ESTIMATING THE SCHEDULE DELAY OF MARINE PROJECTS IN TURKEY DUE TO POSSIBLE DELAY CAUSES BY USING BAYESIAN BELIEF NETWORK MODEL

by

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ABSTRACT

ESTIMATING THE SCHEDULE DELAY OF MARINE PROJECTS IN TURKEY DUE TO POSSIBLE DELAY CAUSES BY USING BAYESIAN BELIEF NETWORK MODEL

Marine projects have become one of the most fascinating industries in Turkey because of their enormous contribution to the local economic growth. Thereof, the completion of these projects on time has critical importance for the future of Turkey's economy. In this study, the major delay factors that are encountered in the marine construction industry in Turkey are listed through an exhaustive review of the literature and the final delay factors list is approved by the experts. Each delay factors is ranked according to their frequencies by collecting data from the experienced professionals in the industry using a survey. Moreover, the findings of the survey enable to determine the dependencies between the delay factors by calculating the Pearson Correlation Coefficient of each delay factor pair. Once the dependent delay factors are identified, the Bayesian Belief Network is drawn so that the path causing delay is determined. By utilizing the correlation coefficients, means and standard deviations of the delay factors, the conditional probability tables are obtained. The implementation of the proposed model is carried out by a case study. The results show that the delay duration of an uninitiated marine project in Turkey can be estimated by utilizing the proposed model. Also, since the dependencies between the delay factors are identified, the practitioners could define the cause-effect relations and may prevent the delays by focusing on the origin of the delay factors.

ÖZET

TÜRKİYE'DEKİ MARİNA PROJELERİNİN MUHTEMEL GECİKME SEBEPLERİNDEN DOLAYI OLUŞAN SÜRESEL GECİKMENİN BAYES KANI AĞLARI MODELİ İLE TAHMİN EDİLMESİ

Yerel ekonomiye yaptığı büyük katkılarından dolayı, Türkiye'de marina projeleri en çok ilgi çeken endüstrilerden biri olmaktadır. Bu sebeple, bu projelerin zamanında tamamlanması, Türkiye ekonomisinin geleceği için kritik öneme sahiptir. Bu çalışmada, Türkiye marina yapım endüstrisinde karşılaşılan ana gecikme faktörleri, kapsamlı bir literatür araştırması yoluyla listelenmiş ve gecikme faktörleri listesi uzmanlar tarafından onaylanmıştır. Gecikme faktörleri, olasılıklarına göre sıralanabilmesi için, sektörde tecrübeli profesyoneller tarafından anketler aracılığıyla puanlanmıştır. Buna ek olarak, anketlerden elde edilen bulgular, gecikme faktörleri arasındaki ilişkilerin Pearson korelasyon katsayısı kullanılarak belirlenmesine imkan sağlamaktadır. Bağımlı gecikme faktörleri belirlendikten sonra, Bayes kanı ağı çizilir, böylece gecikmeye neden olan yol belirlenir. Korelasyon katsayıları, gecikme faktörlerinin ortalamaları ve standart sapmaları kullanılarak koşullu olasılık tabloları elde edilmiştir. Önerilen modelin geçerliliği bir vaka çalışmasıyla kanıtlanmıştır. Sonuçlar, henüz başlamamış olan bir marina projesinin gecikme süresinin, önerilen model kullanılarak tahmin edilebileceğini göstermektedir. Ayrıca, gecikme faktörleri arasındaki bağımlılıklar belirlendiğinden, uygulayıcılar neden-sonuç ilişkilerini tanımlayabilir ve gecikme faktörlerinin kaynağına odaklanarak gecikmeleri önleyebilir.

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LIST OF SYMBOLS

$P(A_i \mid B)$	Probability of Occurrence of A_i given B
$cov(x, y)$	Covariance of x and y
ρ	Pearson Correlation Coefficient
σ_x	Standard Deviation of x
Σ	Summation
μ_x	Average of x

LIST OF ACRONYMS/ABBREVIATIONS

BBN	Bayesian Belief Network
GDP	Gross Domestic Product
SEM	Structural Equation Modeling
SOCR	Statistics Online Computational Resource
UCLA	University of California Los Angeles

1. INTRODUCTION

1.1. General Context of Research

The construction industry is becoming more complex in the modern world since it is faced with new challenges such as increasing population, the application of new technologies and innovative methodologies, growing demand of societies, sustainability, etc. However, the construction industry addresses this complexity with tremendous innovations such as technological advances, advanced building materials and new construction technics. These innovations enable the construction industry to decrease construction time and costs, design more environmentally friendly projects and contribute the global and local economic growth.

The importance of the construction industry is directly related to its effect on both the global and local economies. The construction industry accounts for 6% of global Gross Domestic Product (GDP) and this rate continues to grow. Also, in developing countries, such as in India, it accounts for more than 8% of GDP as stated in Shaping the Future of Construction A Breakthrough in Mindset and Technology report in 2016 by World Economic Forum. According to the Construction Sector Report published by INTES in 2017, the Turkish construction industry has contributed approximately 8.1% in 2013, 8.1% in 2014, 8.2% in 2015 and 8.8% in 2016 to the Turkish GDP. Due to its intensive effect on the other industries, the construction industry in Turkey is the driving industry for economic growth.

As one of the expertise area in the construction industry, the marine construction has the same complex nature and also crucial economic influence. Especially, for the countries, which are surrounded by water like Turkey, the marine construction projects are extremely important in terms of the local economy. According to "2015 Maritime Sector Report" published by the Turkish Chamber of Shipping (2016), 85% of world trade is being carried out through the maritime transportation.

This rate shows the importance of marine, port and other offshore construction projects for the economic growth of countries surrounded by water. Seas, which play an important role in the globalization of the world, have become a center of attraction for all countries, especially for the tourism industry by rapidly increasing marine tourism in recent years (Deniz Ticaret Genel Müdürlüğü, 2013). Sea tourism, an entertainment and recreation industry, has developed rapidly in tourism activities in recent years. With the pressure of people's intense urban life, the increasing maritime and nature aspirations, the desire to be active, the response to standard life, the rise of economic prosperity and technological developments has rapidly improved the marina industry. The geographical location, nature and climate of Turkey increase the importance and attractiveness of international markets in the field of marine tourism (Deniz Ticaret Genel Müdürlüğü, 2013). Although the marina industry has developed rapidly in recent years, marine tourism, which is one of the high value-added tourism activities, has come to the conclusion that it does not get enough shares in the region when compared to the leading countries (Deniz Ticaret Genel Müdürlüğü, 2013).

In Turkey‘s local economy, the revenue of the sea tourism constitutes 20% of the total revenue of tourism according to the Maritime Sector Report published by the Turkish Chamber of Shipping in 2015. When compared with the developed countries such as United Kingdom having 238 coastal marines under operation (Economic Benefits of Coastal Marinas UK and Channel Islands, 2005), Turkey has only 85 marine facilities in spite of its longer shoreline (Marinalar, 2016). For this reason, many marine construction projects are initiated by public and private sector or by their partnerships to increase the number of facilities and their contribution to the local economy in Turkey. According to Sezer (2012), the number of marine facilities was 76 in 2012, with additional 9 facilities in the following 5 years, the total number reached to 85 facilities. According to the "Marinalar" report published by Turkish Chamber of Shipping (2016), the number of marine facilities and their distribution in Turkey in 2015 are shown in Table 1.1. As can be seen in the table, these facilities are located in the areas in which the sea tourism consists of the main mean of living in that area.

Table 1.1. Number of Facilities with Capacities in Cities of Turkey in 2015 (Marinalar, 2016).

City	**Number of Facilities**	**Yacht Capacity**
Antalya	8	2.464
Aydın	2	1.777
Balıkesir	3	740
Çanakkale	2	260
İstanbul - Asia	4	2.900
İstanbul - European	8	5.112
İzmir	7	2.010
İzmit	1	100
Mersin	2	1.520
Muğla	47	10.628
Yalova	1	320
Grand Total	**85**	**27.831**

As a matter of course, the successful and timely completion of the marine construction projects are essential for the immediate economic contribution of these projects. The completion of marine construction projects on time not only contributes the economic growth of the country, but it also enables the project to stay within the budget and decrease their expenditures of delay. In other words, the investors may obtain higher profits by completing the projects on time.

The identification of the delay factors is obviously indispensable and critical due to the increasing number of investments to this industry and their economic contributions in the short term. Since the marine projects contain more uncertainties, greater risks, less technically skilled professionals, more unnecessary bureaucratic processes and are more subject to seasonal impacts when compared with the other types of construction projects, a systematic approach about the delay factors in this industry is required.

1.2. Aim and Significance of Study

Since the timely completion of marine construction projects is very crucial due to their great economic contribution, this thesis aims to respond the following major question: "What are the main delay factors encountered and how much do they affect the completion time in a marine project"

Therefore, the objectives of this thesis are as follows:

- To identify and classify possible delay causes encountered in marine projects.
- To identify the frequencies of each delay cause on project duration.
- To identify the degree of interdependence between delay factors.
- To develop a Bayesian Belief Network Model to estimate the duration of delay.
- Testing the proposed model by comparing the estimated and actual delay duration of a real marine project.

This research has also great significance due to the following theoretical and practical contributions:

- Delay factors, which are unique in the marine construction industry, will be identified and classified by investigating and filtering all probable delay factors through literature review. Determination of unique delay factors in the marine construction industry will be helpful for preventing such cases and will be used as precautions in practice by project managers.
- The risk path of interdependent delay factors in the marine construction industry will be identified. By this way, the predecessor of some delay factors will be known and may be prevented during the execution of the project.
- The schedule delay of a marine construction can be estimated within a range during the pre-construction period.

1.3. Scope of Study

The scope of this research is mainly limited to the literature review, developing a model that estimates the delay duration of marine projects and conducting a case study.

After a detailed literature survey, the identification of delay factors and their classification in the marine construction industry were completed. A survey was prepared based on the data obtained from the literature review and distributed to the different professional stakeholders who have satisfactory experience in the marine construction projects in Turkey. By this way, the frequencies of each delay factor and their interdependencies were identified by taking into account different perspectives. In the case study section, a marine construction project constructed in 2015 in Istanbul is used to compare the actual delay duration and output of the model. As the total delay duration of the marine project examined in the case analysis section is known, thus the model developed by utilizing Bayesian Belief Network could be tested.

1.4. Organization of Thesis

As a summary, this thesis has the following chapters:

- In Chapter 2, previous studies about the delays in marine and other types of construction projects are presented. Moreover, the gap in the literature is identified and the research question is stated.
- In Chapter 3, the research methodology, including the literature review, the theoretical background of Pearson Correlation Coefficient and Bayesian Belief Network, the questionnaire design and the data collection method are examined in detail.
- In Chapter 4, the literature review findings, the statistical output of the questionnaire and the results of the data via Pearson Correlation Coefficients and Bayesian Belief Network are presented.

- In Chapter 5, a case study is presented as the application of the proposed model.
- In Chapter 6, the discussion of this study with its limitations and recommendations for future studies are stated.
- In Chapter 7, the conclusion of this study is presented.

2. LITERATURE REVIEW

2.1. Introduction

This Chapter presents the summary of the literature review about the definition of the "delay" for the construction industry, identification, categorization of the construction delay factors and their most probable effects on the construction projects. After the summary of the literature review, the statement of the research question will be clearly defined.

Determination of the delay factors and their categories for this research is discussed later in Chapter 3.

2.2. The Definition of Construction Delays and Their Effects on Construction Projects

In general, "delay" means not being able to complete the project within a certain time period agreed upon a contract because of some factors affecting the project (Assaf and Al-Hejji, 2006). However, it can be defined variously depending on the side of the stakeholders. According to the owner or client, "delay" means loss of revenue because of not being able to start up the facility production or to rent the spaces in its facilities (Assaf and Al-Hejji, 2006). On the other hand, the contractor perceives the meaning of "delay" as higher overhead costs due to longer work period, higher material costs and labor costs due to inflation (Assaf and Al-Hejji, 2006).

Delays play a key role in the achievement of project success in the construction industry. In general terms, the project success is measured by the total cost, total duration and the quality when compared with the planned cost, time and scope of work defined in the contract signed between the stakeholders. The effects of delays on construction projects can be listed as follows:

- Contribution to the time and cost overrun,
- Disputes between the parties of a contract,
- Litigation or arbitration as a result of disputes,
- Termination of the contract by the contractor or the owner,
- Deviation of the long term aims of public institutions, local authorities or private companies.
- Negative reputation for the foreign investors,

As the main scope of this research, marine construction industry has its own characteristics so the causes of delay differ than the causes of delay in other types of projects. Depending on this reality, the delay factors in the marine construction industry should be evaluated separately in terms of their frequencies and effects.

2.3. Previous Studies about Delay Factors in Construction Industry

Due to its great significance in the construction industry, examining the delay factors is one of the major topics in the literature related to the construction projects. Many researchers have investigated the sources of delays in various project types (e.g. Marine (Tam and Shen, 2012), residential (Sweis *et al.*, 2008) etc.), contract types (e.g. Build-Operate-Transfer (Yang *et al.*, 2010) etc.) and countries (e.g. Turkey (Kazaz *et al.*, 2012), Vietnam (Luu *et al.*, 2009) etc.). They also tried to categorize these sources depending on the stakeholders or project stage or resources. According to a research examining the delay factors for construction projects in Turkey (Gündüz *et al.*, 2013), 83 delay factors and 9 major groups are identified through a detailed literature review and interviews with the experts from the Turkish construction industry in different roles such as project managers, site managers, technical officers and procurement managers.

The Fishbone diagram is utilized to visualize the delay factors causing construction delay. As the research methodology, relative importance index method is used to rank the delay factors and their major groups. The results of the research show that the most significant major group is contractor-related factors and the most significant factor is inadequate contractor experience. On the other hand, the least significant major group is externality-related factors and the least significant factor is slow site clearance. In summary, this study specifically points out what the delay factors are and how they are categorized specific to Turkish construction projects.

In another study conducted again in the Turkish construction industry (Kazaz *et al.*, 2012), 34 delay factors and 7 major groups affecting the project duration are considered. These findings are gathered from interviews with people from 71 Turkish construction companies. Similar to the previous study, the relative importance index method is utilized to understand the ranking of these delay factors. According to the results, design, and material changes, delay in payments and cash flow problems appeared as the most significant factors (Kazaz *et al.*, 2012). In terms of the major groups, financial-related factors are the most significant major group, whereas environmental-related factors are the least significant major group (Kazaz *et al.*, 2012). Diversely, this study emphasizes on which categories of delay factors appear in developing countries and which of them appear in developed countries. Similar to the previous study, this study indicates the list of delay factors and their categories for the Turkish construction industry.

Luu and the colleagues (2009) identified only 16 delay factors without having major categories by conducting a questionnaire from 166 professionals. Also, 18 cause-effect relationships between these delay factors are listed via expert interview surveys. The importance of this study stems from the application of Bayesian Belief Network to quantify the probability of construction delay. This is achieved by using the frequencies of each delay factor and cause-effect relationships and then a computerized model with Bayesian Belief Network Model is established. By this way, the effect of each factor on delay and their conditional probabilities are explained mathematically.

Also, the computerized model is validated with two real case studies successfully by comparing the real amount of delay with the output of the model. At the end of the research, the most important factors are selected as; owner‘s financial difficulties, inadequate contractor‘s experience and shortage of materials.

Crucially, this research (Luu *et al.*, 2009) proves that the Bayesian Belief Network Model could estimate the amount of total delay when the frequencies and conditional probabilities are provided. Besides, the study obtains the list of delay factors and their dependencies with the participation of huge number of professionals from the Vietnam construction industry.

Since there are many studies about the identification and classification of delay factors and each of them has different delay factors, groups and rankings, Ramanathan and the colleagues (2012) decide on compiling earlier studies for a more updated research. Earlier studies, which form the basis of Ramanathan's and the collagues research (2012), contain 41 studies around the world. The final list of this research contains 113 delay factors within 18 major groups by compiling 41 previous studies in the literature. The final list of delay factors is presented to the professionals via questionnaire surveys to be able to rank the delay factors. The responses are analyzed by using Importance Index, Frequency Index, Severity Index, Relative Importance Index, Relative Importance Weight, Weighted Average, Mean, and Standard Deviation and Variance methods. The authors conclude that the ranking given by each of the researchers is different. In other words, this collective research indicates that depending on the ranking method, all studies bring about different rankings of delay factors. As a result, the authors emphasize on developing another approach instead of using the methods in the literature to list and rank the delay factors. Importantly, this study presents the compilation of the literature written about the delay factors and their categories. Also Ramanathan and colleagues (2012) utilized previous studies while determining the delay factors such as the studies of Chan and Kumaraswamy (1997), Odeh and Battaineh (2002), Frimpong and the colleagues (2003) and Sambasivan and Soon (2007).

Assaf and Al-Hejji (2006) investigate the delay factors, which may be encountered in the Saudi Arabian construction industry, and their importance according to the different stakeholders, which are 15 owners, 23 contractors and 19 consultants, via a questionnaire survey.

The authors obtain 73 delay factors grouped into 9 categories. The most common delay factor among the stakeholders is change orders during construction. 76% of the contractors and 56% of the consultants argue that the average of time overrun is between 10% and 30% of the original duration. Also, the results show that according to the owners, the most frequent major groups are contractor-related and labor-related delay factors, whereas the contractors think that owner-related delay factors are the main issue for causing the time overrun of the project.

Tam and Shen (2012) focused on the delay factors in the marine construction industry from contractor‘s view considering the great contribution of marine projects to the construction business in Hong Kong. They also believe that the delay factors in marine projects should be analyzed differently from the other types of projects because they include serious risky factors. Via questionnaires and structured interviews, the authors list the probable delay factors, especially in marine projects from contractor‘s view. According to the findings, 18 delay factors in 6 different groups were identified specific to marine projects. “Difference of underwater conditions from tender stage” is the most common delay factor in marine projects. Also, this study shows that the most severe delay factor in marine projects is “the unavailability of materials, plant and labor”.

In contradistinction to the previous studies, Yang and the colleagues (2010) argue the delay factors in various stages of Build - Operate - Transfer (B.O.T.) projects, which is one of the types of Public - Private partnerships (PPP). In the scope this study, the delay factors are gathered by using questionnaires from the participants who have already worked on projects with B.O.T. model. As the outcome of the questionnaires, 80 delay factors in 8 groups are listed. In the analysis of the data, the Structural Equation Modeling (SEM) is used besides the traditional statistics methods. SEM enables the users to identify interrelated dependent relationships between the variables. The findings of the study show that the improper contract planning, debt problem and uncertainty on political issues and government-finished items are the most important delay factors causing the postponement of BOT projects during the stage of “negotiation and signing of concession agreement”.

This study serves the probable delay factors apart from the benefits of the SEM method to investigate the relationships between the variables. Similar to the study of Yang and the colleagues (2010), Yang and Ou (2008) also focus on how different delay factors behave together to influence the schedule delay by utilizing the SEM method while describing and quantifying the delay factors. Based on the literature reviews and interviews, 37 delay factors in 6 major groups are obtained. The analytical results of the study show that defining the correlation between the variables is the key method to overcome the future delay problems in the construction industry. Also, according to the statistical model, the nonhuman-related group and unforeseen site condition have tremendous impact on the delay of a construction project.

By utilizing the questionnaire surveys, Acharya and the colleagues (2006) communicate with 208 professionals from different stakeholders such as owner, contractor or consultant with various roles such as project managers, contract managers, resident engineers or project management officers. Diversely, the authors use statistical tools (SPSS computer program) to determine the critical factors within 208 questionnaires of the participants from around the world. According to the findings, 27 delay factors in 5 categories are the most critical ones when compared with the others. Some of the delay factors are “frequent interruptions from public”, “changed site condition”, “failure to provide required construction site”, “unrealistic project time estimation” and “design errors”. As an advantage of this study, the participants of the questionnaire are from various countries including Republic of Korea and Japan. This enables to observe the delay factors from different views of professionals.

As distinct from the previous studies, the authors specifically examine the delay factors of the residential buildings in Jordan by utilizing the literature (Sweis *et al.*, 2008). The 40 delay factors grouped under 8 categories are presented via questionnaires to the professionals working on residential projects as consultant engineers, contractors, and owners and via interviews with senior professionals working in the same field. The findings show that most correspondents agreed that, financial difficulties faced by the contractor and too many change orders by the owner are the leading causes of construction delay. Severe weather conditions and changes in government regulations and laws ranked among the least important causes.

Similarly, Kaliba and the colleagues (2009) specifically focus on road projects in Zambia since road construction constitutes a major component of the construction industry for developing countries. This study examines the cost escalation and delay factors in road projects. By utilizing the literature review, the questionnaires and the structured interviews, 14 delay factors are attained under 3 categories. According to the results, delayed payments, financial processes and difficulties on the part of contractors and clients, contract modification, economic problems, materials procurement, changes in drawings, staffing problems, equipment unavailability, poor supervision, construction mistakes, poor coordination on site, changes in specifications and labor disputes and strikes are found to be the major causes of schedule delays in road construction projects in Zambia. This study is well worth of attention because the road projects have great significance for developing countries like Zambia and govern higher amount of budgets when compared with the other types of projects. According to the key project participants working as clients, consultants or contractors in the building projects in Ghana, the study aims to attain the list of delay factors (Fugar and Agyakwah-Baah, 2010). The authors identified 32 delay factors by literature review and interviews under 9 major groups. Distributing the questionnaires to 130 respondents (39 contractors, 37 clients and 54 consultants), the ranking of the delay factors and their categories are tried to be found by relative importance index method. The overall finding of the study points out that the participants generally agree that the financial group factors ranked highest among the major factors causing delay in construction projects in Ghana. The financial group factors are as follows; delay in honoring payment certificates and difficulty in accessing credit and fluctuation in prices. Materials group factors are ranked second followed by the scheduling and controlling factors. Similar to the previous study (Kaliba et al., 2009), this study serves the delay factors belonging to the special type of construction projects.

In the aforementioned studies, the categories of the delay factors are determined in a subjective way. For example, Gündüz and the colleagues (2013) prefer to classify according to the responsible parties (contractor, owner and consultant) of the delay factors and the resources used in the construction industry (materials, equipment, labor etc.). On the other hand, in the research of Tam and Shen (2012), the categorization is classified as “Acts of God, physical, financial-economic, political-environmental, design and construction-related”. When compared with the study of Gündüz and the colleagues (2013), Tam and Shen (2012) prefer completely different categorization due to the nature of the project type and the country in which the project is built. These various considerations about the categories of the delay factors indicate that there is no standardized way for classification and it is directly dependent on the construction project type and the characteristics of the projects like the country, the procurement type etc.

To conclude, the list of references are summarized in Table 2.1. as shown below:

Table 2.1. Some of Previous Studies Obtaining List and Categories of Construction Delays.

Reference	**Method Used**	**# of Delay Factors**	**# of Categories of Delay Factors**	**Country**	**Type of Project**
(Gündüz *et al.*, 2013)	Literature Review	83	9	Turkey	All
(Kazaz *et al.*, 2012)	Interviews	34	7	Turkey	All
(Luu *et al.*, 2009)	Questionnaire	16	9	Vietnam	All
(Ramanathan *et al.*, 2012)	Literature Review	113	18	Worldwide	All
(Assaf and Al-Hejji, 2006)	Questionnaire	73	9	Saudi Arabia	All
(Tam and Shen, 2012)	Questionnaire And Interviews	18	6	Hong Kong	Marine
(Yang *et al.*, 2010)	Questionnaire	80	8	Taiwan	All (B.O.T)

Table 2.1. Some of Previous Studies Obtaining List and Categories of Construction Delays (cont.).

Reference	**Method Used**	**# of Delay Factors**	**# of Categories of Delay Factors**	**Country**	**Type of Project**
(Yang and Ou, 2008)	Literature Review and Interviews	37	6	Taiwan	All
(Acharya *et al.*, 2006)	Questionnaire	27	5	Worldwide	All
(Sweis *et al.*, 2008)	Literature Review	40	8	Jordan	Residential
(Kaliba *et al.*, 2009)	Questionnaire and Interviews and Literature Reviews	14	3	Zambia	Road
(Fugar and Agyakwah-Baah, 2010)	Literature Review and Interviews	32	9	Ghana	Building
(Chan and Kumaraswamy, 1997)	Questionnaire and Interviews	18	4	Hong Kong	Building
(Odeh and Battaineh, 2002)	Questionnaire	30	6	Worldwide	All
(Frimpong *et al.*, 2003)	Literature Review and Interviews	30	5	Ghana	Infrastructure
(Sambasivan and Soon, 2007)	Questionnaire	41	7	Malaysia	All

2.4. Statement of Research Question

As presented in the previous section, all of the research is conducted about the delay factors in the construction industry and their probable effects on a project. Their findings vary relying on the country and the type of project in which they are conducted. Due to the differences in the findings, there is a need to determine the list of delay factors and their categories unique to marine projects in Turkey. Although all of the aforementioned studies examine the delay factors and they can be represented as the point of departure of this thesis, the following two studies Gündüz and the colleagues (2013) and Kazaz and the colleagues (2012) are more significant than the others since they are specifically conducted for the projects in Turkey so they present valuable data as a starting point. Also, the study of Tam and Shen (2012) is really significant since it focuses on the delay factors in marine projects from contractor‘s view. All of the 16 studies mentioned in the previous section prefer to gather data by using several methods such as literature review, questionnaires and interviews with the professionals from the related industry. Since there is no study in the literature written about the frequencies of delay factors in Turkish marine construction industry, there is a need to quantify the frequencies of the probable delay factors with collecting data from the professionals working in Turkish marine construction industry. On the other hand, since there are limited numbers of experienced professional in marine projects of Turkey, the conversion of know-how in this area into a theoretical contribution is crucially required. At this point, Tam and Shen (2012) presents valuable information about the frequencies of delay factors in marine construction industry of Vietnam from contractor‘s view.

Also, the definition of the dependencies between the delay factors is highly crucial to be able to identify the path of delay factors causing schedule delay. Luu and the colleagues (2009) try to define the dependencies via gathered data from the respondents whereas Yang and the colleagues (2010) utilize Structural Equation Modeling (SEM) for this purpose. Obviously, a more scientific method compared with the Luu and the colleagues‘ (2009) study and a more practical method when compared to SEM method is needed. The study of Luu and the colleagues (2009) forms the other point of departure of this thesis. In that study, the Bayesian theory enables to quantify the amount of schedule delay. Combining the list of delay factors and dependencies with the benefits of Bayesian theory enable to build a model to estimate the quantity of schedule delay. By this way, the estimation of schedule delay in an uninitiated marine project in Turkey is made possible. Research questions of this thesis can be summarized as follows:

- What are the main delay factors encountered in marine construction projects in Turkey?
- What are the frequencies of these delay factors according to the professionals who have experience at different levels in marine construction projects in Turkey?

- What are the degrees of dependencies between delay factors by calculating the correlation between them?
- How can the project overrun of an uninitiated marine project in Turkey be estimated?

3. RESEARCH METHODOLOGY

3.1. Introduction

In order to estimate the schedule delay of marine projects in Turkey due to possible delay causes by using Bayesian Belief Networks, the following steps will be taken:

- Listing the delay factors that can be encountered during the development of a marine project built in Turkey,
- Prioritizing these delay factors according to their frequencies by gathering data from experienced professionals via questionnaire survey,
- Detecting and quantifying strong correlations between the delay factors to understand the dependencies between them by utilizing Pearson Correlation Coefficient and then exploring the conditional probabilities derived from calculated correlations.
- Estimating the probable schedule delay of a marine project by utilizing the correlation coefficients and Bayesian Belief Network Diagrams.

At the beginning of this Chapter, the methods used for the literature review are presented. Later on, the theoretical backgrounds behind the Pearson Correlation Coefficient, Bayesian Belief Network Methods and the calculation of conditional probabilities by using the correlations are elaborately discussed. Afterwards, the data collection including the questionnaire design is explained. The general framework and process of the study is summarized in Figure 3.1.

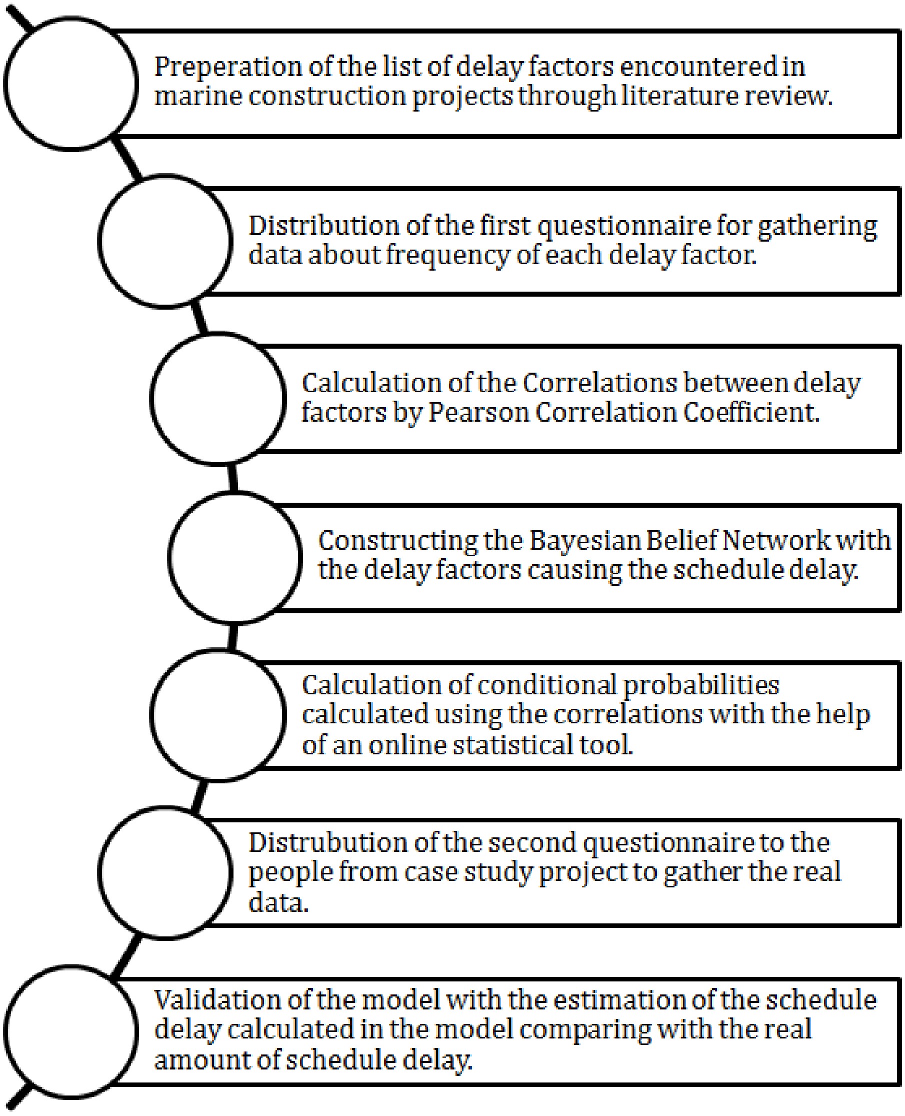

Figure 3.1. General Framework of Research.

3.2. Literature Review

While reviewing the literature, some keywords such as “construction delay”, “marine construction projects”, “Pearson correlation coefficient” and “Bayesian theory” are tried to be found. Although there are quite limited numbers of studies related to the delay factors of marine projects, many studies (e.g. Gündüz *et al.*, 2013, Tam and Shen, 2012, Kaliba *et al.*, 2009 etc.) examine the delay factors in various other types of construction projects in different countries including Turkey. The delay factors of marine projects built in Turkey should have been listed distinctively since the delay factors are country and project type specific. However a study exploring the delay causes of marine construction projects specific to Turkish industry does not exist in the literature.

In each of the previous studies, the number of delay factors and their categories vary according to the countries in which the study has been conducted. In order to develop the delay factor lists, the questionnaires are usually distributed to the professionals from the construction industry and accordingly a quantitative data set is gathered. The purpose of gathering quantitative data is to rank the delay factors according to their frequencies and severities. By this way, the researchers could be able to rank the delay factors according to their impact on schedule delay and project success.

On the other hand, as stated in Chapter 2, within 16 studies examined in the literature review section, there is only a single study examining the delay factors in marine projects which built in Hong Kong yet this study represents only the contractor‘s view (Tam and Shen, 2012). Due to the absence of related marine specific studies in Turkey, delay factors of the marine projects in Turkey should have been registered again. For this reason, all possible delay factors are listed by reviewing the previous studies (e.g. Gündüz *et al.*, 2013; Tam and Shen, 2012; Kaliba *et al.*, 2009 etc.). As a result, 257 delay factors in 25 different categories are obtained at the end of the literature review. In spite of a large number of studies in the literature on this topic, it is observed that the contents of the studies start to look like each other. In other words, these studies show the other ones as references and this causes repetitions in their contents. By combining and eliminating the delay factors, the final delay factor list of marine projects built in Turkey is prepared. Subsequently, the final delay factor list specific to marine projects in Turkey is approved by a focus group consists of academician and experienced professional from private sector working as the designer of the marine projects.

3.3. Theoretical Background

3.3.1. Bayesian Approach

One of the most commonly used statistical inference method which combine previously obtained information about a population parameter with the evidence of information contained in a sample is called as the Bayesian Approach. The Bayesian Approach is set up on the conditional probability theory, which can be defined as the probability of an event given that another event has occurred or will occur (Box and Tiao, 1992). For example:

- The probability of schedule delay of a construction project increases given that the stakeholders in different roles do not have sufficient experience in the related industry.
- The probability of selling new cars increases given that the taxes are decreased by the governmental institute.

As shown in Figure 3.2, the parent node represents the cause variable whereas the child node depicts the affected variable. Also, the dependency arc shows the direction from the cause variable to affected variable.

Figure 3.2. Depiction of Bayesian Theory.

In the Bayesian Approach, the parameters are considered as random variables from a prior belief. These parameters are used to update the beliefs in the posterior distribution with the evidences (Harrel and Shieh, 2001).

Some of the basic advantages of the Bayesian Approach can be summarized as follows (Winkler, 2001):

- It provides explicit probability distribution and future outcome for each variable. These distributions can be updated when the new information becomes available. It means that all distributions are fragile to observed data.
- It is originated by the likelihood principle. It utilizes the outcomes of the likelihoods, which has actually occurred.
- As the outcome of the Bayesian Approach, the posterior distribution plays a critical role for the decision makers. Also, the prior distributions are important for the preliminary decisions.
- It requires much more number of inputs when compared with the other frequentist approaches. This forces the researcher to collect more reliable and valuable data for the analysis.

The fundamental constituents of the Bayesian Approach are prior distribution, likelihood function and posterior distribution. The prior distribution presents the prior belief of the analysts; the likelihood function modifies the prior belief with the currently available data and posterior distribution presents the quantitative result in a probabilistic manner.

General mathematical equation of the Bayesian Approach is shown in Equation 3.1:

$$P\left(A_i|B\right) = \frac{P\left(B|A_i\right) * P\left(A_i\right)}{P\left(B|A_1\right) * P\left(A_1\right) + P\left(B|A_2\right) * P\left(A_2\right) + \ldots + P\left(B|A_i\right) * P\left(A_i\right)} \quad (3.1)$$

In Equation 3.1, P(A_i) is called as the prior distribution or the marginal probability of Ai, P(B|A_i) is the likelihood function showing the probability of B given that Ai occurs and P(A_i|B) presents the posterior distribution of A_i when the available data is uploaded to the prior distribution.

On the other hand, the Bayesian Belief Networks (BBN‘s) exhibit the graphical distribution of a set of variables in terms of conditional and posterior probabilities. In the graphical representation, the arrows indicate the causality relationships from observed data or opinions of an experienced professional. According to Heckerman (2004), the Bayesian Networks allow the users to observe the conditional dependencies easily. By this way, the analysts can understand the logical sequence in the domain of parameters by reviewing the causal relationships between the variables.

BBN's are utilized in different type of industries and research areas such as biomedicine (Lucas *et al.*, 2004), agriculture industry (Tellaechea *et al.*, 2006), etc. Similarly, in the research related to the construction industry, several usages of BBN‘s can be observed (Luu *et al.*, 2009).

In this study, BBN will be utilized to modify the prior beliefs with the causal relationships of the variables, which are gathered from the experienced professionals in the Turkish marine construction industry. The delay factors prepared as a result of the literature review are presented to the professionals and the prior probability of each delay factor is obtained. Once the causal dependencies between each delay factor are determined by the correlation method in terms of a quantitative approach, the posterior distribution of the schedule delay will be quantified in different states.

3.3.2. Pearson Correlation Coefficient

The strength and direction of the dependencies between two random variables can be determined by calculating the correlation between them. There are several correlation coefficients measuring the degree of correlation for different scenarios. One of the commonly used coefficients is Pearson Correlation Coefficient, which can be denoted by as represented in the following Equation 3.2:

$$\rho_{x,y} = \frac{cov\,(x, y)}{\sigma_x.\sigma_y} = \frac{E((x-\mu_x)\,(y-\mu_y)}{\sigma_x.\sigma_y} \tag{3.2}$$

Many researchers have various suggestions about the interpretation of the Pearson Correlation Coefficient, ρ. For example, Evans (1996) recommended the values shown in Table 3.1 to evaluate the strength of ρ describing the relationship between variables.

Table 3.1. Values and Strengths of ρ (Evans, 1996).

0.00 - 0.19	Very weak
0.20 - 0.39	Weak
0.40 - 0.59	Moderate
0.60 - 0.79	Strong
0.80 - 1.00	Very strong

In the scope of this study, Bayesian Belief Networks are developed by using the schedule delay factors in the Turkish marine construction industry, which are generated by a literature review. As one of the crucial points, Kwoh and Gilles (1996) propose using the Pearson Correlation Coefficient to evaluate the conditional dependencies of variables in a system. In other words, this enables to utilize Pearson Correlation Coefficient in the drawing of Bayesian Belief Networks and also in the calculations of likelihood functions. By this way, Bayesian Belief Networks will be constructed and the strength of each dependency will be obtained quantitatively.

3.3.3. Calculation of Conditional Probabilities

The principle of Bayesian Belief Network model is based upon the conditional probabilities between the variables. Previously, with the gathered information via a questionnaire (See Appendix A), the average, standard deviation and the Pearson Correlation Coefficients between variables are calculated. By using these values, the conditional probabilities are calculated.

Dinov and the colleagues (2013) advises the usage of a web application (http:// socr. ucla .edu/ htmls/ HTML5/ BivariateNormal/) to estimate how the correlation influences the conditional probability between two variables. The Statistics Online

Computational Resource (SOCR) designed by the University of California Los Angeles (UCLA) serves online applications with user interfaces for probability and statistics education, technology based statistical computing. It is widely used by the instructors, the students and the developers. One of the applications built on SOCR web site enables to calculate the conditional probability between two variables by assuming that they have bivariate normal distributions. To be able to obtain the conditional variables by using the parameters calculated before, all variables are assumed to have bivariate normal distribution in pairwise comparisons (Figure 3.3).

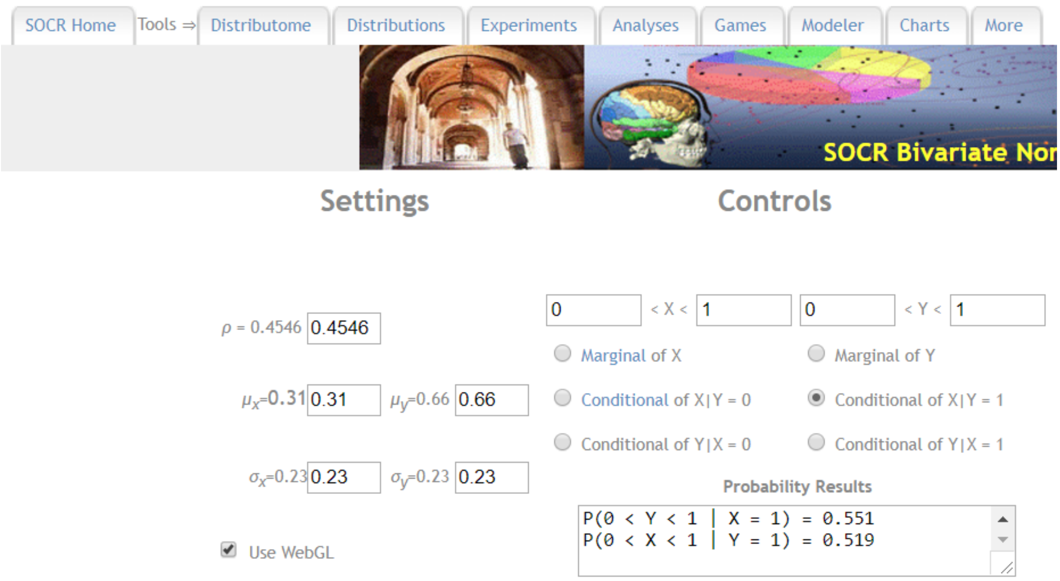

Figure 3.3. View of UCLA Statistics Web Site.

3.4. Questionnaire Design

To gather industry-specific and reliable data, one of the most convenient methods is to prepare and distribute questionnaires to the experts who have the credentials to provide the required data for the study. In the scope of this research, two questionnaires are designed depending on the targeted respondents. The first questionnaire (See Appendix A) is distributed to all professionals, excluding those working for the case study project, whereas the second questionnaire (See Appendix B) is only distributed to case study's professionals for gathering related data.

As mentioned in the previous Chapters, since there are limited numbers of studies focusing on the delay factors of marine construction projects, this study requires a questionnaire to gather reliable data from the professionals who have experience in the Turkish marine construction industry. Accordingly, this questionnaire (See Appendix A) consists of three main parts. The first part is designed to gather participants' demographic information, such as their work experience duration and occupation title, and also to gather information about the projects the participants are involved in such as the stakeholders they worked with, project delivery method and contract type. In the second part, the questionnaire focuses on the amount of schedule delay and its results on a marine project in which the participant worked. The fundamental questions are about the duration of the project and the percentage of the schedule delay in terms of the duration specified in the contract. Also, the impact of the schedule delay in these marine construction projects is asked to understand the possible effects on the project success. As the final and most important part of the questionnaire, the third part is organized to gather the frequencies of the delay factors, which can be encountered in a marine construction project. This data constructs the basis of marginal probabilities of the delay factors and it is utilized to calculate the Pearson Correlation Coefficient.

3.5. Gathering Data

Initially the questionnaire is distributed to professionals from the marine construction industry, having different years of experiences and roles in various stakeholders. The professionals are contacted via e-mails and social media. While collecting the data, Google Forms are used since it summarizes the data and serves in the tabular form as a spreadsheet.

The data gathered at the end of the questionnaire are used to construct the Bayesian Belief Network by calculating the Pearson Correlation Coefficients between the delay factors. The combined effect of delay factors on the amount of schedule delay is estimated. This enables the researchers to estimate the amount of total schedule delay of a marine project by considering the frequencies at the beginning of the project.

In order to evaluate and analyze the delay factors, a wide range of professionals was involved in this research. The total number of questionnaires distributed to the professionals from marine construction industry was 153. This population was constituted among the professionals who have experience in the Turkish marine construction industry and who have worked under different roles including owners, consultants, designers or contractors. At the end of this process, 35 questionnaires with feedback were gathered. This statistic means the rate of response is 23%. The demographic information of the respondents is presented in the following Table 3.2:

Table 3.2. Demographic Information about Data Gathered By Questionnaire Survey.

Years of Experience in Marine Construction Projects	**Frequency**	**Percent**
>20 years	5	14.29%
10-20 years	5	14.29%
<5 years	13	37.14%
6-10 years	12	34.29%
Involved Organization	**Frequency**	**Percent**
Owner	8	16.00%
Consultant	7	14.00%
Designer/Engineer	17	34.00%
Contractor	18	36.00%
Area of Expertise	**Frequency**	**Percent**
Project Manager	8	13.11%
Contract Manager	2	3.28%
Designer/Engineer	13	21.31%
Resident / Site Engineer	15	24.59%
Quality / Control	5	8.20%
Project Management Officer (Planner, quantity surveyor etc.)	18	29.51%
Procurement Methods	**Frequency**	**Percent**
Design - Build	11	29.73%
Design - Bid - Build	11	29.73%
Build - Operate - Transfer	6	16.22%
Construction Management	9	24.32%
Contract Types	**Frequency**	**Percent**
Lump Sum	25	43.86%
Unit Price	23	40.35%
Cost Plus Fixed Fee	4	7.02%
Cost Plus Percentage Fee	5	8.77%

The respondents of the questionnaire may select more than one choice in involved organization, area of expertise, procurement methods and contract types, whereas they have to choose at most one criterion in years of experience in the marine construction projects. Because of this reason the sum of the frequencies might exceed the total number of respondents, which is 35.

Also, the information about the contract durations of the projects in which the respondents are involved and the amount of schedule delay was obtained. The collected information is presented in the following Table 3.3:

Table 3.3. Add caption

Contractual Duration of the Marine Project	**Frequency**	**Percent**
<1 years	6	17.14%
>4 years	1	2.86%
1-2 years	15	42.86%
2-4 years	13	37.14%
Amount of Schedule Delay	**Frequency**	**Percent**
<6 months	17	48.57%
>24 months	1	2.86%
6-12 months	14	40.00%
12-24 months	3	8.57%

Another output of the questionnaire is about the probable effects of the schedule delay on the marine projects. These are listed in Table 3.4:

Table 3.4. Probable Effects of Delay Factors on Project Success.

Results of Schedule Delays	**Frequency**	**Percent**
Time Overrun	29	46.77%
Cost Overrun	19	30.65%
Dispute	9	14.52%
Arbitration or Litigation	5	8.06%
Termination	0	0.00%

To test the model proposed, the questionnaire was distributed again to the professionals who have worked on the case study, a marine construction project in Turkey. The collected data is used as the case study example to test the Bayesian Belief Network model and also the correlations are used as the conditional dependencies. In the first distribution of the questionnaire, the professionals working in this case study project were excluded. They were assigned as the participants in the second distribution of the questionnaire.

4. RESEARCH FINDINGS

4.1. Identification and Categorization of Delay Factors in Marine Industry through Literature Review

Listing the delay factors that can be encountered during marine projects is succeeded by utilizing the 16 papers mentioned in the second section of the previous Chapter. The delay factors and their categories in these studies are listed together with the authors who refer them in their studies. According to the initial list of delay factors, there are 257 delay factors in 25 different categories. When the list of delay factors is examined, it was observed that there is a great number of recurrent delay factors in these studies. In other words, the studies written on this topic have lots of same delay factors mentioned in the other studies. On the other hand, some of the delay factors have very close meaning, so they are combined by merging their definitions. For instance, one of the delay factors called black of experience of stakeholders in marine construction projects is formed by merging the delay factors such as black of experience of consultant, black of experience of contractor, black of experience of designer and black of experience of owner. To determine the final delay factor list and their categories, the approval of a focus group consisting of the academicians and professionals are taken so that the final list could be isolated from the delay factors, which are irrelevant to the marine industry. At the end of this process, 46 delay factors grouped under 6 categories are formed as shown in Figure 4.1 and Table 4.1:

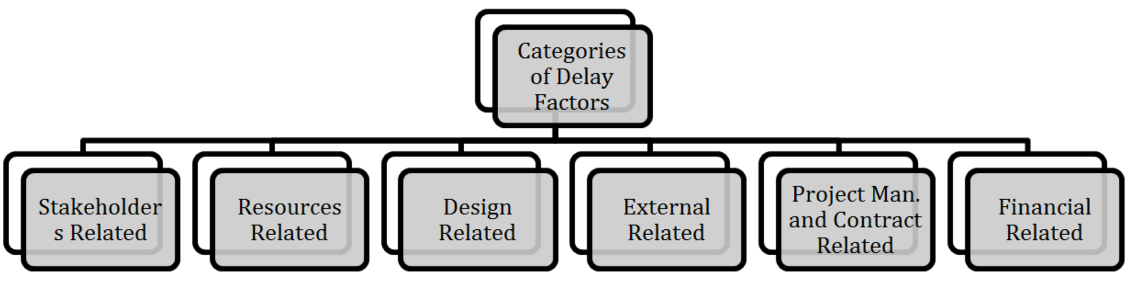

Figure 4.1. Categories of Delay Factors.

Table 4.1. List of Delay Factors.

Category	**Delay Factor**	**References**
	x1, Lack of experience of stakeholders in marine construction projects	Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006, Tam and Shen, 2012
	x2, Conflicts and poor coordination between stakeholders	Yang *et al.*, 2010, Yang and Ou, 2008, Acharya *et al.*, 2006
	x3, Delays in approval processes by consultant or owner	Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
	x4, Inflexibility of consultant	Luu *et al.*, 2009, Ramanathan *et al.*, 2012
	x5, Frequent change of subcontractors because of their inefficient work	Assaf and Al-Hejji, 2006, Tam and Shen, 2012, Yang *et al.*, 2010, Yang and Ou, 2008
	x6, Improper construction methods implemented by contractor	Acharya *et al.*, 2006, Sweis *et al.*, 2008, Kaliba *et al.*, 2009
	x7, Inadequate number of or incompetent project team of contractor	Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012, Luu *et al.*, 2009, Ramanathan *et al.*, 2012
	x8, Poor site management, site work and supervision by contractor	Assaf and Al-Hejji, 2006
Stakeholders Related	x9, Unstable management structure and style of consultant	Tam and Shen, 2012, Yang *et al.*, 2010

Table 4.1. List of Delay Factors (cont.).

Category	**Delay Factor**	**References**
Resources Related	x11, Lack of capable owner representative or management failures of owner side	Yang and Ou, 2008, Acharya *et al.*, 2006, Sweis *et al.*, 2008, Kaliba *et al.*, 2009
	x12, Late project commencement of contractor	Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
	x13, Unstable management structure and style of contractor	Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006, Tam and Shen, 2012, 43
	x15, Equipment allocation problem	Yang and Ou, 2008, Acharya *et al.*, 2006
	x16, Frequent equipment breakdowns / Failure or improper equipment	Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013
	x17, Shortage of resources	Kazaz *et al.*, 2012, Luu *et al.*, 2009, Ramanathan *et al.*, 2012
	x18, Slow mobilization or slow/late delivery of resources	Assaf and Al-Hejji, 2006, Tam and Shen, 2012, Yang *et al.*, 2010, Yang and Ou, 2008, Acharya *et al.*, 2006
	x19, Unskilled equipment operators or low worker skills/productivity	Sweis *et al.*, 2008
	x20, Labor strike	Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010
	x21, Changes in material types and specifications construction	Gündüz *et al.*, 2013, Kazaz *et al.*, 2012, Luu *et al.*, 2009, Ramanathan *et al.*, 2012
	x22, Damage of stored materials	Assaf and Al-Hejji, 2006, Tam and Shen, 2012, Yang *et al.*, 2010
	x23, Quality of materials or improper material selection	Yang and Ou, 2008, Acharya *et al.*, 2006, Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010

Table 4.1. List of Delay Factors (cont.).

Category	**Delay Factor**	**References**
	x24, Accidents during construction	Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
	x26, Inaccurate site investigation by consultant	Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006, Tam and Shen, 2012
	x27,Complex or impractical project design	Yang *et al.*, 2010, Yang and Ou, 2008, Acharya *et al.*, 2006
	x28, Design changes by owner or his agent during construction	Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
Design Related	x29, Design errors and delays made by designers	Luu *et al.*, 2009
	x30, Inadequate details	Ramanathan *et al.*, 2012,
	in drawings	Assaf and Al-Hejji, 2006
	x31, Providing site instructions by designer not on time	Tam and Shen, 2012, Yang *et al.*, 2010, Yang and Ou, 2008, Acharya *et al.*, 2006
	x32, Inconsistency between site conditions and design outcomes	Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010
	x33, Unexpected surface and subsurface conditions (such as soil, hw table)	Gündüz *et al.*, 2013, Kazaz *et al.*, 2012, Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006
	x35, Force majeure	Tam and Shen, 2012, Yang *et al.*, 2010
	x36, Unfavorable weather conditions	Yang and Ou, 2008, Acharya *et al.*, 2006, Sweis *et al.*, 2008, Kaliba *et al.*, 2009
External	x37, Fraudulent practices	Fugar and Agyakwah-Baah,
	and corruption	2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
	x38, Contract management	Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006, Tam and Shen, 2012, Yang *et al.*, 2010

Table 4.1. List of Delay Factors (cont.).

Category	**Delay Factor**	**References**
Project Management and Contract Related	x39, Ineffective quality assurance/Control	Yang and Ou, 2008
	x40, Unsuccessful project planning and scheduling	Acharya *et al.*, 2006, Sweis *et al.*, 2008
	x41, Lack of incentives or penalties for contractor to finish ahead or behind schedule	Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010, Gündüz *et al.*, 2013, Kazaz *et al.*, 2012
	x42, Unrealistic contract durations imposed by client	Luu *et al.*, 2009, Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006
	x43, Improper type of construction contract or project delivery system (Turnkey, DBB,BOT.)	Tam and Shen, 2012, Yang *et al.*, 2010, Yang and Ou, 2008, Acharya *et al.*, 2006, Sweis *et al.*, 2008
	x44, Type of project bidding and award (negotiation, lowest bidder, ...)	Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010
	x45, Improper project feasibility study	Gündüz *et al.*, 2013, Kazaz *et al.*, 2012, Luu *et al.*, 2009, Ramanathan *et al.*, 2012
	x46, Difficulties in financing project or cash flow management	Assaf and Al-Hejji, 2006, Tam and Shen, 2012, Yang *et al.*, 2010
Financial Related	x47, Global financial crisis	Yang and Ou, 2008, Acharya *et al.*, 2006, Sweis *et al.*, 2008, Kaliba *et al.*, 2009, Fugar and Agyakwah-Baah, 2010
	x48, Price fluctuations	Gündüz *et al.*, 2013
	x49, Inflation	Kazaz *et al.*, 2012, Luu *et al.*, 2009
	x50, Exchange rate fluctuation	Ramanathan *et al.*, 2012, Assaf and Al-Hejji, 2006

4.2. Findings

4.2.1. Rank of Delay Factors According to Mean of Frequencies

The delay factors were scored by the respondents using the Likert Scale as shown in Table 4.2:

Table 4.2. Likert Scale and Values in Calculations.

Score	Explanation	Value in Calculations
0	Never	0.00
1	Very Rarely	0.25
2	Occasionally	0.50
3	Frequently	0.75
4	Constantly	1.00

According to the values of frequencies provided by the respondents, the rank of delay factors is shown in Table 4.3:

Table 4.3. Rank of Delay Factors According to Mean of Frequencies.

Delay Factors	**Mean of Frequency**
x42, Unrealistic contract durations imposed by client	0.6643
x46, Difficulties in financing project or cash flow management	0.6643
x28, Design changes by owner or his agent during construction	0.6571
x29, Design errors and delays made by designers	0.6429
x31, Providing site instructions by designer not on time	0.6429
x36, Unfavorable weather conditions	0.6286
x44, Type of project bidding and award (negotiation, lowest bidder,.)	0.6286
x32, Inconsistency between site conditions and design outcomes	0.6143
x50, Exchange rate fluctuation	0.5929
x27, Complex or impractical project design	0.5786
x30, Inadequate details in drawings	0.5786
x38, Contract management	0.5714
x40, Unsuccessful project planning and scheduling	0.5714
x48, Price fluctuations	0.5714
x1, Lack of experience of stakeholders in marine construction projects	0.5643
x3, Delays in approval processes by consultant or owner	0.5643
x33, Unexpected surface and subsurface conditions (such as soil, hw table)	0.5643
x45, Improper project feasibility study	0.5643
x16, Frequent equipment breakdowns / Failure or improper equipment	0.5571
x47, Global financial crisis	0.550
x39, Ineffective quality assurance/Control	0.5429
x18, Slow mobilization or slow/late delivery of resources	0.5357
x26, Inaccurate site investigation by consultant	0.5143
x2, Conflicts and poor coordination between stakeholders	0.5071
x4, Inflexibility of consultant	0.5071
x17, Shortage of resources	0.5071
x15, Equipment allocation problem	0.5000
x41, Lack of incentives or penalties for contractor to finish ahead or behind schedule	0.5000
x49, Inflation	0.4929
x12, Late project commencement of contractor	0.4857
x43, Improper type of construction contract or project delivery system (Turnkey, DBB,BOT,.)	0.4857
x5, Frequent change of subcontractors because of their inefficient work	0.4786
x19, Unskilled equipment operators or low worker skills/productivity	0.4786
x11, Lack of capable owner representative or management failures of owner side	0.4643
x13, Unstable management structure and style of contractor	0.4643
x8, Poor site management site work and supervision by contractor	0.4571
x6, Improper construction methods implemented by contractor	0.4286
x7, Inadequate number of or incompetent project team of contractor	0.4286
x21, Changes in material types and specifications during construction	0.4214
x23, Quality of materials or improper material selection	0.3786
x9, Unstable management structure and style of consultant	0.3714
x35, Force majeure	0.3714
x24, Accidents during construction	0.3071
x22, Damage of stored materials	0.2429
x37, Fraudulent practices and corruption	0.2143
x20, Labor strike	0.1643

Also, the mean frequencies of the categories are summarized in Table 4.4:

Table 4.4. Mean Frequencies of Main Categories.

Categories	**Mean of Frequency**
Design Related	0.5991
Financial Related	0.5743
Project Management and Contract Related	0.5661
Stakeholders Related	0.4775
External	0.4161
Resources Related	0.4125

4.2.2. Pearson Correlation Coefficients between the Delay Factors

To be able to recognize the relationships between the delay factors and to build the Bayesian Belief Network model accordingly, Pearson Correlation Coefficients were utilized by carrying out pairwise computations. Since the Pearson Correlation Coefficient cannot evaluate which variable is parent variable, the comments of the supervisor of this study and an experienced professional were utilized to understand the direction of the relationship between the variables exactly.

As an example, the Pearson Correlation Coefficient between “inadequate number of or incompetent project team of contractor” (x7) and “poor site management, site work and supervision by contractor” (x8) is calculated by utilizing Equation 3.2 as shown below:

- $\Sigma\left(x7-\mu_{x7}\right)*\left(x8-\mu_{x8}\right)=1.9554$
- $\sqrt{\Sigma(x7-\mu_{x7})^2*(x8-\mu_{x8})^2}=2.3161$
- $\rho_{x7,x8}=\frac{1.9556}{2.3161}=0.8443$

The pairwise calculations were carried out for all variables and then the coefficients greater than 0.40 were taken into account as an indication of strong relationships. The values are shown in Table 4.5.

Table 4.5. Strong Dependencies between Variables

Factor 1	Factor 2	Correlation		Factor 1	Factor 2	Correlation
x9	x41	0.519		x29	x27	0.4968
x42	x9	0.5062		x26	x27	0.4222
x5	x7	0.4342		x24	x46	0.4546
x8	x6	0.7435		x7	x23	0.4450
x23	x6	0.5052		x40	x23	0.4626
x50	x49	0.7598		x19	x22	0.5421
x49	x48	0.646		x24	x22	0.7627
x47	x50	0.4594		x46	x21	0.4586
x48	x46	0.4609		x46	x20	0.4052
x45	x43	0.4876		x49	x20	0.4091
x45	x44	0.4025		x2	x6	0.4402
x43	x28	0.5713		x7	x2	0.5074
x4	x5	0.4336		x2	x8	0.5332
x37	x39	0.5357		x19	x24	0.5043
x38	x3	0.4404		x40	x19	0.4197
x38	x40	0.4158		x19	x18	0.7235
x38	x43	0.6235		x17	x15	0.4551
x36	x16	0.4055		x18	x17	0.5816
x35	x36	0.5374		x20	x17	0.4507
x9	x32	0.4229		x24	x17	0.4120
x30	x32	0.692		x13	x16	0.4016
x32	x39	0.486		x16	x17	0.4695
x9	x31	0.5048		x16	x46	0.4776
x31	x39	0.6075		x13	x7	0.5059
x27	x30	0.4952		x13	x12	0.5337
x3	x31	0.4001		x11	x2	0.5268
x28	x29	0.4645		x11	x9	0.5217
x29	x31	0.7324		x1	x7	0.6321
x33	x29	0.518		x1	x19	0.4215
x40	x28	0.5889		x1	x32	0.4379

4.2.3. Building the Bayesian Belief Network Model

Bayesian Belief Network was established by considering the relationships between the variables obtained by the correlation coefficients. During this process, the dependencies indicated in Table 4.4 served for the preparation of network diagram. Figure 4.3 depicts this complex diagram by using software, Microsoft MsBNX, which will be described later in Chapter 5 - Case Study Section.

Some of the delay factors do not have a parent node, whereas some of them do not have a child node. It is accepted that the delay factors, which do not have child nodes, become the parent nodes of "DELAY" variable, which is the resultant variable of all other variables. As shown in Figure 4.2, "DELAY" variable has 8 parent nodes once the relations were defined and the network was built.

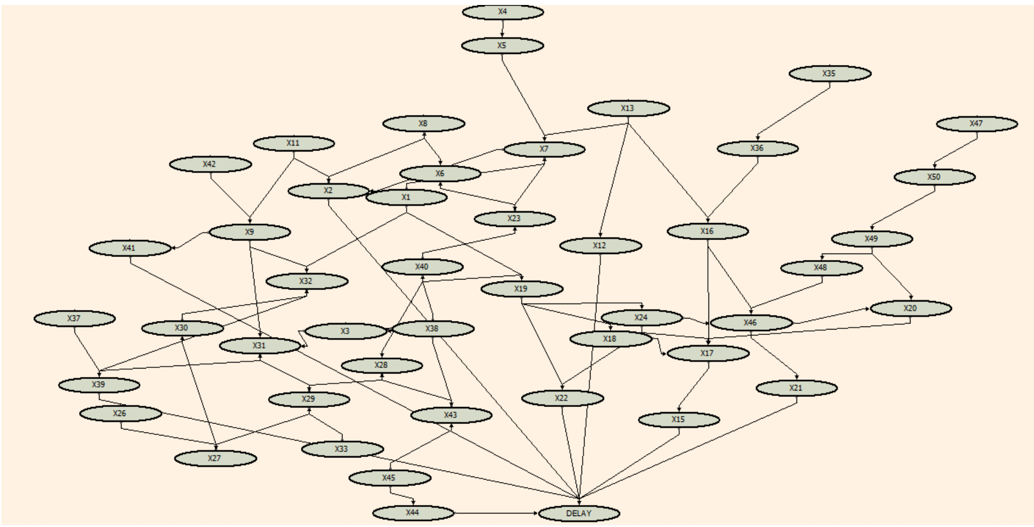

Figure 4.2. Bayesian Belief Network Diagram.

4.2.4. Calculation of Conditional Probabilities

The principle of Bayesian Belief Network model is based upon the conditional probabilities between the variables. Previously, with the gathered information via a questionnaire (See Appendix A), the averages, standard deviations and the Pearson Correlation Coefficients between variables were calculated. By using these values, the conditional probabilities could be calculated.

Dinov and the colleagues (2013) state that the Statistics Online Computational Resource (SOCR) designed by the University of California, Los Angeles (UCLA) serves online applications with user interfaces for probability and statistics education, technology based statistical computing. It is widely used by the instructors, the students and the developers. One of the applications built on SOCR web site enables to calculate the conditional probability between two variables by assuming that they have bivariate normal distributions. To be able to obtain the conditional probabilities between variables by using the parameters calculated before, all variables are assumed to have bivariate normal distribution in pairwise comparisons. As an example, when two variables are taken into account, the application provides the conditional probability between them as shown in Figure 4.3:

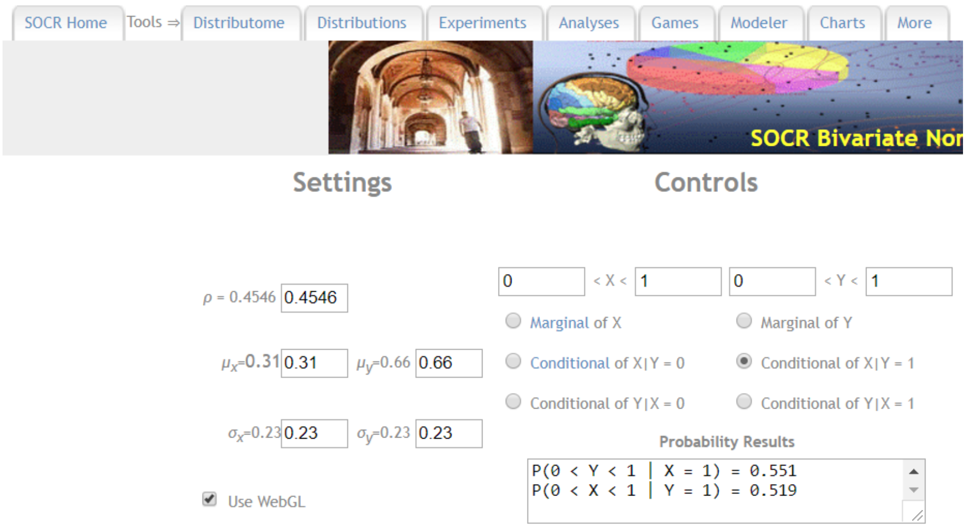

Figure 4.3. Calculation of Conditional Probability Utilizing SOCR Web Application.

In the example shown above, "the accidents during construction" (x24) and "the difficulties in financing project or cash flow management" (x46) were examined. Their Pearson Correlation Coefficient is 0.4546, averages are 0.31 and 0.66 and standard deviations are 0.23 and 0.23, respectively. When these parameters are entered into the application developed by UCLA, the probability of occurring of x24 is 0.519 given that x46 occurs.

The pairwise calculations are completed for all variables, which have a strong correlation coefficient. In other words, this process is executed for all variables, which have a relationship in Bayesian Belief Network Model in a pairwise manner.

4.2.5. Calculating Joint and Conditional Probabilities for Bayesian Belief Network Model

To be able to estimate the probability behavior of each delay factor node, the joint and conditional probabilities should be entered into the model. For nodes, which do not have parent nodes, the probabilities can be entered as their frequencies with the values collected from the respondents. For example, "the global financial crisis" (x47) does not have a parent node so its frequency, 0.55 which is loaded as its joint probability.

On the other hand, most of the nodes have at least one parent node. Due to the complex relations in the Bayesian Belief Network Model, the number of parent nodes may rise up to 8 for some nodes. Even if this complexity is difficult to overcome by addressing Equation 3.1, this equation can be further simplified. Since there is not any relation within the parent nodes, the parent nodes are accepted as statistically independent, so their frequencies can be used directly in the simplified Bayesian Equation 4.1.

$$P\left(X|\left(A_i|A_j\right)\right)=\frac{P\left(A_i|X\right)xP\left(A_{i+1}|X\right)x\ldots xP\left(A_{j-1}|X\right)xP\left(A_j|X\right)xP\left(X\right)}{P\left(A_i\right)xP\left(A_{i+1}\right)x\ldots xP\left(A_{j-1}\right)xP\left(A_j\right)} \quad (4.1)$$

Equation 4.1 can be utilized when there are one or more parent nodes prior to a node. As stated before, this equation was summarized by considering the parent nodes are independent of each other.

As an example, "the labor strike" (x20) has two parent nodes, which are "difficulties in financing project or cash flow management" (x46) and "inflation" (x49). The conditional probabilities can be calculated by using Equation 4.1. These parent nodes are statistically independent in the model. For the calculation of probability of x20 given that x46 and x49 occur, the following Equation 4.1 can be utilized as shown in

Equation 4.2:

$$\rho_{x,y} = \frac{cov(x,y)}{\sigma_x . \sigma_y} = P\left(x_{20} \middle| \left(x_{46} | x_{49}\right)\right) = \frac{P(x_{46}|x_{20})xP(x_{49}|x_{20})xP(x_{20})}{P(x_{46})xP(x_{49})} \frac{E((x-\mu_x)(y-\mu_y)}{\sigma_x . \sigma_y} \tag{4.2}$$

Whereas the joint probabilities of x20, x46 and x49 are already known as 0.16, 0.66 and 0.49 respectively, the conditional probabilities of x46 given that x20 and x49 given that x20 could be calculated separately by using The Statistics Online Computational Resource (SOCR) web application:

- $P\left(x_{46} | x_{20}\right) = 0.978$
- $P\left(x_{49} | x_{20}\right) = 0.979$
- $P\left(x_{20} \middle| \left(x_{46} | x_{49}\right)\right) = \frac{0.978x0.979x0.16}{0.66x0.49} = 0.48$

When the values are inserted into Equation 4.2, the conditional probability is calculated as 0.48. The number of parent nodes varies for each node, but the Equation 4.1 is used by modifying it according to the number of parent nodes.

In the following Chapter, the computerized model built is tested via a case study by comparing the delay quantity given as the output of the software with the actual delay duration in that case study.

5. CASE STUDY

5.1. Description of Case Study

Since the thesis examines the delay causes and quantification of delays in the marine construction industry in Turkey, a marine construction project, which has just been constructed in Istanbul, Turkey, has been selected as the case study to test the model proposed in this thesis.

The construction of the aforementioned marine project in Istanbul started in February 2013. According to the contractual agreement, the construction period was planned as 24 months. Because of some delay causes, the construction period of this project was extended to 30 months, which means that the length of schedule delay is 6 months. In other words, the project was exposed to 25% schedule delay when compared with the contract duration assigned by the owner/client in the contract signed with the contractor. The summary of the case study project is on the Table 5.1 shown below:

Table 5.1. Case Study Project‘s Details.

Description	**Case Study Project**
Project	Marine Construction Project in İstanbul
Owner	Private Sector (Owned by Build-Operate-Transfer Model)
Commencement Date	February, 2013
Planned Completion Date Signed in Contract	February, 2015 (24 months)
Actual Completion Date	August, 2015 (30 months)
Time Overrun	6 months
Percentage of Time Overrun	25%

In the previous section, the Bayesian Belief Network together with joint and conditional probability were prepared. For the verification of the model, another set of data for the case study is required. In other words, besides the 35 questionnaires (See Appendix A), additional modified 10 questionnaires (See Appendix B) are distributed to the professionals working in this case study project from the owner‘s side, contractor‘s side or designer‘s side. These 10 questionnaires enabled to analyze the delay causes of the case study project. The difference between the previous questionnaire and the modified questionnaire is the number of delay causes. In the modified version of the questionnaire, the 12 delay causes, which do not have parent nodes, are presented to the respondents and they evaluated the delay causes in terms of their frequencies. Since the conditional probabilities are already known in the model, the behavior of remaining delay causes will be automatically varied when the joint probabilities of 12 delay causes not having a parent node are changed. The respondents from the case study project evaluated the delay causes and the following results of average frequencies are presented in Table 5.2:

Table 5.2. Mean of Frequencies in Modified Questionnaire Given in Appendix B.

Delay Factors	**Mean of Frequency**	**Observed?**
x1. Lack of experience of stakeholders in marine construction projects	0.725	Yes
x4. Inflexibility of consultant	0.55	Yes
x11. Lack of capable owner representative or management failures of owner side	0.425	No
x13. Unstable management structure and style of contractor	0.375	No
x26. Inaccurate site investigation by consultant	0.65	Yes
x33. Unexpected surface and subsurface conditions (such as soil. hw table)	0.625	Yes
x35. Force majeure	0.3	No
x37. Fraudulent practices and corruption	0.275	No
x38. Contract management	0.525	Yes
x42. Unrealistic contract durations imposed by client	0.625	Yes
x45. Improper project feasibility study	0.4	No
x47. Global financial crisis	0.4	No

As observed in Table 5.2, the frequencies of the delay causes are changing between 0,725 and 0,275 according to the data from the respondents of the case study project. Since the software, MsBNX, does not allow the users to load the observed data as frequencies, the delay causes must be separated as observed or not observed depending on the magnitude of frequencies. For this reason, the frequencies larger than 0,50 are accepted as observed data and the others are accepted as not observed delay causes in this case study project.

5.2. Description of Software, MsBNX

In the scope of the thesis, a computer-based software is needed to solve the complex Bayesian Belief Networks. MsBNX is one of these softwares created by Microsoft as a free Windows application and used for creating, assessing and evaluating Bayesian Networks.

First of all, the nodes that represent the delay causes are placed into the model. Then, the dependencies between the nodes are defined according to the cause-effect relationships. To represent the dependencies, the arcs are drawn starting from the parent node to a child node (from causal node to resultant node). After the complex network is defined, each node is separately considered in terms of their joint and conditional probabilities. Finally, the evidences are entered into the model to evaluate the resultant frequencies of each node. In MsBNX software, the evidences can be either observed or not observed so the gathered data from the respondents of the case study project is analyzed accordingly.

5.3. Computerized Model

Based on the delay causes and their dependencies, the Bayesian Belief Network model is built on MsBNX software. The conceptual model is shown in Figure 5.1:

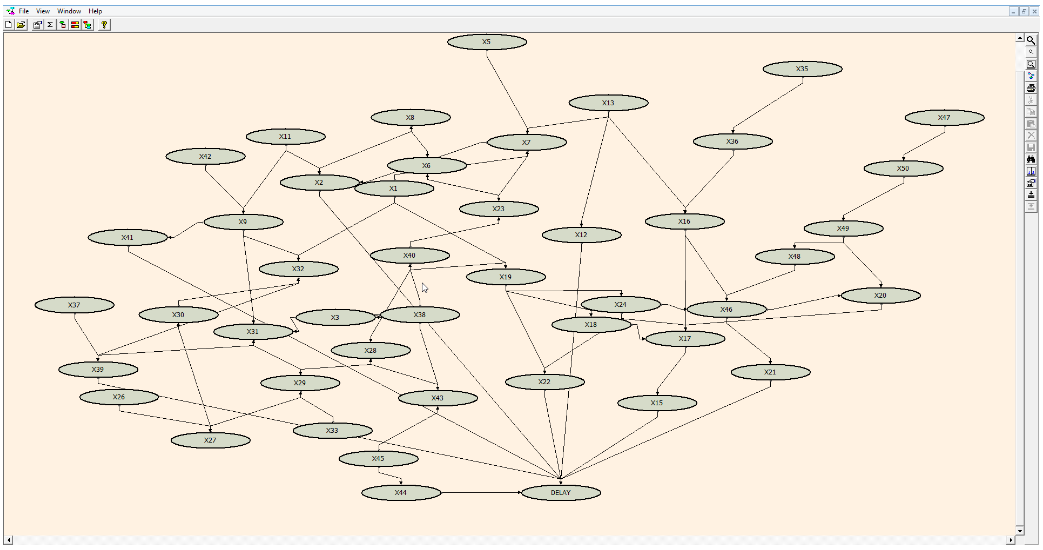

Figure 5.1. Conceptual Bayesian Belief Network Model.

According to Luu and the colleagues (2009), eight delay factors, which directly affect the schedule delay, are called as proximal factors, whereas the other delay causes are called as distal factors. Each node in the model must have four different characteristics; (i) the variable name, (ii) the variable state, (iii) the relationships with other nodes and (iv) the data table containing joint and conditional probabilities.

Each node is named with its number of order decided during the preparation of questionnaires such as x15, x21 etc. One of the most important issues is the determination of node states because these states reflect the behaviors of nodes. Each node representing delay causes has two states; “Yes” or “No”. “Yes” shows the probability of occurrence of that node, whereas “No” quantifies the probability of not occurrence of that node. On the other hand, the states of node of schedule delay differ from the other nodes. It has three states named as; “<33%”, “33-66%”, “>66%”. These states represent the amount of the time overrun according to the contractual time for completion.

The most critical step while building the model is entering the data to joint probability and conditional probability tables. In Chapter 4 Section 4.2.5, the calculation of conditional probability of a variable, which has at least one causal variable, was examined. For the nodes, which do not have a parent node, the probability table is filled by the frequency data gathered from the first questionnaire as shown for X11 in Figure 5.2. Similarly, the joint probabilities of the nodes not having a parent node are entered as their frequencies collected from the questionnaire data.

Assessment (Model: BuSonOlsunBuSon3, Node: X11)

X11		
Yes	No	bar charts
0,4643	0,5357	

Figure 5.2. Frequency Data of a Variable Not Having a Parent Node.

In other respects, the conditional probabilities of the nodes should be entered into the model. The conditional probability of X20 that has already been calculated in Chapter 4 Section 4.2.5 is entered into the conditional probability table in the software as shown in Figure 5.3. For instance, when X46 does not occur and X49 occurs, the probabilities of occurrence and not an occurrence of X20 are calculated as 0.02 and 0.98 respectively. This process is completed for all scenarios of the other nodes having at least one parent node.

Assessment (Model: BuSonOlsunBuSon3, Node: X20)

Parent Node(s)		X20		
X46	X49	Yes	No	bar charts
Yes	Yes	0,4804	0,5196	
	No	0,01	0,99	
No	Yes	0,0214	0,9786	
	No	0,0004	0,9996	

Figure 5.3. Frequency Data of a Variable Having at Least One Parent Node.

5.4. Model Output and Evaluation of Resultl

Once the model has been built in MsBNX, the evidences of the case study should be entered into the model. This software allows the users to enter the evidences as "observed" or "not observed" so the data of the case study collected from the respondents are analyzed as "observed" or "not observed" according to their frequencies in Table 5.2. As an example, x26 has an evidence showing that it is in sight in the case study and is flagged as "observed" in the software as shown Figure 5.4:

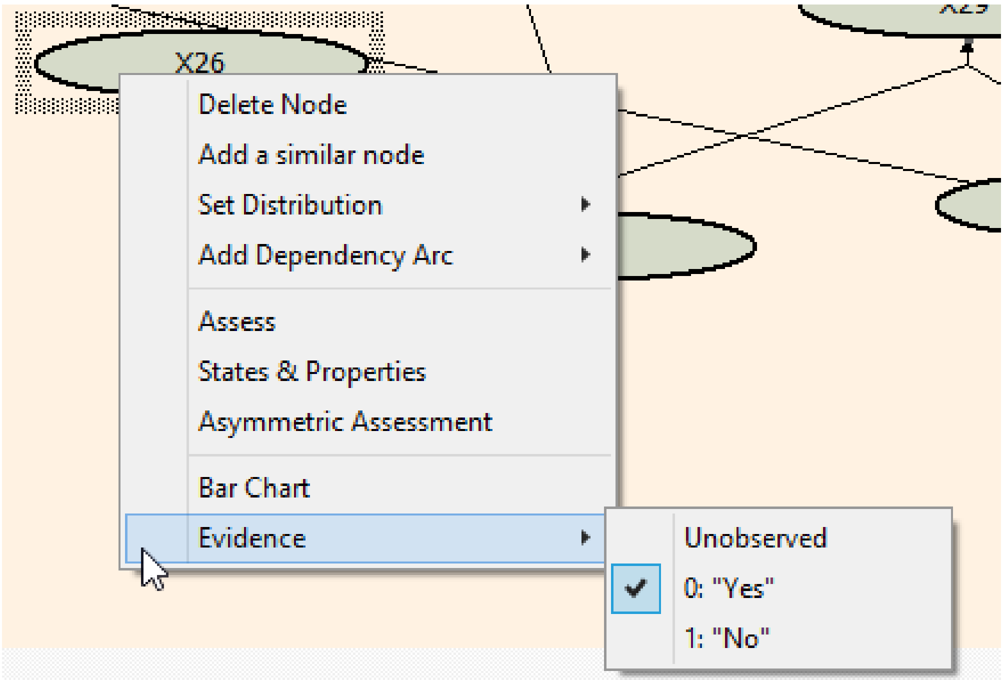

Figure 5.4. Loading Evidence to a Node.

After the data of case study is entered into the model as evidences, MsBNX facilitates the data and the probabilities of all nodes are shown in Figure 5.5:

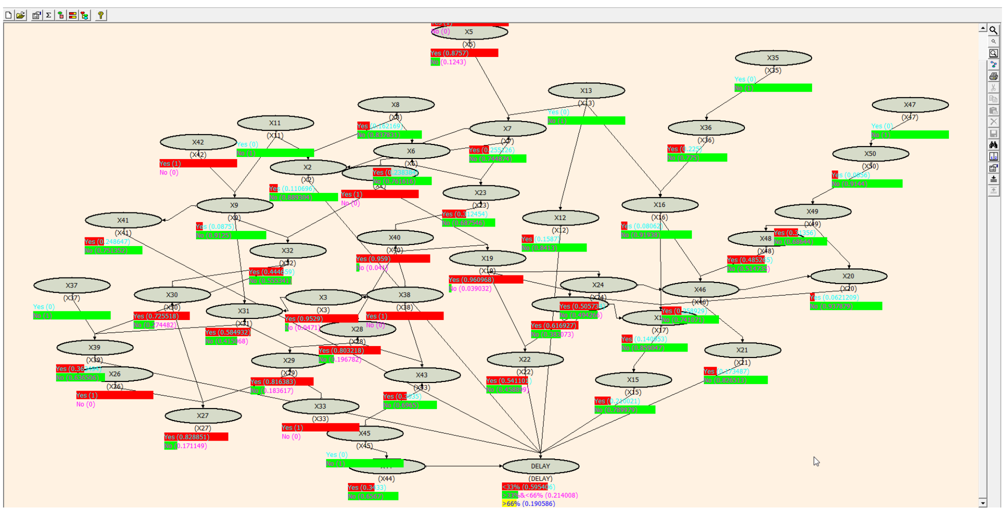

Figure 5.5. Resultant Frequencies of Nodes.

According to the model indicated in Figure 5.5, the likelihood of the delay in the case study project is shown in Table 5.3.

Table 5.3. Likelihood of Delay in Case Study.

States	***Likelihood of Delay***
<33%	60.00%
>33% and <66%	21.00%
>66%	19.00%

In reality, the amount of schedule delay was 6 months, which equals to 25% of the original duration of the project stated in the agreement. In detail, the project started in February 2013 and was planned to be completed in February 2015. However, due to some delay causes, it could be completed in August 2015. Accordingly, the Bayesian Belief Network model developed in this thesis presents reliable results when compared with the reality. This implies that the model gives a very good estimation about the quantity of the schedule delay in the case study project.

6. DISCUSSION

The marine construction projects are one of the fastest growing industries in Turkey so that their contribution to the country economy reaches the levels of the ones‘ in the developed countries. With its geographical location, nature and climate, Turkey presents suitable conditions for new investments. In order to be able to fulfill the demands of this growing industry, the issues related to the delay factors that prevent these projects to be completed on time gain great significance. In this manner, this study focuses on the identification and categorization of delay factors encountered in marine projects, the frequencies of these delay factors, the interdependencies between them and quantification of schedule delay as a result of these delay factors.

To begin with, this research targets to define and categorize the commonly encountered delay factors in marine construction projects. Through a detailed literature review by focusing specifically on selected 16 studies, all probable delay factors in all types of construction projects are listed. The delay factors, which are recurrent and have close meanings, are merged to prepare the final list. This list is filtered by excluding the irrelevant delay factors with marine projects by taking the comments of both academicians and experienced professional from the marine construction industry into consideration. Similarly, the categorization is completed depending on expert opinions. Finally, 46 delay factors in 6 categories are obtained as shown in Figure 4.1 and Table 4.1.

The aforementioned 16 studies conducted in different countries and for different types of construction projects have various numbers of delay factors ranging between 14 and 113. For instance, Kaliba and the colleagues (2009) list 14 delay factors under 3 categories whereas Ramanathan and the colleagues (2012) list 113 delay factors under 18 categories. On the other hand, two studies conducted to examine the Turkish construction industry for all types of projects, identify 83 delay factors (Gündüz *et al.*, 2013) and 34 delay factors (Kazaz *et al.*, 2012).

This difference stems from the attitude of the author, research conducted country and the type of project. Also, a study conducted in Hong Kong (Tam and Shen, 2012) focuses on the delay factors in marine projects from the view of contractors and obtains 18 delay factors under 6 categories. In the study of Tam and Shen (2012), the categorization is classified as "Acts of god, physical, financial-economic, political-environmental, design and construction-related". The authors of the aforementioned studies try to follow different ways to classify the delay factors. Among these studies, Gündüz and the colleagues (2013) prefer to classify according to the responsible parties (contractor, owner and consultant) of the delay factors and the resources such as materials, equipment, labor etc. This shows that the categorization of the delay factors is being shaped depending on the types of projects and the distinctive features of the project such as the contract type, the country etc. At this point, this research prefers to classify the delay factors under 6 categories called "stakeholders-related, resources-related, design-related, external-related, project management-contract related and financial related". On the other hand, whereas Tam and Shen (2012) observe the most frequent delay factor as "unexpected underground conditions", this research obtains "Unrealistic contract durations imposed by client" and "Difficulties in financing project or cash flow management" as the most frequent delay factors. Since the study of Tam and Shen evaluates the delay factors only from the contractor's view, this difference may be seen usual when compared the findings in this research. When compared with the studies conducted for the different types of construction projects (such as road, building, etc.), the distinctive characteristics of the marine projects arise. For instance, in the study conducted for the road projects in Zambia (Kaliba *et al.*, 2009), the most common delay factor is observed as "Delayed payments" and the least common is "labor disputes and strikes". In another study conducted for building projects in Ghana (Fugar and Agyakwah-Baah, 2010), the most encountered delay factors is "delay in honoring payment certificates" and the least encountered is "public holidays". The difference between the findings of the previous studies and of this research obviously stems from the distinctive characteristics of marine projects. Because, as stated before, the marine projects contain more uncertainties, greater risks, less technically skilled professionals, more unnecessary bureaucratic processes and are more subject to seasonal impacts when compared with the other types of construction projects.

This study contributes to the literature by presenting the probable delay factors in Turkish marine construction projects not only from the contractors' view but also from the owners', consultants' and designers' views. Number of delay factors and categories differ in each study since the authors have different attitudes in different countries for different types of projects. Especially, the marine projects have many uncertainties, great risks, less technically skilled professionals, unnecessary bureaucratic processes and are subject to seasonal impacts so the number of delay factors and categories inherently differ from the other studies in the literature. On the other hand, this study presents practical contributions to project managers working in marine projects while identifying the probable delay factors and preventing the schedule delay.

Secondly, the research aims to collect the data of frequencies of 46 delay factors. The way of collecting the real data is to touch the professionals from the marine construction industry in Turkey having different roles such as project managers, contract managers, designers, site engineers or project management team. As the most effective way of gathering data, the questionnaires are distributed to these experienced professionals via e-mails, social media and one on one interview. The feedback from the professionals is obtained with a response rate of 23% (35 responses). Besides the frequencies of the delay factors, the data related to the schedule delay of the project in which they have worked and the possible effects of delay on the projects are gathered. The respondents score the delay factors, according to the Likert Scale as shown in Table 4.2. The results show that the most frequent delay factors in the Turkish marine construction industry are "unrealistic contract durations imposed by client" and "Difficulties in financing project or cash flow management" whereas the least frequent delay factor is "Labor strike" as shown in Table 4.3. When the categories are considered, the most frequent category is "design-related" and the least frequent category is "resources-related" as shown in Table 4.4.

In the literature, previous studies usually utilize the questionnaires for collecting data from the respondents, however the ranking methods of delay factors differ in each of them. For example, Kazaz and the colleagues (2012) prefer to rank the delay factors according to their importance levels by using the relative importance index method. In the other study (Ramanathan *et al.*, 2012), importance, frequency and severity indices are used to rank the delay factors. Similar to this thesis, the study of Tam and Shen (2012), which specifically focuses on marine projects in Hong Kong from contractor‘s view, examines the delay factors in terms of their frequencies. This study concludes "Difference of underwater conditions from tender stage" is the most common delay factor in marine projects (Tam and Shen, 2012).

This research has theoretical contribution to the literature by ranking the delay factors in the Turkish marine construction industry according to their frequencies. Since the participants of the questionnaires are well distributed in terms of their years of experience, organizations and the areas of expertise as shown in Table 3.2. Therefore, this research presents reliable information regarding the frequencies of the delay factors. When compared with the Tam and Shen‘s study (2012), the most common delay factor is different because this thesis study deals with the delay factors, not only from contractor‘s view but also from the owners‘ consultants‘ and designers‘ views. As the practical contribution, this research enables the project managers to identify the more possible delay factors and take precautions without coming up with a problematic issue.

Thirdly, the research sets sight on defining the dependencies (cause-effect relationships) between the delay factors. For this purpose, a correlation coefficient named as Pearson Correlation Coefficient is utilized to understand the directions of these dependencies. After the pairwise correlation coefficient calculations, 60 strong relationships are observed as shown in Table 4.5. Since the Correlation Coefficient does not indicate the causal and resultant variables separately, the guidance of the supervisor and the experienced professional determines the causal variable and resultant variable.

The joint and conditional probabilities are calculated by using SOCR web application derived from the correlation coefficient and Equation 4.1. With the information indicating and quantifying the dependencies, the Bayesian Belief Network Model is drawn as shown in Figure 4.2. In the literature, researchers prefer different methods for defining and quantifying the dependencies between the delay factors. For instance, Luu and the colleagues (2009), try to collect information from the respondents of the questionnaire. In their study, the respondents determine not only the causal and resultant variables, but also the conditional probabilities between them. Luu and the colleagues (2009) present a subjective approach instead of a mathematical expression. By utilizing the gathered data from the respondents, the Bayesian Belief Network model was developed in their study. On the other hand, Yang and the colleagues (2010) express the dependencies between the delay factors with the help of Structural Equation Modeling (SEM). SEM is widely used approach for defining the relationships with very scientific manner.

At this point, this research has a great theoretical contribution by showing the conditional relations between the delay factors of a marine construction projects in Turkey. This research presents a more scientific approach when compared with the previous study (Luu *et al.*, 2009) that uses questionnaire surveys. Besides, it brings about much easier and simpler method when compared with the studies, which utilize SEM (Yang *et al.*, 2010). In terms of the practical contributions, this research presents the path and direction of delay factors. In other words, the professionals working in the marine construction industry of Turkey could identify the causal variable of a delay factor. This enables them to arrive at the origin of the delay causes and solve the root cause of the schedule delay.

Finally, this research purposes to determine the quantity of the schedule delay of an uninitiated marine project in Turkey within a specified range. This purpose is succeeded by utilizing the Bayesian Belief Network Model loaded with the joint and conditional probabilities onto each delay factor. The delay factors in the proposed model eventually depend on the "Schedule Delay node indicating the range of schedule delay. In order to test the model, an already completed marine construction project in Istanbul is selected as the case study application as summarized in Table 5.1. The proposed model requires only the states of the delay factors without a parent node as whether it is observed or not observed in that case study project. With the help of the data gathered from the respondents, who have already worked on the case study, the 12 delay factors not having parent nodes in the Bayesian Belief Network Model are loaded with the observation data as shown in Table 5.2. Eventually, the states of "Delay" node verify the amount of schedule delay when compared to the actual schedule delay in that project.

In the literature, Luu and the colleagues (2009) try to obtain the amount of schedule delay by using the Bayesian Belief Network Model. According to the method proposed in this study, the Bayesian Belief Network Model should be established for each project separately. As stated before, this is achieved by using questionnaire surveys, which define the relationships and quantify the conditional probabilities in a subjective way. In other words, the structure of the Bayesian Belief Network is subject to change for every project. This makes this procedure much time consuming.

This research has a very significant theoretical contribution to the literature as it presents a verified Bayesian Belief Network model to estimate the amount of schedule delay within a specified range for the uninitiated marine construction projects in Turkey. Unlike the procedure proposed in the previous study (Luu *et al.*, 2009), stating the observation status of 12 delay factors, which do not have a parent node, is sufficient to obtain the amount of schedule delay. On the other hand, this research assists the practitioners in the planning and execution phases of the marine projects to determine the possible amount of schedule delay and which delay factors cause this delay mostly. Since this type of construction projects necessitates managing the budget and time by the investors, the identification and analysis of schedule delay is easier by utilizing the proposed model in this research.

7. CONCLUSION

Since marine construction projects are one of the developing industries in Turkey, this research tries to arrive at the following objectives: the identification and categorization of the delay factors encountered in the Turkish marine construction industry; the ranking of the delay factors in terms of their frequencies; the degree of dependencies between the delay factors; estimating the schedule delay of an uninitiated marine project in Turkey by utilizing the proposed Bayesian Belief Network model.

The delay factors that can be encountered in the marine construction industry in Turkey are summarized through a detailed literature survey with the inspection of the academic experts and an experienced professional working as the designer of the marine projects in the private sector. In this process, the previous delay factors in the literature are merged or eliminated depending on whether it is relevant to marine projects or not. The final list of the delay factors is scored via questionnaires by the experienced professionals, which are working in different roles in the marine construction industry, to rank them in terms of their frequencies. Moreover, the findings enable to identify the interrelations between the delay factors, by utilizing the pairwise calculations of Pearson Correlation Coefficients. After the relationships between the delay factors are defined, the Bayesian Belief Network is built to be able to draw the path causing delay. By benefiting from the correlation coefficients, means and standard deviations of the delay factors, the conditional probability tables are calculated and entered into the Bayesian Belief Network model. This model estimates the amount of schedule delay with the observation data of the 12 delay factors that do not have a parent node. The implementation of the proposed model is carried out with the gathered data from the respondents of the case study. Since the proposed model makes an accurate estimation, the delay duration of an uninitiated marine project in Turkey can be estimated by utilizing this tested model.

In terms of the theoretical contributions to the literature, this research presents the list of delay factors and their rankings according to their frequencies in marine construction projects in Turkey. Since the relationships between the variables are defined, the Bayesian Belief Network model is obtained with the conditional probabilities. This model could be used for all uninitiated marine projects in Turkey to estimate the schedule delay in a specified range. On the other hand, this research helps the practitioners could define the cause-effect relations and may prevent the delays by focusing on the root cause of the delay factors.

This research provides unique recommendations about the approach to delay factors in the Turkish marine construction industry. It enables the practitioners to manage the probable risks and investments in the developing countries like Turkey. Since these kind of construction projects has a great impact on the country's economy, foreseeing the probable delay factors and amount of delay is very crucial. Also, the practitioners can easily define the sources of the delay factors because the path between the delay factors are investigated in this study.

Also, this study has some limitations as well. One of these limitations is the number of respondents to the questionnaire surveys. This study has 35 respondents with a response rate of 23%. Another limitation in this study is related with the number of case studies. Further case studies can be conducted to validate the proposed model. Since the observation data of the delay factors that do not have a parent node is collected from the professionals working in the presented case study via questionnaires, much more time and effort is required to communicate with these professionals.

In the future studies, as the number of the respondents is increased, the reliability of the gathered data and proposed model is increased because the gathered data forms the foundation of the proposed model. In other words, when the sample space gets bigger, the researcher may obtain the more realistic results. On the other hand, the number of case studies in the future works may be increased to test the validity of the proposed model. Since there is a limited number of a marine project in Turkey, it may be more difficult to reach the professionals in these projects and communicate with them. However, for the validity of the model, further case studies should be conducted.

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APPENDIX A: QUESTIONNAIRE FOR THESIS RESEARCH A

11/27/2017 Questionnaire for Thesis Research

Questionnaire for Thesis Research

I am currently conducting a research for my Masters degree research. Its purpose is to estimate the schedule delay of marine projects due to possible delay causes encountered during the construction by using Bayesian Belief Network Model.

Given your rich expertise in the marine construction industry, we kindly request you to spare about 15 minutes of your time to duly fill the questionnaire.

This data is collected as a part of my Masters degree research at Boğaziçi University under the supervision of Asst. Prof. Semra Çomu.

Please note that your name and your responses will remain confidential. The collected data will be statistically analyzed and the conclusions will be used for only academical purposes.

We appreciate your effort in responding to the questionnaire and we are very thankful for your participation in this study.

*Required

1. **Name and Surname**

2. **How many years of experience do you have in marine construction projects?** *
Mark only one oval.
   - <5 years
   - 6-10 years
   - 10-20 years
   - >20 years

3. **Which of the following organization are you from?** *
You may select more than one
Tick all that apply.
   - Owner
   - Consultant
   - Designer/Engineer
   - Contractor
   - Other:

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Figure A.1. Questionnaire for Thesis Research 1.

4. **What is your area of expertise in marine construction projects?** *
You may select more than one
Tick all that apply.

- [ ] Project Manager
- [ ] Contract Manager
- [ ] Designer/Engineer
- [ ] Resident/Site Engineer
- [ ] Quality/Control
- [ ] Project Management Officer (Planner, quantity surveyor etc.)
- [ ] Other: ____________________

5. **Which procurement methods are you familiar with?** *
You may select more than one
Tick all that apply.

- [ ] Design - Build
- [ ] Design - Bid - Build
- [ ] Build - Operate - Transfer
- [ ] Construction Management
- [ ] Other: ____________________

6. **Which contract types are you familiar with?** *
You may select more than one
Tick all that apply.

- [ ] Lump Sum
- [ ] Unit Price
- [ ] Cost Plus Fixed Fee
- [ ] Cost Plus Percentage Fee
- [ ] Other: ____________________

General Questions About Your Marine Construction Projects

7. **What was the duration of your marine construction project according to the contract?** *
Mark only one oval.

- ( ) <1 year
- ( ) 1-2 years
- ( ) 2-4 years
- ( ) >4 years

Figure A.2. Questionnaire for Thesis Research 2.

11/27/2017 Questionnaire for Thesis Research

8. **How long has the project delayed according to the initial contract duration?** *

Mark only one oval.

- ( ) <6 months
- ( ) 6-12 months
- ( ) 12-24 months
- ( ) >24 months

9. **What were the results of delays in your marine construction projects?**

You may select more than one

Tick all that apply.

- [ ] Time overrun
- [ ] Cost overrun
- [ ] Dispute
- [ ] Arbitration or Litigation
- [ ] Termination

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

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Figure A.3. Questionnaire for Thesis Research 3.

11/27/2017 Questionnaire for Thesis Research

10. **Stakeholders-related (Consultant, contractor or owner) Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Lack of experience of stakeholders in marine construction projects	◯	◯	◯	◯	◯
Conflicts and poor coordination between stakeholders	◯	◯	◯	◯	◯
Delays in approval processes by consultant or owner	◯	◯	◯	◯	◯
Inflexibility of consultant	◯	◯	◯	◯	◯
Frequent change of subcontractors because of their inefficient work	◯	◯	◯	◯	◯
Improper construction methods implemented by contractor	◯	◯	◯	◯	◯
Inadequate number of or incompetent project team of contractor	◯	◯	◯	◯	◯
Poor site management, site work and supervision by contractor	◯	◯	◯	◯	◯
Unstable management structure and style of consultant	◯	◯	◯	◯	◯
Lack of capable owner representative or management failures of owner side	◯	◯	◯	◯	◯
Late project commencement of contractor	◯	◯	◯	◯	◯
Unstable management structure and style of contractor	◯	◯	◯	◯	◯

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

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Figure A.4. Questionnaire for Thesis Research 4.

11/27/2017 Questionnaire for Thesis Research

11. **Resources-related (Equipment (plant), material or labour) Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Equipment allocation problem					
Frequent equipment breakdowns / Failure or improper equipment					
Shortage of resources					
Slow mobilization or slow/late delivery of resources					
Unskilled equipment operators or low worker skills/productivity					
Labor strike					
Changes in material types and specifications during construction					
Damage of stored materials					
Quality of materials or improper material selection					
Accidents during construction					

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

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Figure A.5. Questionnaire for Thesis Research 5.

12. **Design-related Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Inaccurate site investigation by consultant					
Complex or impractical project design					
Design changes by owner or his agent during construction					
Design errors and delays made by designers					
Inadequate details in drawings					
Providing site instructions by designer not on time					
Inconsistency between site conditions and design outcomes					
Unexpected surface and subsurface conditions (such as soil, hw table)					

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

13. **External Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Force majeure					
Unfavorable weather conditions					
Fraudulent practices and corruption					

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

Figure A.6. Questionnaire for Thesis Research 6.

11/27/2017 Questionnaire for Thesis Research

14. **Project Management and Contract-related Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Contract management					
Ineffective quality assurance/Control					
Unsuccessful project planning and scheduling					
Lack of incentives or penalties for contractor to finish ahead or behind schedule					
Unrealistic contract durations imposed by client					
Improper type of construction contract or project delivery system (Turnkey, DBB,BOT,.)					
Type of project bidding and award (negotiation, lowest bidder,.)					
Improper project feasibility study					

Delay Factors

Please provide the values of frequency using the following scale:

Frequency: 0 (never), 1 (very rarely), 2 (occasionally), 3 (frequently), 4 (constantly)

15. **Financial-related Delay Factors - FREQUENCY** *

Mark only one oval per row.

	0-Never	1-Very Rarely	2-Occasionally	3-Frequently	4-Constantly
Difficulties in financing project or cash flow management					
Global financial crisis					
Price fluctuations					
Inflation					
Exchange rate fluctuation					

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Figure A.7. Questionnaire for Thesis Research 7.

APPENDIX B: QUESTIONNAIRE FOR THESIS RESEARCH B

11/27/2017 Questionnaire for Thesis Research

Questionnaire for Thesis Research

I am currently conducting a research for my Masters degree research. Its purpose is to estimate the schedule delay of marine projects due to possible delay causes encountered during the construction by using Bayesian Belief Network Model.

Given your rich expertise in the marine construction industry, we kindly request you to spare about 5 minutes of your time to duly fill the questionnaire.

This data is collected as a part of my Masters degree research at Boğaziçi University under the supervision of Asst. Prof. Semra Çomu.

Please note that your name and your responses will remain confidential. The collected data about the marine project constructed in Istanbul will be statistically analyzed and the conclusions will be used for only academical purposes.

We appreciate your effort in responding to the questionnaire and we are very thankful for your participation in this study.

*Required

1. **Name and Surname**

2. **Which of the following organization are you from in this project?** *
Mark only one oval.
   - Owner
   - Consultant
   - Designer/Engineer
   - Contractor
   - Other: ____________

3. **What is your area of expertise in this project?** *
Mark only one oval.
   - Project Manager
   - Contract Manager
   - Designer/Engineer
   - Resident/Site Engineer
   - Quality/Control
   - Project Management Officer (Planner, quantity surveyor etc.)
   - Other: ____________

Delay Factors

Please provide the responses using the following scale:

Observed: If you observed this delay factor during any phase of this project

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Figure B.1. Questionnaire for Thesis Research 1.

11/27/2017 Questionnaire for Thesis Research

Not Observed: If you did not observe this delay factor during any phase of this project

4. Delay Factors *

Mark only one oval per row.

	Observed	Not Observed
Lack of experience of stakeholders in marine construction projects	⬭	⬭
Inflexibility of consultant	⬭	⬭
Lack of capable owner representative or management failures of owner side	⬭	⬭
Unstable management structure and style of contractor	⬭	⬭
Inaccurate site investigation by consultant	⬭	⬭
Unexpected surface and subsurface conditions (such as soil, hw table)	⬭	⬭
Force majeure	⬭	⬭
Fraudulent practices and corruption	⬭	⬭
Contract management	⬭	⬭
Unrealistic contract durations imposed by client	⬭	⬭
Improper project feasibility study	⬭	⬭
Global financial crisis	⬭	⬭

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Figure B.2. Questionnaire for Thesis Research 2.