in the integrated model (Chen, Hsu and Tzeng, 2011). By applying this approach, the interdependencies strength between the main factors and sub-factors is examined. Then, the ANP method is implemented with the purpose of calculating the relative importance of all the factors and sub-factors (Hung, Chou and Tzeng, 2011). It is also applied to recognize how these factors are weighted and prioritized (Huang, Shyu and Tzeng, 2007).

The methodology of DEMATEL-ANP was applied in various researches and several fields. As an example, a hybrid MCDM model of DEMATEL-ANP was proposed to resolve the dependency and feedback problems of the real-world (Yang et al., 2008). The DEMATEL-ANP method was used also to study the strategic drivers for green innovation (Lu and Lin, 2010). Likewise, the combination of DEMATEL-ANP was applied to observe the maintenance management indicators of the vehicle fleet (Vujanović et al., 2012).

Nevertheless, there are numerous combinations between DEMATEL and other MCDM techniques. Several DEMATEL-Fuzzy methods were established in supplier selection, supply chain management in automotive industries, customers' choice behavior and environmental performance (Mirmousa and Dehnavi, 2016; Irajpour et al., 2012; Chen, Hsu and Tzeng, 2007; Tsai et al., 2015). Besides, a DEMATEL-ANP-Fuzzy methodology was implemented to assess business intelligence performance (Büyüközkan and Çifçi, 2012). Also, a DEMATEL-ANP-VIKOR technique was developed to resolve the problem of conflicting criteria with dependence and feedback Yang, Shieh and Tzeng, 2009).

CHAPTER 3 : METHODOLOGY

3.1 Contractor Selection Framework

This research focuses essentially on the final selection of construction contractor. After expansively analyzing the current bidding process which is briefly summarized above, it was concluded that we cannot change the bidding process as it is a well-established contract award mechanism and it has legal background and support, but instead we can enhance the bidding process by suggesting a support mechanism for the decision makers to have a better, scientific-based judgment on the final contractor selection. This proposed enhancement is a novel contractor selection framework that comprises of assorted studies (selection criteria, pareto analysis, new hybrid decision making technique, survey design, data acquisition and calculations, final contractor selection) that are added up together to form the novel contractor selection framework. Figure 2 below shows a flowchart of the steps for the proposed unique contractor selection framework:

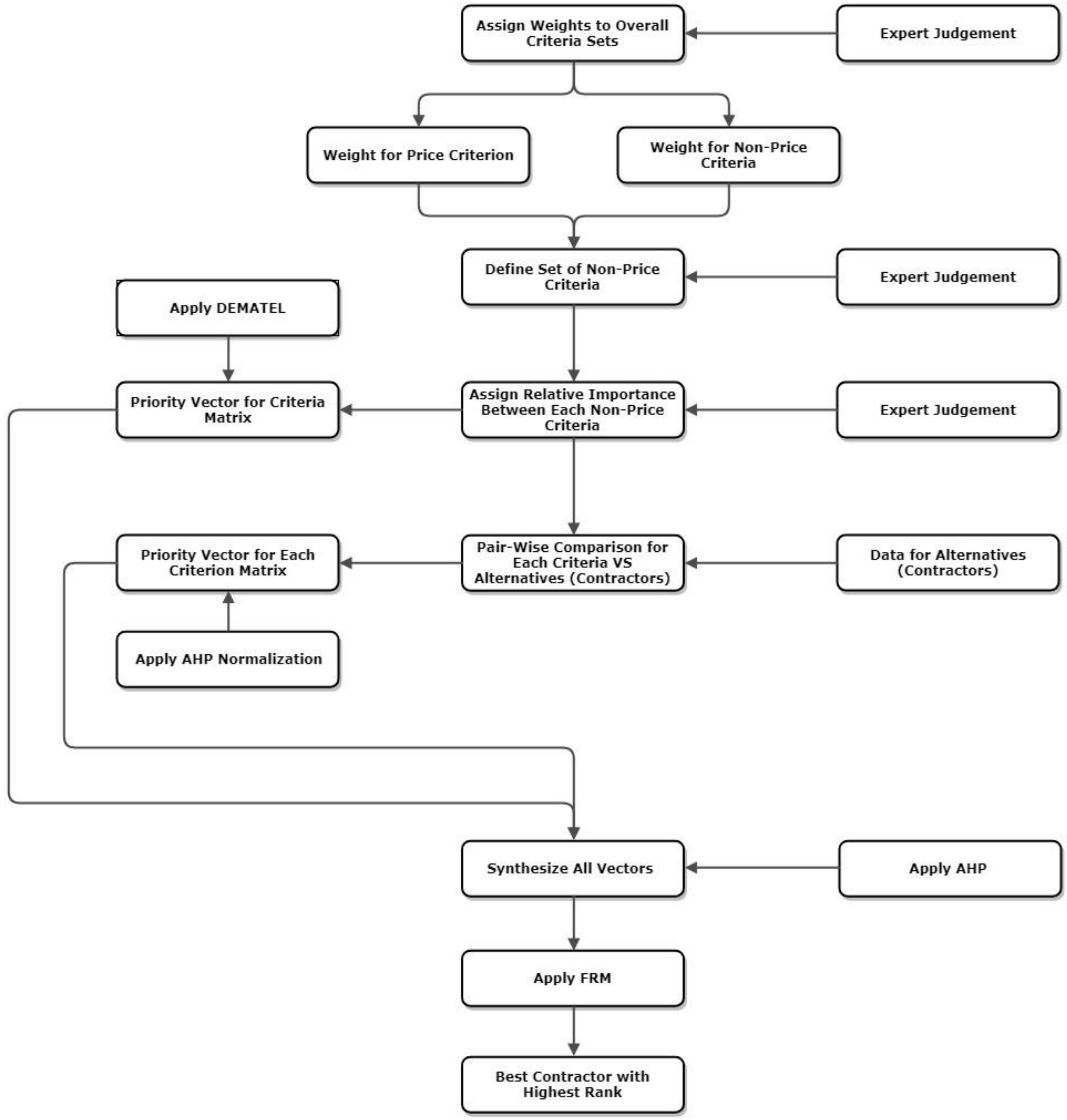

Figure 2. Proposed Contractor Selection Framework.

3.2 Criteria Classification and Selection (Pareto Analysis)

The criteria for contractor selection has been explored by researchers and implemented in the contractor selection models developed. However, the criteria discussed in the literature regarding the contractor selection diversify in terms of representation, connotation and implementation. This is because each research is conducted in different country and the reflected importance and used criteria differs from country to country as well as the contractor selection procedures. That's why there is no common list of contractor selection criteria in which everyone can use for the contractor selection process in the literature. Therefore it was important to conduct a study on the existing contractor selection criteria and prepare a set of criteria for this research paper.

For the purpose of obtaining the set of non-price criteria to be fused with the price criterion for the final selection of contractors, the literature was reviewed for the last ten years for all publications that are related to this field of study (see literature review section 2.2). Furthermore, all non-price criteria were extracted from these publications and Table 2 was constructed for the non-price criteria.

It should be noted that only main criteria were considered from the reviewed papers, not any sub-criteria. The reason behind this is that these sub-criteria are highly dependent on the country and/or region the contractor selection is being conducted in. This can be clearly seen from the reviewed papers, as each criterion had different sub-criteria from country to another.

The next step performed was to establish a frequency table of the non-price criteria for the reason of performing required analysis. However, in order to make better assessment of the obtained criteria, combinations of similar criteria was done, as below:

- Resources, equipment and personnel were combined into "Resources"
- Environmental considerations was combined with health and safety into "HSE" (Health, Safety and Environment)
- Previous projects, past performance and reputation were combined into "Reputation"
- Planning and control capability combined with Management Capability into "Management Capability"

Thus, the following Table 4 was generated:

Table 4

Filtered Non-Price Criteria Table

ID	Contractor Selection Criteria (CSC)	References
1	Experience	(Semaan and Salem, 2017), (Marzouk, 2008), (Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
2	Reputation	(Semaan and Salem, 2017), (Vahdani et al., 2013), (Wang et al., 2013), (Ibadov, 2015), (Nassar and Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Watt, Kayis and Willey, 2010), (Wang et al., 2013), (Idrus, Sodangi and Amran, 2011), (YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and

		Willey, 2010), (Semaan and Salem, 2017), (Zavadskas, Turskis and Tamošaitiene, 2008), (Alzahrani and Emsley, 2013)
4	Financial Standing	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (Wang et al., 2013), (Ibadov, 2015), (San Cristóbal, 2012), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
5	Technical Ability	(Vahdani et al., 2013), (Huang, 2011), (Wang et al., 2013), (Ibadov, 2015), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Mazaheri-Zadeh and Naji-Azimi, 2015), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010)
6	Management Capability	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (Wang et al., 2013), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010), (Doloi,

		2009), (Nassar and Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015)
7	HSE	(Vahdani et al., 2013), (Marzouk, 2008), (Huang, 2011), (San Cristóbal, 2012), (Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013), (YILMAZ and ERGONUL, 2011), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Nassar and Hosny, 2013), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013)
8	Experience of Personnel/Staff	(Marzouk, 2008), (Chou, Pham and Wang, 2013), (Bendaña, del Caño and Pilar de la Cruz, 2008)
9	Past Failed Contracts	(Marzouk, 2008), (Doloi, 2009)
10	Quality Management and Control	(Huang, 2011), (Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Doloi, 2009)
11	Current Workload, Capacity & Progress	(Huang, 2011), (Idrus, Sodangi and Amran, 2011), (Idrus, Sodangi and Amran, 2011), (Doloi,

		Iyer and Sawhney, 2011), (Watt, Kayis and Willey, 2010)
12	Organizational Skills	(Wang et al., 2013), (Ibadov, 2015), (YILMAZ and ERGONUL, 2011), (Alzahrani and Emsley, 2013), (Watt, Kayis and Willey, 2010)
13	Communication & Relationships	(Wang et al., 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (Idrus, Sodangi and Amran, 2011), (Idrus, Sodangi and Amran, 2011), (Doloi, Iyer and Sawhney, 2011), (Watt, Kayis and Willey, 2010), (Doloi, 2009)
14	Construction Completion Time	(Chou, Pham and Wang, 2013), (Zavadskas, Turskis and Tamošaitiene, 2008), (San Cristóbal, 2012), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013)
15	Guarantees	(Zavadskas, Turskis and Tamošaitiene, 2008), (Zavadskas, Turskis and Tamošaitiene, 2008)
16	Resources	(Huang, 2011), (YILMAZ and ERGONUL, 2011), (Bendaña, del Caño and Pilar de la Cruz, 2008), (Doloi, Iyer and Sawhney, 2011), (Alzahrani and Emsley, 2013), (Nassar and

		Hosny, 2013), (Mazaheri-Zadeh and Naji-Azimi, 2015), (YILMAZ and ERGONUL, 2011)
17	Risks	(Bendaña, del Caño and Pilar de la Cruz, 2008)
19	Technology Implementation	(Idrus, Sodangi and Amran, 2011), (Nassar and Hosny, 2013), (Watt, Kayis and Willey, 2010)
20	Political Considerations	(Idrus, Sodangi and Amran, 2011)
25	Project specific	(Doloi, 2009)
26	Flexibility	(Doloi, 2009)

After filtering the criteria, a frequency table was generated as below (Table 5):

Table 5

Initial Criteria Frequency Table

ID	Contractor Selection Criteria (CSC)	Frequency
1	Experience	13
2	Reputation	16
4	Financial Standing	11
5	Technical Ability	10
6	Management Capability	13

7	HSE	12
8	Experience of Personnel/Staff	3
9	Past Failed Contracts	2
10	Quality Management and Control	8
11	Current Workload, Capacity & Progress	5
12	Organizational Skills	5
13	Communication & Relationships	8
14	Construction Completion Time	6
15	Guarantees	2
16	Resources	8
17	Risks	1
19	Technology Implementation	3
20	Political Considerations	1
25	Project specific	1
26	Flexibility	1

The criteria frequency table was developed for the purpose of establishing a Pareto analysis of the non-price criteria extracted from the literature. As it is known, the Pareto principle (80/20 rule) states that 80 percent of the criteria can be represented by 20 percent of them. The Pareto fundamental has numerous implementations in quality control. It is the foundation for the Pareto diagram, one of the crucial tools applied in total quality control and Six Sigma. In PMBOK, Pareto organization is applied to monitor corrective action and to assist the project group follow steps to solve the problems that are creating the highest amount of defects first (Pareto Analysis Step by Step, n.d.).

The Pareto analysis is essential to the case of selecting the most effective non-price criteria as it is not practical to conduct such study with a set of 26 criteria, knowing that some of them are not having that much of effect on the selection process. And this is proven from the analysis done on the non-price criteria, that is, it can be clearly seen from the criteria frequency table that some of the criteria have very high frequency, whereas others have as much frequency as 1.

In order to establish the Pareto analysis, the following assumption was made: any criterion with a frequency of only one was eliminated from the Pareto analysis. Thus, the criteria frequency table was modified resulting in the final criteria frequency table, as represented by Table 6 below:

Table 6

Final Criteria Frequency Table

ID	Contractor Selection Criteria (CSC)	Frequency
1	Experience	13
2	Reputation	16
4	Financial Standing	11
5	Technical Ability	10
6	Management Capability	13
7	HSE	12
8	Experience of Personnel/Staff	3
9	Past Failed Contracts	2
10	Quality Management and Control	8
11	Current Workload, Capacity & Progress	5
12	Organizational Skills	5
13	Communication & Relationships	8
14	Construction Completion Time	6
15	Guarantees	2
16	Resources	8
19	Technology Implementation	3

The Pareto analysis was performed using Microsoft Excel, and the following Figure 3 was obtained:

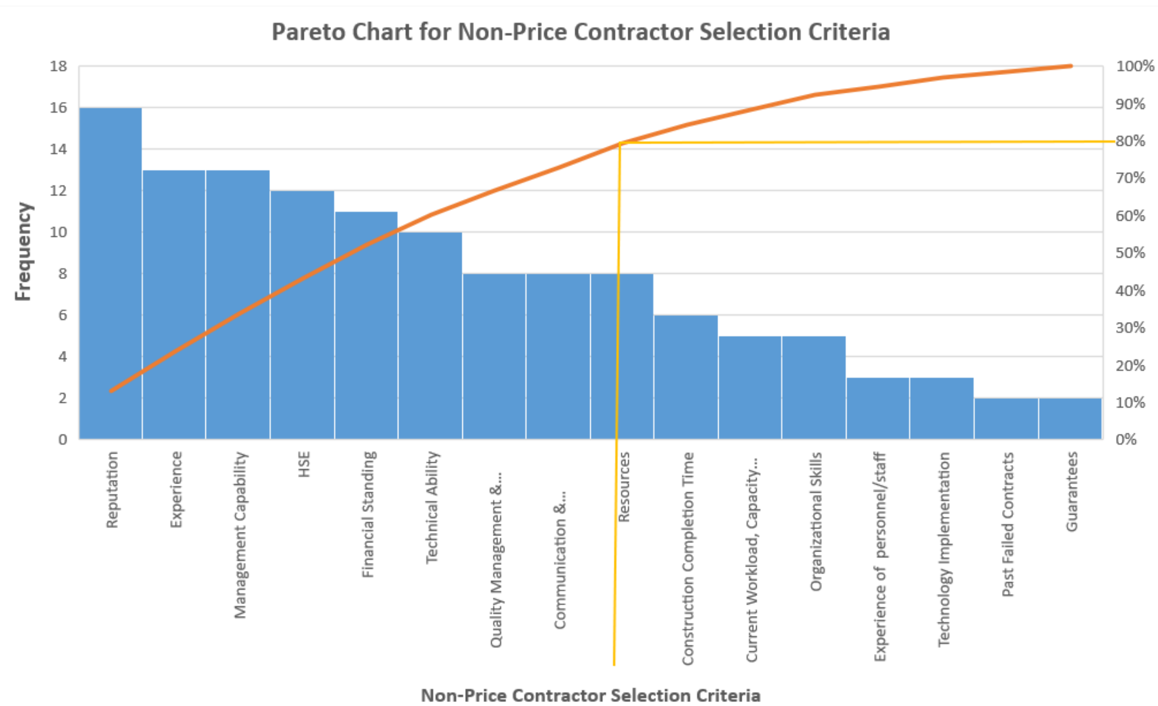

Figure 3. Pareto Chart for Non-Price Criteria.

The results of the Pareto analysis are summarized in Table 7 (highlighted criteria are the selected ones):

Table 7

Summary of Pareto Analysis Results

ID	Contractor Selection Criteria (CSC)	Frequency
1	Experience	13
2	Reputation	16
4	Financial Standing	11
5	Technical Ability	10
6	Management Capability	13
7	HSE	12
8	Experience of Personnel/Staff	3
9	Past Failed Contracts	2
10	Quality Management and Control	8
11	Current Workload, Capacity & Progress	5
12	Organizational Skills	5
13	Communication & Relationships	8
14	Construction Completion Time	6
15	Guarantees	2
16	Resources	8
19	Technology Implementation	3

As a result, the selected set of non-price criteria as a result from the Pareto analysis were:

- Experience (EXP)
- Reputation (REP)
- Financial Standing (FS)
- Technical Ability (TA)
- Management Capability (MC)
- HSE
- Quality Management and Control (QMC)
- Communication & Relationships (CR)

These selected non-price criteria will be used simultaneously with the price criteria for the final contractor selection.

3.3 DEMATEL Technique Implementation

As discussed in the literature review, the DEMATEL method is powerful in the way that it takes into consideration the interdependencies and interrelations among a set of factors/criteria. As was discussed already in chapter 2, DEMATEL technique has been implemented in studies in various fields, however, it is evidential that DEMATEL implementation in construction field is minimal and not implemented at all in the contractor selection problem resolution. Hence, in this study, an effort is being presented to implement this powerful technique of DEMATEL into the construction industry, and mainly in the contractor selection field of study.

The concept behind the technique was already discussed, but here the details of the model and steps to make the calculations is discussed. There are four major steps to apply the technique of DEMATEL to a ranking problem, as follows:

Step 1: Generate the Average Matrix *Z*

This step starts with setting up the pair-wise comparison matrix for the factors under observation. After preparing the pair-wise comparison matrix, experts shall be conducting the assessment of the relative influence among the criteria, through a survey for instance. Each expert is requested to assess the direct influence between each two criteria according to the following scale:

0 - Not Important

1 - Low Important

2 - Medium Important

3 - High Important

4 – Very High Important

Let's assume that "X" is the respondent matrix, then each received respondent matrix is denoted as: X^1, X^2, … , X^k, where $1 \leq k \leq L$. Here, L represents the total number of respondents and k denotes a respondent.

Also, let n be the number of factors under observation, then we have a matrix of $n \times n$. If the letter i is denoted to the rows and j to the columns, then x_{ij} specifies the degree in which a respondent believes factor i affects factor j. It is worthy to mention that the diagonal of the respondent matrix X is set to zero (where $i = j$) because the influence of each factor to itself is zero. After obtaining the responses from the experts ($X^k = [X_{ij}^k]$), then the average matrix Z is calculated, as follows:

$$z_{ij} = \frac{1}{L} \sum_{k=1}^{L} X_{ij}^k \qquad (1)$$

Step 2: Calculate the Normalized Initial Direct-Influence Matrix *D*

The normalized initial direct-influence matrix D is calculated according to the following equation:

$$D = \alpha \times Z \qquad (2)$$

Where Z is the average matrix; and α is:

$$\alpha = \min\left[\frac{1}{max_i \sum_{j=1}^{n} |z_{ij}|}, \frac{1}{max_j \sum_{i=1}^{n} |z_{ij}|}\right] \qquad (3)$$

Step 3: Calculate the Total Influence Matrix *T*

The total influence matrix T is derived from the equation:

$$T = D(I - D)^{-1} \qquad (4)$$

Where D is the normalized initial direct-influence matrix, I is the identity matrix.

Let's assume that:

r_i be the sum of i_{th} row in matrix T, so the vector is:

$$R = [r_i]_{n\times 1} = [\textstyle\sum_{j=1}^{n} t_{ij}]_{n\times 1}^{T} \qquad (5)$$

And c_j be the sum of j_{th} column in matrix T, so the vector:

$$C = [c_j]_{1\times n} = [\textstyle\sum_{i=1}^{n} t_{ij}]_{1\times n}^{T} \qquad (6)$$

Then r_i demonstrations both direct and indirect effects specified by factor i to the other factors, and c_j expresses both direct and indirect effects by factor j from the other factors.

When $j = i$, the sum $(r_i + c_j)$ denotes the total effects received and given by factor i. Consequently, $(r_i + c_j)$ specifies the level of importance for factor i in the total system. On the other hand, the difference $(r_i - c_j)$ signifies the net effect that factor i contributes to the system. Precisely, if $(r_i - c_j)$ is a positive value, then factor i is a net cause. Whereas if $(r_i - c_j)$ is a negative value, then factor i is a net effect.

Step 4: Produce the Influential Relation Map (IRM)

This step is done by first setting up a threshold value, which is obtained by calculating the average of the elements in matrix T:

$$Threshold = \sum_{i=1,j=1}^{n} t_{ij} \qquad (7)$$

Then digraph can be obtained by plotting the dataset of $(r_i + c_j, r_i - c_j)$. Only the elements that are greater than the threshold are shown on the digraph.

3.4 AHP Technique Implementation

The detailed procedure to conduct the necessary calculations for the AHP model was first introduced by its author Saaty, however, a lot of research and investigation have been done on this famous technique. However, Al-Harbi (2001) has summarized the steps as follows:

1. State the problem and define its goal.
2. Build the hierarchy from the top (the objectives from a decision-maker's point of view) over the intermediate levels (criteria that subsequent levels depend on) to the lower level that commonly consists of the list of alternatives.
3. Build a set of pair-wise comparison matrices (size $n \ x \ n$) for each lower level with single matrix for each element in the level directly above by applying the relative scale calculation as shown in Figure 4 below. The pair-wise comparisons are accomplished in a way of which element dominates the other.

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Figure 4. Table of AHP Scale.

4. There are $n(n-1)$ judgments needed to establish the set of matrices in step (3) Reciprocals are assigned in each individual pair-wise comparison automatically.

5. Now the Hierarchical synthesis is applied to weight the eigenvectors by the weights of the criteria and the summation is taken over all weighted eigenvector entries consistent to those in the following lower level of the hierarchy.
6. After having all the pair-wise comparisons made, the consistency is resolved by the use of the eigenvalue, λ_{max}, to determine the consistency index, CI as follows: $CI = (\lambda_{max} - n)/(n-1)$, where n is the matrix size. Judgment consistency can be verified by using the consistency ratio (CR) of CI with the appropriate value in Figure 5 below.

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Figure 5. Random Index (RI) Scale Based on Matrix Size.

The CR is acceptable, if it does not go above 0.10. If the CR is more, the judgment matrix is inconsistent. To achieve a consistent matrix, judgments have to be reviewed and enhanced.

7. Steps 3-6 are executed for all levels in the hierarchy.

To summarize and simplify, the AHP algorithm is fundamentally composed of two main steps:

1. Resolve the relative weights of the decision criteria.
2. Resolve the relative rankings (priorities) of alternatives.

Together qualitative and quantitative data can be compared by using informed judgments to acquire weights and priorities, as in the following steps:

Step 1: Build a hierarchy. State the problem, resolve the criteria and categorize the alternatives.

Step 2: Create pairwise comparisons. Rank the relative importance among each pair of decision alternatives and criteria (use a scale of 1-9 for the prioritization process).

Step 3: Synthesize the results to resolve the best alternative. Acquire the final results.

The output of the AHP is the set of priorities of the alternatives.

3.5 Hybrid method of DEMATEL, AHP and FRM for the Contractor Selection Problem

The major contribution of this thesis to the literature is the unique implementation of the hybrid method AHP with DEMATEL. As discussed before, the AHP is a powerful tool in terms of ranking and prioritizing various alternatives, however, AHP lacks the consideration of the interrelationships between factors/criteria. Thus, and in order to overcome this weakness of AHP, DEMATEL was implemented to be used together with the AHP, since DEMATEL is very powerful in showing the interrelationships between factors/criteria and prioritizing them based on their influences.

The below diagram (Figure 6) illustrate the difference between AHP and DEMATEL in terms of the interrelationships between the criteria:

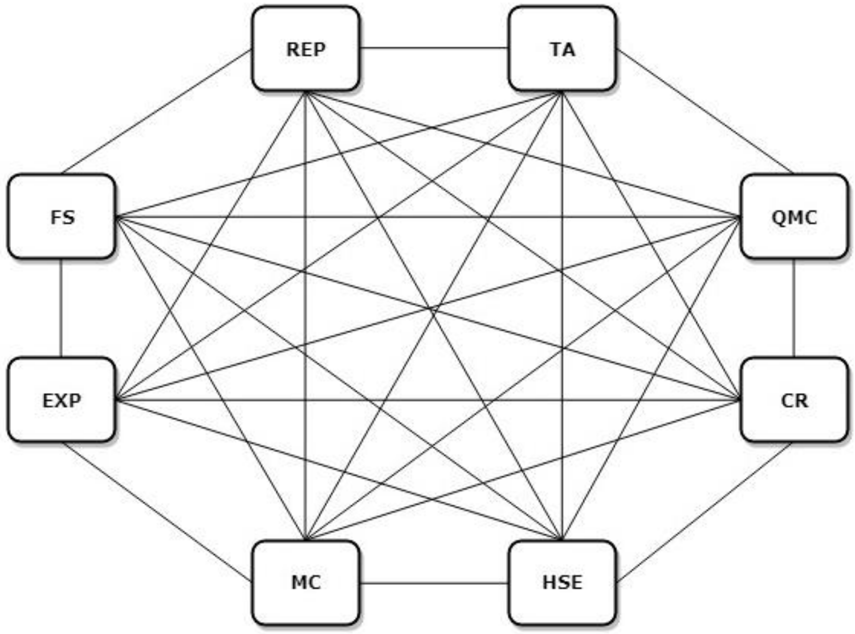

Figure 6. Interrelationships between criteria using DEMATEL.

By developing such unique hybrid method, the advantage of using the well-known method of AHP is kept in place while making for the drawbacks of not considering the interrelationships by the implementation of DEMATEL. The proposed unique hybrid method of AHP and DEMATEL is described as follows:

If we start defining the contractor selection problem to be solved using AHP method, then this implies the following steps in order to solve the problem:

Goal: Selecting the Best Contractor

Criteria: Set of Non-Price Criteria

Alternatives: Contractors in which the selection will be applied to

The below diagram (Figure 7) summarizes the contractor selection problem according to the AHP method:

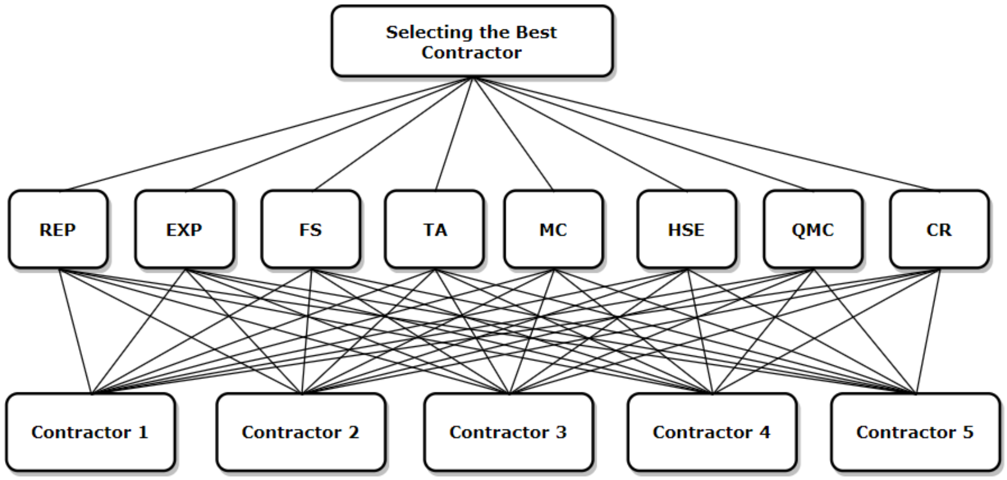

Figure 7. AHP Diagram for Contractor Selection.

Now, to solve this with AHP, a total of 9 matrices must be developed, one criteria matrix and 8 matrices, each comparing all contractors to a specific criterion, as follows:

Criteria matrix: Pair-wise comparison matrix for the eight criteria, see Table 8:

Table 8

Pair-Wise Comparison Matrix for Non-Price Criteria

Non-Price Criteria for Contactor Selection	REP	EXP	MC	HSE	FS	TA	QMC	CR
REP	1							
EXP		1						
MC			1					
HSE				1				
FS					1			
TA						1		
QMC							1	
CR								1

Reputation Matrix: Pair-wise comparison matrix for reputation, see Table 9:

Table 9

Pair-Wise Comparison Matrix for Reputation Criterion

REP	C1	C2	C3	C3	C4	C5
C1						
C2						
C3						
C4						
C5						

Similar pair-wise comparison matrices to reputation matrix will be developed for each criterion, as below:

- experience matrix
- management capability matrix
- health, safety and environment matrix
- financial stability matrix
- technical ability matrix

- quality management and control matrix
- communication and relationships matrix

After filling in the matrices with the pair-wise comparison data, normalization is done by calculating the sum of each column and then divide all the values in that column by the sum value, as shown in Tables 10 and 11:

Table 10

Normalization for Reputation Matrix

REP	C1	C2	C3	C3	C4	C5
C1	a					
C2	b					
C3	c					
C4	d					
C5	e					
Sum	Sum C1					

Table 11

Normalized Reputation Matrix

REP	C1	C2	C3	C3	C4	C5
C1	A= a/ Sum C1					
C2	B = b/ Sum C1					
C3	C = c/ Sum C1					
C4	D = d/ Sum C1					
C5	E = e/ Sum C1					

After that, the average of each row is calculated, and this represents the ranking of each matrix (priority vector), as in Table 12:

Table 12

Calculation Of Priority Vector for Reputation Matrix

REP	C1	C2	C3	C3	C4	C5	priority vector
C1							$= \frac{(A+B+C+D+E)}{5}$
C2							
C3							
C4							
C5							

By synthesizing resulting priority vectors and performing the overall ranking calculation, the contractors are ranked, and the selection of the best contractor is done based on the highest achieving rank contractor. This is done by multiplying the criteria matrix priority vector by the vector constructed by each individual criterion comparison to contractors, as illustrated below in Table 13:

Table 13

Synthesizing Resulting Priority Vectors and Performing the Overall Ranking Calculation

	REP	EXP	MC	HSE	FS	TA	QMC	CR		Criteria priority vector
C1										
C2									X	
C3										
C4										
C5										

Now, we implement the DEMATEL model into the above mentioned AHP model to have the hybrid AHP/DEMATEL model for the contractor selection. First of all, the observation from the AHP method is that for the criteria matrix, the interrelationships (influence) between the criteria is ignored, although the relative importance through pair-wise comparison is performed comparing the criteria by themselves. However, for the remaining matrices, reputation, …, communication and relationships, the pair-wise comparison compares data for the alternatives (contractors) for the same criteria at a time, so the interrelationships between the alternatives is not necessarily mandatory for a better judgment, and the relative importance through pair-wise comparisons will be sufficient to reasonably compute the priority vectors. Therefore, it can be seen that the method of AHP will be accurate for the contractor selection if the model is adjusted such that the criteria matrix takes into consideration the interrelationships between the criteria, and here where the DEMATEL model is implemented.

If we can implement the DEMATEL model in such a way that the hybrid model of AHP/DEMATEL will take into consideration the interrelationships between the criteria and at the same time result in assessment of the best candidate contractor, this will provide a unique, yet more accurate model for the contractor selection.

In order to implement such concept, the criteria matrix in the AHP model will be calculated based on the DEMATEL technique instead of the AHP technique, resulting in the same size priority vector, but with more accurate results considering the interrelationships between criteria. However, the remaining matrices will be kept as is in the AHP model. The final calculation of the best contractor will then be a mix between DEMATEL and AHP calculations, resulting in better assessment of the contractor selection problem. Table 14 is a demonstration of implementing the DEMATEL technique for the calculations of the criteria matrix:

Table 14

Demonstration of Implementing the DEMATEL Technique

Non-Price Criteria for Contactor Selection	REP	EXP	MC	HSE	FS	TA	QMC	CR
REP	0							
EXP		0						
MC			0					
HSE				0				
FS					0			
TA						0		
QMC							0	
CR								0

First of all, the scale in which the data comparison is changed from 1-9 scale to 0-4 scale, where 0 indicates no importance, 1 indicates low importance, 2 indicates medium importance, 3 indicates high importance and 4 indicates very high importance. Then it can be seen from the previous demonstration in Table 14 that the diagonal values are now zeros instead of ones to accommodate the DEMATEL model.

The first step in the DEMATEL calculations is the acquisition of data, in which the judgment of experts is obtained for the relative importance of criteria compared to each other as in the above table. Then, the average matrix is calculated by taking the average of the responses of experts for the criteria matrix. Next is to calculate the normalized initial direct-influence matrix, which is done by:

1. Calculating the sum of rows and columns of the average matrix.
2. Extracting the maximum value of the summation of the rows, and similarly for the columns.
3. Selecting the minimum of the two summation values considered.
4. Taking the reciprocal of the selected value.
5. Multiplying this reciprocal value to each element of the average matrix

After obtaining the normalized initial direct-influence matrix, the total influence matrix is to be calculated. This is done by:

1. Introducing the identity matrix, which is the matrix of any size but with diagonal elements equal to one and all remaining elements equal to zero.
2. Substituting the normalized initial direct-influence matrix from the identity matrix.
3. Taking the inverse of the matrix resulted from the subtraction.

4. Multiplying the normalized initial direct-influence matrix by the inverse matrix.

Once the total influence matrix is generated, the following steps are performed to get the priority vector for the criteria:

1. Calculate the sum of rows and columns of the total influence matrix and consider each one to be a vector, that is, row summation vector and column summation vector.
2. Add up the row and column summation vectors as pairs, for instance, the summation of the first row of the total influence matrix is added up with the summation of the first column of the total influence matrix.
3. The result is a summation vector.
4. Normalize the resulted summation vector by taking the sum of this vector and then divide each element of the vector by the summation.
5. Priority vector for the criteria matrix is obtained.

Therefore, the priority vector for the criteria matrix was obtained by the DEMATEL technique instead of the AHP technique to overcome the weaknesses of the AHP model for this part of the contractor selection. The remaining steps of the AHP model is carried out as for the AHP model (the remaining 8 matrices) and the priority vectors for each criterion by itself is generated.

Then, the priority vectors are synthesized together and AHP calculation are performed. The result of this AHP calculation is the non-price criteria ranking.

The final step in this contractor selection model is to apply the factor rating method to make the final selection. This is done by multiplying the percentage weight of the non-price criteria by its ranking to obtain the non-price score. At the same time, the percentage weights for the price criterion are multiplied by prices to obtain the price score. Lastly, by combining the scores for the price and non-price criteria, we obtain the overall score per contractor; the contractor with the highest total score is selected.

3.6 Design of Survey

In order to test out the proposed unique hybrid model of DEMATEL-AHP-FRM, a survey through questionnaire was prepared and interviews with experts from the public sector were conducted, as this study focuses only on the procurement of the public sector because the competitive bidding is dominating other methods of procurement in the public sector. In terms of quantity, nine interviews were conducted and thus nine surveys were obtained. In fact, following this method of data acquisition is proven to be much more accurate than distribution of questionnaires and relying on the number of returned questionnaires, since the survey in our case is conducted by interview with the experts in the field directly. This assures the quality of the data obtained and that the data input to the survey form was done with full understanding of the questions as well as with high level of accuracy. To support this argument, a number of published papers have followed this methodology for data acquisition, and some of them have based their study on a similar number of respondents, namely 11 respondents (Sumrit and Anuntavoranich, 2013). Also, obtaining expert judgment and controlling the quality of responses by limiting the data input to the questionnaire to experts does directly affect the total quality and accuracy of the survey results and thus gives better chance to assess the proposed unique contractor selection model’s full potential.

3.6.1 Combining Price and Non-Price According to Percentage Weights

Firstly, the experts were introduced to the idea of implementing non-price criteria in addition to the price criterion at the final selection stage. Then the first question asked to them was to put a percentage weight to price criterion versus non-price criterion, as shown in Table 15:

Table 15

Percentage Weights for Price Versus Non-Price Criteria

Criteria Percentage Weight	Price	Non-Price
□	80 %	20 %
□	85 %	15 %
□	90 %	10 %
□	95 %	5 %
Other (Specify)	_______________	_______________

The above percentages were provided based on the most common percentages used in such alternations of the final selection process (YILMAZ and ERGONUL, 2011).

3.6.2 Data for DEMATEL

After the experts have decided the percentage weights of price and non-price criteria, the pair-wise comparison for the criteria matrix is performed by the experts using the DEMTEL scale, as can be seen in Table 16:

Table 16

Criteria Matrix to be Filled According to DEMATEL Scale

Non-Price Criteria for Contactor Selection	REP	EXP	MC	HSE	FS	TA	QMC	CR
REP	0							
EXP		0						
MC			0					
HSE				0				
FS					0			
TA						0		
QMC							0	
CR								0

3.6.3 Data for AHP

Since the criteria in which the survey is concerned with constitutes of qualitative and quantitative aspects, even each one of these criteria might implicitly represent both qualitative and quantitative aspects of the criteria itself, the data acquisition for the criteria – except for the price – were based on the percentage scale, to accommodate both qualitative and quantitative aspects. For the AHP model data, only one sample of alternative contractors, mainly five is required from any of the institutions contacted for the survey. Just to be in the safe side, all reached to institutions were asked to provide a sample of five alternative contractors for a construction project that they have performed the selection for previously, according to the following Table 17:

Table 17

Sample Data from Interviewees

Criteria for Contactor Selection	Contractors' Data				
	C1	C2	C3	C4	C5
Price (Millions)					
Reputation (%)					
Experience (%)					
Management Capability (%)					
HSE (%)					
Financial Standing (%)					
Technical Ability (%)					
QM&C (%)					
C&R (%)					

CHAPTER 4 : RESULTS AND DATA ANALYSIS

In this chapter, the data obtained from interviews is presented with statistical analysis accompanying these data. More importantly, the unique hybrid model for contractor selection developed for this research was applied to the data obtained from the interviews to make the selection of the best contractor based on the sample contractor data provided by one of the interviewees. All the calculation steps with actual data is shown in this chapter.

4.1 Data from Survey (by interview)

For the data collection of the survey discussed in chapter 3, all the surveys were conducted through interviews with the expert professionals from the construction industry, namely the public sector (governmental institutions). The surveys were conducted by first having an interview with the experts discussing the following:

- Their background and experience
- Competitive bidding process and relating it to project delivery aspects
- Describing and illustrating the proposed model of this research paper
- Questionnaire to address their expert judgment on the criteria relative importance

This method to conduct the survey was followed on favor of the traditional way of distributing the surveys on all targeted public-sector institutions and then receive the responses to control the quality of the data. Since the required data are of unique structure and demand, traditional method of distributing the questionnaires will definitely not result in accurate data. On the other hand, interviewing the experts and illustrating to them the model and the correct way to fill in the table for the relative importance of criteria yields to accurate data. In fact, by following this approach, no big number for survey returns is required as the data is very focused and accurate, unlike the traditional way.

This was already proven from the interviews conducted with the experts. In order to take appointments with the experts, a copy of the questionnaire was sent to them prior to the interviews, as indeed, all of them did not fully understand the right way of filling up the questionnaire until the interview was conducted, the model was explained and the right way to denote the relative importance of criteria compared to themselves was properly illustrated. Moreover, during the questionnaire session, the survey conductor was following up with the experts on every and each numeric inputted. That's why the data obtained is considered to be of high accuracy and importance to this research.

A total of nine interviews were conducted for the purpose of this study from different governmental institutions in Qatar (public sector). However, due to the extreme confidentiality of data acquired, the names and details of these institutions will not be mentioned in this research. Nonetheless, these institution represents well the public sector in Qatar.

It is worthy to mention that all the interviewees were with experience of 15 years and above, and all of them were directly related to the contract awarding of contractors and decision-making, which give extreme credibility to the acquired data.

The data obtained from the survey is constituted from the below parts:

- Percentage weights of price versus non-price criteria

- Relative importance of non-price criteria compared to themselves according to the DEMATEL scale and approach

It is worthy to mention that each respondent is denoted by X and superscripted by a number in the chronological order. For instance, the fifth respondent was denoted by X^5.

For the percentage weight of price versus non-price criteria, the following responses were obtained, as shown in Table 18:

Table 18

Acquired Percentage Weight Data

Respondent	Price % Weight	Non-Price % Weight
X^1	90	10
X^2	85	15
X^3	80	20
X^4	80	20
X^5	80	20
X^6	60	40
X^7	85	15
X^8	60	40
X^9	70	30
X^{avg}	76.7	23.3

As can be seen in the table above, the average from the respondents was taken to be considered for the calculations of the best contractor.

For the sample contractors data to make the selection of, one of the institutions reached kindly provided me with data from a real project that they have completed. The project was to deliver a bridge that connects two canals, and the candidate contractors for this specific project were as shown in Table 19 below:

Table 19

Sample Data Acquired from One of the Interviewees

Unit	Criteria	C1	C2	C3	C4	C5
Millions	Price	320	338	328	334	323
%	Rep	75	75	90	75	85
%	Exp	70	85	75	80	80
%	MC	80	80	85	80	75
%	HSE	75	85	85	75	80
%	FS	80	90	80	85	75
%	TA	85	85	80	80	75
%	QMC	70	80	85	80	80
%	C&R	80	80	90	75	75

For the relative importance of the non-price criteria compared to themselves, the data were collected as per described in chapter 3, and the following criteria matrices for each respondent were generated:

$$X1 \begin{bmatrix} 0 & 4 & 3 & 4 & 4 & 3 & 3 & 4 \\ 4 & 0 & 3 & 4 & 4 & 3 & 3 & 4 \\ 2 & 1 & 0 & 4 & 2 & 2 & 1 & 3 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 3 \\ 4 & 4 & 4 & 4 & 0 & 4 & 3 & 4 \\ 1 & 1 & 2 & 3 & 1 & 0 & 1 & 3 \\ 1 & 1 & 3 & 3 & 1 & 3 & 0 & 4 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix}$$

$$X2 \begin{bmatrix} 0 & 2 & 1 & 3 & 2 & 1 & 3 & 4 \\ 3 & 0 & 3 & 3 & 2 & 2 & 3 & 4 \\ 4 & 2 & 0 & 3 & 1 & 2 & 2 & 4 \\ 1 & 1 & 2 & 0 & 2 & 1 & 1 & 2 \\ 3 & 3 & 2 & 4 & 0 & 3 & 2 & 2 \\ 2 & 1 & 3 & 2 & 1 & 0 & 2 & 2 \\ 1 & 1 & 2 & 1 & 1 & 2 & 0 & 2 \\ 1 & 1 & 2 & 2 & 2 & 1 & 1 & 0 \end{bmatrix}$$

$$X3 \begin{bmatrix} 0 & 4 & 4 & 2 & 4 & 4 & 2 & 1 \\ 4 & 0 & 3 & 4 & 2 & 3 & 3 & 4 \\ 2 & 2 & 0 & 2 & 1 & 2 & 2 & 2 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 \\ 3 & 3 & 3 & 4 & 0 & 2 & 4 & 4 \\ 2 & 2 & 2 & 3 & 1 & 0 & 2 & 3 \\ 1 & 2 & 2 & 1 & 1 & 1 & 0 & 2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix}$$

X4	0	1	2	1	1	1	1	1
	4	0	2	3	2	2	3	4
	4	2	0	3	2	2	2	3
	3	1	0	0	1	1	2	3
	4	2	3	3	0	2	4	4
	3	2	2	2	1	0	3	3
	3	2	2	2	1	2	0	3
	3	1	2	1	2	2	2	0

X5	0	1	1	2	1	1	1	1
	4	0	2	3	2	2	3	3
	4	2	0	3	2	2	2	3
	3	1	2	0	1	1	2	3
	3	2	2	3	0	2	2	2
	4	2	2	4	2	0	3	3
	3	1	1	2	2	2	0	1
	2	1	1	2	1	1	1	0

X6	0	1	1	1	1	1	1	2
	3	0	1	2	2	1	3	3
	3	3	0	1	2	3	4	4
	3	2	2	0	1	1	2	3
	4	2	3	4	0	3	4	4
	3	3	2	3	2	0	3	4
	3	2	2	1	1	2	0	2
	2	1	1	1	1	1	2	0

X7	0	2	3	1	1	3	2	2
	2	0	3	1	2	3	2	1
	3	4	0	3	2	2	1	2
	1	2	1	0	2	2	2	3
	4	2	3	3	0	2	2	3
	1	2	3	3	2	0	3	2
	2	1	2	2	2	3	0	2
	2	1	1	2	1	2	2	0

X8

0	1	1	1	1	1	1	1
4	0	2	2	1	2	2	1
3	2	0	2	2	2	1	2
4	3	4	0	2	2	4	3
2	2	1	1	0	2	3	4
4	3	2	1	2	0	3	2
4	3	2	1	1	2	0	2
4	4	2	1	2	2	2	0

X9

0	1	1	2	2	1	3	1
4	0	3	2	2	2	4	4
4	3	0	2	2	3	2	2
2	2	2	0	2	2	1	1
2	2	2	3	0	2	1	1
4	4	3	3	3	0	3	3
2	2	2	2	3	2	0	2
2	2	2	2	2	2	1	0

4.2 Data Analysis

Then the average non-price criteria matrix was calculated by summing up element with the same position on each respondent matrix with each other, then dividing by the total number of respondents, which is nine in this case. The average matrix is shown below:

Xavg

0.000	1.545	1.545	1.545	1.545	1.455	1.545	1.545
2.909	0.000	2.000	2.182	1.727	1.818	2.364	2.545
2.636	1.909	0.000	2.091	1.455	1.818	1.545	2.273
1.727	1.273	1.364	0.000	1.182	1.091	1.455	2.000
2.636	2.000	2.091	2.636	0.000	2.000	2.273	2.545
2.182	1.818	1.909	2.182	1.364	0.000	2.091	2.273
1.818	1.364	1.636	1.364	1.182	1.727	0.000	1.818
1.636	1.182	1.182	1.182	1.182	1.182	1.182	0.000

The normalized initial direct-influence matrix D was calculated next according to equation (2), where α was calculated to be $\alpha = 0.064$:

D [

0.000	0.099	0.099	0.099	0.099	0.094	0.099	0.099
0.187	0.000	0.129	0.140	0.111	0.117	0.152	0.164
0.170	0.123	0.000	0.135	0.094	0.117	0.099	0.146
0.111	0.082	0.088	0.000	0.076	0.070	0.094	0.129
0.170	0.129	0.135	0.170	0.000	0.129	0.146	0.164
0.140	0.117	0.123	0.140	0.088	0.000	0.135	0.146
0.117	0.088	0.105	0.088	0.076	0.111	0.000	0.117
0.105	0.076	0.076	0.076	0.076	0.076	0.076	0.000

]

The identity matrix is defined to be (8x8) to have the same size as matrix D, as below:

I [

1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0
0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	1

]

The total influence matrix T was generated next according to equation (4). However, to ease calculations and follow-up with the steps, the calculation of matrix T was breakdown into the below steps:

1. **Subtracting *D* Matrix from *I* Matrix**

$$I - D = \begin{bmatrix} 1.000 & -0.099 & -0.099 & -0.099 & -0.099 & -0.094 & -0.099 & -0.099 \\ -0.187 & 1.000 & -0.129 & -0.140 & -0.111 & -0.117 & -0.152 & -0.164 \\ -0.170 & -0.123 & 1.000 & -0.135 & -0.094 & -0.117 & -0.099 & -0.146 \\ -0.111 & -0.082 & -0.088 & 1.000 & -0.076 & -0.070 & -0.094 & -0.129 \\ -0.170 & -0.129 & -0.135 & -0.170 & 1.000 & -0.129 & -0.146 & -0.164 \\ -0.140 & -0.117 & -0.123 & -0.140 & -0.088 & 1.000 & -0.135 & -0.146 \\ -0.117 & -0.088 & -0.105 & -0.088 & -0.076 & -0.111 & 1.000 & -0.117 \\ -0.105 & -0.076 & -0.076 & -0.076 & -0.076 & -0.076 & -0.076 & 1.000 \end{bmatrix}$$

2. **Inverse of Subtraction Resulted Matrix**

$$(I - D)^{-1} = \begin{bmatrix} 1.404 & 0.389 & 0.404 & 0.436 & 0.356 & 0.384 & 0.420 & 0.482 \\ 0.711 & 1.408 & 0.542 & 0.594 & 0.463 & 0.512 & 0.582 & 0.676 \\ 0.641 & 0.476 & 1.384 & 0.542 & 0.412 & 0.470 & 0.494 & 0.608 \\ 0.471 & 0.351 & 0.369 & 1.317 & 0.316 & 0.340 & 0.388 & 0.474 \\ 0.720 & 0.539 & 0.564 & 0.638 & 1.378 & 0.538 & 0.596 & 0.698 \\ 0.619 & 0.471 & 0.494 & 0.547 & 0.408 & 1.366 & 0.523 & 0.609 \\ 0.509 & 0.380 & 0.409 & 0.426 & 0.337 & 0.399 & 1.330 & 0.497 \\ 0.427 & 0.316 & 0.328 & 0.355 & 0.289 & 0.316 & 0.342 & 1.321 \end{bmatrix}$$

3. **Multiplying *D* Matrix by Inverse Matrix**

$$D(I - D)^{-1} = \begin{bmatrix} 0.404 & 0.389 & 0.404 & 0.436 & 0.356 & 0.384 & 0.420 & 0.482 \\ 0.711 & 0.408 & 0.542 & 0.594 & 0.463 & 0.512 & 0.582 & 0.676 \\ 0.641 & 0.476 & 0.384 & 0.542 & 0.412 & 0.470 & 0.494 & 0.608 \\ 0.471 & 0.351 & 0.369 & 0.317 & 0.316 & 0.340 & 0.388 & 0.474 \\ 0.720 & 0.539 & 0.564 & 0.638 & 0.378 & 0.538 & 0.596 & 0.698 \\ 0.619 & 0.471 & 0.494 & 0.547 & 0.408 & 0.366 & 0.523 & 0.609 \\ 0.509 & 0.380 & 0.409 & 0.426 & 0.337 & 0.399 & 0.330 & 0.497 \\ 0.427 & 0.316 & 0.328 & 0.355 & 0.289 & 0.316 & 0.342 & 0.321 \end{bmatrix}$$

The threshold value was calculated to be (0.461).

The R and C vectors were calculated based on equations (5&6), as shown in Table 20:

Table 20

R and C vectors

ri	cj
3.274	4.502
4.488	3.329
4.026	3.493
3.026	3.855
4.670	2.960
4.038	3.324
3.287	3.675
2.695	4.365

Then, the $(r_i + c_j)$ and $(r_i - c_j)$ were calculated, as can be found in Table 21:

Table 21

Summation and Subtraction of R & C Vectors

$(r_i + c_j)$	$(r_i - c_j)$
7.776	-1.228
7.817	1.158
7.520	0.533
6.882	-0.829
7.630	1.710
7.362	0.714
6.961	-0.388
7.060	-1.670

From the $(r_i + c_j)$, the weights for the non-price criteria are extracted by performing normalization. The normalization was performed by calculating the sum of the $(r_i + c_j)$ values, then divide each value of the $(r_i + c_j)$ by the summation to obtain the normalized values, as in Table 22 below:

Table 22

Normalized Values of Summation and Subtraction of R & C Vectors

$(r_i + c_j)$	Normalized
7.776	0.1318
7.817	0.1325
7.520	0.1274
6.882	0.1166
7.630	0.1293
7.362	0.1248
6.961	0.1180
7.060	0.1196
Sum	Sum
59.008	1

So, the weights for the non-price criteria is obtained, and shown below in Table 23:

Table 23

Non-Price Criteria Weights

Criteria	Weight
Rep	0.1318
Exp	0.1325
MC	0.1274
HSE	0.1166
FS	0.1293
TA	0.1248
QMC	0.1180
C&R	0.1196

For the remaining matrices (pair-wise comparison matrix for each non price criteria), they were evaluated based on the obtained data from survey and the generated matrices are shown below (Tables 24-31):

Table 24

Pair-wise comparison matrix for Reputation

	c1	c2	c3	c4	c5
c1	1	1	1/9	1	1/6
c2	1	1	1/9	1	1/6
c3	9	9	1	9	3
c4	1	1	1/9	1	1/6
c5	6	6	1/3	6	1

Table 25

Pair-wise comparison matrix for Experience

	c1	c2	c3	c4	c5
c1	1	1/9	1/3	1/6	1/6
c2	9	1	6	3	3
c3	3	1/6	1	1/3	1/3
c4	6	1/3	3	1	1
c5	6	1/3	3	1	1

Table 26

Pair-wise comparison matrix for Management Capability

	c1	c2	c3	c4	c5
c1	1	1	1/5	1	5
c2	1	1	1/5	1	5
c3	5	5	1	5	9
c4	1	1	1/5	1	5
c5	1/5	1/5	1/9	1/5	1

Table 27

Pair-wise comparison matrix for HSE

	c1	c2	c3	c4	c5
c1	1	1/9	1/9	1	1/5
c2	9	1	1	9	5
c3	9	1	1	9	5
c4	1	1/9	1/9	1	1/5
c5	5	1/5	1/5	5	1

Table 28

Pair-wise comparison matrix for Financial Standing

	c1	c2	c3	c4	c5
c1	1	1/6	1	1/3	3
c2	6	1	6	3	9
c3	1	1/6	1	1/3	3
c4	3	1/3	3	1	6
c5	1/3	1/9	1/3	1/6	1

Table 29

Pair-wise comparison matrix for Technical Ability

	c1	c2	c3	c4	c5
c1	1	1	5	5	9
c2	1	1	5	5	9
c3	1/5	1/5	1	1	5
c4	1/5	1/5	1	1	5
c5	1/9	1/9	1/5	1/5	1

Table 30

Pair-wise comparison matrix for Quality Management & Control

	c1	c2	c3	c4	c5
c1	1	1/6	1/9	1/6	1/6
c2	6	1	1/3	1	1
c3	9	3	1	3	3
c4	6	1	1/3	1	1
c5	6	1	1/3	1	1

Table 31

Pair-wise comparison matrix for Communication & Relationships

	c1	c2	c3	c4	c5
c1	1	1	1/6	3	3
c2	1	1	1/6	3	3
c3	6	6	1	9	9
c4	1/3	1/3	1/9	1	1
c5	1/3	1/3	1/9	1	1

Then normalization for each of the above pair-wise comparison matrices was done (see Appendix B), after that the average of each row was calculated (see Appendix B) to obtain the ranking of the contractors for each specific non-price criterion. However, the rankings are shown below:

Table 32

Compiled Priority Vectors for AHP

	Rep	Exp	MC	HSE	FS	TA	QMC	C&R
c1	0.054	0.037	0.137	0.038	0.095	0.385	0.034	0.138
c2	0.054	0.483	0.137	0.397	0.530	0.385	0.172	0.138
c3	0.553	0.080	0.555	0.397	0.095	0.099	0.451	0.617
c4	0.054	0.200	0.137	0.038	0.239	0.099	0.172	0.053
c5	0.284	0.200	0.036	0.131	0.040	0.031	0.172	0.053

In order to perform the final AHP step, the following multiplication of the vector matrix in Table 23 by the matrix produced from Table 32, as shown in Table 33:

Table 33

Synthesizing Priority Vectors

	REP	EXP	MC	HSE	FS	TA	QMC	CR		
										0.1318
										0.1325
C1	0.054	0.037	0.137	0.038	0.095	0.385	0.034	0.138		0.1274
C2	0.054	0.483	0.137	0.397	0.530	0.385	0.172	0.138	X	0.1166
C3	0.553	0.080	0.555	0.397	0.095	0.099	0.451	0.617		0.1293
C4	0.054	0.200	0.137	0.038	0.239	0.099	0.172	0.053		0.1248
C5	0.284	0.200	0.036	0.131	0.040	0.031	0.172	0.053		0.1180
										0.1196

The resulting ranking of contractors based on the non-price criteria considerations are eventually obtained by performing the calculations of the above Table 33, as the resulted ranking can be shown below in Table 34:

Table 34

Final Weights for Non-Price Criteria

Criteria	Weight
C1	0.115
C2	0.288
C3	0.352
C4	0.125
C5	0.119

The final stage of the contractor selection in the proposed framework of this research paper is to apply the factor rating method (FRM) to make the selection of the best contractor by aggregating the price criteria score with the non-price criteria score. As shown in Table 35, the ranking for the non-price criteria was already obtained. Now, to obtain the scoring for the non-price criteria, they are multiplied by their percentage weight (23.3% in this case). Likely, the scoring for the price criterion is obtained as following:

- The prices are normalized by obtaining the sum of all prices then dividing each price by the summation, Table 36.
- Multiply each normalized price by the percentage weight (76.7% in this case), Table 37.

Finally, the scores for both price and non-price criteria are added together and the total contractor score is obtained, as presented in Table 37:

Table 35

Price and Non-Price Criteria Weights

Contractor	Non-Price	Price
C1	0.115	320
C2	0.288	338
C3	0.352	328
C4	0.125	334
C5	0.119	323

Table 36

Normalized Price Criteria Weights

Contractor	Normalized Price Criterion
C1	0.195
C2	0.206
C3	0.200
C4	0.203
C5	0.197

Table 37

Single and Total Scores of Criteria

Contractor	Non-Price Score	Price Score	Total Score
C1	0.027	0.149	17.6%
C2	0.067	0.158	22.5%
C3	0.082	0.153	23.5%
C4	0.029	0.156	18.5%
C5	0.028	0.151	17.9%

CHAPTER 5 : DISCUSSION OF RESULTS

In chapter 4, the results and analysis of data were described in detail to illustrate the proposed model capability through a case study. However, in this chapter, the obtained results will be discussed in terms of implications, consistencies, graphical representations, comparison between current and future states as well as findings from this analysis and model.

After comprehensively reviewing the literature regarding the non-price criteria that researchers reconsidered in the evaluation process of the best contractor to be selected, a Pareto analysis was conducted on the data gathered from the literature, which was represented in Figure 3. This Pareto analysis is very precious as it scientifically implies that the 8 non-price contractor selection criteria resulted from the Pareto analysis are the most important criteria; and at the same time they have the dominant effect on the contractor selection whilst they represent only 20 percent of the total population (contractor selection criteria).

The importance of such finding is that it can be the base of future studies. In fact, as this research paper is focused on developing a novel framework for the contractor selection process, it was very advantageous to use the output of the Pareto analysis, which are the eight contractor selection criteria. Moreover, the research can be directed in the way to investigate the effects of these 8 criteria rather than defining which criteria to be used, as this study addresses the most important criteria for the contractor selection problem.

The results obtained from the DEMATEL analysis have many inferences and implications, in which the author of this research paper considers of extreme importance.

First of all, as the DEMATEL technique was developed to address the relative importance of the non-price criteria for contractor selection and thus define the ranking weights for each of those non-price criteria accurately; the weights were obtained from the summation of $(r_i + c_j)$. This was done by performing normalization to the summation and thus obtaining the weights of the criteria. It can be seen from Table 23 that reputation and experience almost got the same weights and they were the highest achieving criteria in terms of weight. The non-price criteria were sorted in descending order to represent the ranking according to the DEMATEL technique in Table 38 below:

Table 38

Ordered Non-Price Criteria Weights in Descending Order

Non-Price Criteria	Ranking (Weights)
EXP	0.1325
REP	0.1318
FS	0.1293
MC	0.1274
TA	0.1248
CR	0.1196
QMC	0.1180
HSE	0.1166

However, obtaining the weights are not the only implication that can be extracted from the $(r_i + c_j)$ summation, which is also defined as the prominence. The prominence is an indication of the total effect per criteria regardless if the effect was by or on the criteria. It is also an indication of the degree of the overall influence of each criteria (influencing and being influenced).

On the other hand, the measure $(r_i - c_j)$ infers interesting and important sightings. This measure, which is also denoted as relation, expresses the net contribution by the criteria on the system, such that a positive value for $(r_i - c_j)$ indicates that the criterion is a net cause whereas a negative value indicates that the criterion is a net effect. Indeed, the observation of the output of the DEMATEL technique shows interesting behavior of the non-price criteria under study. By examination of the value represented in Table 21, it can be seen that the criteria are divided into two categories: cause and effect.

The criteria that have a positive value, namely EXP, MC, FS and TA are marked as cause criteria, whereas the remaining criteria, namely REP, HSE, QMC and CR are marked as effect criteria. The following Table 39 summarizes these two categories:

Table 39

Characterizing the Criteria as Cause or Effect

Non-Price Criteria	(ri- cj)	Cause/Effect
Rep	-1.228	Effect
Exp	1.158	Cause
MC	0.533	Cause
HSE	-0.829	Effect
FS	1.710	Cause
TA	0.714	Cause
QMC	-0.388	Effect
CR	-1.670	Effect

Moreover, a Cause-Effect diagram is plotted as can be shown below in Figure 8:

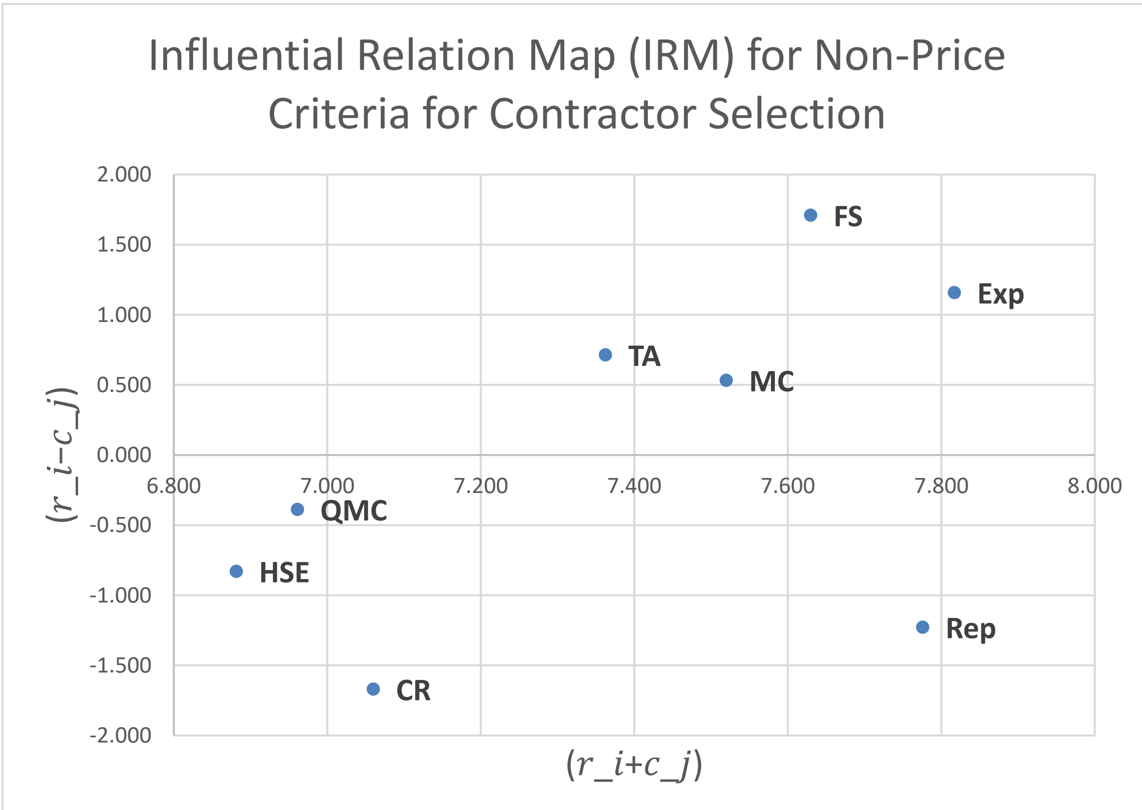

Figure 8. Cause-Effect Diagram for Non-Price Criteria.

The data points on the above graph represent the non-price criteria that were analyzed in this research paper. The points that lay above the positive x-axis represent the cause criteria, while the data points below the positive x-axis (negative y-values) represent the effect criteria.

The yield of this analysis is very important, as it clearly shows the interrelationship and influence among the non-price criteria and justifies the interview discussions with the experts. The experts that were interviewed for the contractor selection have had discussions regarding the interrelationships between the criteria and they have considered for example the reputation to be not a standalone criteria but a consequence of the experience and other criteria in which collectively will yield into the reputation criterion. Indeed, this can be clearly seen in Figure 8 were the reputation criterion lays down the positive x-axis line and is considered as an effect criterion. This finding is also important as it suggests that considering only the cause criteria for the contractor selection can be a substitute and as effective as the whole set of non-price criteria in the contractor selection problem.

In addition, after calculation the threshold value (0.461), all the elements in the total influence matrix T were evaluated such that any element with a value greater than the threshold value was considered, otherwise lower values that the threshold were omitted, as can be seen in the below matrix:

$$\begin{matrix} D(I-D)^{-1} \\ \text{“>Threshold”} \end{matrix} \begin{bmatrix} - & - & - & - & - & - & - & 0.482 \\ 0.711 & - & 0.542 & 0.594 & 0.463 & 0.512 & 0.582 & 0.676 \\ 0.641 & 0.476 & - & 0.542 & - & 0.470 & 0.494 & 0.608 \\ 0.471 & - & - & - & - & - & - & 0.474 \\ 0.720 & 0.539 & 0.564 & 0.638 & - & 0.538 & 0.596 & 0.698 \\ 0.619 & 0.471 & 0.494 & 0.547 & - & - & 0.523 & 0.609 \\ 0.509 & - & - & - & - & - & - & 0.497 \\ - & - & - & - & - & - & - & - \end{bmatrix}$$

From the data in the above matrix, the interrelationships or influences between the criteria can be characterized. That is, is we consider the first value in the second row (0.711), it denotes that a relationship between experience and reputation takes place and its direction is from experience to reputation.

In order to make sure the data obtained for the pair-wise comparison matrices for each non-price criteria compared to the alternatives (contractors) are consistent, the consistency ratio was calculated. This was done by following the below steps:

1. Calculate Consistency Index: $CI = (\lambda_{max} - n)/(n - 1)$
2. Define Random Index RI (refer to table)
3. Calculate Consistency Ratio: $CR = CI/RI$

The calculated consistency ratios for the 8 pair-wise comparison matrices are shown in Table 40 below:

Table 40

Summary of Consistency Ratio Calculations

Criteria	λ_{max}	CI	RI	CR	<0.1
Rep	5.122	0.031	1.120	0.027	yes
Exp	5.125	0.031	1.120	0.028	yes
MC	5.199	0.050	1.120	0.044	yes
HSE	5.304	0.076	1.120	0.068	yes
FS	5.141	0.035	1.120	0.031	yes
TA	5.257	0.064	1.120	0.057	yes
QMC	5.078	0.019	1.120	0.017	yes
CR	5.164	0.041	1.120	0.037	yes

It can be clearly seen in the above table that all the pair-wise comparison matrices are consistent, with a consistency ratio of less than 0.1, which shows that the data collected, and pair-wise comparison matrices are mathematically accepted.

It can be shown from Table 34 that contractor 3 have achieved the highest priority (ranking) for the non-price criteria, followed by contractor 2 which is relatively close in terms of priority to contractor 3. On the other hand, it can be inferred from Table 34 that the results for contractors 1, 4 and 5 are close to each other and are almost half of the other two contractors ranks. These observations imply that contractors 2 and 3 are competitive in terms of the non-price criteria and they excel by virtue over the remaining contractors. However, this gives indication – from this step and without going further in the analysis – that the selection of the best contradictor for this specific project might be one of these two contractors (contractors 2 and 3) if the price criterion plays in favor of them as well. In addition, it can be clearly seen from the results of the ranking of the contractors based on the non-price criteria that the candidate contractors for the specific project under study are not similar in the technical and other aspects which are represented in this research by the non-price criteria, although all of these candidate contractors have passed through the prequalification process, technical and financial evaluation. Nonetheless, it can be still clearly seen the difference between these contractors in terms of the technicality and other aspects. Indeed, this observation is typically the case with the competitive bidding, where all qualified contractors that passed the prequalification and technical and financial evaluations are considered capable of delivering a specific project on time, budget and according to agreed quality, whereas the candidate contractors are still not similar in their capabilities. Moreover, this observation justifies the problem that this research paper is trying to solve, by reconsidering the final selection of candidate contractors and adding to the final selection a weighted percentage of the non-price criteria along with the price criterion to make better decisions that will yield better project delivery. It is not only in the literature that this phenomenon is defined as problematic and full of problems, it is a witnessed issue from practice and by the tongues of professional experts in the construction industry that suffer and complain from repetitive delays, cost overruns and quality issues with the delivered projects. All of the experts that were interviewed have admitted that the contractor selection based on the competitive bidding strategy is one of the biggest causes of these issue with project delivery as contractors are main stakeholder of the project.

The final step in the proposed contractor selection framework of this research paper was to apply the factor rating method to obtain the overall scores of the candidate contractors and then select the contractor with the highest score. For the case study discussed in this research paper, the final overall scores of the candidate contractors were shown in Table 37 and the best contractor for the specific project under study was contractor 3, achieving an overall score of 23.5%. It is worthy to mention that contractor 2 achieved an overall score close to that for contractor 3. This is because of two reasons:

1. The contractors scores for the non-price criteria were close.
2. The bided price by contractor 2 was the highest amongst all candidate contractors and giving a percentage weight of more than 75 % for the price criteria will definitely have its impact on the overall scores.

On the other hand, and again, the remaining three contractors achieved poorly with overall scores close to each other. From above discussion, it can be clearly noticed the effect and impact of the non-price criteria when integrated with the price criterion on the final selection of the contractor and how it can change the final selection to contractors that are not the lowest bidders but with better other criteria. Although not quantifiable in this research paper, but the project delivery aspects are expected to be improved by following such optimized selection process as it shifts the selection of the contractor to a slightly higher price, but guarantees better technical and other capabilities for the selected contractor, in which should affect the overall progress and quality of the project and result in better delivery of the project.

In the case where we apply the conventional competitive bidding strategy to our case study, the contractor selection will go directly to contractor 1. However, it can be deduced from the ranking results of the non-price criteria that contractor 1 has the lowest ranking, which means that contractor 1 is the least capable contractor amongst the candidates in terms of the technical and other criteria (non-price criteria). The argument here is not about whether or not a contractor is capable of delivering the project as all of the candidate contractors have already passed through the prequalification process and technical and financial evaluations, however, the argument is which contractor is capable of delivering the project with the best delivery aspects. Since variations and change orders are very common to the construction industry and almost no project is free of variation, and at the same time it is very rare to complete a project within the budget allocated, most of the times projects end up costing more that the budgeted amount of money. So, it is a matter of reducing the probability of cost overruns by carefully and wisely selecting the contractors that will work on the project. The same ideology applies to the rest of project delivery aspects, that is time and quality.

The final selection of construction contractor as a result of applying the proposed framework in this research paper has indeed resulted in selection of a contractor that have balance of both sets of criteria, namely price and non-price criteria. This balance does not put burden on the decision makers to select higher bid prices knowing that the ending up price will be lesser due to better handling the project because of better non-price criteria rankings.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This thesis has studied the contractor selection process that is enforced in the public sector, namely competitive bidding, and as a result proposed enhancement to the competitive bidding by re-implementation of non-price criteria score again in the final selection of contractor. This was achieved through the proposed novel framework to perform the selection of the best candidate contractor based on combination of price and non-price criteria scores.

Basically, the contractor selection problem was studied from all angles. Firstly, it was revealed that the project success is essentially related to the proper contractor selection. Secondly, the criteria used in addition to the price criteria to make the final selection of the contractor were comprehensively reviewed and analyzed using Pareto chart. It was obtained from the Pareto chart that the most important and effective non-price criteria were reputation, experience, management capability, HSE, financial stability, technical ability, quality management and control and communication and relationships. Furthermore, a unique new hybrid technique was developed using DEMATEL, AHP and Factor Rating Method all combined together in a single model to enhance the selection.

A case study was developed to test the proposed framework for contractor selection. For this purpose, a survey was designed to obtain data from experts through interviews. The new hybrid model was applied to the data obtained through the survey and it was found out that the best candidate contractor for the project under study was contractor 3, which achieved the highest score in terms of the non-price criteria, but with the price criterion averaging the alternatives.

The practical implications of this study is the reshaped final selection of contractors according to the competitive bidding process, as was verified through the conducted case study. The re-implementation of the non-price criteria scores that resulted from the technical evaluation of contractors again in the final selection was proven to be practical through the case study and yields better contractor selection, since the selected contractor has balance of price and non-price criteria scores; which is predicted to lead to better project delivery. One the same note, the identification of the most important non-price criteria for contractor selection establishes a set of non-price criteria that is verified from literature and practice. Interestingly, this set of non-price criteria can be used to technically evaluate the contractors and to investigate specifically the effect of these criteria on the contractor selection results.

6.2 Recommendations

It is very important to notice that this model is best applicable to the case were the differences in prices between the alternatives (contractors) are relatively small, such that the non-price criteria weight can play a role in the selection process. Otherwise, and knowing that the price criterion has a massive weight compared to the non-price criteria, the price criterion will be always dominating. The proposed approach in this paper will be very useful in the cases were the contractors' prices are close to each other, then the non-price criteria will have impact on the final selection.

6.3 Future Works

As for future work, the following are suggested by the paper author:

- Integration of a project success prediction model (forecasting model) with the proposed framework to have more clear and quantifiable forecasting resulting from the contractor selection.
- Implementation of goal programing and multi-objective linear programming at the final stage of the proposed framework, instead of the factor rating method, and test out the improvement in the selection (if any).
- Implementation of Value Stream Mapping (VSM) in the competitive bidding process to study more in deep areas for improvement.

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Appendix – A: Summary Table for Criteria for Contractor Selection

Number	Paper Title	Authors	Year	Contractor Selection Criteria (CSC)
5	A deterministic contractor selection decision support system for competitive bidding	Nabil Semaan Michael Salem	2017	1. Time a. Work Load b. History of Delays c. Availability of Equipment 2. Cost a. Capital Assets b. Performance Bonds c. Availability of Qualified Staff 3. Safety a. Safety Record b. HSE Policy

				c. Internal Safety Regulations 4. Quality a. ISO Certifications b. Internal QA/QC Program
19	A new compromise solution method for fuzzy group decision-making problems with an application to the contractor selection	Behnam Vahdani S.MeysamMousavi H.Hashemi M.Mousakhani R.Tavakkoli-Moghaddam	2012	1. Financial soundness a) Financial stability b) Credit rating c) Banking arrangements and bonding d) Financial status 2. Technical ability a) Experience b) Plant and equipment

c) Personnel
d) Ability

3. Management capability
    a) Past performance and quality
    b) Project management organization
    c) Experience of technical personnel
    d) Management knowledge
4. Health and safety
    a) Safety
    b) Experience modification rating
    c) Occupational safety and

				housing administration incidence rate d) Management safety accountability 5. Reputation a) Past failures b) Length of time in business c) Past owner/contractor relationship d) Other relationships
22	A superiority and inferiority ranking	Mohamed Marzouk	2008	1. Capital bid 2. Financial stability

	model for contractor selection			3. Length of time in industry 4. Management organization 5. Experience of technical personnel 6. Safety program 7. Past failed contracts
28	An Analysis of the Selection of Project Contractor in the Construction Management Process	Xiaohong Huang	2011	1. Financial standing a) financial stability b) turnover c) profit d) obligations e) amounts due f) owned financial funds 2. Technical ability a) Experience b) plant and equipment

c) personnel

3. Management capability

    a) past performance and quality
    b) quality control policy
    c) quality management system
    d) project management system
    e) experience of technical personnel
    f) management knowledge

4. Quality, safety, senior management

a) Experience
b) tenure with firm
c) division of responsibilities

5. Current projects/backlog
    a) Number
    b) Size
    c) location of projects
    d) percent of capacity being utilized
    e) status and expected completion
    f) past failures in completed projects

				g) number of years in construction h) past client relationships i) cooperation with contactors
31	Application of the graph theory and matrix methods to contractor ranking	Maryam Darvish Mehrdad Yasaei Azita Saeedi	2008	1. Work experience 2. Technology and Equipments 3. Management 4. Experience and knowledge of the operation team 5. Financial stability 6. Quality 7. Being familiar with the area or being domestic 8. Reputation

				9. Creativity and innovation
34	APPLYING THE AHP TO SUPPORT THE BEST-VALUE CONTRACTOR SELECTION – LESSONS LEARNED FROM TWO CASE STUDIES IN TAIWAN	Wei-Chih Wang Wen-der Yu I-Tung Yang Chun-Chang Lin Ming-Tsung Lee Yuan-Yuan Cheng	2013	1. Technical and quality a) technical ability b) Environmental protection c) Quality management plan 2. Management a) Organization b) Financial condition c) Emergency management 3. Past performance a) Experience b) Performance records 4. Commercial terms

				a) Construction duration b) Bidder's promises c) Maintenance service 5. Price a) Total bid price b) Item bid price 6. Question/ answer
35	Assessing contractor selection criteria weights with fuzzy AHP method application in group decision environment	Piotr Jaskowski Slawomir Biruk Robert Bucon	2009	1. manpower and equipment 2. financial capacity 3. past project performance 4. organizational experience 5. certified management systems (quality

				system, safety policy)
38	Bidding strategy to support decision-making by integrating fuzzy AHP and regression-based simulation	Jui-Sheng Chou Anh-Duc Pham Hsin Wang	2013	1. Construction a) Project complexity b) Government level c) Project duration d) Experience of project staff 2. Environment a) Site condition b) Geologic types c) Climate d) Cultural conditions 3. Planning

				a) Design concepts b) Design drawings c) Construction method d) Interface management 4. Estimation a) Contractors fitness b) Indirect costs c) Direct costs d) Risk assessment
42	Construction Contractor Selection in Taiwan Using AHP	Fu-Yuan Chiang Vincent F. Yu Pin Luarn	2017	1. Technical ability (TA) a) Experience b) Plant and equipment c) Personnel d) Ability

2. Management capability (MC)
    a) Past performance and quality
    b) Project management organization
    c) Experience of technical personnel
    d) Management knowledge
3. Financial soundness (FS)
    a) Financial stability
    b) Credit rating
    c) Banking arrangements and bonding

d) Financial status

4. Reputation (R)

   a) Past failures

   b) Length of time in business

   c) Past client/contractor relationship

   d) Other relationships

5. Health and safety (HS)

   a) Safety

   b) Experience modification rating (EMR)

   c) Occupational Safety and Health

				Administration (OSHA) incidence rate d) Management safety accountability
53	Contractor selection for construction project, with the use of fuzzy preference relation	Nabi Ibadov	2015	1. Reputation 2. Technical capabilities 3. Financial situation 4. Organizational skills
57	CONTRACTOR SELECTION OF CONSTRUCTION IN A COMPETITIVE ENVIRONMENT	Edmundas Kazimieras Zavadskas Zenonas Turskis Jolanta Tamošaitienė	2008	1. bid estimates 2. construction duration 3. guarantee period for screen works 4. guarantee period for finishing works

				5. experience of firm in construction 6. total amount of works performed by contractor 7. communication level with stakeholders 8. quality of performed projects
59	Contractor Selection Using Multicriteria Decision-Making Methods	José Ramón San Cristóbal	2012	1. Technical capability 2. Cost 3. Completion time 4. Experience in similar jobs 5. Financial status 6. Management capability 7. Safety
62	Contractor selection: fuzzy-control approach	Ricardo Bendan˜ a Alfredo del Can˜ o	2008	1. Experience of the company and key staff in similar

	M. Pilar de la Cruz	projects in recent years 2. Managerial organization and resources 3. Technical organization and resources 4. The ability to meet the time objective, taking into account the proposed time and the risk of exceeding it 5. The ability to meet the cost objective, taking into account the proposed price and the risk of exceeding it 6. The ability to meet the quality objective,

				taking into account the quality issues of the proposal and the risk of failing in this objective 7. Other risks
65	Decision Criteria for Selecting Main Contractors in Malaysia	Arazi Idrus Mahmoud Sodangi Mohamad Afeq Amran	2011	1. Track Performance 2. Financial capacity 3. Technical capacity 4. Bid price 5. Experience in similar projects 6. Management efficiency 7. Time of completion quoted 8. Occupational health & safety 9. Progress of existing project 10. Relationship with client

				11. No of projects at hand 12. Level of technology 13. Friendship 14. Political considerations
78	Fuzzy clustering validity for contractor performance evaluation: Application to UAE contractors	Khaled Nassar Ossama Hosny	2012	1. Staff and equipment quality a) Staff Training program b) Project Manager performance c) Availability of key personnel d) Equipment condition e) Equipment suitability

				2. Safety and environmental protection a) Health record b) Risk management c) Environment protection d) Environment Protection record 3. Other criteria a) Time control b) Cost control c) Reputation d) Technology
82	Identification and Evaluation of Parameters Influencing the selection of Finance Project	YOONES MAZAHERI-ZADEH ZAHRA NAJI-AZIMI	2015	1. Technical and Planing power a) Key personnel sufficiency

Contractors of Mashhad Water and Wastewater Company Using an AHP and Fuzzy Pramty	b) Project planning and control power 2. Equipmental power a) Project equipment and machinery b) Hardware equipments 3. Financial power 4. Background goodness a) Qualification from previous employers 5. Quality assurance system a) Qualitive documents

				6. Experience a) In executive projects b) In costumer department c) In ware preparation
94	Selection of Contractors for Middle-Sized Projects in Turkey	Aysegul YILMAZ Sema ERGONUL	2011	1. Contractor’s Organization a) Age b) Permenant Place of Business c) Quality Control Certification 2. Past Performance a) Past Quality Grade b) Maintenance Services During

defects liability period

3. Past Experience
   a) Experience in local area
   b) Experience with construction of hospitals
4. Plant and Equipment
   a) Ownership of plant and equipment
   b) Testing equipment
5. Personnel
   a) Qualifications of key personnel
   b) Years of key personnel

with the company

6. Project Management
    a) Site supervision / management
    b) Market information system
7. Quality Management
    a) QA/QC programs
    b) Qualifications of QA/QC personnel
8. Health and Safety Management
    a) Safety measures on site
    b) Safety records

				9. Environmental Management a) Environmental control policy
95	Structural equation model for assessing impacts of contractor's performance on project success	Hemanta Doloi K.C. Iyer Anil Sawhney	2010	1. Soundness of business and workforce (SBW) a) Technical expertise (SBW1) b) Defects liability attitude (SBW2) c) Successful past projects (SBW4) d) Yearly turnover (SBW5)

e) Relevant work experience (SBW6)
f) Working capital (SBW7)

2. Planning and control (PC)
   a) Plant maintenance programs (PC1)
   b) Work method statement (PC2)
   c) Work's quality record (PC3)

d) Flexibility in the critical paths (PC4)

e) Failure to comply with quality specifications (PC5)

f) Failure in on-time delivery (PC6)

3. Quality performance (QP)

   a) Tender quality (QP1)

   b) Tender timeliness (QP2)

   c) Safety Initiatives record (QP3)

d) Quality control and quality assurance programs (QP4)

e) Query response timeliness (QP5)

f) Failure to perform safety requirements (QP6)

4. Past performance (PP)

a) Length of relationships (PP1)

b) Regulation knowledge (PP2)
c) Turnover fluctuations (PP3)
d) Time in business (PP4)
e) Overall trade experience (PP5)
f) Past record of conflicts and disputes (PP6)

5. Overall project success (OPS)
    a) On-time project delivery (PS1)

				b) On budget project delivery (PS2) c) Desired quality outcomes (PS3) d) Cost savings (PS4)
99	The impact of contractors' management capability on cost and time performance of construction projects in Nigeria	O.I. Aje K.T. Odusami D.R. Ogunsemi	2009	1. Technical capability 2. Financial capability 3. Managerial capability a) past performance and quality achieved b) contractors' experience c) management knowledge

				d) quality control programme e) amount of own workforce 4. General information 5. Past performance 6. Health and safety records
100	The impact of contractors' attributes on construction project success: A post construction evaluation	Jaman I. Alzahrani Margaret W. Emsley	2012	1. Health, safety and quality a) Quality policy b) Quality assurance c) Occupational safety and health administration rate (OSHAIR)

d) Health and safety records
e) Quality control
f) Experience Modification Rating (EMR)

2. Past performance
    a) Contract cost overruns
    b) Contract time overruns
    c) Past record of conflict and disputes
    d) Failure to have completed a contract
3. Environment

a) Waste disposal during construction
b) Environmental plan during construction
c) Materials and substances used in the project

4. Management and technical aspects
    a) Management capability
    b) Site organisation
    c) Knowledge of particular construction method

d) Work programming

5. Resources
   a) Adequacy of labour resources
   b) Adequacy of plant resources
6. Organization
   a) Size of the company
   b) Company image
   c) Age in business
7. Experience
   a) Experience in the region
   b) Length of time in business

				8. Size/type of pervious project a) Type of past project completed b) Size of past project completed 9. Finance a) Turnover history b) Credit history c) Cash flow forecast
111	Selection of construction enterprises management strategy based on the SWOT and	E.K. ZAVADSKAS Z. TURSKIS J. TAMOSAITIENE	2011	1. Technology skills 2. Leading brands 3. Customer relationship 4. Management skills 5. Products quality

multi-criteria analysis	6. Changing customer tastes 7. Liberalization of geographic markets 8. Technological advances 9. Changes in government policies 10. Absence of important skills 11. Weak brands 12. Low customer retention 13. Management 14. Unviable product 15. Changing customer tastes 16. Closing of geographic markets 17. Technological advances

				18. Changes of government policies
112	The relative importance of tender evaluation and contractor selection criteria	D.J. Watt B. Kayis K. Willey	2009	1. Organisational experience 2. Project management expertise 3. Tendered price 4. Technical Expertise 5. Past Project Performance 6. Company Standing (Reputation) 7. Method/Solution 8. Client–supplier relations 9. Workload/Capacity
116	CONTRACTOR SELECTION FOR CONSTRUCTION WORKS BY APPLYING SAW-G AND TOPSIS	Edmundas Kazimieras Zavadskas Tatjana Vilutiene	2010	1. Experience of executives (years) 2. Number of constructed houses (units in 2005-2008, years)

	GREY TECHNIQUES	Zenonas Turskis Jolanta Tamosaitiene		3. Turnover (in 10^6 €, 2005-2008, years) 4. Number of executives (persons in 2005-2008, year) 5. Market share (portion of sales) 6. Production method (in point)
117	Analysis of pre-qualification criteria in contractor selection and their impacts on project success	HEMANTA DOLOI	2009	1. Project specific 2. Management expertise 3. Quality control systems 4. Flexibility 5. Experience/past projects 6. Success and failures 7. Financial viability 8. Relationships

	9. Tender price and quality

Appendix – B: Normalized Matrices for AHP and Row Summations

Reputation

0.056	0.056	0.067	0.056	0.037	0.054
0.056	0.056	0.067	0.056	0.037	0.054
0.500	0.500	0.600	0.500	0.667	0.553
0.056	0.056	0.067	0.056	0.037	0.054
0.333	0.333	0.200	0.333	0.222	0.284

Experience

0.040	0.057	0.025	0.030	0.030	0.037
0.360	0.514	0.450	0.545	0.545	0.483
0.120	0.086	0.075	0.061	0.061	0.080
0.240	0.171	0.225	0.182	0.182	0.200
0.240	0.171	0.225	0.182	0.182	0.200

Management Capability

0.122	0.122	0.117	0.122	0.200	0.137
0.122	0.122	0.117	0.122	0.200	0.137
0.610	0.610	0.584	0.610	0.360	0.555
0.122	0.122	0.117	0.122	0.200	0.137
0.024	0.024	0.065	0.024	0.040	0.036

HSE

0.040	0.046	0.046	0.040	0.018	0.038
0.360	0.413	0.413	0.360	0.439	0.397
0.360	0.413	0.413	0.360	0.439	0.397
0.040	0.046	0.046	0.040	0.018	0.038
0.200	0.083	0.083	0.200	0.088	0.131

Financial Standing

0.088	0.094	0.088	0.069	0.136	0.095
0.529	0.563	0.529	0.621	0.409	0.530
0.088	0.094	0.088	0.069	0.136	0.095
0.265	0.188	0.265	0.207	0.273	0.239
0.029	0.063	0.029	0.034	0.045	0.040

Technical Ability

0.398	0.398	0.410	0.410	0.310	0.385
0.398	0.398	0.410	0.410	0.310	0.385
0.080	0.080	0.082	0.082	0.172	0.099
0.080	0.080	0.082	0.082	0.172	0.099
0.044	0.044	0.016	0.016	0.034	0.031

Quality Management & Control

0.036	0.027	0.053	0.027	0.027	0.034
0.214	0.162	0.158	0.162	0.162	0.172
0.321	0.486	0.474	0.486	0.486	0.451
0.214	0.162	0.158	0.162	0.162	0.172
0.214	0.162	0.158	0.162	0.162	0.172

Communication & Relationships

0.115	0.115	0.107	0.176	0.176	0.138
0.115	0.115	0.107	0.176	0.176	0.138
0.692	0.692	0.643	0.529	0.529	0.617
0.038	0.038	0.071	0.059	0.059	0.053
0.038	0.038	0.071	0.059	0.059	0.053

Appendix – C: Survey

This survey is conducted as part of data collection for Master's Thesis at Qatar University. We highly appreciate your time to complete the survey. Your responses are extremely confidential.

You may contact the research focal person at:

Email: me1000217@qu.edu.qa / Mobile: -

Description of the Study

This study aims to enhance and improve the construction contractor selection process. This is mainly targeting competitive bidding type of projects where the lowest bid is selected after passing the prequalification process. The proposed method is to add most important non-price criteria from the prequalification process to the price criterion while making the selection decision of the construction contractor.

In this survey, we will get your expert judgement about the weight of price criterion compared to non-price criteria for contractor selection. Also, we would like to obtain relative importance of the non-price contractor selection criteria amongst each other. Lastly, we would like to get sample contractor data to be used for the Analysis of the proposed model.

By getting this valuable input from your side, we will be able to establish a model for selection of construction contractors implementing non-price criteria in the selection process along side with the price criterion to yield better selection which would result in more satisfactory project delivery aspects.

Part 1: Weight Distribution for Price and Non-Price Criteria for Contactor Selection

Q1)

Here, we would like to know your expert judgment regarding the weights of non-price criteria that will be added to the price criteria to enhance the contractor selection process.

Please mark your response as **Percentage Weights** for the price criterion compared to non-price criteria as below:

Criteria Percentage Weight	Price	Non-Price
□	80 %	20 %
□	85 %	15 %
□	90 %	10 %
□	95 %	5 %
Other (Specify)	_______________	_______________

Part 2: Relative Importance of Each Non-Price Contractor Selection Criteria Amongst Each Other

Q2)

Here, we would like to obtain your expert judgment on the relative importance of the non-price contractor selection criteria amongst each other.

Please mark your response (0 to 4) for the relative importance of non-price criteria for contractor selection. The scale is as follows:

0 - Not Important
1 - Low Important
2 - Medium Important
3 - High Important
4 – Very High Important

Kindly mark your responses on the following page:

Non-Price Criteria for Contactor Selection	Reputation	Experience	Management Capability	HSE	Financial Standing	Technical Ability	QM&C *	C&R **
Reputation	0							
Experience		0						
Management Capability			0					
HSE				0				
Financial Standing					0			
Technical Ability						0		
QM&C *							0	
C&R **								0

**** Quality Management & Control (QM&C)***

***** Communication & Relationships (C&R)***

Q3)

Please provide sample data for five contractors according to the selection criteria (Price and Non-Price combined) below. You can put real data or hypothesize the data based on your experience in the field (**C** represents contractor alternative):

Criteria for Contactor Selection	Contractors' Data				
	C1	C2	C3	C4	C5
Price (Millions)					
Reputation (%)					
Experience (%)					
Management Capability (%)					
HSE (%)					
Financial Standing (%)					
Technical Ability (%)					
QM&C (%)					
C&R (%)					

Q4)

Please provide your valuable suggestion for any other improvements that should be considered in the Contractor Selection Process

____

____

____

Part 3: General Information:

1- Bidding Type "Contract Award Mechanism" used in your current project:

□ Competitive Bidding □ Negotiation Bidding

2- Years of experience in the construction industry:

□ Less than 5 years □ 5 - 10 years

□ 10 - 15 years □ 15 or more years

3- Your discipline in the current project & organization:

□ Civil & Structural □ Architecture □ Oil & Gas

□ Electrical □ Mechanical □ Other _________________

4- Role of your organization in the current project:

□ Owner □ PMCM □ Supervision Consultant

□ Design Consultant □ Contractor □ Subcontractor/Supplier

5- Your department in the organization at the current project:

□ Contracts Dept. □ Design Dept. □ Finance Dept.

□ Construction Dept. □ Projects Control □ Other _______________