SELECTING THE APPROPRIATE PROJECT DELIVERY METHOD FOR REAL ESTATE PROJECTS USING FUZZY AHP

by

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ABSTRACT

SELECTING THE APPROPRIATE PROJECT DELIVERY METHOD FOR REAL ESTATE PROJECTS USING FUZZY AHP

The real estate industry holds a remarkably significant share in the Turkish economy. Due to the nature of the dynamic characteristics of the real estate industry, project achievement is not an easy task. Since selecting the appropriate project delivery method is significantly important considering that it does not only mean economic contribution but it is also time saving and it has other additional benefits, this study aims to determine the main factors affecting PDM selection with the most suitable analysis method for real estate projects in Turkey. The PDM types used in the real estate sector and the factors affecting appropriate PDM selection process will be identified with the help of literature review and interviews with professionals related to the Turkish real estate industry. The model generated by benefiting from the literature review and the perspectives of the professionals in Turkey will be used as a tool in choosing the appropriate PDM in real estate projects by utilizing Fuzzy AHP. In terms of the theoretical contribution to the literature, this thesis provides the probable factors affecting the selection of the PDM in the Turkish real estate industry with 5 main factors categorized as "time related issues, cost, funding and cash flow related issues, scope related issues, owner organization, risk and relationship related issues and project characteristic issues" with 13 sub-factors. Furthermore, another theoretical contribution of this thesis is exhibiting the main PDMs used in Turkish real estate industry as "DBB", "DB" and "CM at Agency". In addition to the theoretical contribution, a hierarchical model with a questionnaire to select the appropriate project delivery method for the real estate projects in Turkey is provided as a practical contribution.

ÖZET

BULANIK ANALİTİK HİYERARŞİ PROSESİ KULLANILARAK GAYRİMENKUL PROJELERİNDE UYGUN PROJE TESLİM YÖNTEMİNİN SEÇİLMESİ

Gayrimenkul sektörü Türkiye ekonomisinde oldukça önemli bir paya sahiptir. Gayrimenkul sektörünün dinamik doğası gereği, başarılı projeler gerçekleştirmek kolay bir iş değildir. Uygun proje yönetimi, sadece ekonomik katkı sağlaması bakımından değil, aynı zamanda vakit tasarrufu ve başka bir çok avantaj getirmesi açısından önemli olduğundan, bu çalışma Türkiye'deki gayrimenkul projelerindeki proje teslim yöntemlerinin seçimini etkileyen ana faktörleri en uygun analiz yöntemleriyle belirlemeyi amaçlamaktadır. Gayrimenkul sektöründe kullanılan proje teslim yöntemi türleri ve uygun proje teslim yöntemi seçimi sürecini etkileyen faktörler, literatür taraması ve Türkiye'deki gayrimenkul sektörüyle ilgili profesyonellerle yapılan görüşmeler yardımıyla belirlenecektir. Literatür taramasından ve Türkiye'deki profesyonellerin bakış açılarından yararlanılarak oluşturulan model, Bulanık Analitik Hiyerarşi Prosesi kullanılarak gayrimenkul projelerinde uygun proje teslim yöntemi seçiminde bir araç olarak kullanılacak-tır. Literatüre teorik katkı olarak, bu tez, Türk gayrimenkul sektöründe proje teslim yöntem-lerinin seçimini etkileyen olası faktörleri, "zaman ile ilgili konular, maliyet, finansman ve nakit akışı ile ilgili konular, kapsam ile ilgili konular, mülk sahibinin organizasyonu, risk ve ilişkiler ile ilgili konular ve proje karakteristiği konuları" olarak gruplandırılan 5 ana faktör ve 13 alt-faktörle sunmaktadır. Ayrıca, bu tezin bir diğer teorik katkısı, Türk gayrimenkul sektöründe kullanılan "Tasarım-İhale-Yapım", "Tasarım-Yapım" ve "Temsilci/Danışman Olarak Yapım Yöneticisi" ana proje teslim yöntemlerini ortaya koymasıdır. Teorik katkıya ek olarak, Türkiye'deki gayrimenkul projelerine uygun proje teslim yöntemini seçmek için bir anketi de içeren hiyerarşik bir model pratik bir katkı olarak sunulmaktadır.

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Σ	Summation
λ	Eigenvalue of Pairwise Comparison Matrix

LIST OF ACRONYMS/ABBREVIATIONS

C	Column Vector
CI	Consistency Index
CMA	Construction Management at Agency
CMR	Construction Management at Risk
CR	Consistency Ratio
DB	Design-Build
DBB	Design-Bid-Build
PDM	Project Delivery Method
RI	Random Index
W'	Weight Vector
W	Normalized Weight Vector

1. INTRODUCTION

1.1. Background of Research

The construction industry holds a remarkably significant share in the Turkish economy. The substantial part of this industry might be regarded as real estate which is classified, considering the purpose of use of property, as residential, commercial and industrial. In consequence of the increasing population and the inter-regional migration, the demand for sheltering and other needs for real state have been growing day by day. According to the Real Estate and Real Estate Investment Trusts Association (GYODER)'s report with the title 'Construction Industry in 2023 Vision', the augmentation in the demand is mainly stemming from three elements: the increase in population based upon urbanization, urban transformation and renovation. The data on the forecasted demand numbers in this report is presented in Table 1.1. Moreover, the incrementation rates in the population from previous years, the number of the buildings detected as risky for earthquakes as well as the number of the buildings above 50 years old were identified and these are the substantial components used in the preparation of the report.

Table 1.1. The Anticipated Demand for Residential Units in Turkey (GYODER, 2012).

Years	**The Anticipated Demand for Residential Units**				
	Increase in Population (1,000)	**Urban Transformation (1,000)**	**Renovation (1,000) (1,000)**	**Total (1,000) (1,000)**	**Just for İstanbul (1,000)**
2019	419	200	50	669	120
2020	426	200	50	676	122
2021	430	200	50	680	122
2022	440	200	50	690	124
2023	430	200	50	680	122
Total	2145	1000	250	3395	610

The locomotive affect of the construction industry in Turkey is widely recognized. The ‘Construction Sector Report’ published by the Turkish Employers Association of Construction Industries (INTES) in September 2018 declares that there are more than 200 sub-sectors fed by the construction industry. Therefore, the industry is directly related to not only the local economy but also the global economy by making great contribution to employment. While the sole share of the construction industry is around 8% in the Global Domestic Product (GDP) of Turkey, the rate of the sub-sectors in relation with construction constitute a remarkable share of 30%. Stemming from the unbalanced nature of the Turkish economy in political and social terms, the success of the construction industry faces the dangers of uncertainty and instability. To illustrate this, the rate of exchange going up leading the increase in the project costs and preventing high demand in the industry, might be given as an example. This situation may be seen as the source of the vicious circle and the cause of the permanent crises in many sectors for the long run.

With respect to the report prepared by the Real Estate and Real Estate Investment Trusts Association (GYODER) and Colliers International in 2019 named ‘Restate Turkey- A Close Look to Compatible Markets’, the construction industry is experiencing shrinkage taking into account the previous years’ growth, demonstrated in Figure 1.1, prepared by virtue of the data from GYODER and Colliers International. Particularly for Turkey, the rate goes down remarkably after 2017 as it does in Europe as well.

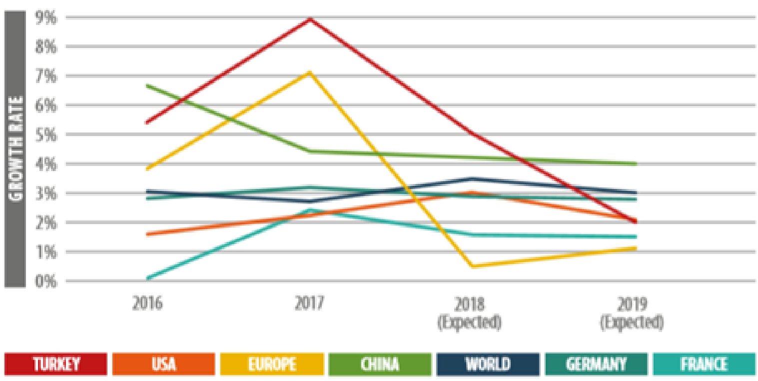

Figure 1.1. Construction Sector Growth (GYODER and Colliers International, 2019).

As stated in the same report, the impact of the geopolitical risks in Turkey accompanied by the economic slowdown leads to flatness in the real estate yields as shown in Figure 1.2, with the data from Colliers International. However, a progressive upward trend has recently occurred.

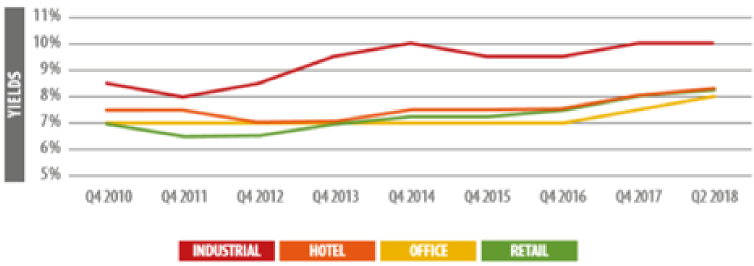

Figure 1.2. Construction Sector Yields (GYODER and Colliers International, 2019).

Due to the nature of the dynamic characteristics of the real estate industry, project achievement is not an easy task. At this point, proper project management is an essential factor for project success including completion with planned schedule, costs and quality. Moreover, the selection of the appropriate project delivery method is an indispensable part of the project management issue. When the literature is examined, several definitions for project delivery method (PDM) are found. El-Sayegh (2007), for example, describes it as the owner's approach to organizing the project team to handle the whole process of design and construction. Mahdi and Alreshaid (2005), on the other hand, see PDM as a means to ensure that delivery risk and performance in the design and construction processes, which are typically under the responsibility of the owner, are assigned to other party/parties. For Oyetunji and Anderson (2006), PDM determines the roles and responsibilities for each party who take part in a construction project; therefore, it presents a roadmap covering all the steps in order, from design to actual construction. Lastly, according to ASCE (2000), project delivery method explains the way the different parties in a project collaborate to realize the owner's expectations.By virtue of a suitable project delivery method, the project will be much more durable in case of any contingency. When we consider the Turkish construction industry with respect to the topics mentioned above, it is obvious that the industry is highly fragile in being affected by the variables. Therefore, determining possible PDMs and the factors affecting the selection of them is highly required.

1.2. Aim and Objective of Study

Since selecting the appropriate project delivery method is significantly important considering that it does not only mean economic contribution but it is also time saving and it has other additional benefits, this study aims to determine the main factors affecting PDM selection for real estate projects in Turkey.

In this respect, the main objectives of this research are as follows:

- To examine the PDM types with respect to their area of utilization
- To identify and classify the factors that are outstanding for PDM selection
- To examine some analysis methods before deciding to use the Fuzzy AHP
- To generate a model by considering the steps just mentioned above
- To put this model into practice according to the steps just mentioned above, a case study is conducted based on a completed real estate project.

Furthermore, this thesis aims to contribute to the literature with the following theoretical and practical findings:

- The PDM types used in the real estate sector and the factors affecting appropriate PDM selection process will be identified with the help of literature review, filtering the ones preferred in Turkey via interviews with professionals sharing the literature investigation with them and collecting their opinions for the Turkish real estate construction industry.
- The model generated by benefiting from the literature review and the perspectives of the professionals in Turkey will be used as a tool in choosing the appropriate PDM in real estate projects.

1.3. Scope and Limitations of Study

The scope of this thesis is substantially based on literature review and the opinions of some professionals to develop a Fuzzy AHP model for the PDM selection and conducting a case study. Due to the lack of literature review in the Turkish real estate market for PDM selection, the literature review is mainly based on the researches excluding Turkey. Therefore, the interviews with the professionals are quite crucial for identifying and implementing the findings related to the literature review on the Turkish real estate market. The scope of the study is to examine general real estate projects without focusing on a specific one like urban transformations.

In the case study section, a real estate project that was completed in Istanbul in 2015 was used to implement the model for the selection of the appropriate PDM. By virtue of the questionnaire that was designed and distributed to the professionals in face-to-face form, the decision-making process was properly fulfilled with respect to their responses.

On the other hand, this research has some limitations as well. Initially, the number of the interviews with the sector professionals can be considered as one of the limitations. Then, another limitation in this study is concerning the number of the case studies. Further case studies can be conducted to augment the reliability of the proposed model. This way, the data about consistency can be achieved in order to analyze the results deriving from this proposed model.

1.4. Organization of Thesis

To sum up, this thesis includes the following chapters:

- In Chapter 2, the previous studies about the PDM types used in the real estate industry and the factors affecting the selection of them are examined. Furthermore, the gap in the literature for Turkey is identified and the research question is stated.
- In Chapter 3, the research methodology, the literature review, the theoretical background of the AHP and the Fuzzy AHP, the interview questionnaire design and the main questionnaire to be used in practical application to determine the suitable PDM are put forward.

- In Chapter 4, the findings generated from the literature review and the interviews with Turkish professionals are presented.
- In Chapter 5, a case study is applied for the proposed model.
- In Chapter 6, the discussions related to the limitations of this thesis in addition to the recommendations for further research are shared.
- In Chapter 7, the conclusion is stated.

2. LITERATURE REVIEW

2.1. Introduction

This chapter of the thesis presents the literature on the project delivery methods as well as the factors that are essential for choosing the appropriate PDM. In other words, the aim of this chapter does not only include the identification of the PDM, but also listing the factors based on the studies in the literature for the purpose of suitable selection process. By virtue of the summary of the literature review, the statement of the research question will be clarified explicitly.

2.2. Real Estate Industry

Real estate is the property, land, buildings, air rights above the land and underground rights below the land. The substantial part of construction industry might be regarded as real estate which is classified, considering the purpose of use of property, as residential, commercial and industrial. According to New Report on Global Construction Market report created by Orbis Research, global construction output is forecast to rise to US$12.7 trillion in 2022, up from US$10.6 trillion in 2017. In Turkey, the sole share of the construction industry is around 8% in the Global Domestic Product (GDP) that means about 100 billion USD. The report named Global Real Estate Investment Volumes Reach Record High by Cushman & Wakefield states that global real estate investment volumes reach US$1.75 trillion in 2018. In consequence of the increasing population and the inter-regional migration, the demand for sheltering and other needs for real state have been growing day by day. According to the Real Estate and Real Estate Investment Trusts Association (GYODER)'s report with the title 'Construction Industry in 2023 Vision', the augmentation in the demand is mainly stemming from three elements: the increase in population based upon urbanization, urban transformation and renovation. To meet this requirement, Turkey has been a country which pays attention to real estate industry since 1980's. Thanks to construction studies which gains more speed with big momentum in recent years particularly, interest in real estate industry maintains its liveness.

2.3. Definition of Project Delivery Method (PDM)

When the literature is examined, several definitions for project delivery method are found. El-Sayegh (2007), for example, describes it as the owner's approach to organizing the project team to handle the whole process of design and construction. Mahdi and Alreshaid (2005), on the other hand, see PDM as a means to ensure that delivery risk and performance in the design and construction processes, which are typically under the responsibility of the owner, are assigned to other party/parties. For Oyetunji and Anderson (2006), PDM determines the roles and responsibilities for each party who take part in a construction project; therefore, it presents a roadmap covering all the steps in order, from design to actual construction. Shortly, project delivery method explains the way the different parties in a project collaborate to realize the owner's expectations.

In line with the abovementioned definitions of PDM, when owners aim to start a new project, they come across an important question as to how they should create a group of people to handle their construction project from the beginning (design) to the end (construction). Moreover, according to Gould (2005), the concept of PDM helps in ideally arranging different parties within a construction project with consideration of the matters related to the contract. Some main parties in construction projects are designers and contractors as well as construction management companies. Liu *et al.* (2015) argue that for a construction project to achieve success (which means reaching the goals and the objectives established in advance), scientific methods should be employed while choosing the most suitable PDM. This, on the other hand, is directly related to the ability of the contractor to utilize the selected PDM. In other words, a construction project will be successful if the contractor's features are in accordance with the chosen PDM.

Completion of a specific project requires a robust project management approach. This process has some constraints according to Dr. Martin Barnes, the creator of the

Iron Triangle model which defines the indispensable part of a project management constraint as quality, time and cost within determined scope. In the modern project management logic of the Project Management Institute (PMI), besides time, quality, cost and scope, additional constraints are resources, risk and benefits that deeply affect the project life cycle. Nevertheless, the relationship between project management and project delivery in the construction industry is inherently an inseparable whole. In the beginning of any project, the aim is to carry out the project conveniently within the owner's goals which generally consist of being on budget without any contingent costs, on schedule without any delay and satisfied in quality constraints in order to appeal to the intended scope successfully.

The issues mentioned above necessitate different kinds of PDMs related to the solution for a satisfactory project management. In the literature, there are various PDMs that are applied to different types of projects meeting their specific requirements as Design-Bid-Build, Design-Bid-Build with early procurement and construction manager, Construction Management, Turkey, Fast Track, Design-Build, Multiple Design-Build (Mostafavi and Karamouz, 2010). From this point of view, the principal types of PDMs applied in the industry are:

- Design-Bid-Build (DBB)
- Design-Build (DB)
- Construction Management at Risk (CMR)
- Construction Management at Agency (CMA at Agency)

The following gives detailed information about these types of PDMs by considering the studies in the literature.

2.3.1. Design-Bid-Build (DBB)

Design-Bid-Build (DBB) is a traditional type of PDM which is well-known among the construction industry. Ibbs *et al.* (2003) give information about DBB in their study. Accordingly, the project is separated into two phases as design and construction.

Therefore, the owner of the project follows two different steps which are independent of, but support, each other. The DBB structure is shown in Figure 2.1.

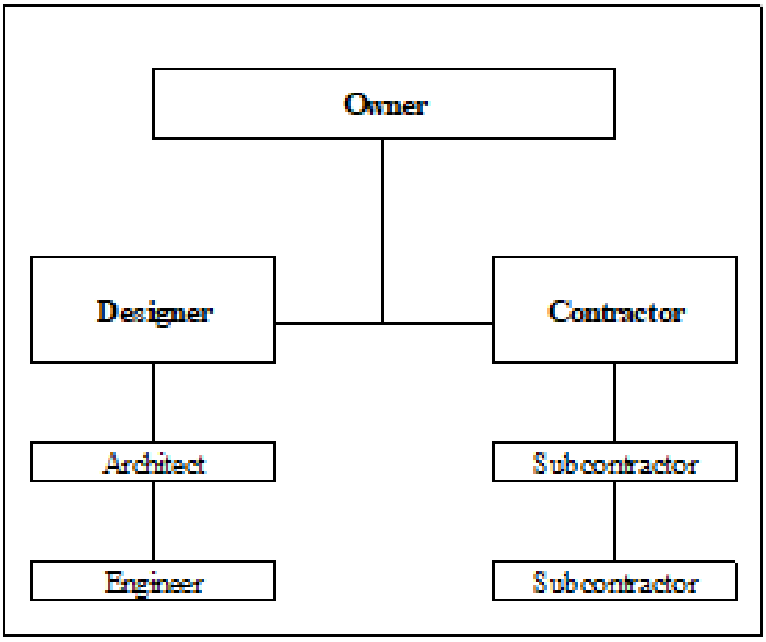

Figure 2.1. Design-Bid-Build Structure Related to the Parties of a Project.

In these two well-defined phases, the designer focuses on preparing a design package containing the contract documents (Al Khalil, 2002). By using the documents prepared by the design team, the owner initiates the bid process sending the design package and gathers the proposal from the contractors to award the construction contract. Since the designer is responsible for the documentation of the initial phase without any connection with the contractor, the risk of fostering adversaries among parties is inevitable in DBB. Moreover, the linear nature of DBB requires the finalization of one task before moving to another. This prevents the minimization of the project duration. Thus, in general, it is known as the longest delivery method.

To conclude, the main advantages of using DBB and its disadvantages are summarized below in accordance with the ideas of Rojas and Kell (2008), Ibbs *et al.* (2003) and Konchar and Sanvido (1998).

(i) Advantages

- Constraint control of design
- Well-defined legal/regulatory guidance
- Low bids for the project
- Low initial investment for the owner

(ii) Disadvantages

- Three linear phases (design, bid, build) preventing any overlap, decreasing the project duration
- All responsibility on the owner's shoulders
- The most adversarial method because of the lack of connection among parties and change order process is difficult
- The contractor does not have any input to the project before the contract is awarded

2.3.2. Design-Build (DB)

Design-Build (DB) method refers to the process during which the owner of the project works only and directly with one party which holds the responsibility for the whole project cycle from design to construction (Konchar and Sanvido, 1998). Through this method, the owner is able to assign the overall liability to a sole entity. The structural relationship among parties is shown in Figure 2.2.

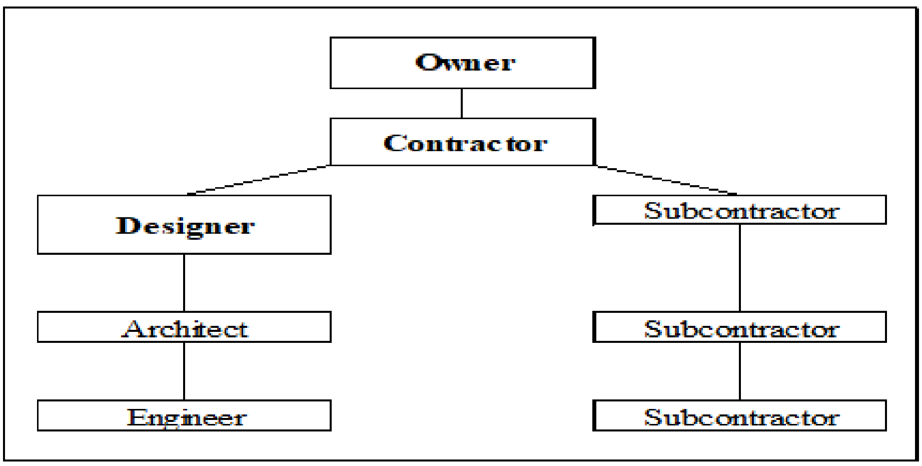

Figure 2.2. Design-Build Structure Related to the Parties of a Project.

Ibbs *et al.* (2003) emphasize that the master builder used to be in charge of the whole project cycle, and towards the end of 1800s, this practice was still favored. As distinct from DBB, this approach tends to eliminate the complexity and the confusion in the relationship of the parties by providing design and construction via a single entity (Al Khalil, 2002). Furthermore, this method enables the reduction of the overall completion time by keeping constructability alive during the design process and provides convenience for the implementation of change orders to the project. Al Khalil (2002) underlines that DB is more suitable for projects with a well-defined scope, a standard and repetitive design, and a tight schedule.

Finally, the application of DB is prone to generate some advantages and disadvantages summarized below in accordance with Mahdi and Alreshaid (2005), Ibbs *et al.* (2003), and Konchar and Sanvido (1998).

(i) Advantages

- Ensures control of design for the owner
- Enables contractor to contribute with necessary input during design phase
- Determines overlaps as well as gaps within the project before the construction
- Provides the fastest project completion
- Ensures lower costs owing to the possibility of direct procurement from vendors
- Guarantees the identification of the contract value in advance
- Assures better time management related to the increased ability to solve problems in a shorter period of time
- Provides the opportunity to maintain the foreseen budget
- Determines a sole party responsible for the whole project cycle
- Ensures creating a project team by considering individuals' competence and previous job experience as well as their ability to function in a group

(ii) Disadvantages

- Keeps the owner of the project responsible for any modification, gap, or overlap within the project
- Poses a risk for the late participation of subcontractors in the project

- Requires identification of the performance criteria in advance
- Leaves the owner as the sole decision-maker when it comes to quality
- Forces the owner to make decisions earlier in the process
- Appeals to more standard and repetitive projects

2.3.3. Construction Management at Risk (CMR)

Construction Management at Risk (CMR) is a type of PDM which first requires identifying a designer and then separately selecting a construction manager (CM). The selected CM serves as a general contractor as shown in Figure 2.3. In other words, CMR entails two contracts: one between the owner and the designer and one between the owner and the CM. It takes into account other aspects apart from total cost (Rojas and Kell, 2008). While the hired designer provides a facility design, a construction management company acting as a contractor is selected to perform not only construction management services but also construction work (Konchar and Sanvido, 1998).

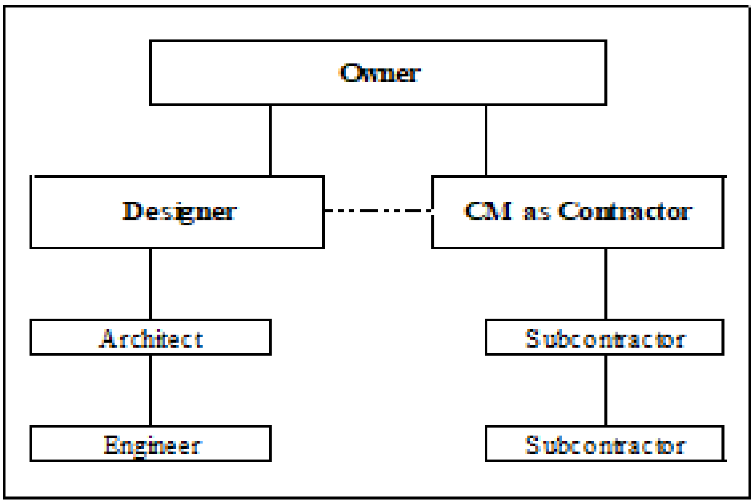

Figure 2.3. CMR Structure Related to the Parties of a Project.

In CMR, the CM is chosen by considering competence, previous job experience, and the number of employees they have. Choosing the CM earlier in the project enables receiving feedback on several aspects such as project schedule or budget during the design process. According to Mahdi and Alreshaid (2005), having the CM as a general contractor contributes massively in terms of significant input during the design process. This, therefore, reduces the need for modifications after the start of the construction and increases the capacity to manage the modifications within the project. This way, the CMR aims to achieve a fast-track schedule (Al Khalil, 2002). To sum up, the advantages and disadvantages of CMR are shown below within the scope of the opinions of Mahdi and Alreshaid (2005), Rojas and Kell (2008), Konchar and Sanvido (1998) and Al Khalil (2002).

(i) Advantages

- Retains control of design
- Involves CM as a general contractor in the early phases of the project
- Gives flexibility in pricing the project by virtue of earlier knowledge on the cost
- Enables fast-track schedule, making the process faster than DBB
- Reduces the need for modifications owing to the dialogue between the two main parties (designer and CM) within the project

(ii) Disadvantages

- Leaves owner as the sole responsible person for modifications
- Requires owner to choose the CM on the basis of competence
- Requires more time than DB
- Requires two contracts to be handled
- Gives each party the possibility of having different agendas stemming from discrete contracts

2.3.4. Construction Management at Agency (CMA)

Construction Management at Agency (CMA) refers to a type of PDM which includes a construction manager whom the owner of the project selects for monitoring the whole project (Konchar and Sanvido, 1998). Therefore, use of this method, generally in case of multiple prime contractors, brings upon the CM several responsibilities. Some examples can be preparing various contracts for the completion of different tasks within the project and realizing those contracts throughout all the phases. This enables fast-track scheduling which ensures time and cost efficiency (Mahdi and Alreshaid, 2005). The structural relationship in CMA is shown inFigure 2.4.

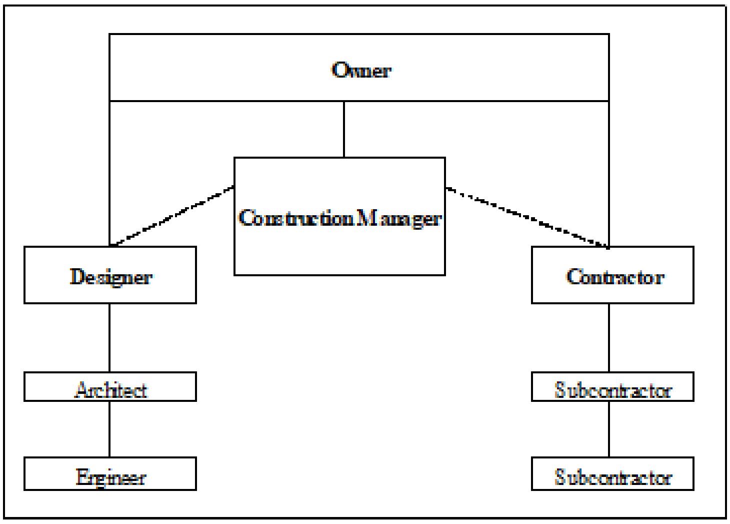

Figure 2.4. CMA Structure Related to the Parties of a Project.

Based upon the articles of Mahdi and Alreshaid (2005) and Konchar and Sanvido (1998), the advantages and the disadvantages are summarized below.

(i) Advantages

- The project is divided into multiple packages and this leads to the overlap of some phases.
- All control about all trade contracts are held by the owner and the role of the CM includes facilitating the management of the project.
- The CM is chosen early in the project which enables timely phase management and implementation of fast-track schedule, which contributes to time and cost efficiency within the project.

(ii) Disadvantages

- A complicated network of contractors, therefore there is not any sole party to be held responsible.
- The possibility of cost overrun is high.
- The number of contracts to be managed by the owner is high.

- The owner risk is higher.

2.4. Previous Studies on the Factors Affecting the Suitable PDM Selection

Due to its great significance in the industry, examining the factors that influence the decision-making process for choosing a suitable PDM is a fundamental area of interest in the literature concerning the construction projects. Many researchers have investigated the factors affecting the PDM selection in various projects such as El-Sayegh (2007), Chen *et al.* (2010), and Liu *et al.* (2015). While some of the studies are based solely on literature studies, others include both literature review and practice with the masters in the industry.

Chen *et al.* (2010) conducted a study on the PDMs in the Chinese context, benefiting from data envelopment analysis. With their study, the researchers aimed to visualize the factors that have impact on choosing the PDM and to determine a suitable method to be used in a given construction project. The data were collected through the use of survey technique. 300 PMs working at the Top 100 Chinese companies participated in the study. Multivariate Statistical Analysis was used for proper delivery selection. By taking into consideration project objectives such as quality, cost, schedule, safety in addition to owner's satisfaction, they benefited both from the literature and the Likert scale pre-questionnaire to acquire the main indicators. Through literature review and survey, the researchers identified 20 factors having impact on choosing the PDM. Finally, owing to the collected questionnaires, the researchers came to a conclusion for the appropriate PDM selection.

El- Sayegh (2007) examined three main delivery methods which are DBB, DB, and CM. Through literature review, a comprehensive list of 21 factors divided into 8 groups was detected. These 8 groups are cost, quality, scope, project characteristics, owner organization, time, cash flow, risk and relationship. A study was conducted via a survey with the experts in the construction industry in the United Arab Emirates (UAE) with the aim of having an understanding of their perceptions about the significance of the abovementioned factors according to their Relative Importance Index (RII). As the result, owner organization and quality were found to be the most significant factors.

While investigating a suitable project delivery method by decision-making, Liu *et al.* (2015) questioned the relevance between the PDM and the factors influencing its selection. According to their research, the factors influencing the selection of PDMs are mostly related to the owner's features, the project's features, and the external factors that have impact on the project. Specifically, their study was based on the owner's features and the factors influencing the selection of PDMs. 22 factors were discovered through literature review; from among these 22, 14 rather significant factors were selected after the discussions with the construction experts in 76 different projects in the Chinese context. By virtue of the detailed study about design-bid-build, design - build and engineering - procurement - construction, the five most significant factors were identified for the owner's features as risk allocation, responsibility, in - house technical capacity, willingness to be involved, and willingness to have ultimate control over design.

Focusing on how to reasonably choose a suitable PDM to achieve successful project management, Liu *et al.* (2016) elaborated on the contractor's fundamental characteristics which contribute to the efforts for a successful project in the context of various PDMs. The study consists of two data collection processes including literature review and actual completed projects. While gathering 12 factors on contractor features by literature review, the research samples from 73 successful projects using different kinds of PDMs in China were applied for an investigation of questionnaires by the rough set model. The results revealed four significant factors for a successful project in the context of various PDMs. These are contractor's coordination, communication, demonstrated capacity for financial management, previous experience in similar projects, and design capability.

Ibbs *et al.* (2003) focused on the PDM and the project change by adopting a quantitative approach. By declaring the perception of previous studies in favor of DB more than DBB and by virtue of 67 projects on global scale extracted using the database of the Construction Industry Institute, the researchers found that DB can fall short of ensuring expected benefits necessary in terms of performance. According to the results, time-efficiency, which is ensured by fast-track schedule, was a definite advantage. On the other hand, cost and productivity change were not adequate enough. The study also showed that the contractor's expertise and experience in managing projects had a great impact on the project performance.

Through the analysis of the four principal types of PDMs (DBB, DB, CMR, and CMA), Mahdi and Alreshaid (2005) aimed to compare different kinds of PDMs with particular sorts of projects and owners. By virtue of literature review and questionnaires, 30 fundamental factors were identified and were classified in seven groups: project features, owner features, design properties, risk, regulatory, contractor features, claims and disputes. Considering these factors in addition to technical factors and low costs, a multi-criteria decision-making methodology following the analytical hierarchy process (AHP) was applied in order to support the concerned parties in choosing the suitable PDM for their construction projects.

Similar to the aforementioned studies, Mostafavi and Karamouz (2010) conducted a study about choosing the suitable PDM using the Fuzzy AHP and analyzing the risks. For the selection factors, the researchers benefited from the study of Oyetunji and Anderson (2001) that included 20 key factors related to the PDM selection. These factors were mainly about cost, time, risk, regulatory, project features, and owner features. Being the Fuzzy Multi-Attribute decision-making model, the study ensures choosing the most suitable PDM.

The study using a model based on the analytical hierarchy process carried out by Al Khalil (2002) aims to select the appropriate project delivery method in construction projects. The main delivery methods examined in this study can be listed as DBB, DB, and CM at agency. Moreover, Al Khalil (2002) identified and categorized factors influencing the PDM selection in 3 main groups consisting of owner's needs, project features, and owner's preferences consisting of 8 sub-groups. The team members working for the project need to discuss and identify the significance of every relevant factor if this AHP model is used for the construction project (Al Khalil, 2002). After the comparison of the factors, the suitable PDM selection was realized via the AHP and its outcomes.

Callistus *et al.* (2014) explored the factors having impact on construction companies' quality performance. The study was conducted in Ghana focusing on small-scale contractors. Due to the nature of manual manpower, the work in the construction site is substantially based on manual performance which sometimes prevents the completion of the construction work without quality problems. To recognize the reasons lying behind the low quality, the researchers addressed questionnaires to the professional staff including the architects, the engineers, and the quality surveyors by using the Relative Importance Index. The results showed that fraudulent practices and bribery were among the factors having impact on the quality performance. Another influencing factor was the inability to ensure coordination between the designers and the contractors. Lastly, insufficiency in terms of feedback and monitoring was found to be affecting the quality performance (Callistus *et al.*, 2014). Besides, regarding the contractors, not providing quality training to the staff members, not possessing leadership qualities, and lacking experience were discovered to be of the influencing factors.

Another study was conducted by Konchar and Sanvido (1998) for 351 building projects in the US with respect to the three main PDMs of DBB, DB and CMA, comparing cost, schedule and quality performance. In this study, the researchers collected, checked and validated data on the industry; they conducted significance testing for univariate comparisons and they developed multivariate linear regression modes to predict the average project performance. This study, with the aim of identifying the quality performance, the cost, and the schedule, employed 100 integrating variables.

Pan (2008) generated a model using the Fuzzy AHP to choose the appropriate method for bridge construction. Due to the inability of the AHP for handling uncertainty and vagueness, the determination of the proper method was based on the Fuzzy AHP multi-criteria decision-making. This study comprises of five main factor groups including quality, cost, safety, duration and scope, and 11 sub-groups to find the best construction method. By virtue of the structure that was created considering the essentials of the projects, the proper delivery was provided to the project owner, the Taiwan National Expressway Engineering Bureau.

Rojas and Kell (2008) carried out a comparative research analyzing the cost performance of the PDMs in the Pacific Northwest Public Schools. In their study, there was a comparison of CMR and DBB in terms of their cost growth performance. By virtue of the data collected from 297 Pacific Northwest public school projects, a detailed analysis was made. While the collected data did not demonstrate any considerable difference between CMR and DBB in terms of construction change order costs, after detailed statistical analysis, there appeared a remarkable difference in the cost growth during the buy-out. As a result, the CMR method was shown to be inadequate in managing the growth of cost at the buy-out.

The ever-increasing need for sustainability in building projects requires optimum responses in addition to teams with multi-disciplinary backgrounds (Swarup *et al.*, 2011). This research implies that the project delivery features greatly influence the outcomes of the project like cost growth and sustainability. Data in regards to 12 Green Office buildings in the US. was collected. To confirm the quality, reliability, and validity of the data, interviews were conducted with the owner of the project, the constructor as well as the designer. Moreover, the metrics selected for this study are, among others, cost, schedule, quality, levels of high performance and sustainability, owner's perception of resource consumption, and user satisfaction (Swarup *et al.*, 2011). The analysis of the performance metrics, the variables and the examination during the interviews showed that the owner's pledge to sustainability, adopting green methods in early stages of the project, and an integrated delivery process with the constructor's participation were of utmost importance in the delivery phase (Swarup *et al.*, 2011). It was also stated that these factors have the possibility of changing the outcomes of the project.

Execution of a project is substantially affected by the PDM selection which is a challenging work due to the existing ambiguity in the project (Chen *et al.*, 2011). The identification of similar projects providing similar metrics and also literature review assist the formation of the main indicators of PDM selection according to Chen *et al.* (2011) who used the data envelopment analysis-bound variable (DEA-BND). Furthermore, there was a postal questionnaire applied in China for the issues of reliability and validation of the model with the comparison of the DEA-BND and the analytical neural network (ANN). As a result of this study, the researchers proved that inputting project specific data gives more accurate and more reliable results than the ANN model and this model is less dependent on the experts' judgment.

2.5. Statement of Research Question

As mentioned in the previous sections, there are various studies about the project delivery methods and the factors affecting them. Their scopes and findings mainly rely on the country and the project types, generating different results for the studies. Although almost all studies presented before examine some of the project delivery methods and specifically its variables, the following two studies of Chen *et al.* (2011) and Mahdi and Alreshaid (2005) are much more comprehensive than the others since their scopes are remarkably holistic. The studies in the literature mainly benefit from literature review, the questionnaires and the interviews applied to the sector professionals with respect to specific countries and projects. Related to the Turkish real estate construction industry, there are not any studies in the literature which explore the PDM selection and the factors influencing their selection and the success of the project. The identification and the categorization of the key factors affecting the PDM selection are quite crucial (Chen *et al.*, 2011). By creating a structure, multi-criteria decision-making in an appropriate selection is precisely fulfilled (Pan, 2008). In Turkey, as it was stated in the previous sections, the construction industry, especially the real estate market, is considerably important based on its locomotive role on the economy. At this point, factors such as conducting projects in an efficient way and using the appropriate delivery method are fundamental. Considering the lack of studies analyzing the PDMs and the factors affecting the selection of them in Turkey, the research questions of this thesis can be summarized as follows:

- What are the main project delivery methods preferred in real estate in Turkey?

- What are the main factors affecting the suitable PDM selection for the real estate projects in Turkey?

3. RESEARCH METHODOLOGY

3.1. Introduction

In the literature review, there are some different methods such as the ANN, the multivariate linear regression model, the AHP, the Fuzzy AHP to analyze the data obtained from different kinds of perspectives. While some of the studies examine a great number of realized projects in the analysis phase, the other ones include literature and interview-based data. Due to the diverse contents of the studies, the applied methods can be different from each other. To illustrate, the ANN is one of the main tools used in machine learning and it analyzes the relationship between the input variables. The multivariate linear regression model aims to explain the dependency or the independency between the variables. Meanwhile the AHP refers to a multi-criteria decision-making method which applies pairwise comparison. The Fuzzy AHP also uses pairwise comparison in a more sensitive way to get rid of vagueness and uncertainty in the analysis phase. There are a lot of studies in the literature, like Mostafavi and Karamouz (2010) which utilize the Fuzzy AHP. The main reason of this is that the studies take into account the uncertainties and the imprecisions in the decision scope. Fundamentally, it is due to the fuzziness in the nature of the decision factors strongly present in the real estate industry. For the manufacturing industry, almost all the processes are well-defined and there is a low level of contingency risks compared to the real estate industry. To decrease the ambiguity and the vagueness in the decision-making process, the present thesis uses the Fuzzy AHP which caters to the conditions including uncertainty.

In order to create a model for choosing the suitable PDM using the Fuzzy AHP, determination of the key factors affecting the selection and the probable project delivery method used in Turkey will be realized by taking the following steps:

- Examining the project delivery methods used in the real estate industry with literature review

- Listing the key factors affecting the selection of the suitable PDM with literature review
- Generating a questionnaire for the sector professionals to learn their points of view related to the issues just stated above and combining their ideas with literature review
- Prioritizing the PDMs used in Turkey and the factors affecting the selection of the appropriate PDM
- Generating the final model for the selection of the PDMs by the implementation of the Fuzzy AHP

At the beginning of this chapter, the studies in literature review are presented. Afterwards, the theoretical background behind the AHP and the Fuzzy AHP are examined. Then, a questionnaire design for the interviews with the sector professionals and the data collection phases are explained. The main framework of this thesis is indicated in Figure 3.1.

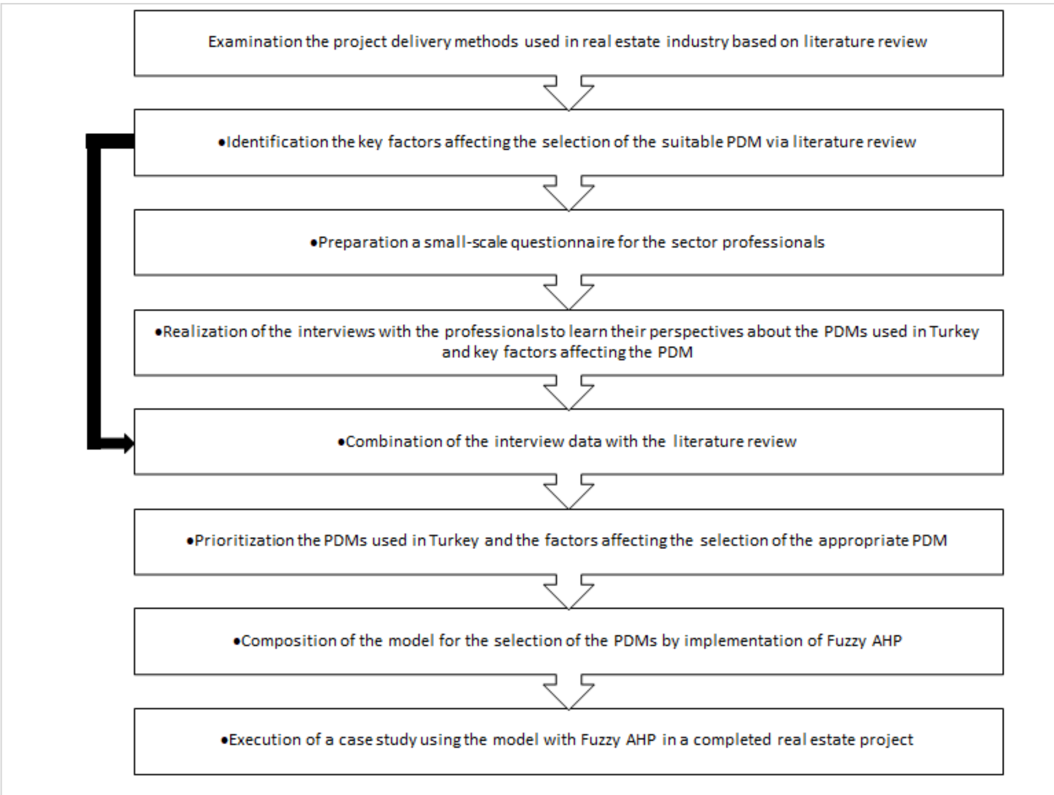

Figure 3.1. Main Framework of Research.

3.2. Literature Review

In the process of literature review, the main issues are to investigate the project delivery methods used in the construction industry, the fundamental factors influencing the selection of the PDMs and the methods to be utilized for data analysis. Although there is a great number of studies about the PDMs and the factors related to the selection of them with different kinds of data analysis methods such as the AHP, the Fuzzy AHP and DEA-BND in many countries, there are not any comprehensive studies in the literature aiming the identification of the PDMs in the Turkish real estate industry and the important factors affecting their appropriate selection. Taking this into consideration, this thesis seeks to fill the gap in the literature about the Turkish real estate industry.

In each of the previous studies, the PDMs and the key factors affecting them vary from project to project and from country to county where the research is applied. Aiming to determine the major PDMs and the influencing factors for the construction industry, some researchers such as Al Khalil (2002) and Liu *et al.* (2015) preferred to tackle only the literature when creating the structure for the selection process containing the PDMs and the key factors. On the other hand, other researchers like Callistus *et al.* (2014) used not only literature review but also questionnaires to conduct their study. The purpose of all the researchers was to reach a precise determination for the appropriate PDMs that enable managing projects in the most proper way.

Moreover, as presented in Chapter 2, among many studies that were examined in the literature review section, the ones focusing on the PDMs and the factors affecting their selection, via various analysis methods are selected. During the literature review, almost all of the papers published after 2000, excluding Konchar and Sandivo (1998) in well recognized peer reviewed journals and conferences are examined. The title of the journals that were taken into account are as follows: 1)Journal of Management Engineering, 2)Journal of Construction Engineering and Management, 3) Automation in Construction, 4) Civil and Environmental Research, 5)International Journal of Project Management, 6) Expert Systems with Applications,7) 5th LACCEI

International Latin American and Caribbean Conference for Engineering and Technology(LACCEI?2007).The key words used during the literature review can mainly be listed as follows: "construction" "construction industry", "real estate", "real estate industry", "project delivery", "project management", "multi-criteria decision making".

On the other hand, none of these studies are related to the Turkish construction industry. Thus, this thesis focuses on both the literature related to the construction industry and the sectors professionals in Turkey to combine data and get a model also being valid for the Turkish construction industry. Due to the fact that the construction industry has a strong presence around the world, the studies in the literature might still be comprehensive for the Turkish real estate industry. To understand and verify the situation, interviews containing questionnaires with the sector professionals are fulfilled in order to collect data. As a result, the combination of the literature review study and the viewpoints of the professionals show the probable PDMs and the factors affecting their selection in the Turkish real estate industry.

3.3. Theoretical Background

3.3.1. Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP) refers to a multi-criteria decision-making method which was first created by Thomas L. Saaty (Saaty and Bennet, 1977). The AHP is considered as a significant tool which was designed to help providing solutions to unorganized problems on several decision-making instances which can be either simple individual problems or complicated business investment issues (Al Khalil, 2002). According to Saaty (1997), the AHP focuses on the measurement of numerous intangibles that do not have any existent scale to bring them together with the tangibles that are inherently measurable. This way, the situations requiring the evaluation phase of the tangible and the intangible factors considered in the same pool might be achieved by using the AHP. Moreover, this process helps to organize the tangible and the intangible factors in a systematic way by breaking the case down into a logical structure and it provides a systematic solution to the decision-making problems (Benítez *et al.*, 2011).

Richard *et al.* (2015) declare the importance of the AHP methodology aiming the optimization of the processes through the prioritization of the variables in complex decisions especially when a mix of quantitative, qualitative problems involving distinct factors is encountered. In other words, the AHP first prioritizes criteria for the selection and then identifies the major criteria. Due to its easily applicable characteristics, there are many fields that prefer the use of the AHP including engineering, education, health, business, and management. As per the nature of the AHP, its fundamental part is to make pairwise comparison for determining the importance of the factors affecting the solution of a problem in the hierarchy (Alonso and Lamata, 2006). Therefore, the AHP benefits from real measurements such as price or numbers; or subjective ideas which are included in a matrix to get the output embodying the ratio scales and the consistency indices to be acquired by the computation of the primary eigenvectors and eigenvalues (Ansah *et al.*, 2015).The utilization of the decision makers' judgments related to the hierarchy including the factors that are components of the solutions provides a weighting score indicating the relative importance of each factor and generates an ultimate solution for the problem.

According to Saaty (1987) and Alam *et al.* (2012), there are four fundamental steps of the AHP's requirements. These are construction of comparative judgments, namely pairwise comparison matrices, construction of structural hierarchy, weight determination through normalization procedure and synthesis of weight and consistency tests. From this point of view, Richard *et al.* (2015) examine all four steps as follows:

(i) A complicated decision need to be dissolved into a structural hierarchy from the goal to the various criteria and sub-criteria to the very lowest level in descending order.

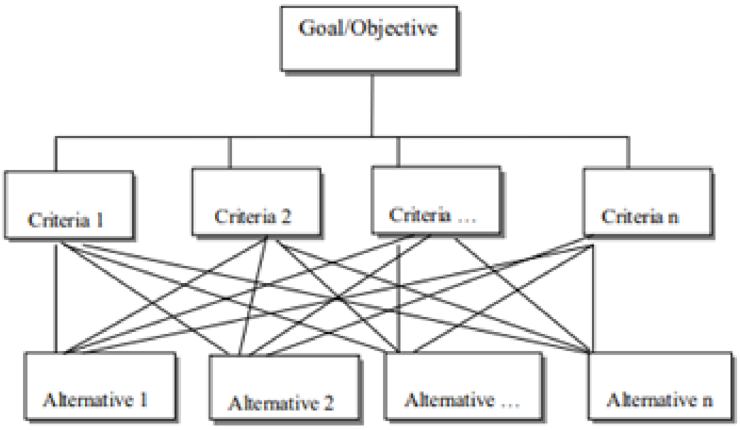

Figure 3.2. Construction of Structural Hierarchy (Richard *et al.*, 2015).

(ii) Pairwise comparison creating a matrix should be applied to get comparative judgments of the decision makers to identify the priorities of each variable at every stage by comparing the matrices of all the variables in relation to each other via one to nine (1-9) scaling in ascending order for the importance of the variables in Table 3.1 (Cay and Uyan, 2013). The matrix is shown in Equation 3.1:

Table 3.1. AHP evaluation scale (Cay and Uyan,2013).

Ahp evaluation scale,	
Numerical value of a	**Definition**
1	Equal importance ıf i and j
3	Moderate importance of i over j
5	Strong importance of i over j
7	Very strong importance of i over j
9	Extreme importance of i over j
2,4,6,8	İntermediate values

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{3.1}$$

where

$$A = a_{ij}, a_{ij} > 0\text{and}\frac{1}{a_{ji}} = a_{ij}\left[a_{ij}\right], \text{where}, i, j = 1, 2, \ldots .n,$$
$$If, a_{ij} = 1\text{then}, i = j, \tag{3.2}$$
$$If, a_{ij} = \frac{1}{a_{ji}}\text{then}, i \neq j$$

By given "n" number(s) for pairwise comparison, the AHP executes the process mentioned above to state the weights of each criteria. In this equation, "A" is a square matrix with an equal number of rows and columns as "n" indicates the comparison number of variables. The value of the variables linking with the diagonal of the matrix is equal to one like α_{ij}=1 According to Equation 3.1, there is a reciprocal preference for each variable as $\alpha_{ij} = \frac{1}{\alpha_{ji}}$ excluding $i = j$ For example, if i-th variable is K times more favorable than j-th variable, $\alpha_{ij} = K$ and $\alpha_{ji} = \frac{1}{K}$

(iii) After all pairwise comparison process is applied considering the matrix above, the weights are determined through the normalization procedure with Equation 3.3 (Cay and Uyan, 2013). In this equation, every component of the matrix is divided by the sum of its column to get the normalized relative weight. his way, the total of every column is equal to one.

$$Aw = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \cdots & \frac{a_{1n}}{\sum a_{in}} \\ \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum a_{i1}} & \cdots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix} \tag{3.3}$$

(iv) Acquiring the global weights of the alternatives through the synthesis of the local weights is an essential part of conducting the calculations concerning Equation 3.4 (Cay and Uyan, 2013). In the AHP, there is a phase for the determination of C_i through determining the matrix's principal eigenvector.

Initially, matrix A's eigenvector should be acquired by calculating the C_i as the average. The following step is to calculate the C_i as the average of the values in row i of Aw matrix to yield the column vector C where C_i value shows the relative degree of importance, in other words weight, of the i^{th} objective.

$$C = \begin{bmatrix} C_1 \\ \vdots \\ C_n \end{bmatrix} = \begin{bmatrix} \frac{\frac{a_{11}}{\sum^{a_{i1}}}}{n} + & \cdots & \frac{\frac{a_{1n}}{\sum^{a_{in}}}}{n} \\ \vdots & \ddots & \vdots \\ \frac{\frac{a_{n1}}{\sum^{a_{i1}}}}{n} & \cdots & \frac{\frac{a_{nn}}{\sum^{a_{in}}}}{n} \end{bmatrix} \tag{3.4}$$

After the calculations are fulfilled based on Equation 3.3, the consistency of the weight values (C_i) should be checked. Firstly, the consistency vector is calculated by multiplying AxC matrix. This multiplication enables to find x_i values as shown below.

$$A \times C = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} C_1 \\ \vdots \\ C_n \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \tag{3.5}$$

Then, λ, the eigenvalue of the pairwise comparison matrix is estimated based on Equation 3.6.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{x_1}{C_1} \tag{3.6}$$

Owing to having λ_{max} calculated, the Consistency Index (CI) is calculated with Equation 3.7

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.7}$$

According to Table 3.2 (Saaty and Tran 2007), the proper Random Index (RI) is acquired based on the n value. Later, the Consistency Ratio (CR) is calculated by the implementation of the CI and the RI values into Equation 3.8. If the CR is smaller than 0.10, the degree of consistency is considered as satisfactory; otherwise, there is an indication of serious inconsistencies that might prevent reaching the goal (Cay and

Uyan, 2013).

Table 3.2. Random Index (Saaty and Tran, 2007).

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.52	1.54	1.56	1.58	1.59
First Order Differences		0.00	0.52	0.37	0.22	0.14	0.10	0.05	0.05	0.04	0.03	0.02	0.02	0.02	0.01

$$CR = \frac{CI}{RI} \tag{3.8}$$

3.3.2. Fuzzy AHP Method

The word "fuzzy" means vagueness, in other words; ambiguity. It originates from the lack of a boundary of a piece (Kousalya and Reddy, 2011). Particularly in complex situations, taking the appropriate decision is quite difficult due to the uncertainty in the judgment of decision makers. To cope with the vagueness of human thought, the theory of fuzzy set developed by Zadeh (1965) was oriented to the rationality of uncertainty resulting from imprecision. A fuzzy set enables the development of a conceptual framework which is similar to the framework utilized for ordinary sets but it is seen as a more generalized version and has the possibility to be applied within various scopes, especially in pattern classification and information processing (Kousalya and Reddy, 2011). Moreover, the most important aspect of the fuzzy set theory is known as its ability to provide vague data (Kahraman *et al.*, 2004).

In addition to the AHP, there is another method called the Fuzzy AHP which can be considered as an advanced analytical method deriving from the AHP and the fuzzy set theory. The main aim of the Fuzzy AHP, unlike the AHP, is to mitigate the high uncertainty level in the judgments for multi-criteria decision-making. Various Fuzzy AHP methods are recommended by several researchers such as Laarhoven and Pedrycz (1983), Chang (1996) and Cheng (1997). In their study, Van Laarhoven and Pedrycz

(1983) presented the first study which applied the fuzzy logic principle to the AHP in which triangular fuzzy numbers were used for pairwise comparisons' modelling. Moreover, Chang (1996) provided a new point of view to the Fuzzy AHP by making use of triangular fuzzy numbers for pairwise comparison scale of the Fuzzy AHP. Owing to the responses on the question form, the corresponding triangular fuzzy values for the linguistic variables are placed and for a peculiar level on the hierarchy, the pairwise comparison matrix is structured (Özdağoğlu and Özdağoğlu, 2007). According to Kahraman *et al.* (2004), the recommended methods are systematic approaches for getting the alternative selection and the justification problem by the utilization of the fuzzy set theory and the AHP to enable interval judgments providing decision-makers with more confidence rather than fixed judgments.

According to Kousalya and Reddy (2011), the mathematical theory and the algorithm of the Fuzzy AHP method consistent with the Zadeh's fuzzy set theory is shown below.

Let $X = x_1, x_2, x_3, ..., x_m$ be an object set and $G = g_1, g_2, g_3, ..., g_n$ be a goal set. According to this method, each object is taken and extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained with the following signs:

$M^1_{gi}, M^2_{gi}, ..., M^m_{gi}.i = 1, 2, 3..., n$ where $M^J_{gi}, (j = 1, 2, 3, ..., m)$ all are Triangular Fuzzy Numbers.

(Step i) The value of the fuzzy synthetic extent with respect to the i^{th} object is defined as:

$$S_i = \sum_{j=1}^{m} M^j_{gi} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{gi} \right]^{-1} \tag{3.9}$$

To get $\sum_{j=1}^{m} M_{gi}^{j}$ perform the fuzzy addition operation of the m extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{3.10}$$

and to acquire $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, perform fuzzy addition operation of $M_{gi}^{j}, (j = 1, 2, 3, ..., m)$ values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{3.11}$$

and then calculate the inverse of the vector above, such that

(Step ii) As $\widetilde{M_1} = (l_1, m_1, u_1)$ and $\widetilde{M_2} = (l_2, m_2, u_2)$ are two TFNs, the degree of possibility of $\widetilde{M_2} = (l_2, m_2, u_2) \geq \widetilde{M_1} = (l_1, m_1, u_1)$ is defined as

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{3.12}$$

This can be equivalently expressed as follows:

$$V = \left(\widetilde{M_2} \geq \widetilde{M_1} \right) = sup_{y \geq x} \left[min \left(\mu_{\tilde{M}_1} (x), \mu_{\tilde{M}_2} (y) \right) \right] \tag{3.13}$$

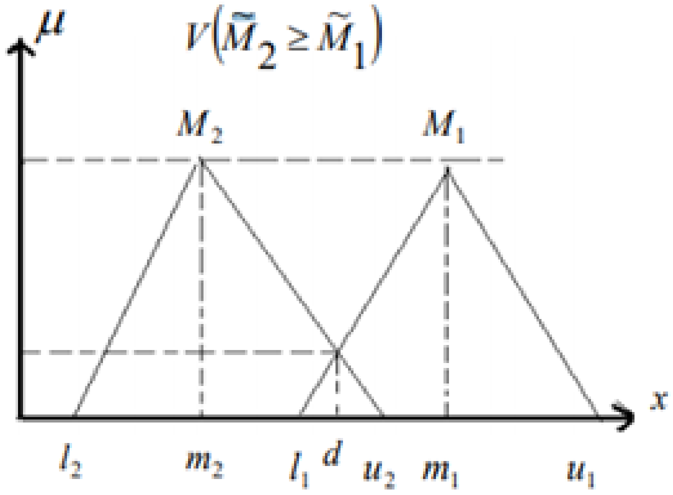

Figure 3.3. Intersection between M_1 and M_2.

(Step iii) The degree of possibility for the convex fuzzy number to greater than k convex fuzzy number $M_i(i = 1, 2, 3..., n)$ can be defined by $V = (M \geq M_1, M_2, M_3...MK) = V[(M \geq M_1)$ and $(M \geq M_1)$ and $(M \geq M_2) and...[(M \geq M_k)]$

$$V = \left(\tilde{M}_2 \geq \tilde{M}_1\right) = hgt\left(\tilde{M}_2 \cap \tilde{M}_1\right) = \mu_{\tilde{M}_2}(d) \tag{3.14}$$

assume that $d'(A_i) = minV(S_i \geq Sk) fork = 1, 2, 3..., n; k \neq i$

Next, the weight vector is given by

$$\begin{cases} 1, if m_2 \geq m_1 \\ 0, if l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (l_1)}, otherwise \end{cases} \tag{3.15}$$

Where $A_i(i = 1, 2, 3..., n)$ are n elements.

(Step iV) Via normalization, the normalized weight vectors are

$$V = (M \geq M_1, M_2, ..., M_k) = minV(M \geq M_i), i = 1, 2, 3..., k \tag{3.16}$$

where W is a non-fuzzy number.

$$W' = \left(d'\left(A_\imath\right), d'\left(A_2\right), d'\left(A_3\right), \ldots d'\left(A_n\right)\right)^T \tag{3.17}$$

$$W = \left(d\left(A_\imath\right), d\left(A_2\right), d\left(A_3\right), \ldots d\left(A_n\right)\right)^T \tag{3.18}$$

3.4. Questionnaire Design and Gathering Data

To acquire data specific to the real industry, interviews with professionals including questionnaires might be seen as one of the most essential methods. The professionals who have sufficient experience in the real estate industry are considered as eligible to provide the required data for this study. Within the scope of this thesis, there are two questionnaires that are designed to gather the targeted respondents of the professionals. While the first questionnaire (See Appendix A) is addressed to the professionals who are only participant in the data collection phase including the determination of the factors affecting the PDM selection, the second questionnaire (See Appendix B) related to the case study is distributed to the professionals, excluding those working in the first questionnaire. Furthermore, the case study questionnaire is based upon Table 3.3 and Table 3.4 during the evaluation process for each factors affecting the selection of the appropriate PDM.

Table 3.3. Likert Scale for Pairwise Comparison for Fuzzy AHP.

Code	**Linguistic variables**
1	Equally preferred
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very strongly to extremely preferred
9	Extremely preferred

Table 3.4. Pairwise Comparison Sheet for PDM Selection based on the Fuzzy AHP.

Example Code Selection for Criteria																		
																		Criteria 2 is Very strongly preferred than Criteria 1
Criteria 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	**Criteria 2**
Criteria 3 is Strongly to very strongly preferred than Criteria 4																		
Criteria 3	9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9	**Criteria 4**

As mentioned in the previous chapters, there is a gap in the literature regarding the Turkish real estate industry for the selection of the appropriate PDMs and the determination of the factors influential in their selection. Thus, this thesis aims to provide reliable data from the professionals who have experience in the Turkish real estate industry by utilizing the questionnaire during the interview. Accordingly, this questionnaire (See Appendix A) comprises of two main parts. The first part is created in order to collect data about the demographic features of the participants, such as their area of expertise, their work experience and their organization type as the stakeholder. In the following part of the questionnaire, the questions about the PDMs and the factors related to their selection take part. As a matter of fact, the most crucial part is the second part consisting of the fundamental questions for the objective of this study. By collecting data from the professionals, the PDMs being used in the Turkish real estate industry and the related factors for selection criteria are determined and become ready for the combination with the global data for the PDMs and the related factors acquired from the literature review study.

In the beginning of the research, the candidate professionals are identified and are informed about the scope of the thesis. Next, the interview dates are appointed to the ones who are available to participate in the study. Then, the abovementioned questionnaire is distributed to the professionals during the interview by giving detailed information about the study via Excel-based documents. The total number of the interviews for data collection with the questionnaire was 10. The professionals with experience in the Turkish real estate industry from 5 companies have worked under different roles such as owners, contractors, designers and consultants in real estate industry as it is stated in Table 3.5. At the end of the interview, all of the professionals replied the questions according to their backgrounds and delivered the questionnaires. The information about the collected data is presented in the following Chapter.

Table 3.5. Demographic Information of Interviewers.

<table>
<tr><th colspan="5">Area of Expertise in Real Estate Projects</th></tr>
<tr><th>Project Manager</th><th>Contract Manager</th><th>Planning & Cost Control Manager</th><th>Designer Engineer</th><th>Site Engineer</th></tr>
<tr><td>3</td><td>2</td><td>2</td><td>2</td><td>1</td></tr>
<tr><th colspan="5">Years of Experience in Real Estate Projects</th></tr>
<tr><th colspan="2">5-10 years</th><th>10-20 years</th><th colspan="2">¿20 years</th></tr>
<tr><td colspan="2">3</td><td>4</td><td colspan="2">3</td></tr>
<tr><th colspan="5">Involved Organization</th></tr>
<tr><th>Owner</th><th>Contractor</th><th>Designer/Engineer</th><th colspan="2">Consultant</th></tr>
<tr><td>4</td><td>3</td><td>2</td><td colspan="2">1</td></tr>
</table>

4. FINDINGS

4.1. Identification of the Main Factors Affecting the PDM Selection and the PDM Types Used in Real Estate Projects through Literature Review and Interview Questionnaire

By virtue of the 14 papers mentioned in the third section of the Literature Review Chapter and the questionnaire stated in the fourth section of the Methodology Chapter which was based on the interview with 10 sector professionals, the factors affecting the PDM selection and the PDM types used in the real estate sectors were determined. The data stated in Table 4.1 is a summary of the papers in the literature review. Some of the studies include the comprehensive point of view meaning that their scope contains and combines the previous studies by referring to them explicitly. During the examination of these papers, it was observed that there was a great number of recurring factors in these studies. In other words, some of the factors presented in the studies have very close meanings. Thus, these are combined and are collected under the same title for each item separately.

Table 4.1. Literature review for the factors affecting PDM selection and PDM types.

No	Reference Author	Article Tittle	Factors	Project Delivery Methods
1	Chen et al. -2010	Analysis of project delivery systems in Chinese construction industry with data envelopment analysis (DEA)	Cost Growth Tolerance(Y3),Minimized Number of Contracted Parties(Y10) ,Level of Compatibility and Communication Amoung Project Team Members(Y11)	Design - Bid - Build (DBB), Design - Build (DB), Construction Management at Risk, Construction Management at Agency
2	El-Sayegh -2007	Significant Factors Affecting the Selection of the Approporiate Project Delivery Method	Normal Schedule(Y1), Fast Track Schedule(Y2), Cost Growth Tolerance(Y3),Facilitate Early Cost Estimates(Y4), Well Defined Scope(Y5), Vague Scope(Y6), Owner's Willingness To Be Involved(Y7),Risk Allocation(Y9), Minimized Number of Contracted Parties (Y10),Level of Compatibility and Communication Amoung Project Team Members(Y11),Standard Project(Y12), Complex Project(Y13)	Design - Bid - Build (DBB), Design - Build (DB), Construction Management at Risk, Construction Management at Agency
3	Liu et al. -2015	Identification of key contractor characteristic factors that affect project success under different project delivery systems: empirical analysis based on a group of data from China	Well Defined Scope(Y5), Owner's Willingness To Be Involved(Y7), Risk Allocation(Y9), Standard Project(Y12)	Design - Bid ? Build (DBB), Design ? Build (DB)

Table 4.1. Literature review for the factors affecting PDM selection and PDM types (cont.).

No	Reference Author	Article Tittle	Factors	Project Delivery Methods
4	Liu et al. -2016	Which owner characteristics are key factors affecting project delivery system decision making? Empirical analysis based on the rough set theory	Level of Compatibility and Communication Amoung Project Team Members(Y11)	Design - Bid - Build (DBB), Design - Build (DB)
5	Ibbs et al. -2003	Project Delivery Systems and Project Change: Quantitative Analysis	Normal Schedule(Y1), Fast Track Schedule(Y2), Cost Growth Tolerance(Y3), Facilitate Early Cost Estimates(Y4)	Design - Bid ? Build (DBB), Design ? Build (DB)
6	Mahdi and Alreshaid -2005	Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP)	Normal Schedule(Y1), Fast Track Schedule(Y2), Cost Growth Tolerance(Y3), Facilitate Early Cost Estimates(Y4), Well Defined Scope(Y5), Owner's Willingness To Be Involved(Y7), Owners Available Human Resources(Y8), Risk Allocation(Y9), Minimized Number of Contracted Parties(Y10), Level of Compatibility and Communication Amoung Project Team Members(Y11), Standard Project(Y12), Complex Project(Y13)	Design - Bid - Build (DBB), Design - Build (DB),Construction Management at Risk, Construction Management at Agency

Table 4.1. Literature review for the factors affecting PDM selection and PDM types (cont.).

No	Reference Author	Article Tittle	Factors	Project Delivery Methods
7	Mostafavi and Karamouz -2010	Selecting appropriate project delivery system: Fuzzy approach with risk analysis	Normal Schedule(Y1), Fast Track Schedule(Y2), Cost Growth Tolerance(Y3), Facilitate Early Cost Estimates(Y4), Well Defined Scope(Y5), Vague Scope(Y6), Owner's Willingness To Be Involved(Y7),Risk Allocation(Y9), Minimized Number of Contracted Parties(Y10),Level of Compatibility and Communication Amoung Project Team Members(Y11), Standard Project(Y12)	Design - Bid ? Build (DBB), Design - Build (DB),Construction Management at Risk, Construction Management at Agency
8	Al Khalil -2002	Selecting the appropriate project delivery method using AHP	Normal Schedule(Y1), Fast Track Schedule(Y2), Cost Growth Tolerance(Y3), Facilitate Early Cost Estimates(Y4), Well Defined Scope(Y5), Vague Scope(Y6), Owner's Willingness To Be Involved(Y7), Owners Available Human Resources(Y8), Minimized Number of Contracted Parties(Y10), Standard Project(Y12), Complex Project(Y13)	Design - Bid - Build (DBB), Design ? Build (DB), Construction Management at Agency

Table 4.1. Literature review for the factors affecting PDM selection and PDM types (cont.).

No	Reference Author	Article Tittle	Factors	Project Delivery Methods
9	Callistus et al. -2014	Factors Affecting Quality Performance of Construction Firms in Ghana: Evidence from Small?Scale Contractors	Level of Compatibility and Communication Amoung Project Team Members(Y11)	Design - Bid ? Build (DBB), Design - Build (DB),Construction Management at Risk
10	Konchar and Sanvido (1998)	Comparison of U.S. Project Delivery Systems	Normal Schedule(Y1), Cost Growth Tolerance(Y3)	Design - Bid ? Build (DBB), Design - Build (DB),Construction Management at Risk
11	Pan -2008	Fuzzy AHP approach for selecting the suitable bridge construction method	Complex Project(Y13)	
12	Rojas and Kell -2008	Comparative Analysis of Project Delivery Systems Cost Performance in Pacific Northwest Public Schools	Normal Schedule(Y1), Fast Track Schedule(Y2), Facilitate Early Cost Estimates(Y4), Level of Compatibility and Communication Amoung Project Team Members(Y11)	Design - Bid - Build (DBB), Design - Build (DB),Construction Management at Risk

Table 4.1. Literature review for the factors affecting PDM selection and PDM types (cont.).

No	Reference Author	Article Tittle	Factors	Project Delivery Methods
13	Swarup et al. -2011	Project Delivery Metrics for Sustainable, High-Performance Buildings	Normal Schedule(Y1), Cost Growth Tolerance(Y3), Well Defined Scope(Y5), Vague Scope(Y6), Owner's Willingness To Be Involved(Y7), Level of Compatibility and Communication Amoung Project Team Members(Y11)	
14	Chen et al. -2011	Project delivery system selection of construction projects in China	Normal Schedule(Y1), Cost Growth Tolerance(Y3), Facilitate Early Cost Estimates(Y4), Well Defined Scope(Y5), Vague Scope(Y6), Owner's Willingness To Be Involved(Y7), Risk Allocation(Y9), Complex Project(Y13)	Design - Bid - Build (DBB), Design - Build (DB),Construction Management at Risk

At the end of this process, 5 main factors were obtained with 13 sub-factors for the determination of the 3 PDMs used in the Turkish real estate industry as it is shown in Table 4.2 and Table 4.3.

Table 4.2. PDMs Used in Real Estate Industry in Turkey.

Design-Bid-Build(Z1)
Design-Build(Z2)
Construction Management Agency(Z3)

Table 4.3. The Key Factors Related to the Selection of the Project Delivery Method.

Name of the Factors	**Definition of the Factors**
Time Related Issues(X1)	
Normal Schedule(Y1)	There is not time restriction about schedule.
Fast Track Schedule(Y2)	There is a time restriction about schedule.
Cost, Funding and Cash Flow Related Issues(X2)	
Cost Growth Tolerance(Y3)	There is a cost growth allowance
Facilitate Early Cost Estimates(Y4)	Early cost estimate is essential
Scope Related Issues(X3)	
Well Defined Scope(Y5)	The scope is well defined and the details are determined precisely at the beginning of the project
Vague Scope(Y6)	The scope is not defined very well at the beginning of the project
Owner Organization ,Risk and Relationships Related Issues(X4)	
Owner's Willingness To Be Involved (Y7)	The degree of involvement of the owner during the execution of the project is high
Owners Available Human Resources(Y8)	There is an avaliable human resources provided by the owner
Risk Allocation(Y9)	The owner would like to share the risks of the project
Minimized Number of Contracted Parties(Y10)	The owner would like to be in a relationship with a low number of contracted parties
Level of Compatibility and Communication Amoung Project Team Members(Y11)	The project necessitates high level of communication amoung project team member
Project Characteristics Related Issues (X5)	
Simple Project(Y12)	The project is a standard, repetitive design.
Complex Project(Y13)	The project is a complex unique design.

Detailed information about the origin of Table 4.2 and Table 4.3 stated above is shown in the following tables. At that point, Table 4.4 is related to key factor determination based on the literature review and the interview questionnaire. Table 4.5 shows the PDMs used in the real estate industry through literature review and the interview questionnaire.

Table 4.4. The References for the Key Factors Related to the Selection of the Project Delivery Method.

Factors	Sub-Factors	References Based on the Literature Review	References Based on the Questionairres
Time Related Issues(X1)	Normal Schedule(Y1)	El-Sayegh, 2007, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Konchar and Sanvido, 1998, Rojas and Kell, 2008, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Fast Track Schedule(Y2)	El-Sayegh, 2007, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Rojas and Kell, 2008,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
Cost, Funding and Cash Flow Related Issues(X2)	Cost Growth Tolerance(Y3)	Chen *et al.*, 2010, El-Sayegh, 2007, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Konchar and Sanvido, 1998, Swarup et al., 2011, Chen et al., 2011,	Professional 2, Professional 4, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Facilitate Early Cost Estimates(Y4)	Chen et al., 2010, El-Sayegh, 2007, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Rojas and Kell, 2008, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 10

Table 4.4. The References for the Key Factors Related to the Selection of the Project Delivery Method (Cont.).

Category	**Factors**	**References Based on the Literature Review**	**References Based on the Questionairres**
Scope Related Issues(X3)	Well Defined Scope(Y5)	El-Sayegh, 2007, Liu et al., 2015, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Vague Scope(Y6)	El-Sayegh, 2007, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10

Table 4.4. The References for the Key Factors Related to the Selection of the Project Delivery Method (Cont.).

Category	**Factors**	**References Based on the Literature Review**	**References Based on the Questionairres**
Owner Organization ,Risk and Relationships Related Issues(X4)	Owner's Willingness To Be Involved(Y7)	El-Sayegh, 2007, Liu et al., 2015, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Owners Available Human Resources(Y8)	Liu et al., 2015, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Risk Allocation(Y9)	El-Sayegh, 2007, Liu et al., 2015, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9
	Minimized Number of Contracted Parties(Y10)	Chen et al., 2010, El-Sayegh, 2007, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002,	Professional 1, Professional 2, Professional 5, Professional 8, Professional 9, Professional 10
	Level of Compatibility and Communication Amoung Project Team Members(Y11)	Chen et al., 2010, El-Sayegh, 2007, Liu et al., 2015, Liu et al., 2016, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Callistus et al., 2014, Rojas and Kell, 2008, Swarup et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 10

Table 4.4. The References for the Key Factors Related to the Selection of the Project Delivery Method (Cont.).

Category	**Factors**	**References Based on the Literature Review**	**References Based on the Questionairres**
Project Characteristics Related Issues (X5)	Standard Project(Y12)	El-Sayegh, 2007, Liu et al., 2015, Liu et al., 2016, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
	Complex Project(Y13)	El-Sayegh, 2007, Mahdi and Alreshaid, 2005, Al Khalil, 2002, Pan, 2008, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10

Table 4.5. The References for the PDMs Used in the Real Estate Industry

Project Delivery Method Name	**References Based on the Literature Review**	**References Based on the Questionairres**
Design - Bid - Build (DBB)	Chen et al., 2010, El-Sayegh, 2007, Liu et al., 2015, Liu et al., 2016, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Konchar and Sanvido, 1998, Rojas and Kell, 2008, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
Design - Build (DB)	Chen et al., 2010, El-Sayegh, 2007, Liu et al., 2015, Liu et al., 2016, Ibbs et al., 2003, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002, Konchar and Sanvido, 1998, Rojas and Kell, 2008, Swarup et al., 2011, Chen et al., 2011,	Professional 1, Professional 2, Professional 3, Professional 4, Professional 5, Professional 6, Professional 7, Professional 8, Professional 9, Professional 10
Construction Management at Risk	Chen et al., 2010, El-Sayegh, 2007, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Konchar and Sanvido, 1998, Rojas and Kell, 2008, Swarup et al., 2011, Chen et al., 2011,	
Construction Management at Agency	Chen et al., 2010, El-Sayegh, 2007, Mahdi and Alreshaid, 2005, Mostafavi and Karamouz, 2010, Al Khalil, 2002,	Professional 1, Professional 3, Professional 6, Professional 7, Professional 9, Professional 10

By combining the data acquired from the literature review and interview-based questionnaires with sectors professionals, the hierarchal model is created as in Figure

4.1.

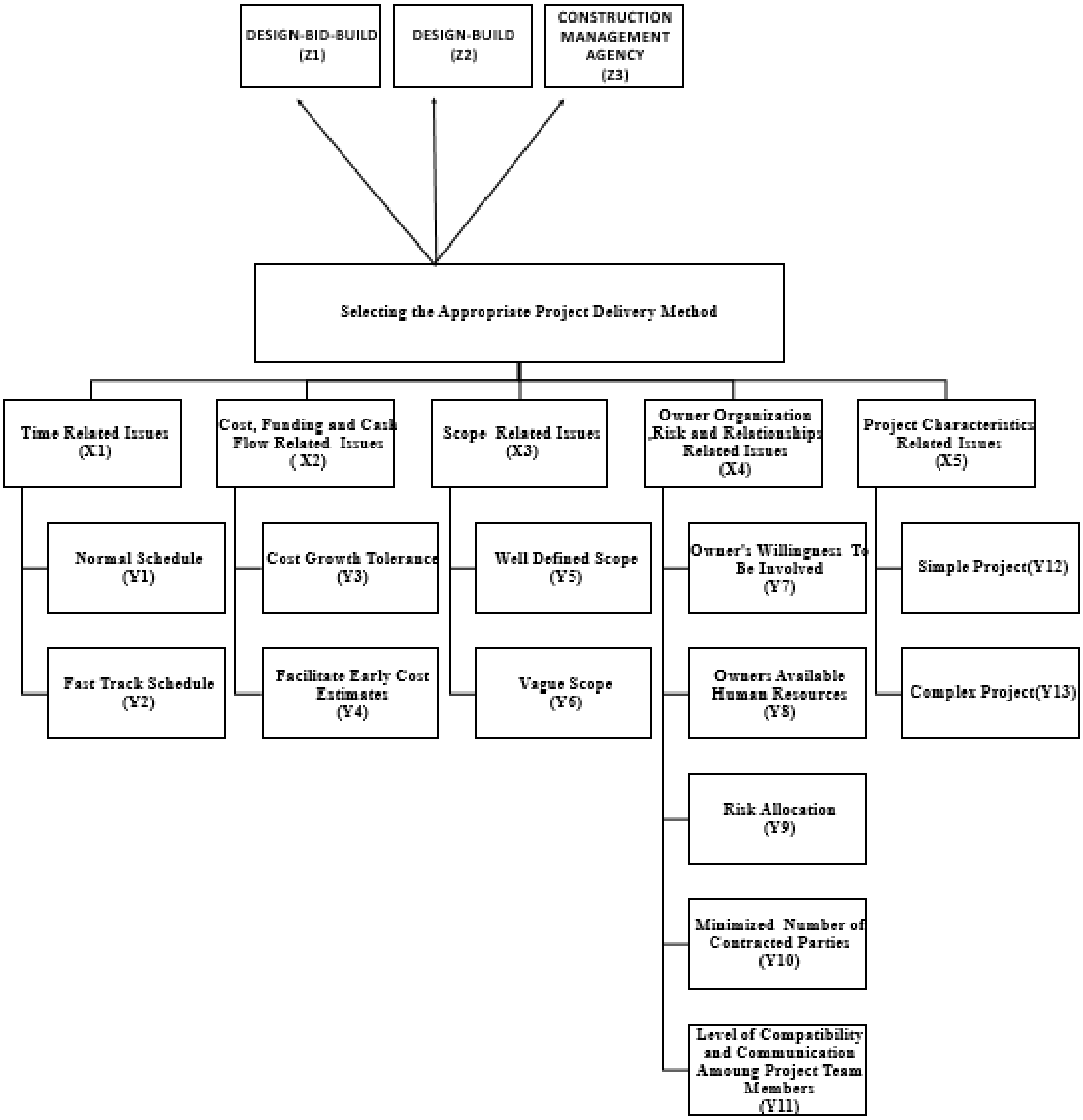

Figure 4.1. The Scheme of Hierarchy.

4.2. The Documents for the Application of the Case Study

As it was mentioned in the Methodology Chapter in detail, this thesis includes the Fuzzy AHP logic during the evaluation phases of each factors affecting the appropriate PDM selection. Due to the nature of decision-making being ambiguous, sensitive analysis to achieve the goal is indispensable. At that point, the Fuzzy AHP enables evaluating the decision of the respondents in a more susceptive way. The hierarchical scheme acquired by the previous studies including literature review and the interviews with the sector professionals is presented in Figure 4.1. During the case study and the real study, this scheme is provided to the respondents to visualize the items in their decision-making process precisely. In other words, the respondents can explicitly embody all the factors via this scheme.

Following the visualization, the distribution of the pairwise comparison sheet takes place. As it is stated in the Methodology Chapter in Table 3.3, there are 9 scoring levels according to this thesis. In the pairwise comparison, the evaluation bases on 3 different steps as it is shown in Table 3.4 with details Appendix B. In the first step, the 5 factors on top level are compared by scoring 1-9. Then, the sub 13 factors under the 5 main factors are scored with pairwise comparison one by one. Finally, the 3 PDMs are evaluated with each other based on the sub 13 factors under the 5 main factors. After getting all the data from this decision process depending on pairwise comparison, any tool created with Excel, Matlab etc. with respect to the Fuzzy AHP logic and analysis can be used. In this thesis, a web-based tool is utilized for the Case Study Chapter.

To summarize, this thesis provides a decision-making model for the selection of the appropriate project delivery method concerning real estate projects.

5. CASE STUDY

5.1. Description of the Case Study

Since this thesis focuses on the factors affecting the PDM selection and the most common PDMs used in the real estate industry, a real estate project which has been implemented in Istanbul, Turkey, was chosen as the case study to test the model proposed in the previous Chapter.

The construction of the mentioned project started in Istanbul. According to the agreement signed between the parties related to the construction works, the project's completion period was determined as 24 months. Based on the information provided from the professionals working in this project, there was not any schedule delay during the construction period. In other words, the project was not extended due to any reasons. Moreover, this real estate project constructed by a private sector company consists of 600 residential units. Besides its on-time completion, the project did not have any cost overrun, in fact it was completed under the budget.

In the previous section, the hierarchical model created based on literature review and the interviews with the sector professionals to visualize the case study structure more apparently from the point of view of the professionals is going to evaluate all the items and answer the questions in detail. Nevertheless, the questionnaire model deducted from this hierarchy to evaluate all items within pairwise comparison is created. The 5 professionals who have experience more than 10 years and who have participated in all phases of this real estate project were identified and were selected for this study. In this case study, the professionals are initially informed about the scope of the study, the hierarchy and how they answer the questions in the questionnaire. Then, five professionals reply all the pair wise comparison questions stated profoundly in the previous chapter. According to their answers, the appropriate PDM is recognized and compared with the actual PDM used during the project.

5.2. Description of the Tool Used in the Case Study

According to the scope of the thesis, there is a need for a tool prepared with respect to the Fuzzy AHP logic taking the pairwise comparison data to evaluate and give the most appropriate decision concerning the selection of the PDM. In this study, a web-based tool "Decision Era-Fuzzy AHP", prepared based on the Fuzzy AHP was preferred to use.

Firstly, all the factors in the hierarchy are labeled in the webpage for both the first and the second level with an uppercase letter and a number, like X1, Y1. At that point, the factors in the lower level are put into the related upper level factors. Then, the PDMs are described with an uppercase letter and a number, like A1. As it is stated in Figure 5.1, the hierarchy is defined in the web-based tool.

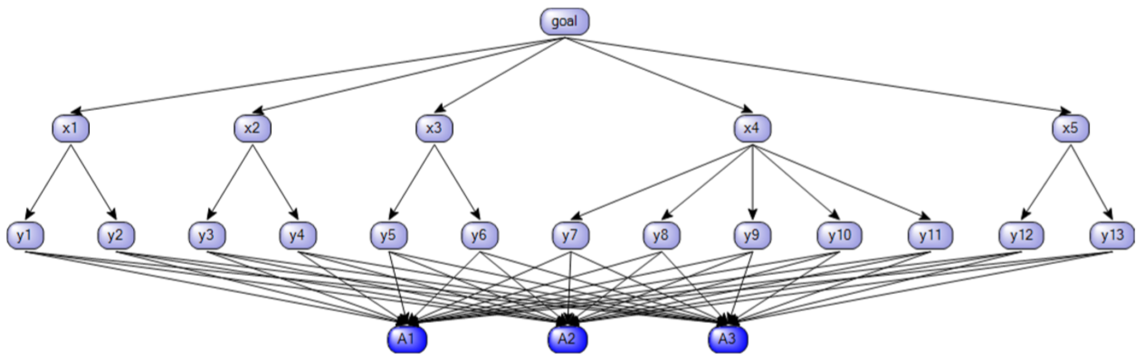

Figure 5.1. Hierarchy Structure.

Based on the data obtained via pairwise comparison sheet mentioned in the previous chapter, the template in the web-based tool for pairwise comparison is filled. Then, the evaluation phase comes true. By means of the algorithm including the Fuzzy AHP logic at the background of the tool, the most appropriate decision is acquired for the selection of the suitable PDM.

5.3. Output of the Case Study

According to the model that was created considering literature review and the interviews with Turkish professionals, the data originated from the answers of the pairwise comparison that are parts of the model is entered in the web-based tool.

After the data of the case study implementation, the final weights of the main and the sub-factors are determined based on the goal which is the decision of the appropriate PDM as it is shown in Table 5.1, Figure 5.2, Table 5.2, Figure 5.2. Moreover, the full version of the analysis report is presented in Appendix C with interface tables before reaching the final weights.

Table 5.1. Matrix of the Final Weights (Main Factors) with Respect to the Decision (Goal).

Component	**Final fuzzy weight**	**Final Crisp weight**
x1	(0.222,0.299,0.417)	0.309
x2	(0.333,0.468,0.617)	0.472
x3	(0.067,0.102,0.138)	0.102
x4	(0.057,0.074,0.111)	0.079
x5	(0.048,0.057,0.095)	0.064

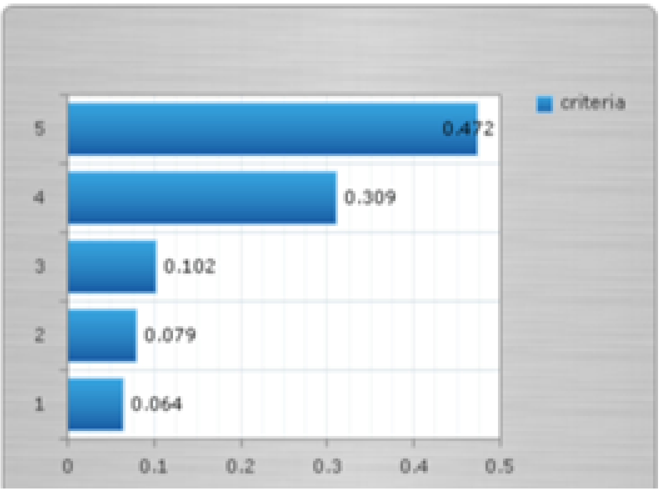

Figure 5.2. Chart of the Final Weights (Main Factors) with Respect to the Decision (Goal).

Table 5.2. Matrix of the Final Weights (Sub Factors) with Respect to the Decision (Goal).

Component	**Final fuzzy weight**	**Final Crisp weight**
y1	(0.038,0.059,0.109)	0.066
y2	(0.141,0.24,0.406)	0.257
y3	(0.035,0.061,0.107)	0.066
y4	(0.224,0.407,0.688)	0.431
y5	(0.045,0.089,0.153)	0.094
y6	(0.007,0.013,0.024)	0.014
y7	(0.004,0.006,0.011)	0.007
y8	(0.003,0.005,0.01)	0.006
y9	(0.004,0.005,0.01)	0.006
y10	(0.016,0.026,0.053)	0.03
y11	(0.017,0.032,0.058)	0.035
y12	(0.034,0.049,0.1)	0.058
y13	(0.005,0.008,0.016)	0.009

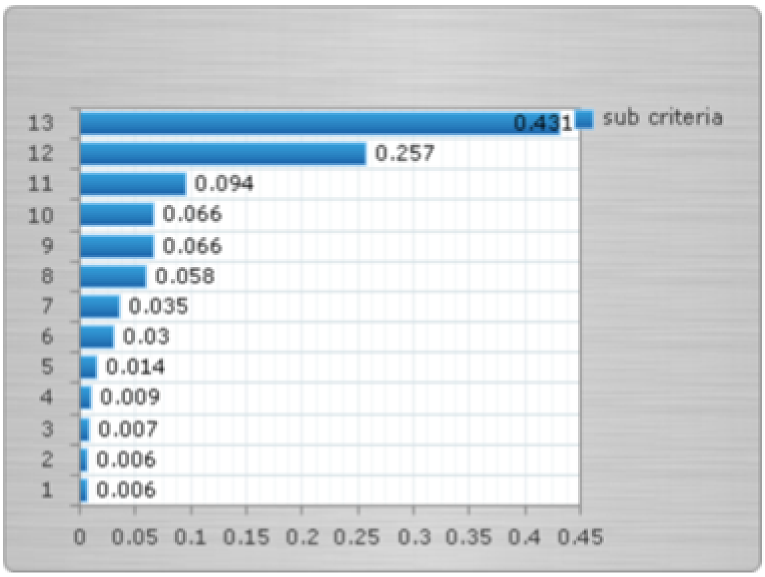

Figure 5.3. Chart of the Final Weights (Sub Factors) with Respect to the Decision (Goal).

By combining all analysis results, the preference weights for 3 PDMs are visually stated in Table 5.3 and Figure 5.3. In this case study, A1, A2 and A3 refer to Design-Bid-Build, Design-Build and Construction Management Agency respectively.

Table 5.3. Matrix of the Final Weights (Alternative PDMs) with Respect to the Decision (Goal).

Component	Final fuzzy weight of Alternatives	Final Crisp Weight of Alternatives	Prioritization based on Crisp weight
A1	(0.077,0.161,0.397)	0.199	3
A2	(0.089,0.192,0.432)	0.226	2
A3	(0.281,0.646,1.415)	0.747	1

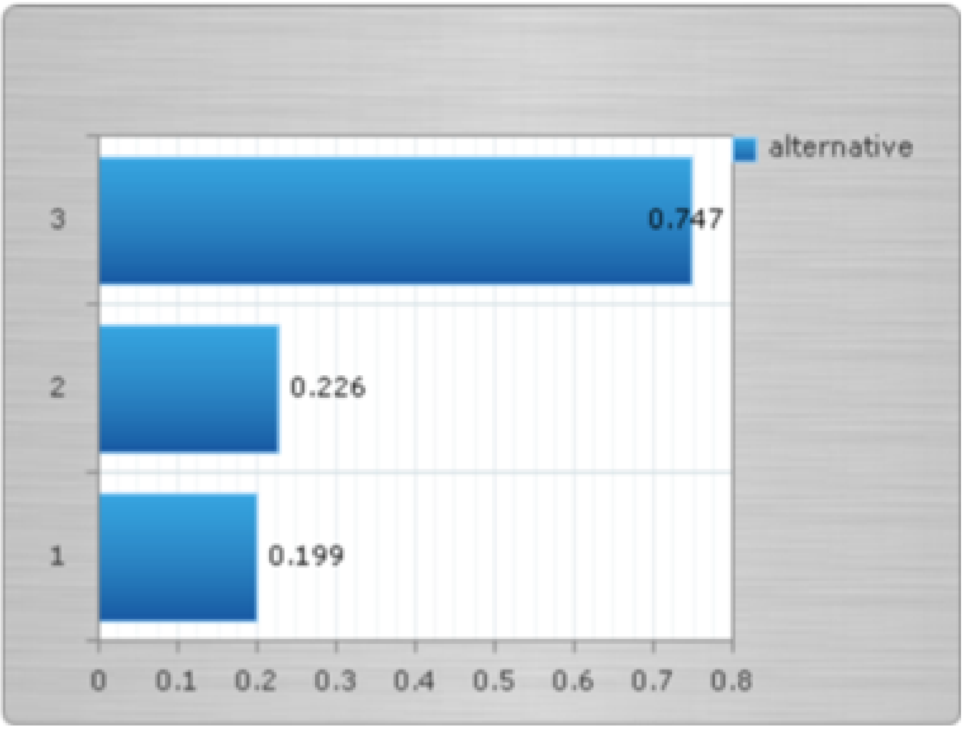

Figure 5.4. Chart of the Final Weights (Alternative PDMs) with Respect to the Decision (Goal).

In Table 5.3 and Figure 5.4, the most appropriate PDM is selected as Design-Bid Build by the professionals of the project. At the end of the data collection with pairwise comparison, the professionals gave the name of the PDM that they used during the project as Design-Bid-Build. Due to the fact that the PDM that is selected based on the case study and the one used in reality are the same, the model developed in this thesis presents reliable results to determine the appropriate PDM to be used in real estate projects.

6. DISCUSSION

The real estate industry is one of the fastest growing industries in Turkey, therefore its contribution to the country's economy is remarkably high. Due to its nature, the industry is involved in interaction with approximately more than 200 sub-sectors. This situation indicates that the real estate industry has a locomotive effect on the Turkish economy. Despite the unbalanced conditions in the Turkish economy regarding political, social and economic risks, the geopolitical position of Turkey fosters and increases the demand of the real estate industry for not only domestic but also for foreigner investors. At that point, to elude the volatility in the economy stemming from political issues in particular, leading sudden increases in the currency, the projects should be managed in a more professional way by foreseeing the contingencies in order to prevent both time and cost overruns. In this manner, this thesis focuses on the selection of the appropriate project delivery method by considering the factors affecting the selection and the most common PDMs used in the real estate industry in Turkey to manage the project in success.

To begin with, this study aims to examine the PDM types used in real estate and to identify and classify the factors which are outstanding for the PDM selection. Through detailed literature review conducted by focusing on 14 specific studies related to the scope of the thesis, the factors affecting the selection of the PDM and the PDMs used in real estate are acquired. The interview based on a questionnaire with 10 sector professionals is concurrently performed. Both in the literature review and in the answers of the questionnaire, there are some common and recurrent factors which have close meanings that are combined to prepare the final factor list. Similarly, the PDMs used in real estate are determined via the deduction of the data originated from both the literature review and the interviews with the professionals. At the end of this process, 5 main factors are obtained with 13 sub-factors for the determination of the 3 PDMs used in the real estate industry for Turkey as shown in Table 4.1 and Table 4.2 in connection with Table 4.3 and Table 4.1 respectively.

The aforementioned 14 studies were conducted in different countries and focused on different kind of PDMs with a great number of factors affecting the selection of the PDM. To illustrate, Chen and the colleagues (2010) examine 4 types of PDMs within 15 sub-factors under 6 main factors whereas El-Sayegh (2007) analyses 21 sub-factors under 7 main factors with 3 types of PDMs. On the other hand, Liu and the colleagues (2015) study the crucial owner characteristics affecting the PDM decision-making. According to Mahdi and the colleagues (2005), there are four main PDMs to be used in projects identified by using the AHP, namely Design-Bid-Build, Design-Build, Construction Management at Agency and Construction Management at Risk. Mahdi and the colleagues (2005) detect at the first level 7 main factors as "owner characteristics, project characteristics, design characteristics, regulatory, contract characteristics, risk and claim and disputes" with 34 sub-factors at the second level to identify the optimum house construction delivery method.

Based on the Fuzzy AHP approach, a study conducted by Mostafavi and Karamouz (2010) examines the 12 PDMs with the implementation of some special facilities to the PDMs mentioned before like Design -Bid-Build with early procurement and Design-Bid-Build with construction manager and 20 different selection factors regarding "cost, time, owner's preferences, contractional issues and type of the project". Design-Build is one of the most preferable PDMs in the study in terms of risk analysis (Mostafavi and Karamouz, 2010). On the other hand, Al Khalil (2002) shows that there are 3 main PDMs as Design-Bid-Build, Design-Build and Construction Management at Agency by creating a hierarchical structure which consists of 3 first level factors as "project characteristics, owner's need and owner's preferences" and 12 second level factors through analysis for the determination of the appropriate PDM using the AHP.

In the study of Ibbs and the colleagues (2003), a comprehensive analysis concerning 67 projects from the Construction Industry Institute's database, the projects are classified into different kinds of categories including project delivery method, contract type and project size. The most common PDMs are Design-Bid-Build and Design-Build with the ratio among the total number of the projects as 45% and 36% respectively which are affected from "time, cost and productivity expectations" for selection (Ibbs and the colleagues,2003). There is also a specific study which focuses on small-scale contractors in Ghana to observe the factors affecting "the project qualityé (Callistus *et al.*, 2014). As the contractor selection is an essential part of the determination of the suitable PDM, 21 factors identified by Callistus and the colleagues (2014) such as "teamwork about stakeholders, planning and control techniques, project team capability and monitoring and feedback" contain common factors with other studies examined in the Literature Review Chapter.

In another study conducted for 351 U.S. building projects, Construction Management at Risk, Design-Build and Design-Bid-Build are defined as the three principal project delivery methods used in the United States with the comparison in terms of "cost, schedule and quality performance" using univariate and multivariate analysis (Konchar and Sanvido, 1998). The authors of the aforementioned studies try to classify and categorize the factors in similar ways, the number and the name of them can be different from each other but the content of the factors actually have close scopes. To illustrate, Rojas and Kell (2008) have a study for comparative analysis of the project delivery methods including Design-Bid-Build, Design-Build and Construction Management at Risk on 297 completed school projects in Oregon and Washington for "the cost performance" via a statistical analysis. Moreover, regarding 12 high-performance Green Office buildings in the United States, Swarup and the colleagues (2011) suggest the crucial attributes for the selection of the proper PDM as "the strong owner commitment toward sustainability, the integration in the delivery process by a nearly involvement of the constructor and the early inclusion of green strategies" after examining a great number of attributes. Furthermore, Chen and the colleagues (2010) provide a study which aims to develop a PDM selection model utilizing 15 main articles to analyze the main factors affecting the selection and define them as "project objectives, project characteristics, characteristics of the owner and the contractor and external environment" at the first level along with 18 sub-factors at the second level for the construction projects in China. There is another study conducted by Liu and the colleagues (2016) specifically investigating contractor characteristics in a sense of the owner under different project delivery methods at 73 projects in China via questionnaire.

On the other hand, there are some different methods used in the studies such as the AHP, the Fuzzy AHP, the ANN, the multivariate linear regression models. A great majority of the studies in the literature, like Mostafavi and Karamouz (2010) utilize the Fuzzy AHP. The main reason of this is that the studies take into account the uncertainties and the imprecisions in the decision scope. In addition, it is due to the fuzziness in the nature of the decision factors especially in the real estate industry. For the manufacturing industry, almost all processes are well-defined and there is a low level of contingency risks compared to the real estate industry. To decrease the ambiguity and the vagueness in the decision-making process, the present thesis uses the Fuzzy AHP which caters to the conditions including uncertainty.

During the determination of the factors affecting the selection of the appropriate PDM, the data obtained from the literature review and the interviews with the sector professionals are found considerably consistent with each other. Regarding the time related issues, the professionals focus on the importance of the schedule type considering whether there is a time restriction or not. In other words, the requirements of the project duration can be examined in two categories as normal schedule and fast-track schedule. According to their knowledge, a project which necessitates fast-track schedule is prone to be managed excluding DBB, not allowing any schedule shortening. In the literature review, the studies of El-Sayegh (2007), Ibbs and the colleagues (2003), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Konchar and Sanvido (1998), Rojas and Kell (2008), Swarup and the colleagues (2011) and Chen and the colleagues (2011) discourse on the importance of the normal schedule condition. Additionally, El-Sayegh (2007), Ibbs and the colleagues (2003), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002) and Rojas and Kell (2008) state the significance of the fast-track schedule in making decisions related to PDM selection in their studies.

For the factors about cost, funding and cash flow, there are two main sub-factors acquired at the end of the interview with the sector professionals: cost growth tolerance and facilitation of the early cost estimate. The data obtained from the studies of Chen and the colleagues (2010), El-Sayegh (2007), Ibbs and the colleagues (2003), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Konchar and Sanvido (1998), Swarup and the colleagues (2011), Chen and the colleagues (2011) are compatible with the interview output regarding the importance of the cost growth tolerance. Moreover, the factor which is defined as facilitation early cost estimate is put forward by Chen and the colleagues (2010), El-Sayegh (2007), Ibbs and the colleagues (2003), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Rojas and Kell (2008) and Chen and the colleagues (2011) through their spectacular studies.

Scope is a fundamental issue for every project because it gives shape to all steps of the project by taking away the ambiguity. Throughout the interviews, the professionals declare the importance of the level of the scope determination for the selection of the suitable PDM. By the way, Accordingly, they provide information about the scope types as well-defined scope and vague scope. This categorization can be considered as logical as while DBB is more preferable for the vague scope projects, DB and CM at Agency are used for the well-defined ones. Regarding the significance of the well- defined scope, there are some studies of El-Sayegh (2007), Liu and the colleagues (2015), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Swarup and the colleagues (2011) , Chen and the colleagues (2011). Furthermore, El-Sayegh (2007), Mostafavi and Karamouz (2010), Al Khalil (2002), Swarup and the colleagues (2011) and Chen and the colleagues (2011) also focus on the substantiality of the vague scope. At this point, there is a positive correlation in the output data originating from the literature review and the interviews with the sector professionals.

Owner organization, risk and relationship related issues are also among the most important factors affecting successful project management with proper PDMs. According to the sector professionals, there are 5 main sub-groups for the aforementioned issues; namely owner's willingness to be involved, owner's available human resources, risk allocation, minimized number of contracted parties, level of compatibility and communication among project team members. To illustrate, DBB consists of a great number of contract parties with a low level of communication among team members, DB and CM at agency focus on minimizing the contract parties and a high level of communication from the beginning of the project to decrease change orders and conflicts of interest. In the literature, El-Sayegh (2007), Liu and the colleagues (2015), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Swarup and the colleagues (2011), Chen and the colleagues (2011)., El-Sayegh (2007), Mostafavi and Karamouz (2010), Al Khalil (2002) also draw attention to these factors during the PDM selection process. At that point, the literature review and the interviews are compatible with each other.

The design of the project is another fundamental concept affecting the project management. Herein, the professionals divide the project characteristic issues into 2 groups as standard project and complex project. Additionally, they emphasize that especially for the standard projects, DBB is used due to its straightforward nature, but the complex projects require DB and CM at Agency to conduct the project in a more conservative way to prevent cost and time overruns. Nevertheless, the studies of El-Sayegh (2007), Liu and the colleagues (2015), Liu and the colleagues (2016), Mahdi and Alreshaid (2005), Mostafavi and Karamouz (2010), Al Khalil (2002), Chen and the colleagues (2011) consider the standard project type as a factor for the selection of the appropriate PDM. Besides, the complex project type is regarded as another significant factor for the project characteristic issues according to El-Sayegh (2007), Mahdi and Alreshaid (2005), Al Khalil (2002), Pan (2008) and Chen and the colleagues (2011).

By taking into account the information provided above in detail, this study contributes to the literature by indicating the probable factors affecting the selection of the PDM in the Turkish real estate industry with 5 main factors categorized as "time related issues, cost, funding and cash flow related issues, scope related issues, owner organization, risk and relationship related issues and project characteristic issues" with 13 sub-factors stated in Table 4.1 and Figure 4.1. In the interview phase with the sector professionals in Turkey, this thesis includes different viewpoints such as those of the contractors, the owners, the designers and the consultants. While Liu and the colleagues (2015) solely focus on the owner characteristics for the selection of the PDM; Swarup and the colleagues (2011) prefer only to use schedule, cost, quality and owner's perception as the most influential factors. The differences between the findings of several previous studies mainly originate from including different kinds of perspectives. In other words, the number of the factors and their categorization are not identical because the authors have different attitudes for different types of projects in different countries.

As it was stated in the previous chapters, the determination of the factors related to the PDM selection and the PDM types used in the real estate industry base on both the literature review and on the interviews including questionnaires in this study. The project managers, the contract managers, the designers, the site engineers, the owners, the contractors who have different kinds of roles provide the data about the Turkish real estate industry. In previous studies, some authors prefer to state the PDM types without including any interview, solely by focusing on the literature like Chen and the colleagues (2010). On the contrary, this thesis aims to provide information by using not only the literature but also the professionals' opinions for the Turkish real estate industry. Reviewing the literature, it is seen that DBB, DB, CM at Risk and CM at Agency are the four main PDMs types used in the real estate industry. The information provided from the professionals implies that the most preferable PDMs in the Turkish real estate industry are DBB, DB and CM at Agency. The reason behind the absence of CM at Risk in the interview-based questionnaire mainly stems from the fact that the owners do not will to transfer all managerial activity and risk to a construction management company in Turkey. Thus, the other theoretical contribution of this thesis is related to introducing the main PDMs used in the Turkish real estate industry as DBB, DB, CM at Agency.

In addition to the elimination of CM at Risk, the "quality factor" is got rid of from the literature review-based data when combining the interview answers to acquire the final list of the factors. In the literature review, while some authors like Rojas and Kell (2008) and Swarup and the colleagues (2011) state that quality is an essential key for the PDM selection, others such as Mahdi and Alreshaid (2005) do not consider quality as a factor affecting the identification of the optimum house construction delivery approach in their comprehensive study. During the interviews, none of the professionals have mentioned quality as a required factor. After all questions were answered, for comparison, they were informed that there were some studies assuming quality is an influential factor for the PDM selection. However, their opinions were the same after giving the information. As quality is an indispensable issue for every project without any doubt, it should be provided in any case.

Finally, this thesis provides a practical contribution via a hierarchical model with a questionnaire including theoretical contributions that are mentioned above to select the appropriate project delivery method for the real estate projects in Turkey. The real estate industry has many uncertainties inside it apart from the project characteristics, namely political, social, economic risks. At that point, this thesis aims to help the professionals who are responsible for the selection of the most appropriate PDM reduce the risks and manage the project in a more proper way.

To sum up, this research provides important theoretical contributions to the literature by showing the factors affecting the selection of the PDM and the suitable PDMs for the Turkish real estate industry. Moreover, this research assists the decision-makers to select the most appropriate PDM by the model created with questionnaire including pairwwise comparison via the Fuzzy AHP in order to enable the proper execution process of the project from the beginning to the end.

7. CONCLUSION

Since the real estate industry is one of the fastest growing industries in Turkey with its remarkable locomotive effect on the economy, this thesis aims to arrive at the following objectives: the identification and the categorization of the factors affecting the selection of the PDM, the determination of the PDMs preferred to use in the real estate and the generation of the model enabling the appropriate PDM selection for the Turkish real estate industry by using the Fuzzy AHP to obtain more accurate results.

The factors that have impact on the selection of the PDM in the real estate industry are summarized through a detailed literature review and the interviews with the sector professionals who have different kinds of roles in the real estate projects such as the project managers, the contract managers, the designers, the site engineers, the owners, and the contractors. During this process, the factors originating from the previous studies in the literature review and the interview with sector professionals are considered or are eliminated depending on whether they are relevant to the real estate industry in Turkey. Moreover, all similar processes are conducted for the determination of the PDM types used for the Turkish real estate industry. By the fulfillment of these processes, a hierarchical model is created including all the factors affecting the PDM selection and the PDM types detected previously. This model provides information about the appropriate PDM type to be used in a real estate project. At that point, the proposed model's implementation is carried out via the collected data from the respondent of the case study. Since the result obtained from this model is consistent with the realized PDM selection which led to success of the project, this model can be utilized to determine the proper PDMs for the real estate projects in Turkey.

In terms of the theoretical contribution to the literature, this thesis provides the probable factors affecting the selection of the PDM in the Turkish real estate industry with 5 main factors categorized as "time related issues, cost, funding and cash flow related issues, scope related issues, owner organization, risk and relationship related issues and project characteristic issues" with 13 sub-factors. Furthermore, another theoretical contribution of this thesis is exhibiting the main PDMs used in Turkish real estate industry as DBB, DB and CM at Agency. In addition to the theoretical contribution, a hierarchical model with a questionnaire to select the appropriate project delivery method for the real estate projects in Turkey is provided as a practical contribution. Stemming from its nature, the real estate industry has many uncertainties in its inside. Thus, the anticipation of the proper PDM is notably difficult. At that point, this thesis aims to help the professionals who are responsible for the selection of the most appropriate PDM to mitigate the risks and manage the project in a proper way.

On the other hand, this research has some limitations as well. Initially, the number of the interviews with the sector professionals can be considered as one of the limitations. Then, another limitation in this study is concerning the number of the case studies. Further case studies can be conducted to augment the reliability of the proposed model. This way, the data about consistency can be achieved in order to analyze the results deriving from this proposed model.

For the future studies, as the number of the interviews increase, the collected data, a spectacular source of the proposed model, also increases and fosters the reliability of the model. In other models, statistically, the broadened sample size helps to obtain more realistic results. Moreover, the number of the future case studies may enable testing the validity of the proposed model. By focusing on these two limitations, further case studies can be conducted to reinforce the reliability of the model.

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APPENDIX A: QUESTIONNAIRE BASED ON THE INTERVIEWS

The Questionairre for the Interview with the Sector Professionals

Demograhic Informations

1. What is your area of expertise in real estate projects?

- Project Manager
- Contract Manager
- Planning&Cost Control Manager
- Designer/Engineer
- Site Engineer
- Other…

2. How many years of experience do you have in real estate projects?

- <5 years
- 5-10 years
- 10-20 years
- >20 years

3. Which of the following organization are you from?

- Owner
- Contractor
- Designer/Engineer
- Consultant
- Other………

Project Delivery Methods and the Factors Related to Their Selection

4. Which project delivery methods are suitable and applicable for real estate industry in Turkey? Please select the proper one/ones in your opinion.

5. What are the main factors affecting project delivery selection in Turkish Real Estate Industry? Please provide information about your opinion.

Figure A.1. Questionnaire Based on the Interviews with Sector Professionals.

APPENDIX B: QUESTIONNAIRE FOR THE CASE STUDY

Information about Expert	
Expert's Name/ Surname	
Job Title	
Work Experience(years)	
The types of Projects Completed by the Expert (Dwelling, Office, Shopping Mall, Infrastructure etc.)	

Code	Linguistic variables
1	Equally preferred
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very strongly to extremely preferred
9	Extremely preferred

Example Code Selection for Criteria

Criteria 2 is **Very strongly preferred** than Criteria 1

Criteria 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Criteria 2**

Criteria 3 is **Strongly to very strongly preferred** than Criteria 4

Criteria 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Criteria 4**

Table 1: Pairwise comparison with respect to selecting the appopriate PDM

Cost ,Funding and Cash Flow Related Issues(X2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time Related Issues(X1)
Scope Related Issues(X3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time Related Issues(X1)
Owner Organization ,Risk and Relationships Related Issues(X4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time Related Issues(X1)
Project Characteristics Related Issues (X5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time Related Issues(X1)
Scope Related Issues(X3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost ,Funding and Cash Flow Related Issues(X2)
Owner Organization ,Risk and Relationships Related Issues(X4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost ,Funding and Cash Flow Related Issues(X2)
Project Characteristics Related Issues (X5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost ,Funding and Cash Flow Related Issues(X2)
Owner Organization ,Risk and Relationships Related Issues(X4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Scope Related Issues(X3)
Project Characteristics Related Issues (X5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Scope Related Issues(X3)
Project Characteristics Related Issues (X5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owner Organization ,Risk and Relationships Related Issues(X4)

Figure B.1. Questionnaire for the Case Study Application Part 1.

Table 2: Pairwise comparison with respect to Time Related Issues (X1)																		
Fast Track Schedule(Y2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Normal Schedule(Y1)

Table 3: Pairwise comparison with respect to Cost ,Funding and Cash Flow Related Issues (X2)																		
Facilitate Early Cost Estimates(Y4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost Growth Tolerance(Y3)

Table 4: Pairwise comparison with respect to Scope Related Issues (X3)																		
Vague Scope(Y6)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Well Defined Scope(Y5)

Table 5: Pairwise comparison with respect to Owner Organization ,Risk and Relationships Related Issues (X4)																		
Owners Available Human Resources(Y8)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owner's Willingness To Be Involved (Y7)
Risk Allocation(Y9)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owner's Willingness To Be Involved (Y7)
Minimized Number of Contracted Parties(Y10)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owner's Willingness To Be Involved (Y7)
Level of Compatibility and Communication Amoung Project Team	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owner's Willingness To Be Involved (Y7)
Risk Allocation(Y9)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owners Available Human Resources(Y8)
Minimized Number of Contracted Parties(Y10)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owners Available Human Resources(Y8)
Level of Compatibility and Communication Amoung Project Team	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Owners Available Human Resources(Y8)
Minimized Number of Contracted Parties(Y10)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Allocation(Y9)
Level of Compatibility and Communication Amoung Project Team Members(Y11)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Allocation(Y9)
Level of Compatibility and Communication Amoung Project Team	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimized Number of Contracted Parties(Y10)

Table 6: Pairwise comparison with respect to Project Characteristics Related Issues (X5)																		
Complex Project(Y13)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Simple Project(Y12)

Figure B.2. Questionnaire for the Case Study Application Part 2.

Table 7: Pairwise comparison of alternatives with respect to Normal Schedule (Y1)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 8: Pairwise comparison of alternatives with respect to Fast Track Schedule (Y2)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 9:Pairwise comparison of alternatives with respect to Cost Growth Tolerance (Y3)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 10: Pairwise comparison of alternatives with respect to Facilitate Early Cost Estimates (Y4)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 11: Pairwise comparison of alternatives with respect to Well Defined Scope (Y5)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Figure B.3. Questionnaire for the Case Study Application Part 3.

Table 12:Pairwise comparison of alternatives with respect to Vague Scope (Y6)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 13: Pairwise comparison of alternatives with respect to Owner's Willingness To Be Involved (Y7)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 14: Pairwise comparison of alternatives with respect to Owners Available Human Resources (Y8)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 15: Pairwise comparison of alternatives with respect to Risk Allocation (Y9)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 16: Pairwise comparison of alternatives with respect to Minimized Number of Contracted Parties (Y10)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Figure B.4. Questionnaire for the Case Study Application Part 4.

Table 17: Pairwise comparison of alternatives with respect to Level of Compatibility and Communication Amoung Project Team Members (Y11)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 18: Pairwise comparison of alternatives with respect to Simple Project (Y12)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

Table 19: Pairwise comparison of alternatives with respect to Complex Project (Y13)																		
Design-Build(Z2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Bid-Build(Z1)
Construction Management Agency(Z3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design-Build(Z2)

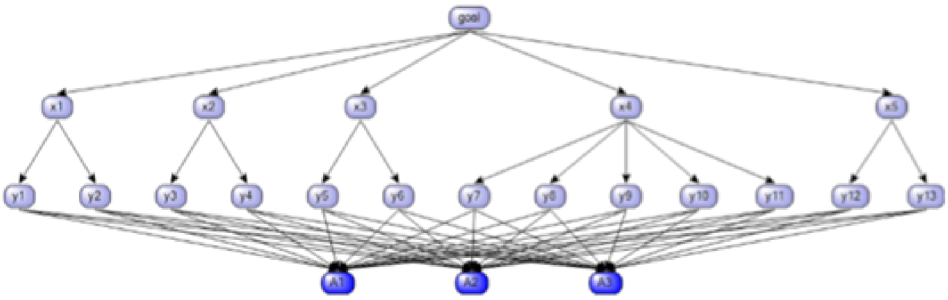
Figure B.5. Questionnaire for the Case Study Application Part 5.

APPENDIX C: CASE STUDY ANALYSIS REPORT

27.10.2016 DecisionEra Project

Project Name:

Hierarchy structure:



Contents

linguistic term and Alternative:

Table 1: linguistic term

Code	linguistic variables	Fuzzy Number
1	Equally preferred	(1,1,1)
2	Equally to moderately preferred	(1,1.5,1.5)
3	Moderately preferred	(1,2,2)
4	Moderately to strongly preferred	(3,3.5,4)
5	Strongly preferred	(3,4,4.5)
6	Strongly to very strongly preferred	(3,4.5,5)
7	Very strongly preferred	(5,5.5,6)
8	Very strongly to extremely preferred	(5,6,7)
9	Extremely preferred	(5,7,9)

Table 2: alternative

Label	Alternatives names
A1	Z1
A2	Z2
A3	Z3

Contents

Inconsistency rate:
Inconsistency rate is obtained according to the following article:
O. Gogus and T.O. Boucher, Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons, Fuzzy Sets and Systems, 94(1), (1998), 133-144.

Section 1:

$$\tilde{r}_i = \left[\prod_{j=1}^{n} \tilde{r}_{ij}\right]^{\frac{1}{n}} \quad \forall i$$

Table 3: Mean of pairwises comparison with respect to goal

goal	x1	x2	x3	x4	x5	Geometric mean
x1	(1,1,1)	(0.415,0.437,0.644)	(3,3.882,4.384)	(3,4.395,4.896)	(4.514,5.284,5.785)	(1.76,2.085,2.402)
x2	(1.552,2.29,2.408)	(1,1,1)	(3.68,4.962,5.547)	(5,5.597,6.188)	(4.514,5.842,6.882)	(2.643,3.266,3.556)
x3	(0.228,0.258,0.333)	(0.18,0.202,0.272)	(1,1,1)	(1,1.783,1.783)	(1,2,2)	(0.528,0.714,0.798)
x4	(0.204,0.228,0.333)	(0.162,0.179,0.2)	(0.561,0.561,1)	(1,1,1)	(1,1.589,1.589)	(0.45,0.515,0.638)
x5	(0.173,0.189,0.222)	(0.145,0.171,0.222)	(0.5,0.5,1)	(0.629,0.629,1)	(1,1,1)	(0.38,0.4,0.547)
Sum						(5.761,6.979,7.942)

$CI^{m} = 0.023$ $CI^{g} = 0.021$

p://www.decisionera.com/project/html/swaoadn.html

Figure C.1. Case Study Analysis Report Part 1.

Consistent

Table 4: Mean of pairwises comparison with respect to x1

x1	y1	y2	Geometric mean
y1	(1,1,1)	(0.218,0.245,0.333)	(0.467,0.495,0.577)
y2	(3,4.082,4.584)	(1,1,1)	(1.732,2.021,2.141)
Sum			(2.199,2.515,2.718)

Table 5: Mean of pairwises comparison with respect to x2

x2	y3	y4	Geometric mean
y3	(1,1,1)	(0.12,0.15,0.2)	(0.347,0.387,0.447)
y4	(5,6.67,8.299)	(1,1,1)	(2.236,2.583,2.881)
Sum			(2.583,2.97,3.328)

Table 6: Mean of pairwises comparison with respect to x3

x3	y5	y6	Geometric mean
y5	(1,1,1)	(5,6.581,8.139)	(2.236,2.565,2.853)
y6	(0.123,0.152,0.2)	(1,1,1)	(0.351,0.39,0.447)
Sum			(2.587,2.955,3.3)

Table 7: Mean of pairwises comparison with respect to x4

x4	y7	y8	y9	y10	y11	Geometric mean
y7	(1,1,1)	(1,1.683,1.683)	(1,1,1)	(0.173,0.189,0.222)	(0.158,0.18,0.222)	(0.486,0.564,0.607)
y8	(0.594,0.594,1)	(1,1,1)	(1,1,1)	(0.167,0.182,0.2)	(0.186,0.205,0.272)	(0.45,0.467,0.559)
y9	(1,1,1)	(1,1,1)	(1,1,1)	(0.168,0.186,0.222)	(0.173,0.189,0.222)	(0.492,0.512,0.547)
y10	(4.514,5.284,5.785)	(5,5.5,6)	(4.514,5.376,5.966)	(1,1,1)	(0.594,0.594,1)	(2.272,2.475,2.906)
y11	(4.514,5.567,6.346)	(3.68,4.876,5.378)	(4.514,5.284,5.785)	(1,1.683,1.683)	(1,1,1)	(2.371,2.996,3.194)
Sum						(6.072,7.014,7.812)

CI^{m} =0.018 CI^{g} =0.019

Consistent

Table 8: Mean of pairwises comparison with respect to x5

x5	y12	y13	Geometric mean
y12	(1,1,1)	(5,6.272,7.505)	(2.236,2.504,2.74)
y13	(0.133,0.159,0.2)	(1,1,1)	(0.365,0.399,0.447)
Sum			(2.601,2.904,3.187)

Table 9: Mean of pairwises comparison with respect to y1

y1	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1.246,1.994,2.048)	(0.247,0.27,0.375)	(0.675,0.814,0.916)
A2	(0.488,0.502,0.803)	(1,1,1)	(0.147,0.17,0.2)	(0.416,0.44,0.544)
A3	(2.667,3.7,4.043)	(5,5.896,6.787)	(1,1,1)	(2.371,2.794,3.016)
Sum				(3.463,4.048,4.475)

CI^{m} =0.006 CI^{g} =0.003

Consistent

Table 10: Mean of pairwises comparison with respect to y2

y2	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.349,0.379,0.517)	(0.197,0.219,0.301)	(0.41,0.436,0.538)
A2	(1.933,2.642,2.862)	(1,1,1)	(0.45,0.506,0.57)	(0.955,1.101,1.177)
A3	(3.323,4.575,5.078)	(1.755,1.978,2.221)	(1,1,1)	(1.8,2.084,2.242)
Sum				(3.165,3.621,3.957)

CI^{m} =0.002 CI^{g} =0.005

Consistent

Table 11: Mean of pairwises comparison with respect to y3

y3	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1,1,1)	(0.261,0.287,0.415)	(0.639,0.66,0.746)
A2	(1,1,1)	(1,1,1)	(0.261,0.287,0.415)	(0.639,0.66,0.746)

Figure C.2. Case Study Analysis Report Part 2.

27.10.2018 Decisi

A3	(2.408,3.482,3.826)	(2.408,3.482,3.826)	(1,1,1)	(1.797,2.297,2.446)
Sum				(3.075,3.617,3.938)
CI^m =0 CI^g =0 Consistent				

Table 12: Mean of pairwises comparison with respect to y4

y4	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.723,0.723,1)	(0.201,0.224,0.301)	(0.526,0.545,0.67)
A2	(1,1.383,1.383)	(1,1,1)	(0.188,0.211,0.272)	(0.573,0.664,0.722)
A3	(3.323,4.469,4.972)	(3.68,4.733,5.318)	(1,1,1)	(2.304,2.766,2.979)
Sum				(3.403,3.974,4.371)
CI^m =0.017 CI^g =0.019 Consistent				

Table 13: Mean of pairwises comparison with respect to y5

y5	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1,1.644,1.644)	(0.205,0.229,0.301)	(0.59,0.722,0.791)
A2	(0.608,0.608,1)	(1,1,1)	(0.194,0.215,0.272)	(0.49,0.508,0.648)
A3	(3.323,4.365,4.868)	(3.68,4.652,5.156)	(1,1,1)	(2.304,2.728,2.928)
Sum				(3.384,3.958,4.367)
CI^m =0.021 CI^g =0.009 Consistent				

Table 14: Mean of pairwises comparison with respect to y6

y6	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1,1.431,1.431)	(0.223,0.251,0.333)	(0.606,0.711,0.781)
A2	(0.699,0.699,1)	(1,1,1)	(0.203,0.231,0.301)	(0.522,0.544,0.67)
A3	(3,3.987,4.489)	(3.323,4.338,4.916)	(1,1,1)	(2.152,2.586,2.805)
Sum				(3.28,3.841,4.256)
CI^m =0.009 CI^g =0.002 Consistent				

Table 15: Mean of pairwises comparison with respect to y7

y7	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1,1.783,1.783)	(0.239,0.272,0.333)	(0.621,0.785,0.841)
A2	(0.561,0.561,1)	(1,1,1)	(0.186,0.208,0.245)	(0.47,0.489,0.626)
A3	(3,3.68,4.183)	(4.076,4.797,5.387)	(1,1,1)	(2.304,2.604,2.824)
Sum				(3.395,3.878,4.291)
CI^m =0.011 CI^g =0 Consistent				

Table 16: Mean of pairwises comparison with respect to y8

y8	A1	A2	A3	Geometric mean
A1	(1,1,1)	(1.246,1.783,1.825)	(0.291,0.322,0.415)	(0.713,0.831,0.912)
A2	(0.548,0.561,0.803)	(1,1,1)	(0.2,0.226,0.301)	(0.478,0.502,0.623)
A3	(2.408,3.107,3.438)	(3.323,4.427,5.008)	(1,1,1)	(2,2.396,2.582)
Sum				(3.191,3.729,4.117)
CI^m =0.006 CI^g =0.001 Consistent				

Table 17: Mean of pairwises comparison with respect to y9

y9	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.922,1.084,1.176)	(0.19,0.21,0.272)	(0.559,0.611,0.684)
A2	(0.85,0.922,1.084)	(1,1,1)	(0.161,0.184,0.222)	(0.515,0.554,0.622)

Figure C.3. Case Study Analysis Report Part 3.

Sum	(3.626,4.123,4.504)
CI^m =0 CI^g =0.006 Consistent	

Table 18: Mean of pairwises comparison with respect to y10

y10	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.922,1.32,1.431)	(0.198,0.22,0.272)	(0.567,0.662,0.73)
A2	(0.699,0.758,1.084)	(1,1,1)	(0.171,0.19,0.222)	(0.493,0.525,0.622)
A3	(3.68,4.543,5.049)	(4.514,5.251,5.842)	(1,1,1)	(2.552,2.879,3.09)
Sum				(3.612,4.066,4.441)
CI^m =0.002 CI^g =0 Consistent				

Table 19: Mean of pairwises comparison with respect to y11

y11	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.431,0.488,0.699)	(0.205,0.229,0.301)	(0.446,0.482,0.595)
A2	(1.431,2.048,2.322)	(1,1,1)	(0.301,0.32,0.467)	(0.755,0.869,1.027)
A3	(3.323,4.365,4.868)	(2.141,3.123,3.323)	(1,1,1)	(1.923,2.389,2.529)
Sum				(3.124,3.739,4.151)
CI^m =0.017 CI^g =0.011 Consistent				

Table 20: Mean of pairwises comparison with respect to y12

y12	A1	A2	A3	Geometric mean
A1	(1,1,1)	(2.667,3.7,4.043)	(0.758,1.084,1.431)	(1.264,1.589,1.795)
A2	(0.247,0.27,0.375)	(1,1,1)	(0.315,0.34,0.517)	(0.427,0.451,0.579)
A3	(0.699,0.922,1.32)	(1.933,2.942,3.17)	(1,1,1)	(1.105,1.395,1.611)
Sum				(2.797,3.435,3.985)
CI^m =0.002 CI^g =0.018 Consistent				

Table 21: Mean of pairwises comparison with respect to y13

y13	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.594,0.594,1)	(0.14,0.164,0.2)	(0.437,0.461,0.585)
A2	(1,1.683,1.683)	(1,1,1)	(0.147,0.17,0.2)	(0.528,0.658,0.696)
A3	(5,6.081,7.137)	(5,5.896,6.787)	(1,1,1)	(2.924,3.298,3.645)
Sum				(3.889,4.417,4.926)
CI^m =0.027 CI^g =0.017 Consistent				

Contents

Section 2:

$$\tilde{r}_{ij} = \tilde{w}_i = \frac{\tilde{z}_i}{\sum_{i=1}^{n} \tilde{z}_i}$$

Table 22: Normalized geometric mean with respect to goal

goal	Normalized geometric mean
x1	(0.222,0.299,0.417)
x2	(0.333,0.468,0.617)
x3	(0.067,0.102,0.138)
x4	(0.057,0.074,0.111)
x5	(0.048,0.057,0.095)

Table 23: Normalized geometric mean with respect to x1

x1	Normalized geometric mean

Figure C.4. Case Study Analysis Report Part 4.

Table 24: Normalized geometric mean with respect to x2

x2	Normalized geometric mean
y3	(0.104,0.13,0.173)
y4	(0.672,0.87,1.115)

Table 25: Normalized geometric mean with respect to x3

x3	Normalized geometric mean
y5	(0.678,0.868,1.103)
y6	(0.106,0.132,0.173)

Table 26: Normalized geometric mean with respect to x4

x4	Normalized geometric mean
y7	(0.062,0.08,0.1)
y8	(0.058,0.067,0.092)
y9	(0.063,0.073,0.09)
y10	(0.291,0.353,0.479)
y11	(0.304,0.427,0.526)

Table 27: Normalized geometric mean with respect to x5

x5	Normalized geometric mean
y12	(0.702,0.862,1.053)
y13	(0.115,0.138,0.172)

Table 28: Normalized geometric mean with respect to y1

y1	Normalized geometric mean
A1	(0.151,0.201,0.264)
A2	(0.093,0.109,0.157)
A3	(0.53,0.69,0.871)

Table 29: Normalized geometric mean with respect to y2

y2	Normalized geometric mean
A1	(0.104,0.12,0.17)
A2	(0.241,0.304,0.372)
A3	(0.455,0.575,0.709)

Table 30: Normalized geometric mean with respect to y3

y3	Normalized geometric mean
A1	(0.162,0.182,0.243)
A2	(0.162,0.182,0.243)
A3	(0.456,0.635,0.795)

Table 31: Normalized geometric mean with respect to y4

y4	Normalized geometric mean
A1	(0.12,0.137,0.197)
A2	(0.131,0.167,0.212)
A3	(0.527,0.696,0.876)

Table 32: Normalized geometric mean with respect to y5

y5	Normalized geometric mean
A1	(0.135,0.182,0.234)
A2	(0.112,0.128,0.191)
A3	(0.528,0.689,0.865)

Table 33: Normalized geometric mean with respect to y6

y6	Normalized geometric mean
A1	(0.142,0.185,0.238)
A2	(0.123,0.142,0.204)
A3	(0.506,0.673,0.855)

Table 34: Normalized geometric mean with respect to y7

y7	Normalized geometric mean

ttp://www.decisionera.com/project/html/swaoadn.html

Figure C.5. Case Study Analysis Report Part 5.

A1	(0.145,0.202,0.248)
A2	(0.11,0.126,0.184)
A3	(0.537,0.671,0.832)

Table 35: Normalized geometric mean with respect to y8

y8	Normalized geometric mean
A1	(0.173,0.223,0.286)
A2	(0.116,0.135,0.195)
A3	(0.486,0.642,0.809)

Table 36: Normalized geometric mean with respect to y9

y9	Normalized geometric mean
A1	(0.124,0.148,0.189)
A2	(0.114,0.134,0.171)
A3	(0.567,0.718,0.882)

Table 37: Normalized geometric mean with respect to y10

y10	Normalized geometric mean
A1	(0.128,0.163,0.202)
A2	(0.111,0.129,0.172)
A3	(0.575,0.708,0.855)

Table 38: Normalized geometric mean with respect to y11

y11	Normalized geometric mean
A1	(0.107,0.129,0.19)
A2	(0.182,0.232,0.329)
A3	(0.463,0.639,0.81)

Table 39: Normalized geometric mean with respect to y12

y12	Normalized geometric mean
A1	(0.317,0.463,0.642)
A2	(0.107,0.131,0.207)
A3	(0.277,0.406,0.576)

Table 40: Normalized geometric mean with respect to y13

y13	Normalized geometric mean
A1	(0.089,0.104,0.15)
A2	(0.107,0.149,0.179)
A3	(0.594,0.747,0.937)

Contents

Section 3:

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{w}_j r_{ij} \quad \forall i$$

$$Crisp(\tilde{U}) = \frac{(u_l + 2 \times u_m + u_r)}{4}$$

Table 41 : matrix of final weights (criteria) with respect to goal

Component	Final fuzzy weight	Final Crisp weight
x1	(0.222,0.299,0.417)	0.309
x2	(0.333,0.468,0.617)	0.472
x3	(0.067,0.102,0.138)	0.102
x4	(0.057,0.074,0.111)	0.079
x5	(0.048,0.057,0.095)	0.064

Figure 1 : Final weights chart (criteria) with respect to goal

Figure C.6. Case Study Analysis Report Part 6.

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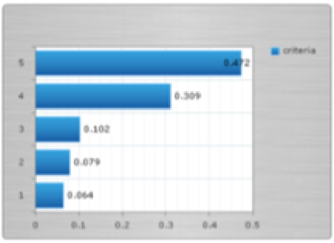

Table 42 : matrix of final weights (sub criteria) with respect to goal

Component	Final fuzzy weight	Final Crisp weight
y1	(0.038,0.059,0.109)	0.066
y2	(0.141,0.24,0.406)	0.257
y3	(0.035,0.061,0.107)	0.066
y4	(0.224,0.407,0.688)	0.431
y5	(0.045,0.089,0.153)	0.094
y6	(0.007,0.013,0.024)	0.014
y7	(0.004,0.006,0.011)	0.007
y8	(0.003,0.005,0.01)	0.006
y9	(0.004,0.005,0.01)	0.006
y10	(0.016,0.026,0.053)	0.03
y11	(0.017,0.032,0.058)	0.035
y12	(0.034,0.049,0.1)	0.058
y13	(0.005,0.008,0.016)	0.009

Figure 2 : Final weights chart (sub criteria) with respect to goal

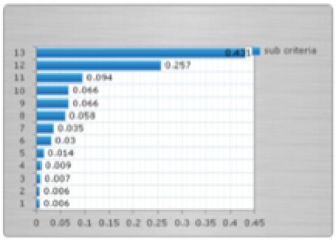

Table 43 : Matrix of final weight (alternatives) with respect to goal

Component	Final fuzzy weight of Alternatives	Final Crisp weight of Alternatives	Prioritization based on Crisp weight
A1	(0.077,0.161,0.397)	0.199	3
A2	(0.089,0.192,0.432)	0.226	2
A3	(0.281,0.646,1.415)	0.747	1

Figure 3 : Alternatives final weights chart with respect to goal

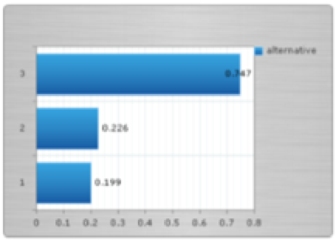

Figure C.7. Case Study Analysis Report Part 7.

Sum				(3.626,4.123,4.504)
CI^m =0 CI^g =0.006 Consistent				

Table 18: Mean of pairwises comparison with respect to y10

y10	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.922,1.32,1.431)	(0.198,0.22,0.272)	(0.567,0.662,0.73)
A2	(0.699,0.758,1.084)	(1,1,1)	(0.171,0.19,0.222)	(0.493,0.525,0.622)
A3	(3.68,4.543,5.049)	(4.514,5.251,5.842)	(1,1,1)	(2.552,2.879,3.09)
Sum				(3.612,4.066,4.441)
CI^m =0.002 CI^g =0 Consistent				

Table 19: Mean of pairwises comparison with respect to y11

y11	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.431,0.488,0.699)	(0.205,0.229,0.301)	(0.446,0.482,0.595)
A2	(1.431,2.048,2.322)	(1,1,1)	(0.301,0.32,0.467)	(0.755,0.869,1.027)
A3	(3.323,4.365,4.868)	(2.141,3.123,3.323)	(1,1,1)	(1.923,2.389,2.529)
Sum				(3.124,3.739,4.151)
CI^m =0.017 CI^g =0.011 Consistent				

Table 20: Mean of pairwises comparison with respect to y12

y12	A1	A2	A3	Geometric mean
A1	(1,1,1)	(2.667,3.7,4.043)	(0.758,1.084,1.431)	(1.264,1.589,1.795)
A2	(0.247,0.27,0.375)	(1,1,1)	(0.315,0.34,0.517)	(0.427,0.451,0.579)
A3	(0.699,0.922,1.32)	(1.933,2.942,3.17)	(1,1,1)	(1.105,1.395,1.611)
Sum				(2.797,3.435,3.985)
CI^m =0.002 CI^g =0.018 Consistent				

Figure C.8. Case Study Analysis Report Part 8.

Table 21: Mean of pairwises comparison with respect to y13

y13	A1	A2	A3	Geometric mean
A1	(1,1,1)	(0.594,0.594,1)	(0.14,0.164,0.2)	(0.437,0.461,0.585)
A2	(1,1.683,1.683)	(1,1,1)	(0.147,0.17,0.2)	(0.528,0.658,0.696)
A3	(5,6.081,7.137)	(5,5.896,6.787)	(1,1,1)	(2.924,3.298,3.645)
Sum				(3.889,4.417,4.926)
CI^m =0.027 CI^g =0.017 Consistent				

Contents

Section 2:

$$\tilde{r}_{ij} = \tilde{w}_i = \frac{\tilde{z}_i}{\sum_{i=1}^{n} \tilde{z}_i}$$

Table 22: Normalized geometric mean with respect to goal

goal	Normalized geometric mean
x1	(0.222,0.299,0.417)
x2	(0.333,0.468,0.617)
x3	(0.067,0.102,0.138)
x4	(0.057,0.074,0.111)
x5	(0.048,0.057,0.095)

Table 23: Normalized geometric mean with respect to x1

x1	Normalized geometric mean

http://www.decisionera.com/project/html/swaoadn.html

Figure C.9. Case Study Analysis Report Part 9.

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y1	(0.172,0.197,0.263)
y2	(0.637,0.803,0.974)

Table 24: Normalized geometric mean with respect to x2

x2	Normalized geometric mean
y3	(0.104,0.13,0.173)
y4	(0.672,0.87,1.115)

Table 25: Normalized geometric mean with respect to x3

x3	Normalized geometric mean
y5	(0.678,0.868,1.103)
y6	(0.106,0.132,0.173)

Table 26: Normalized geometric mean with respect to x4

x4	Normalized geometric mean
y7	(0.062,0.08,0.1)
y8	(0.058,0.067,0.092)
y9	(0.063,0.073,0.09)
y10	(0.291,0.353,0.479)
y11	(0.304,0.427,0.526)

Table 27: Normalized geometric mean with respect to x5

x5	Normalized geometric mean
y12	(0.702,0.862,1.053)
y13	(0.115,0.138,0.172)

Table 28: Normalized geometric mean with respect to y1

y1	Normalized geometric mean
A1	(0.151,0.201,0.264)
A2	(0.093,0.109,0.157)
A3	(0.53,0.69,0.871)

Figure C.10. Case Study Analysis Report Part 10.

Table 29: Normalized geometric mean with respect to y2

y2	Normalized geometric mean
A1	(0.104,0.12,0.17)
A2	(0.241,0.304,0.372)
A3	(0.455,0.575,0.709)

Table 30: Normalized geometric mean with respect to y3

y3	Normalized geometric mean
A1	(0.162,0.182,0.243)
A2	(0.162,0.182,0.243)
A3	(0.456,0.635,0.795)

Table 31: Normalized geometric mean with respect to y4

y4	Normalized geometric mean
A1	(0.12,0.137,0.197)
A2	(0.131,0.167,0.212)
A3	(0.527,0.696,0.876)

Table 32: Normalized geometric mean with respect to y5

y5	Normalized geometric mean
A1	(0.135,0.182,0.234)
A2	(0.112,0.128,0.191)
A3	(0.528,0.689,0.865)

Table 33: Normalized geometric mean with respect to y6

y6	Normalized geometric mean
A1	(0.142,0.185,0.238)
A2	(0.123,0.142,0.204)
A3	(0.506,0.673,0.855)

Figure C.11. Case Study Analysis Report Part 11.

Table 34: Normalized geometric mean with respect to y7

y7	Normalized geometric mean
A1	(0.145,0.202,0.248)
A2	(0.11,0.126,0.184)
A3	(0.537,0.671,0.832)

Table 35: Normalized geometric mean with respect to y8

y8	Normalized geometric mean
A1	(0.173,0.223,0.286)
A2	(0.116,0.135,0.195)
A3	(0.486,0.642,0.809)

Table 36: Normalized geometric mean with respect to y9

y9	Normalized geometric mean
A1	(0.124,0.148,0.189)
A2	(0.114,0.134,0.171)
A3	(0.567,0.718,0.882)

Table 37: Normalized geometric mean with respect to y10

y10	Normalized geometric mean
A1	(0.128,0.163,0.202)
A2	(0.111,0.129,0.172)
A3	(0.575,0.708,0.855)

Figure C.12. Case Study Analysis Report Part 12.

Table 38: Normalized geometric mean with respect to y11

y11	Normalized geometric mean
A1	(0.107,0.129,0.19)
A2	(0.182,0.232,0.329)
A3	(0.463,0.639,0.81)

Table 39: Normalized geometric mean with respect to y12

y12	Normalized geometric mean
A1	(0.317,0.463,0.642)
A2	(0.107,0.131,0.207)
A3	(0.277,0.406,0.576)

Table 40: Normalized geometric mean with respect to y13

y13	Normalized geometric mean
A1	(0.089,0.104,0.15)
A2	(0.107,0.149,0.179)
A3	(0.594,0.747,0.937)

Contents

Section 3:

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{w}_j \tilde{r}_{ij} \qquad \forall i$$

$$Crisp(\tilde{U}) = \frac{(u_l + 2 \times u_m + u_r)}{4}$$

Figure C.13. Case Study Analysis Report Part 13.

Table 41 : matrix of final weights (criteria) with respect to goal

Component	Final fuzzy weight	Final Crisp weight
x1	(0.222,0.299,0.417)	0.309
x2	(0.333,0.468,0.617)	0.472
x3	(0.067,0.102,0.138)	0.102
x4	(0.057,0.074,0.111)	0.079
x5	(0.048,0.057,0.095)	0.064

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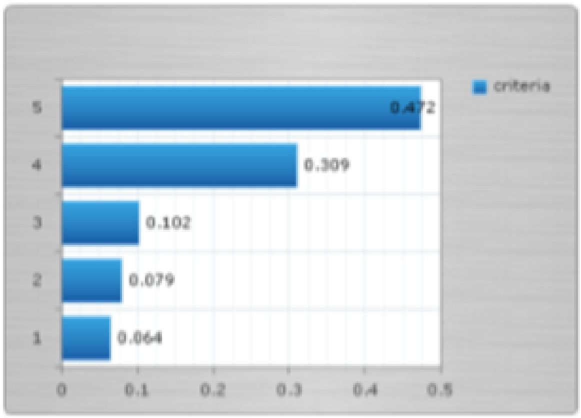

Table 42 : matrix of final weights (sub criteria) with respect to goal

Component	Final fuzzy weight	Final Crisp weight
y1	(0.038,0.059,0.109)	0.066
y2	(0.141,0.24,0.406)	0.257
y3	(0.035,0.061,0.107)	0.066
y4	(0.224,0.407,0.688)	0.431
y5	(0.045,0.089,0.153)	0.094
y6	(0.007,0.013,0.024)	0.014
y7	(0.004,0.006,0.011)	0.007
y8	(0.003,0.005,0.01)	0.006
y9	(0.004,0.005,0.01)	0.006
y10	(0.016,0.026,0.053)	0.03
y11	(0.017,0.032,0.058)	0.035
y12	(0.034,0.049,0.1)	0.058
y13	(0.005,0.008,0.016)	0.009

Figure C.14. Case Study Analysis Report Part 14.

Figure 2 : Final weights chart (sub criteria) with respect to goal

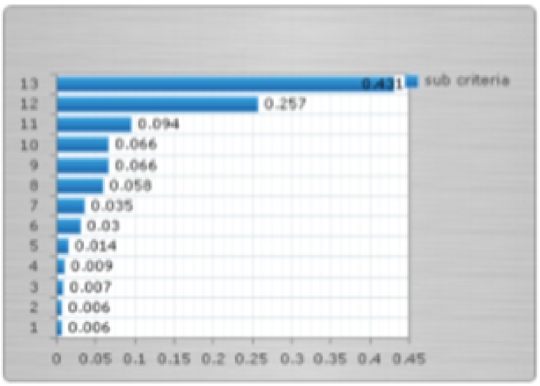

Table 43 : Matrix of final weight (alternatives) with respect to goal

Component	Final fuzzy weight of Alternatives	Final Crisp weight of Alternatives	Prioritization based on Crisp weight
A1	(0.077,0.161,0.397)	0.199	3
A2	(0.089,0.192,0.432)	0.226	2
A3	(0.281,0.646,1.415)	0.747	1

Figure 3 : Alternatives final weights chart with respect to goal

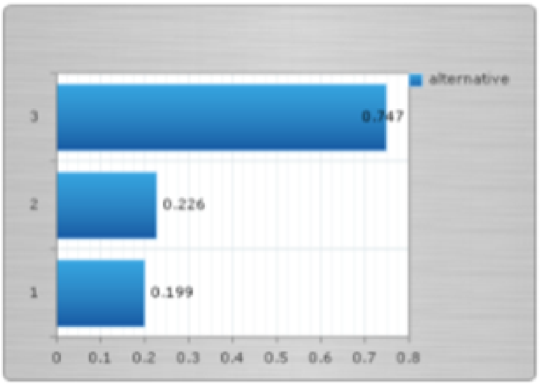

Figure C.15. Case Study Analysis Report Part 15.