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"Key Lessons Regarding Project Delivery Model (PDM) in Mega Suspension Bridge Projects, Case Study: PPP in 1915Çanakkale Bridge Project"

Master's thesis in Project Management
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ABSTRACT

This master's thesis explores the realm of mega infrastructure projects, specifically examining the 1915 Çanakkale Bridge project in Turkey as a case study. The study's motivation arises from the Norwegian Public Road Administration's (NPRA) endeavors to develop the Coastal Highway Route E39, with a particular focus on the E39 Stord-Os (Hordfast) project, which involves constructing suspension bridges of immense scale and complexity. The choice of Project Delivery Model (PDM) for such projects significantly impacts their success, and this research aims to bridge the knowledge gap in the Norwegian context regarding the application of specific PDMs in mega suspension bridge projects.The main objective of this research is to extract key lessons from international experiences in the delivery process of mega suspension bridge projects, elucidating how distinct PDM characteristics influence project performance at different stages. The scope of the research encompasses the entire project delivery process, excluding the operation phase, with a primary focus on the bridge portion of the 1915 Çanakkale project. Research methodology involves extensive literature review, document analysis, and interviews with key project stakeholders.

The research discusses multiple uncertainties inherent in large-scale infrastructure projects like the 1915 Çanakkale Bridge, encompassing financial complexities, technical intricacies, environmental considerations, construction uncertainties, and unforeseen events such as the Covid-19 pandemic. The study underscores the critical role of financial management and accurate cost assessments in mega-projects, emphasizing the need for collaboration with international lenders and banks in public-private partnerships (PPPs). Innovation in design and construction methods is vital for projects of this magnitude, but site-specific challenges and changing specifications can lead to delays and increased costs. The Covid-19 pandemic, classified as a force majeure event, introduced unexpected obstacle, affecting project timelines, costs, and workforce management. Harsh weather conditions in the Çanakkale Strait, coupled with diverse stakeholder collaboration, further added to the project's complexities. Global supply chain issues, safety concerns, heavy lifting operations, and time management were additional sources of uncertainty regarding project execution. Safety considerations were paramount, and the lifting, transportation, and assembly of substantial components demanded meticulous planning. Effective time management was central to project success, given the potential for delays from various sources.

The process of the project underscores a series of invaluable lessons applicable not only to infrastructure development but to diverse fields. The project's capacity to anticipate and plan for diverse uncertainties proved pivotal in mitigating

potential disruptions, highlighting the significance of meticulous risk assessment and robust risk management strategies. Transparent and collaborative communication among stakeholders, particularly in culturally diverse environments, is essential for project success, and trust-based relationships and transparent channels fostered efficient interdisciplinary teamwork. The project's adaptability to changing circumstances, whether due to unforeseen events or design modifications, played a crucial role in maintaining timelines and budgets. Collaborative efforts among various teams with distinct expertise were instrumental in addressing the complex nature of mega-projects, emphasizing the importance of fostering interdisciplinary collaboration. Strategic procurement routes and partnering with experienced entities mitigated uncertainties related to material quality and timely delivery. Well-structured agreement formats that allocate risks effectively and align with project realities are crucial. Adherence to contractual obligations and standardized contract methodologies facilitated smooth project execution. Integrating sustainability considerations, including environmental and social standards, not only ensures long-term benefits but also enhances project quality and eligibility for international funding.

- **Keywords:** Project Delivery Model, Public Private Partnership, Build Operate Transfer, Uncertainty, Project Performance, 1915 Çanakkale project, Cultural Diversity, EPC Contractor, SPV Company, Joiint Venture, Financial Close, Suspension Bridge, Organization Form, Project Structure, Specification, Procurement Route, Agreement Format

PREFACE

This master's thesis represents the culmination of my studies in the Master of Project Management program with a specialization in Civil Engineering at the Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU). The research was undertaken during the spring semester and summer of 2023 and carries a credit value of 30. Remarkably, specific portions of this study, notably the literature review, were conducted in the preceding autumn as part of my specialization project.

Titled "Key Lessons Regarding Project Delivery Model (PDM) in Mega Suspension Bridge Projects, Case Study: PPP in 1915Çanakkale Bridge Project," this master's thesis aims to offer valuable insights into the construction of large-scale infrastructure projects. It places particular emphasis on the significance of the Project Delivery Model (PDM) and its constituent elements, exploring their influence on project performance indicators and their role in effectively managing uncertainties throughout project execution.

I wish to express my gratitude to my supervisor, Ola Lædre, whose support, guidance, and encouragement was instrumental in the successful completion of this thesis. I would also like to extend my thanks to Kristoffer Battegard Narum for his assistance during the research, particularly for his role in facilitating communication with interviewees. Additionally, my appreciation goes to Paulos Wondimu, representing the Norwegian Public Road Administration in this program, as well as Agnar Johansen and Olav Torp from the Department of Civil and Environmental Engineering, who closely followed the progress of this project through virtual meetings, providing valuable insights during the initial stages of the research.

I would like to acknowledge my wife for her unwavering support and patience, especially during the final quarter when I was deeply engrossed in my thesis work. Lastly, I am grateful to all the experts who participated in the interviews conducted for this thesis. Their contributions played a pivotal role in the successful completion of this research. At the end, I would like to share a poem that has written by one of the Executive Committee member of the 1915Çanakkale Project which reflects his emotions during construction activities:

"We are like islands in the sea, separate on the surface but connected in the deep. Towers are like islands now, separate in the sea but finally connected in the Bridge. We are ready for new challenges. Let's go forward together"!

Siamak Akbarnezhad Nesheli

8th September 2023, Trondheim

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ABBREVIATIONS

List of all abbreviations in alphabetic order:

- **AHP** Analytic Hierarchy Process
- **AMD** Active Mass Damper
- **BIM** Building Information Modeling
- **BLT** Build Lease Transfer
- **BOD** Board of Director
- **BOO** Build Own Operate
- **BOT** Build Operate Transfer
- **CAR** Construction All Risk
- **CE** Construction Engineering
- **CEO** Chief Executive Officer
- **CFO** Chief Financial Officer
- **CM** Construction Management
- **CMR** Construction Management at Risk
- **CPDM** Collaborative Project Delivery Model
- **DB** Design Build
- **DBB** Design Build Build
- **DBIA** Design Build Institute of America
- **DFIs** Development Finance Institutions
- **DLSY JV** DL E&C- Limak- SK E&C- Yapi Merkezi- Joint Venture (EPC Contractor)
- **EC** Executive Committee

- **ECIs** Export Credit Agencies
- **EPC** Engineering Procurement Construction
- **FIDIC** International Federation of Consulting Engineer
- **FM** Facility Management
- **GC** General Contractor
- **GDH** General Directorate of Highways
- **GPP** Guaranteed Maximum Price
- **HDPE** High Density Polyethylene
- **HPC** Higher Planning Council
- **HSE** Health safety and Environment
- **ICCP** Impressed Current Cathodic Protection
- **IDC** Independent Design Control
- **IDV** Independent Design Verification
- **IFC** International Finance Corporation
- **IPC** Interim Payment Certificate
- **IPD** Integrated Project Delivery
- **KEXIM** Export Import Bank of Korea
- **KSURE** Korea Trade Insurance Corporation
- **LESA** Lenders' Environmental and Social Advisor
- **LLA** Lenders' Legal Advisor
- **LTA** Lenders' Technical Advisor
- **NPRA** Norwegian Public Roads Administration
- **OECD** Organization for Economic Co- Operation and Development
- **O & M** Operation and Maintenance
- **OSHA** Occupational Safety and Health Administration
- **OGB** Osmangazi Bridge
- **OTOYOL** National Network of Controlled- Access Highways
- **PA** Project Alliance
- **PCM** Project Control and Management

- **PDM** Project Delivery Model
- **PPL** Public Procurement Law
- **PPP** Public Private Partnership
- **PPWS** Prefabricated Parallel Wire Strand
- **RDH** Regional Directorate of Highways
- **RFI** Request for Information
- **RFP** Request for Proposal
- **RFQ** Request for Quote
- **RFQ** Request for Qualification
- **SHMS** Structure Health Monitoring System
- **SPV** Special Purrpose Vehicle
- **TOOR** Transfer of Operation Rights
- **TT JV** Tekfen and T Engineering Joint Venture (Owner's Consultancy Services)
- **TTL** Third Party Liability
- **VO** Variation Order
- **YSSB** Yavus Sultan Selim Bridge
- **VUCA** Volatility, Uncertainty, Complexity, Ambiguity
- **ÇOKA.Ş** Çanakkale Otoyol Köprüsü İnşaat Yatırım İşletme A.Ş. (Çanakkale Motorway Bridge Construction Investment Management Inc.)

CHAPTER

ONE

INTRODUCTION

1.1 Motivation and Problem Statement

The Norwegian Public Road Administration (NPRA) is currently planning the delivery of E39 Stord-Os (Hordfast), which is an important part of the development of a Coastal Highway Route E39. This project includes the construction of some of the largest and most innovative infrastructure, including suspension bridges ever made. In this connection, the role of NPRA is crucial to provide a systematic structure to be sure about the process of value creation in such a mega project. It has been proven that the choice of Project Delivery Model (PDM) at the early stage of projects is one of the most significant corporate decisions which can affect project success and achieve its strategic goals. According to Miller, Gavin, Ibbs, and Mahoney PDM is" a method for organizing and financing design, construction, operation, and maintenance activities that facilitates the delivery of goods or services" [1]. However, it is a comprehensive definition and depending on different types of PDMs, some of the phases like financing, operation, and maintenance could be included or excluded. All in all, the project delivery model will decide the possibility of control, the distribution of responsibility for the uncertainty and the selection of contractors [2].

There is a lot of Knowledge and research about different aspects of wide variety of PDMs in the academic literature. There is also a lot of research and experience about the design and construction process of long span suspension bridges and its challenges around the world. But there is a gap particularly in Norwegian literature regarding the process, challenges, and results of utilizing a specific PDM in a mega suspension bridge project. Regardless of the types of the PDMs which are applied, investigating international experiences of construction process in similar projects by itself could be beneficial for the NPRA as the main responsible for developing road infrastructure in Norway.Moreover, the project's case study, is the longest suspension bridge ever made in 2022 at Turkey. Therefore, on one hand, it is the most appropriate case for the planned bridges in ongoing coastal road in Norway in terms of similarity, scope, and size. On the other hand, since it was completed recently, it employed the most innovative methods, equipment, and technologies which is another motivational reason for this research.

1.2 Objective

The most prominent aim of the present research is finding key lessons regarding international experiences from the delivery process of a mega suspension bridge project. In the other word, how characteristics of a specific PDM can influence on the project performance in different stages. In this regard, three following questions are explored within the research to achieve the main objective:

1) How was the Project Delivery Model (PDM) in the project?

2) How did PDM's elements impact project performance indicators? To what extent did they contribute to managing uncertainties in the project?

3) What were the key lessons regarding the PDM within the project?

1.3 Scope and Limitations

This research is looking at the whole process of Project delivery for the longest suspension bridge ever made from front-end until the construction completion, which means that the operation phase is not included in the research's scope. Due to the extended scope considered for the research, just one case study is considered for the deeper investigation. Although this project comprised of a suspension bridge and 89-kilometer motorway has been completed through the unified agreement package, present research will just focus on the bridge part. Formal components like organization form, Project structure, Specification of work, Procurement route, and agreement format are considered as PDM's elements in the research questions. Also, whenever is pointed to project performance indicators, it means time, cost, and quality of activities on project's critical path.

As will introduce in the next chapter, the case study of present research, is the 1915Çanakkale Bridge project in Turkey. One hand, despite the lots of efforts were initially done to make a connection with Turkey's public sector (through the two virtual meeting conducted with the contact person who was the Ankara university's faculty), managers form the government bodies were not willing to contribute to the research. On the other hand, this project was constructed within the Public Private Partnership (PPP) framework in which the private partners were the main players of the whole life cycle of the project, from financing to design, to construction, and operation phases until the end of concession period. Therefore, the research mostly concentrates on the main contractor's perspective when it comes to answering the research questions.

As will explain deeply in the next chapter, the research methodology is based on literature study, relevant document studies, and interview with key person who were involved in the project. For the last one, research encountered with the numerous obstacles: firstly, finding key people who had been involved in the project from start-up to the hand-over, and from different disciplines who could give comprehensive perspectives regarding all aspects of the project was a time-consuming process. Secondly, finding an appropriate channel to initiate communication with identified candidates was a demanding process. For example, there was not any email address of the identified eligible people for starting the communication and LinkedIn was the only point of departure where people rarely are willing to answer to unknown individual. Even if the feedback was received from individuals, there was not any guarantee to accept the request for an interview. Third, the recent

terrible earthquake occurred in Turkey negatively impacted research progress so that, five interview's candidates from Turkey, canceled their appointed interviews due to their executive responsibilities to handle the earthquake side-effects on that time. while, it had initially been evaluated that at least eight interviews could be sufficient for the research.

CHAPTER

TWO

METHODS

The results presented in this report are derived from a combination of literature review, document analysis, and interviews with key individuals involved in the project's case study. Below, we detail the procedure followed for each component.

2.1 Theoretical Background

Two main objectives were followed for the literature study in this research. First, it aimed to establish a foundational understanding of various Project Delivery Models (PDMs). Second, it delved deeper into the specific PDM applied in the case study. To accomplish these goals, this chapter is divided into two sections. The initial section provides a concise investigation of different types of delivery models typically employed in the construction industry. The subsequent section focuses on Public Private Partnership (PPP), which served as the chosen PDM in this research's case study.

In the PPP section, a comprehensive understanding of PPP and its context in Turkey was sought by examining its various aspects, including legal frameworks, organizational structures, market conditions, risk distribution, and the tendering process. Additionally, two large suspension bridges in Turkey, both completed in 2016 under the PPP framework, were briefly assessed in terms of their general and contractual specifications and the main uncertainties they encountered.

Google Scholar served as the primary web search engine for exploring academic literature in this research. Relevant keywords were used for searches, and after an initial screening, a database was compiled. Selection criteria were based on high citation rates and relevance to the central topic. These criteria were well met for the first section, as substantial academic work has been conducted on PDMs in the literature. However, for the second section (PPP in Turkey), a reliance on more localized academic literature was unavoidable. Surprisingly, the search process for relevant academic papers related to the research's case study yielded only one conference paper, which was unrelated to the project's processes and mainly focused on bridge design and its associated challenges which probably is caused by the novelty of the project.

In total, over 50 distinct references, including academic papers and relevant documents, were utilized in the theoretical background chapter. Among these,

35 papers were directly incorporated into the research, while the remainder were indirectly referenced. Notably, this part of the work had been done as a part of the specialization project, and with some revision is utilized in the research.

2.2 Case description

2.2.1 General specification

The 1915Çanakkale Project, recording the world's longest mid-span suspension bridge, is anticipated to make a significant contribution to Turkey's socioeconomic development. This project involved the construction of a bridge that crosses the Çanakkale Strait, twice the length of the Bosphorus, and plays a vital international role as part of the "One Belt One Road" Project. The construction of the 1915Çanakkale Bridge began immediately after the completion of the Osmangazi Bridge and the Yavuz Sultan Selim Bridge, both of which are among the world's longest bridges. This extensive experience underscores Turkey's expertise in mega bridge construction, particularly in recent years [3].

The 1915Çanakkale Bridge, was built in a remarkably short period, approximately 48 months, nearly 1.5 years ahead of schedule and it finally became operational on 18th March 2022 [4]. Employing cutting-edge engineering techniques and a strong aesthetic sense, this bridge stands out globally due to its unique characteristics. As demonstrated in the figure 2.2.1 , this record-breaking bridge features a mid-span of 2023 meters, making it the world's longest mid-span suspension bridge. Additionally, with a tower height of 334 meters above sea level, it holds the title of the world's tallest bridge in terms of structural height. The 2023-meter distance between the bridge towers signifies the 100th anniversary of the Republic of Turkey's founding, while the 318-meter tower height commemorates the Çanakkale Victory on March 18th, a pivotal date in Turkey's struggle for independence [5, 3].

This bridge is the first suspension bridge to be designed and constructed with twin decks and a main span exceeding 2000 meters. Its mid-span of 2023 meters, along with two by side spans each measuring 770 meters, results in a total bridge length of 3565 meters. The approach viaducts, spanning 365 meters and 680 meters respectively, extend the overall passage length to 4608 meters. The bridge accommodates traffic flow with three lanes in each direction, and its twin decks are 45.06 meters wide and 3.5 meters high. The tower foundations are securely anchored in previously treated seabed areas, with depths reaching -45 meters on the Asian side and -37 meters on the European side [5, 3].

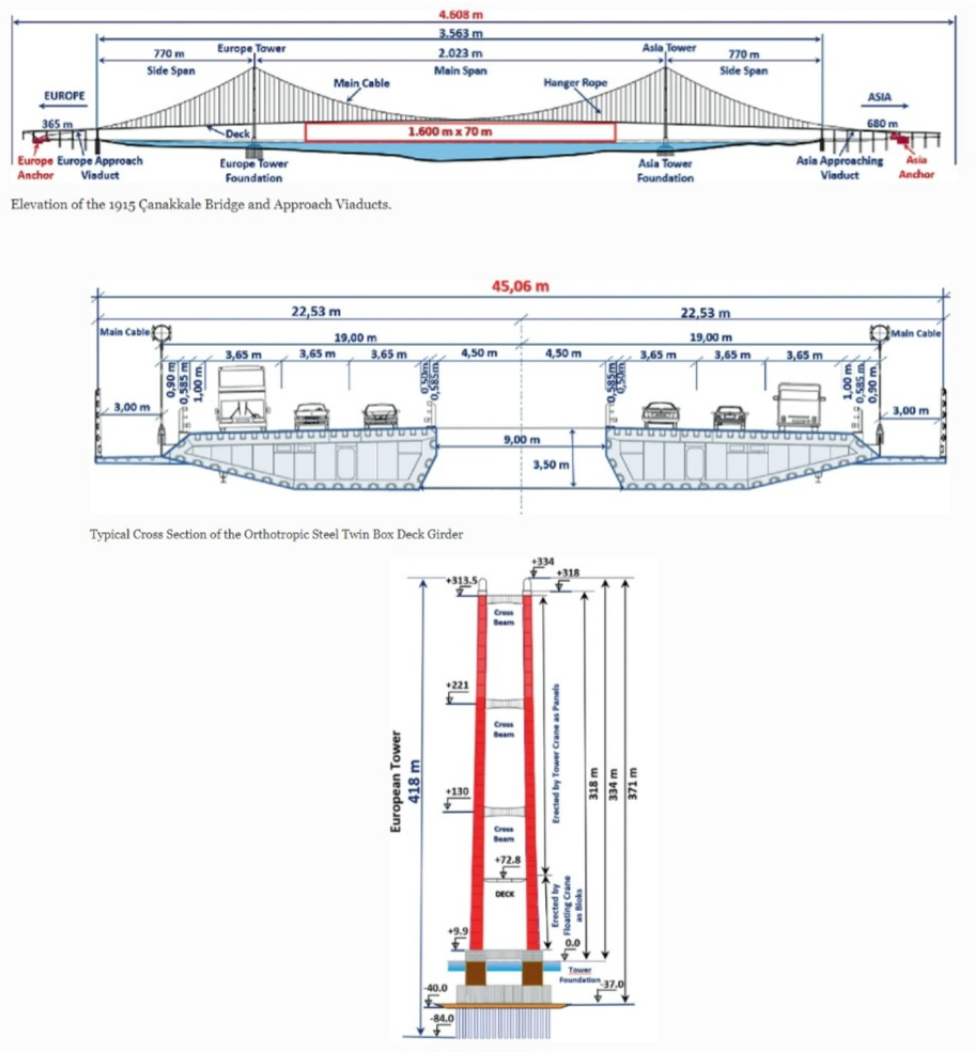

Figure 2.2.1: Geometric Specification of Çanakkale bridge Project [6].

2.2.2 Contractual Specification

The 1915Çanakkale Bridge and Motorway Project were awarded by the General Directorate of Highways (GDH) in 2017 under public-private partnership model (in the format of BOT) to the private sector [3, 7]. A Turkish-Korean consortium consisting of four shareholders, two Korean and two Turkish companies, collaborated as investors. They operated as both sponsors (SPV Company) and the Engineering-Procurement-Construction (EPC) contractor. This project involved an extensive network of stakeholders, including 25 lenders, four sponsors, various advisors, public administrations, construction subcontractors, equipment suppliers, steel fabricators, and engineering firms from over 10 countries. In terms of the scope of this collaborative network, it stands as a record-breaking project [8, 9, 5].

Throughout various stages of the project, more than 30,000 employees contributed, with 17,000 working on the bridge and 13,000 on the motorway. The contract duration encompassed 16 years, 2 months, and 12 days, covering financing, design, construction, and operation. The Implementation Contract's effective date was March 16, 2018, and it became operational on March 18, 2022, surpass-

ing the stipulated deadline by 1.5 years. This achievement becomes even more remarkable when considering that it was accomplished during the COVID-19 pandemic, which had a significantly adverse impact on construction projects [4]. For project financing, a 15-year term loan of 2.265 billion Euros, with a 5-year grace period, was secured from 25 different local and international lenders within a year which is outstanding record for a PPP project. The remaining investment of 900 million Euros was provided by the project's shareholders [8, 9, 3].

In summary, the 1915Çanakkale Bridge and Motorway Project, with its cutting-edge engineering methods, innovative technology, and a wide variety of uncertainties, presented an attractive case study for the research. Furthermore, the Public-Private Partnership (PPP) model, which encompasses the entire infrastructure development process from financing to design, construction, and operation, aligns well with the research's objectives and covers a broad spectrum of production processes. Additionally, the challenging wind conditions faced during the construction and design phases of suspension bridges, a characteristic of the Çanakkale strait due to its windy weather, makes this project suitable for the research, particularly in comparison to similar conditions in Norway.

2.3 Documents Study

As mentioned earlier, due to the novelty of the 1915Çanakkale Bridge project, there were no academic papers available regarding the project's processes. Fortunately, valuable documents were identified through an internet search. This document prepared by the communication department of appointed company (SPV Company). The appointed company for the project, ÇOK. A.Ş., utilized the "Countdown Chronicle," an E-magazine, to introduce the public to the "1915Çanakkale Bridge and Malkara-Çanakkale Motorway" project. This comprehensive document covered various aspects of the project, from technical details to its economic and social implications, and it provided updates on the latest developments. The document was published in nine issues, with the final issue numbered "one" to coincide with the project's completion in March 2022 [7].

The content of this document was based on interviews with a wide range of individuals, from key persons involved in the project to politicians and local residents. The themes selected for the chronicle adopted a "people-oriented" approach, focusing primarily on individual stories [4, 7]. This approach not only accurately reflected a broad spectrum of perspectives but also aligned with the research's strategy of interviewing key project participants.

The data analysis process for this extensive 1100-page document, where almost all content was relevant to the study, was a meticulous and time-consuming task. Initially, a thorough examination of the entire document was conducted, and then the most relevant sections were extracted as primary sources for the study. Even after this filtering process, the resulting database still consisted of 200 pages, presenting a challenge due to the sheer volume of well-suited data available for the research.

Ultimately, the collected data from the document study was categorized based on its relevance to the formal elements of a Project Delivery Model (PDM). This data, combined with the results from our interviews, was presented as the re-

search's findings in Chapter 4. The style of this section has been predominantly narrative, allowing for a direct transition from the responsibility of interviewees to the of quoted information by them. This approach has proven particularly advantageous in crafting the discussion and conclusion segments of the research.

2.4 Interview

2.4.1 Structure of Interview guide

Interviews with key individuals involved in the 1915Çanakkale Bridge project constituted the third research method for data collection. To facilitate this, an interview guide was developed based on the three research questions. The interview guide commenced with an introduction to the research and its objectives, followed by a concise explanation of Project Delivery Models (PDMs) and their elements. Three main questions were then outlined as follows:

1) How was the Project Delivery Model (PDM)?

2) How did PDM's elements impact project performance indicators? To what extent did they contribute to managing uncertainties in the project?

3) What were the key lessons regarding the PDM within the project?

As depicted in figure 2.4.1, The components considered as formal elements of a PDM for this research included Organization Form, Project Structure, Form of Specification, Procurement Route, and Agreement Format [10]. Furthermore, considering that there can be varying interpretations of terms in scientific writing compared to engineering literature in practical applications, a concise description of each PDM element was provided to the interview candidates. This step aimed to ensure clarity and mutual understanding during the interviews.

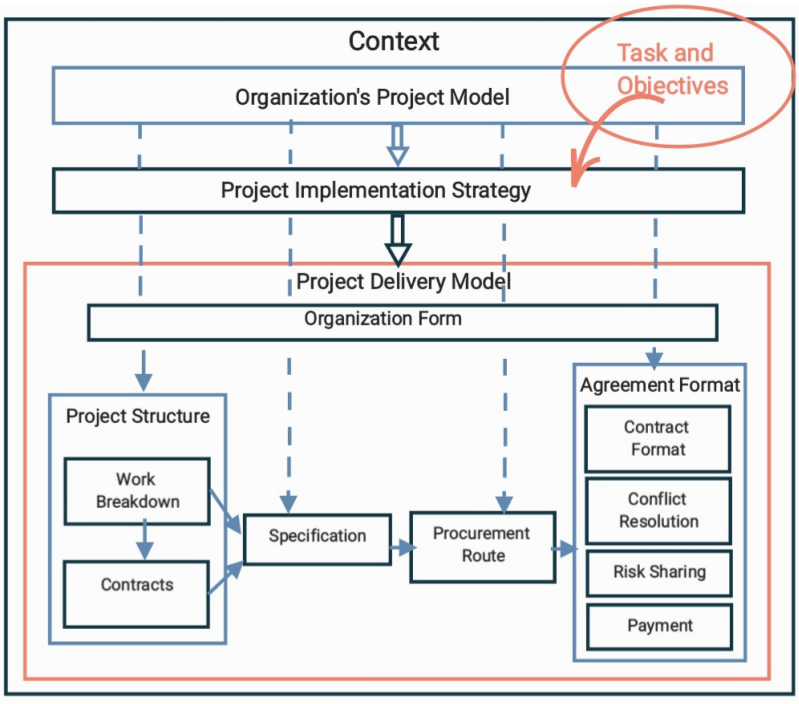

Figure 2.4.1: Elements of Project Delivery Model [10].

Following a brief description of the interview process and some warm-up questions about the interviewee and their responsibilities in the project, questions were posed about the project's critical path and the main uncertainties. This approach aimed to prepare interviewees to respond to the main research questions effectively. To create a comfortable atmosphere for interviewees and to avoid potential ambiguities arising from the generality of the questions, it was decided to address the three main questions separately for each element of the PDM which means 15 question in total. This organization of questions, while aiding the research process during data analysis, also presented challenges due to the number of questions that needed to be covered within a relatively short period (1-1.5 hours). the customized Interview guide for the 1915Çanakkale bridge project is illustrated in appendix A.

2.4.2 Interviewees

The interviewees was required to meet specific qualifications for participation. They either needed to have been involved in the project as a manager or engineer from its early stages or, at the very least, from the construction phase. Additionally, there was a strong emphasis on including individuals from various levels of the management hierarchy to ensure a broad range of perspectives. Despite holding two initial virtual meetings with the contact person from Ankara University to establish an open communication channel with the management body, unfortunately, the desired outcome did not achieve due to unforeseen reasons.

As a result, the process was begun by reviewing project documents and compiling a list of eligible individuals. initial communication was commenced with these individuals through the LinkedIn platform, as mentioned in the introduction. This proved to be a demanding process, as over 70 connection requests was sent to the identified individuals on LinkedIn. Nearly 30 individuals responded to the requests. Subsequently, communication was continued via email, and out of those, only 8 individuals agreed to participate in the research. Unfortunately, four of them had to cancel their interviews due to a terrible earthquake in Turkey on that time, which had a negative impact on the research progress. Finally, thanks to the open communication channel, interviews was arranged with a Korean engineer working on an infrastructure project in Norway, who had served as the project chief engineer for the 1915 Çanakkale bridge project, along with four other interviewees.

The invitation process followed a specific protocol. Official invitations were sent to the candidates, along with the interview guide and a link to Microsoft Teams. In total, nine interviewees from various disciplines and with different responsibilities participated in the research, ensuring a diverse range of perspectives. This group included a deputy director, two deputy project managers, two project control managers, two contract managers, a section manager, and a chief engineer.

Finally, the data collected from this phase, combined with the results of the documents study, is presented in Chapter 4. The writing style of this chapter follows the procedure used in interview guide, so that three main questions systematically is responded for each PDM's elements orderly and is followed by an analytical discussion of the same element. The same procedure is then applied to the all PDM's elements which means that research's results and the related

discussions have merged in a one unified chapter. The discussions conducted in Chapter 4 serve as the foundation for the conclusion presented in Chapter 5.

2.5 Conclusion

Chapter 5, serving as the completion of this research, addresses the three primary questions outlined in the introduction. To provide a comprehensive understanding, the chapter commences with a dedicated section that digs into the main uncertainties that significantly influenced the 1915 Çanakkale Bridge project. These insights are derived from an analysis of documents and findings gained from conducted interviews. Subsequently, the chapter meticulously responds to the three principal questions in a systematic and organized manner. This structured approach ensures clarity and coherence in presenting the research's key findings and conclusions. Conclusively, Chapter 5 concludes by offering potential avenues for future research, thereby contributing to the ongoing discourse in this field.

CHAPTER

THREE

THEORY

3.1 Project Delivery Models (PDMs)

Selecting the right project delivery model represents a critical managerial choice, with a direct effect on a project's success. It notably affects essential project performance metrics, including cost, quality, schedule, and safety. Over time, project delivery approaches have developed, with the construction industry introducing numerous adaptations and alternatives to respond to diverse consumer needs. In this context, we will briefly introduce some of the most commonly employed models in the construction sector.

3.1.1 Design-Bid-Build (DBB)

Mark Konchar and Victor Sanvido, defined the Design-Bid-Build (DBB) project delivery model as follows: "DBB is the traditional project delivery model in the construction industry where the owner contracts separately with a designer and a contractor. The owner typically engages a consulting firm to provide comprehensive design documents. Subsequently, the owner or their representative issues fixed-price bids to construction contractors for project execution. One contractor is usually selected and enters into an agreement with the owner to construct a facility in accordance with the provided plans and specifications" [11].

While the fundamental structure of DBB is globally recognized, its implementation can be tailored to specific circumstances. For instance, in Norway, DBB contracts have been categorized into three sub-types: general contractors, main contractors, and divided contracts. Under the general contractor approach, the owner contracts with the professional designer and the general contractor, with the latter managing subcontractors. In the case of a main contractor, the client contracts with the professional designer, the main contractor, and side contractors. The main contractor holds the primary contract, but the side contractors have equal legal standing. In divided contracts, the client contracts separately with the professional designer and the contractors, assuming responsibility for tasks not covered by the contractor agreements [2].

In summary, the key contractual characteristic of DBB involves two separate contracts: one with the consultant engineer for design and another with the contractor for project execution [2]. Initially, the owner engages a consultant engineer

and, upon nearing 100% design progress, solicits a general contractor (GC) to carry out the project. The GC is typically selected based on competitive bidding. The consultant engineer represents the owner's interests and oversees the contractors during the construction phase [12]. However, the lack of direct interaction between the primary parties involved in the project has often led to disputes, resulting in an increased number of claims and change orders, ultimately causing cost and time overruns [13, 11]. Nevertheless, DBB usually follows the single fixed-price or lump-sum contract approach in tendering, where the contractor undertakes specified work for a predetermined sum. Any changes in the scope of work can typically be addressed through unit pricing/re-measurement or a cost-plus format. Consequently, the owner bears responsibility for design decisions and associated cost fluctuations [14, 15]. A representation of a typical DBB delivery model can be found in Figure 3.1.1.

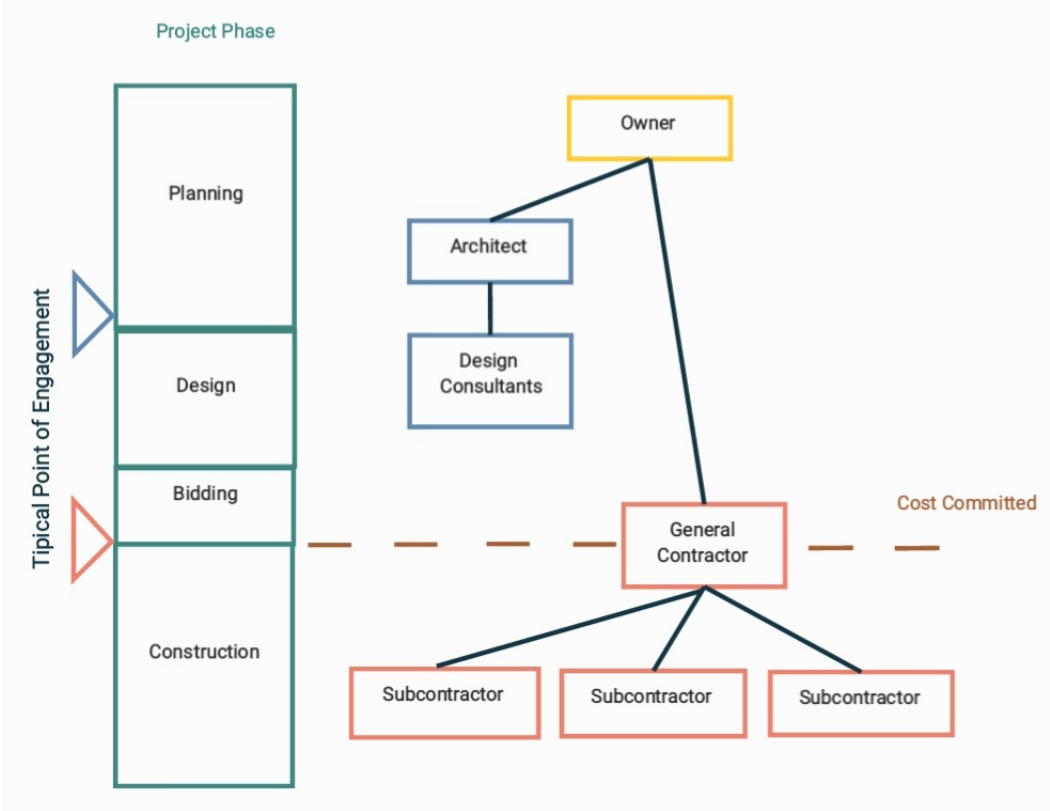

Figure 3.1.1: Typical DBB Delivery Model [16].

3.1.2 Design-Build (DB)

As the 20th century progressed, there was a growing demand for large-scale infrastructure projects of significant complexity. This increased demand necessitated a more precise quantification of the required work and greater coordination among stakeholders. Consequently, alternative project delivery models became essential [17]. It was during this period that the Design-Build (DB) approach began to gain prominence in the construction industry.

According to the definition provided by Mark Konchar and Victor Sanvido, "DB is a project delivery model in which the owner enters into a single contract

with a sole entity responsible for both design and construction under a unified DB contract. Contractually, DB provides the owner with a single point of accountability for design and construction services. The execution of design and construction tasks may be carried out by a single DB entity, selected specialty firms, or, in some cases, subcontracted to other companies" [11].

Under the DB model, the owner establishes a single contract with a primary contractor, who can be a corporation offering integrated design, engineering, and construction services or may delegate specific work portions to other firms. The primary contractor is typically selected based on qualifications, technical solutions, or a combination of these factors, and assumes responsibility for both the design and construction phases. Compensation terms depend on the percentage of design completion within the contract timeline and can take the form of a lump sum or cost-plus fee, with or without a guaranteed maximum price (GMP) [12].

One of the distinctive features of DB is its collaborative construction process, allowing the contractor and designer to function as a unified entity in the early stages of the project. This approach is not only cost-effective but also time-efficient, as it enables a fast-track approach where construction can commence while the design is still in progress [18]. Figure 3.1.2 provides a concise illustration of a typical design and build delivery model.

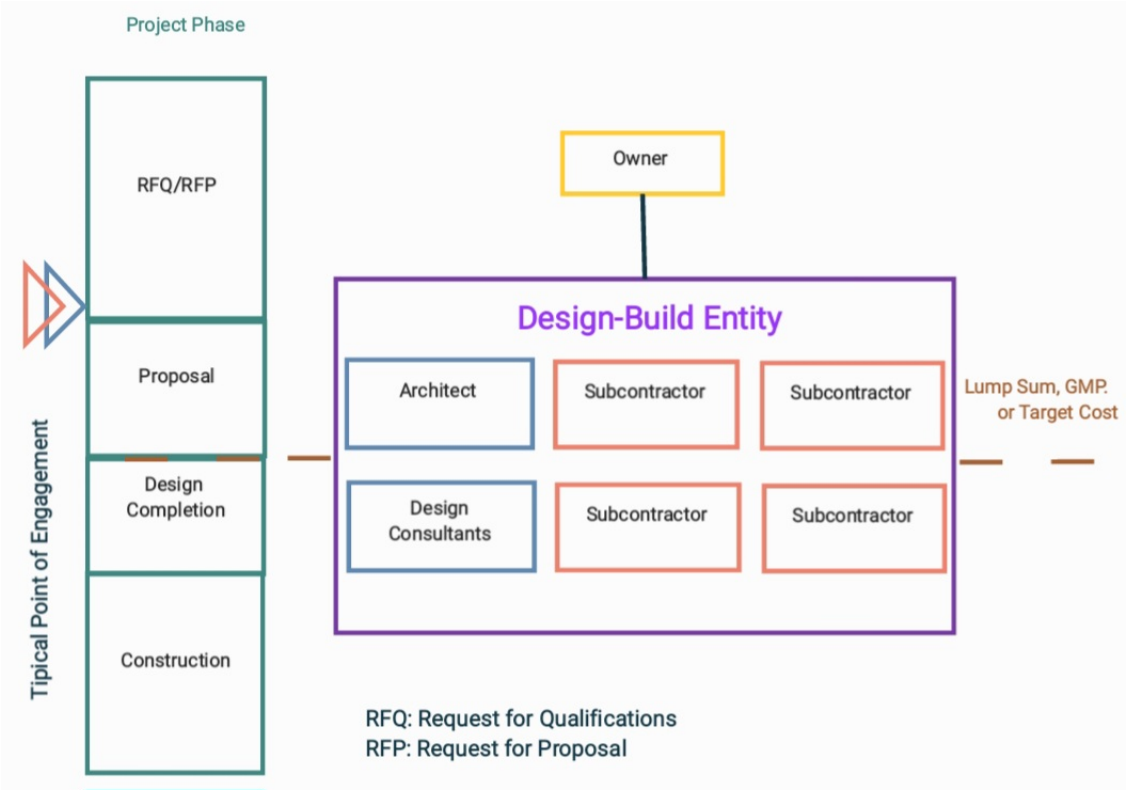

Figure 3.1.2: Typical DB Delivery Model [16].

3.1.3 Public Private Partnership (PPP) & Build-Operate-Transfer (BOT)

Infrastructure projects demand substantial investments and have the potential to positively impact economic growth and productivity [19]. Consequently, govern-

ments worldwide, facing budget constraints, have increasingly turned to private sector participation in large-scale infrastructure endeavors through Public-Private Partnerships (PPPs) over the past four decades [20]. According to the Organisation for Economic Co-operation and Development (OECD), a PPP is described as "a long-term contractual relationship between a state or state-owned entity and a private-sector entity, whereby the latter provides and finances public services using a capital asset, sharing associated risks with the state or state-owned entity, aligning government service delivery goals with the private partner's profit objectives" [21]. In PPPs, the financing and construction risks are shared between the public and private sectors, with the degree of responsibility and risk assigned to the private partner varying widely [20]. Summarizing some of the key characteristics of PPPs, as indicated by Yescombe in 2007 [22], we can state:

- PPPs involve long-term contracts between public and private partners.
- These contracts include the design, construction, financing, and operation of the project by the private sector.
- Agreements are reached between the private sector and public authorities, or the general public (users), or both parties, involving compensation to the private partner for their investment during a predetermined operational period.
- Ownership of the constructed facility is retained, either from the project's beginning or at the end of the PPP contract.

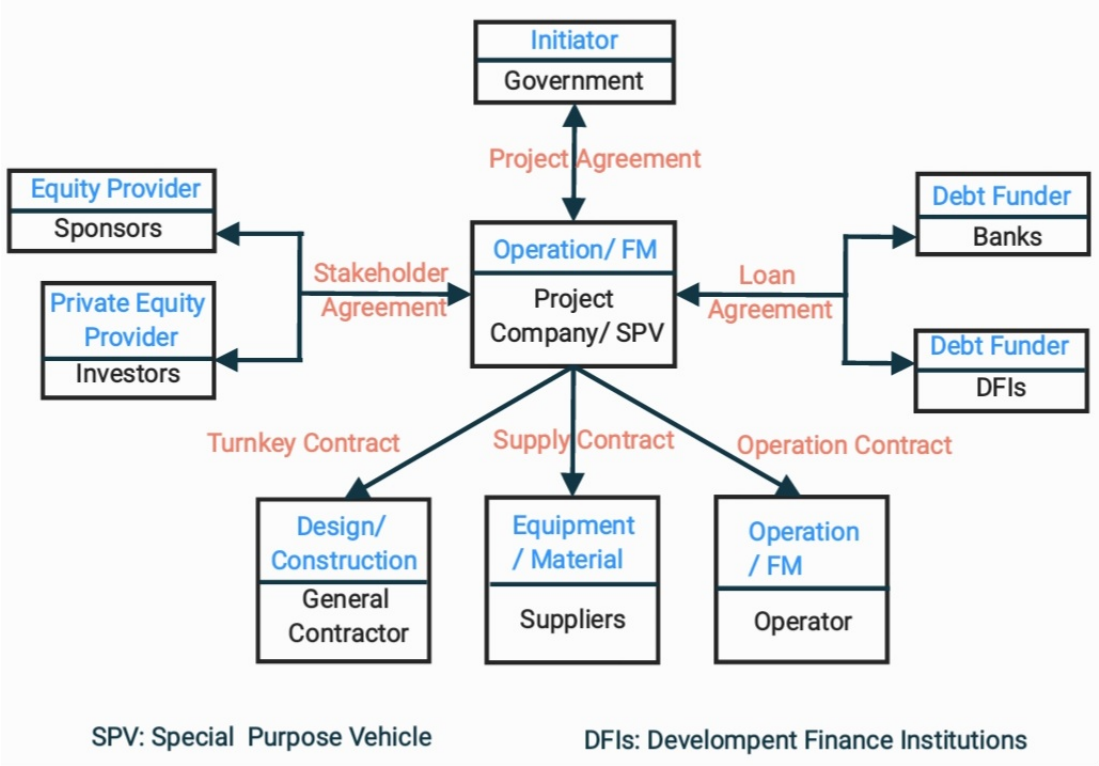

Figure 3.1.3: Typical PPP Delivery Model [23].

PPPs have the potential to enhance publicly financed services' quality under specific conditions by promoting infrastructure development, enhancing efficiency, and allocating the majority of project risks to the private party. Nevertheless, there are critics who express concerns about adverse effects such as limited accessibility for lower-income individuals due to high service prices and negative environmental impacts. In reality, the validity of both arguments depends on the governance structure of PPP projects. Establishing enabling institutions, laws, and procedures around PPP projects is crucial for good governance, with PPP contracts needing to adhere to established standards [24, 25]. Contracts define the formal relationships among various parties involved in PPPs. Figure 3.1.3 illustrates the principal parties and various types of contracts within a typical PPP delivery model.

As previously mentioned, there are several significant variations of Public-Private Partnerships (PPPs), including concessions, build-own-operate (BOO), build-operate-transfer (BOT), build-lease-transfer (BLT), transfer of operation rights (TOOR), etc. The primary distinction between PPPs and concessions lies in how users pay for the services. In concessions, users typically pay the majority or all of the usage fees directly, often through tolls, whereas in PPPs, the public procurer covers costs through shadow tolls and availability payments [26].

BOT, as a variant of PPP projects, involves the public sector benefiting private capital to create opportunities for both public and private partners, especially beneficial for emerging market governments with limited funding capacities to undertake numerous infrastructure projects at minimal taxpayer cost [27]. According to M. Mithat Uner and colleagues in 2018, "A BOT deal refers to a large-scale project where the sponsor, typically a governmental agency, contracts with a prime contractor responsible for completing construction and operating the project for a predetermined period before transferring ownership back to the sponsor. During this predetermined period, the contractor can recover its investment through operations and/or a guaranteed rate of return from the sponsor" [28]. Here are some key features of the BOT model:

- High Political and Commercial Risk: BOT projects are characterized by high costs, extended timelines, and substantial political uncertainty. Governments typically bear political and force majeure risks and may provide guarantees for facility demand [29].

- Strict Completion Schedule: There is a strong alignment of interests between public and private partners in adhering to a strict completion schedule. Governments and the public sector prefer to utilize the facility as soon as possible, while the main contractor aims to begin revenue generation through operation [29].

- Long-Term Presence: Under BOT contracts, companies establish a mid-to-long-term presence in a foreign country, limiting flexibility to adjust operations as market and company conditions evolve over time [30].

- Limited Control and Flexibility: BOT contracts may limit control and flexibility after signing due to the political sensitivity of the project and local

government involvement. This can present challenges for the main contractor in terms of strategy implementation, task coordination, and dispute resolution [31].

- Dependence on Political Stability: The stability of the ruling party and political stability in general play a significant role in creating a favorable climate for BOT projects and multinational contractors [31].

Figure 3.1.4 provides an illustration of the typical contractual and financial relationships between different participants in a BOT infrastructure project.

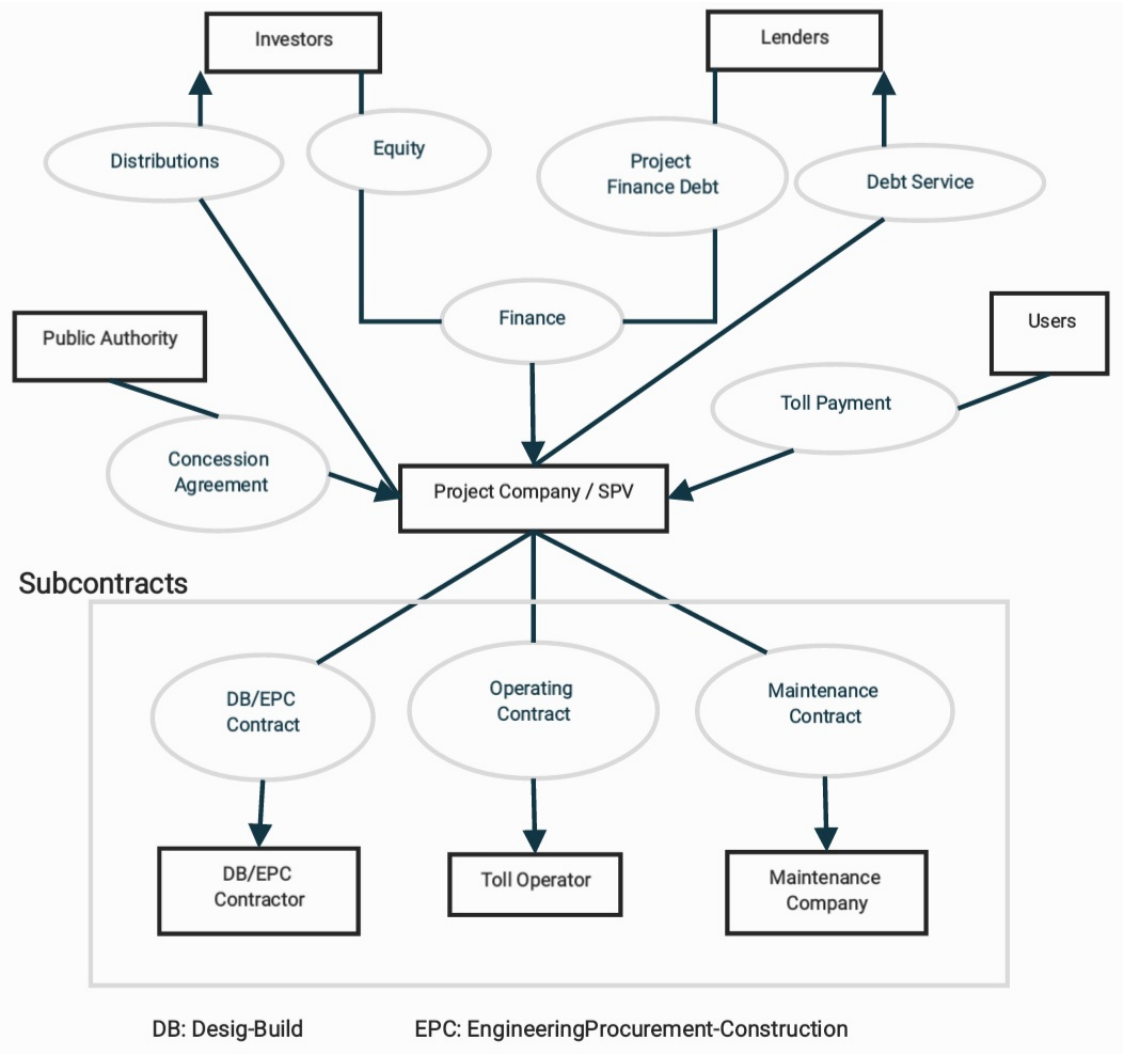

Figure 3.1.4: Typical BOT Delivery Model [22].

3.1.4 Construction Management (CM) & Construction Management at Risk (CMR)

The Construction Management (CM) project delivery model, which emerged around the same time as Design-Build (DB), involves the early engagement of both a design firm and a construction project firm by the owner. The construction manager's role is to advise the owner on design and construction management

activities. This approach requires a high level of collaboration among project participants and extensive owner involvement, making it imperative for the owner to possess knowledge and experience [32]. In this scenario, the CM serves as a professional consultant with a contractual relationship solely with the owner [33]. Figure 3.1.5 provides an illustration of a typical CM project delivery model.

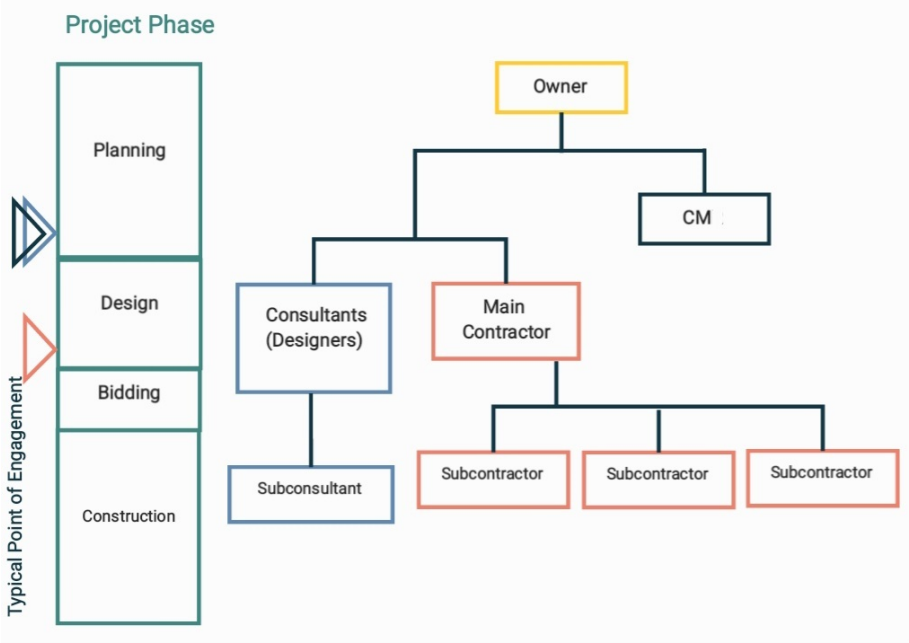

Figure 3.1.5: Typical CM Delivery Model [34, 16].

A derivative of the CM approach is Construction Management at Risk (CMR). Under CMR, the owner initially contracts with a design firm and subsequently with a construction manager firm (CM) when the scope of work is defined, typically between 20% and 60% design completion. The CM is selected based on a combination of qualifications and the offered price. In this method, two separate contracts are established between the CM and the owner. The first contract covers advisory services, including close coordination with the designer to control the design process, reducing change orders, and increasing cost certainty. The second contract relates to construction services, which may be an extension of the CM's initial contract or awarded to another CM. While either contract may initially be cost reimbursable, it often transitions into a Guaranteed Maximum Price (GMP) or lump sum arrangement later in the project [12, 35]. In practice, the CM takes on the role of the main contractor and has the ability to hire its own subcontractors. CMR is also referred to as construction manager/general contractor or construction manager as constructor [33]. A typical CMR model is illustrated in Figure 3.1.6.

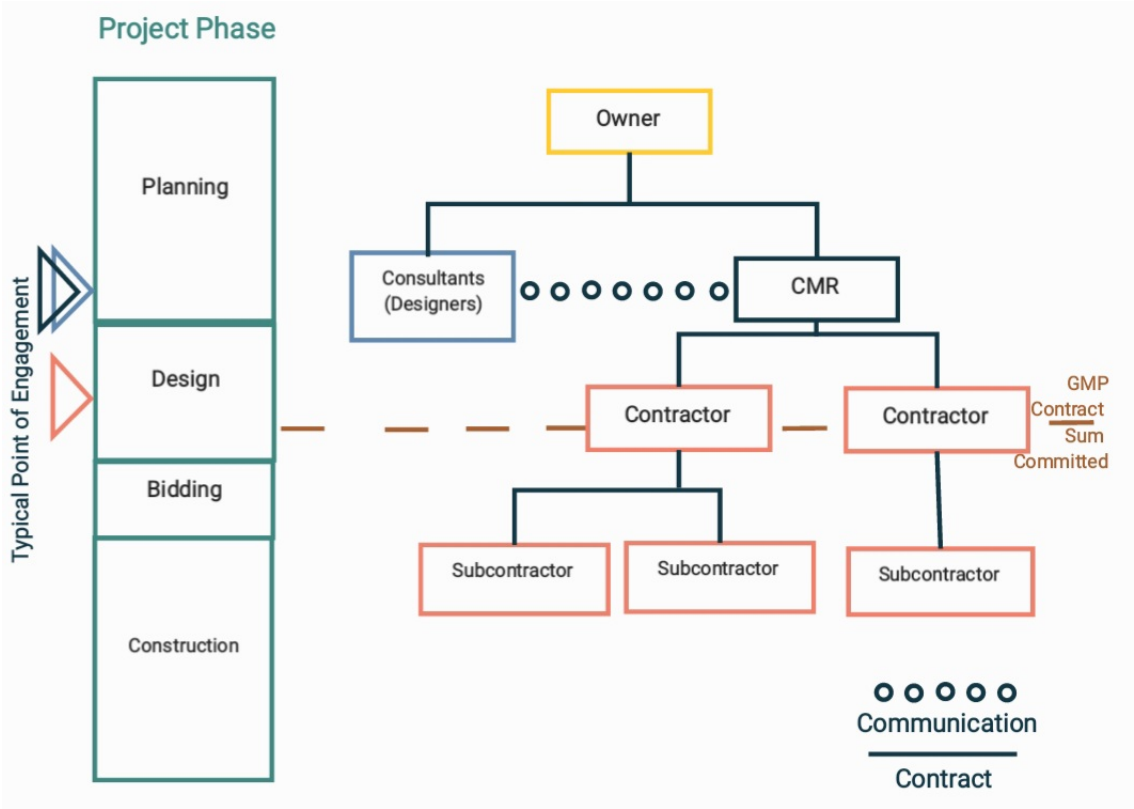

Figure 3.1.6: Typical CMR Delivery Model [36, 16].

3.1.5 Collaborative Project Delivery Models (CPDMs)

The construction industry faces challenges related to inefficiencies and a growing complexity in projects. To address these issues, innovative delivery models have emerged, often referred to as "collaborative" models, as they focus on aligning the interests of project stakeholders with the goal of enhancing project outcomes [37]. There are convincing arguments for adopting these new approaches, where parties aim to collaborate to achieve common objectives. First, Complex projects require the involvement of all parties at an early stage to find optimal solutions for the final product. This contrasts with traditional approaches that often prioritize discussions about risk allocation and dispute resolution. Second, Collaborative models aim to reduce the risk of work-related crimes and address ethical challenges commonly associated with conventional project deliveries [38].

Three of the most prominent collaborative models are project partnering, project alliancing, and integrated project delivery (IPD). These relational project delivery models share several key characteristics to varying degrees, including early involvement of key parties, transparent financial, shared risk and reward structures, joint decision-making, and collaborative multiparty agreements [39].

According to Walker, the primary differences between project partnering and project alliancing derived by the selection process, organizational management framework, and the nature of risk and reward incentives. In alliancing, the profit margins and reward structures of each participant are collectively at risk, meaning that the entire alliance entity benefits or faces challenges as a whole. In contrast, in partnering, individuals may gain rewards at the potential expense of other

partners. Partner selection also differs: partnering places significant emphasis on project cost determination, while alliancing prioritizes establishing the best possible team of project partners in the belief that a real collaborative environment will result in the highest project value [40].

According to Raisbeck applying some lean construction tools and BIM, as well as involving a great number of sub contractor in IPD team has known as the main features of IPD. limitation of legal recourse to instances of wilful default or bankrupt, a well-defined team selection process and, obviously, involvement of financial auditors are considered some of the main characteristics of PA which not embedded in the IPD approach [41]. Concerning team selection, IPD is commonly associated with a non-standardized process due to the diverse types of participants involved. This approach is predominantly adopted within the private sector, where there are minimal constraints on selection methods, ultimately leading to a single contract procedure. In contrast, Project Alliancing (PA) is linked to a competitive selection process, where the presence of different contracts for the development phase serves as an indicator of a real alliance agreement [39]. In scenarios where project uncertainties are tied to factors like complexity, functionality, and compatibility, and these risks can be mitigated through early collaborative planning (as seen in vertical building projects), IPD is deemed an appropriate approach. Conversely, PA is primarily applied to transportation infrastructure projects (horizontal projects), where the most uncertain factors encompass stakeholders, scheduling, traffic management, site conditions, among others. These aspects are typically addressed during the execution phase [42, 43].

Thomsen's suggests that IPD represents a logical evolution of PP, where contractual structures have been combine into the collaborative spirit of partnering [44]. Under IPD, contractors are engaged at an early stage of the project, whereas in PP, the main contractor is selected conservatively through a competitive process based on the owner's initial design. Subcontractors in PP are typically involved through formal competitive procurements following the joint development of the design, minimizing uncertainties related to the construction solution. Lahdenpera also underscores, under PP uncertainties associated with the construction solution are mitigated to a greater extent when compared to the early selection process in Integrated Project Delivery (IPD). This discrepancy arises because IPD often lacks detailed plans, which, in turn, necessitates a transition towards a joint liability framework similar to the Project alliancing (PA). This shift is imperative to reduce the owner's exposure to risks and enhance overall project efficiency [39].

3.2 PPP / BOT at Turkey

The global utilization of the Public-Private-Partnership (PPP) model and its various adaptations for infrastructure projects is a widespread phenomenon. Different countries, whether they are developed or developing, have had unique experiences with PPP projects, shaped by their distinct legal, economic, social, and political conditions. However, despite these variations, there are common challenges, risks, restrictions, and success factors encountered across the board [45].

In the case of developing countries like Turkey, there is a intense need to meet the substantial demand for new infrastructure construction. Particularly when

encountered with limited government funds, collaborating with the private sector emerges as a viable solution to alleviate the financial burden on the government budget. Over the past three decades, the Turkish government has frequently experienced to the public-private partnership model and its variations as a means of generating an alternative financing mechanism for infrastructure projects [46].

Based on the data from the World Bank, between 2008 and 2013, Turkey entered into 124 PPP contracts valued at over 43 billion USD. This figure accounted for nearly 47 percent of the total projects financed by private sectors in Europe and Central Asia during that period. Additionally, a survey conducted by Deloitte in 2012, with participation from 67 global PPP firms, indicated that Turkey had the second most promising PPP market globally, following the United States, in the medium to long term [26]. Turkey's extensive experience in PPP projects positions it as a valuable source of knowledge that can be shared with the global market [28].

3.2.1 Leagal Framework and Limitation

Prior to the 1980s, the responsibility for providing infrastructure services in Turkey was with the public sector, and the concept of privatization was uncommon. However, a significant shift occurred with the introduction of the first Build-Operate-Transfer (BOT) law in 1984 [47]. This marked the commencement of Turkey's mega infrastructure financing and construction programs. Despite this initially step, several limitations prevented the substantial realization of BOT projects until the late 1990s [48]. During this period, various constraints included legal restrictions, a lack of experience, prolonged bureaucratic processes, inefficiencies in procurement procedures, and the government's reluctance to assume host country risks. These factors collectively posed significant barriers to the execution of BOT projects. However, there has been a consistent commitment from the government and parliament to address these limitations. This commitment has manifested in continuous efforts to modify existing laws and introduce new, specialized legislation aimed at eliminating restrictions and establishing a robust legal framework for diverse Public-Private Partnership (PPP) models. The evolution of active PPP laws in Turkey is highlighted in the table 3.2.1 [45].

In Turkey, legislation has played a vital role in enabling Public-Private Partnerships (PPPs) for highway and infrastructure projects. For instance, the Law No. 3465 (1988) ended the monopoly of the General Directorate of Highways, allowing private entities to build, maintain, and operate highways using BOT or TOR models for up to 49 years. At the agreement's end, control reverts to the government. Private bidders must provide a bid bond (1-3% of total investment), and if they fail to fulfill their obligations, the bid bond transfers to the public entity. Also, the Law No. 3996 extends private sector involvement to projects requiring advanced technology or significant funding. It covers various infrastructure types, including highways, dams, airports, and more, with agreements lasting up to 49 years. Project proposals require approval from the Higher Planning Council (HPC), and bidders must have relevant experience. Bid bonds are required, and a performance bond (1% of total investment) is provided upon contract award. All investments and services return to the government at the agreement's end. These laws have created a framework for collaboration between public and private sec-

tors, allowing them to jointly undertake critical infrastructure projects in Turkey [45, 49].

Number	Year	Model	Definition
3096	1984	BOT, TOR	Authorization the private entities to generate, transmit, distribute and trade electricity other than the Turkish Electricity Administration
3465	1988	BOT, TOR	Commissioning of entities for access controlled motorways (highways)construction, maintenance and operation other than the General Directorate of Highways
3996	1994	BOT	Commissioning of certain investments and services for BOT implementations
4046	1994	TOR	Arrangements for the implementation of privatization and amending certain laws and decrees with the force of law
4283	1997	BO	Construction and operation of electricity generation plants and regulation of energy sales in the BO model
5335	2005	TOR	Transfer of operation rights of airports and passenger terminals other than General Directorate of State Airports Authority
5396	2005	BLT	Regulation on the construction of health facilities on a lease-and-build basis and the restoration of the services and areas in facilities other than medical service areas on the restore-and-operate basis

Table 3.2.1: Evolution process of PPP's Law Modification in Turkey (BOT: Build-Operate-Transfer; BO: Build-Operate; TOR: Transfer of Rights; BLT: Build-Lease-Transfer) [49].

3.2.2 Organization

Turkey is a prominent destination for PPP projects, but these initiatives face numerous challenges, including delays in preparing project documents, inadequate impact assessments, limited public sector commitment, and inexperienced officials in the procurement process. To address these issues, Delmon proposed the establishment of a central professional institution offering consulting services for complex public service procurement [50]. This approach has been successful in various countries, such as Australia, the UK, and South Africa. The main responsibilities of such a central unit include formulating a national PPP strategy, ensuring project alignment with national goals, evaluating and monitoring projects, and standardizing procedures and documentation for implementing agencies [45].

3.2.3 Market Situation

Despite mentioned limitations in the legal framework and the lack of interdisciplinary coordination between different administrations, Turkey's different sectors like Electricity, roads, airports, seaports, hospitals, and Telecom during the past decades were benefited by PPP project frequently. Figure 3.2.1 illustrates the number and value of PPP contracts Delivered between 1990 until 2013. According to this diagram, the central government has delivered 174 PPP projects in value of 100.7 billion in this period of time and almost 45 percent of them in terms of number and 70 percent in terms of value, delivered after 2007. The results indicates that the average size of projects considerably is growing in recent years. Table 3.2.2 also provides an overview of the distribution of PPP projects across various sectors in Turkey from the early 1990s to 2013. As is demonstrated, highways sector has a significant market share, amounting to 10.3 billion USD in value. Notably, 9.2 billion USD was allocated to just two projects, namely the Gebze-Izmir Motorway and the Third Yavus Sultan Selim Bridge [26]. Analyzing the data from figure 3.2.2 and table 3.2.2, it becomes apparent that the Build-Operate-Transfer (BOT) model had the largest market share in Turkey during that period, representing 52% of the total project value. Notably, every Turkish highway project utilized the BOT model, emphasizing its dominance as the favored project delivery approach within this sector. However, As demonstrated in figure 3.2.3, Turkey's overall infrastructure investment quality is notably lower compared to other OECD (Organisation for Economic Co-operation and Development) countries. This observation underscores the potential for significant improvements and further advancements in Turkey's infrastructure investment landscape [51].

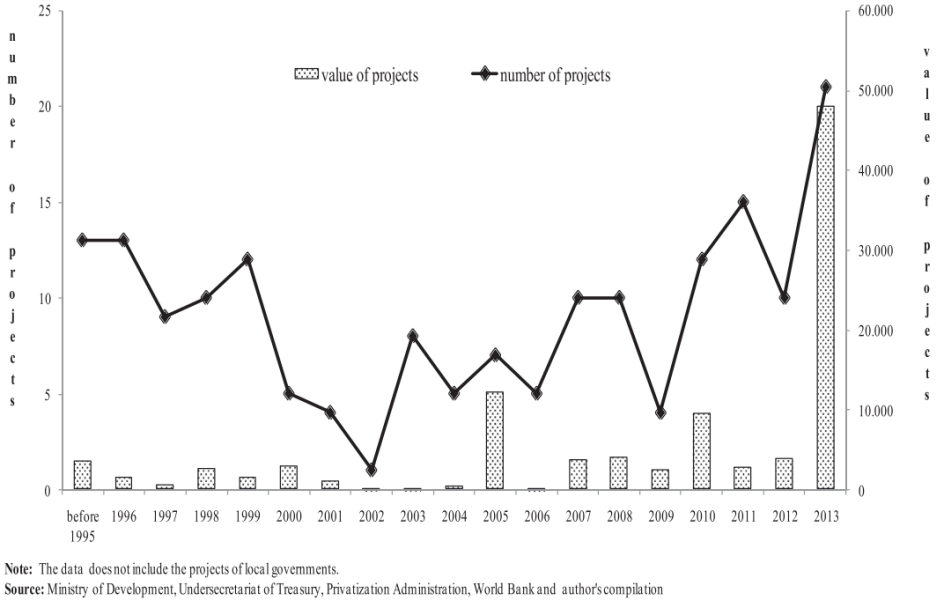

Figure 3.2.1: Number and value of PPP projects in Turkey, 1990e2013 (million USD) [52].

Sectors	BOO	BOT	BLT	Concessions	TOOR	Total
Electricity	3677(5)	3250(25)			13017(46)	19943(76)
Airports		40587(13)			9645(6)	50232(19)
Roads		10306(22)				10306(22)
Seaports		309(16)			1659(17)	1968(33)
Hospitals			3826(5)			3826(5)
Telecom				13208(4)		13208(4)
Border gates		335(13)				335(13)
Water		865(2)				865(2)
Total	3677(5)	55651(91)	3826(5)	13208(4)	24322(69)	100684(174)

Table 3.2.2: Distribution, number, and value of PPP project in Turkey from 1990 to 2013 [52]. (Note: Values in brackets depict the number of projects, while others indicate the value of projects.)

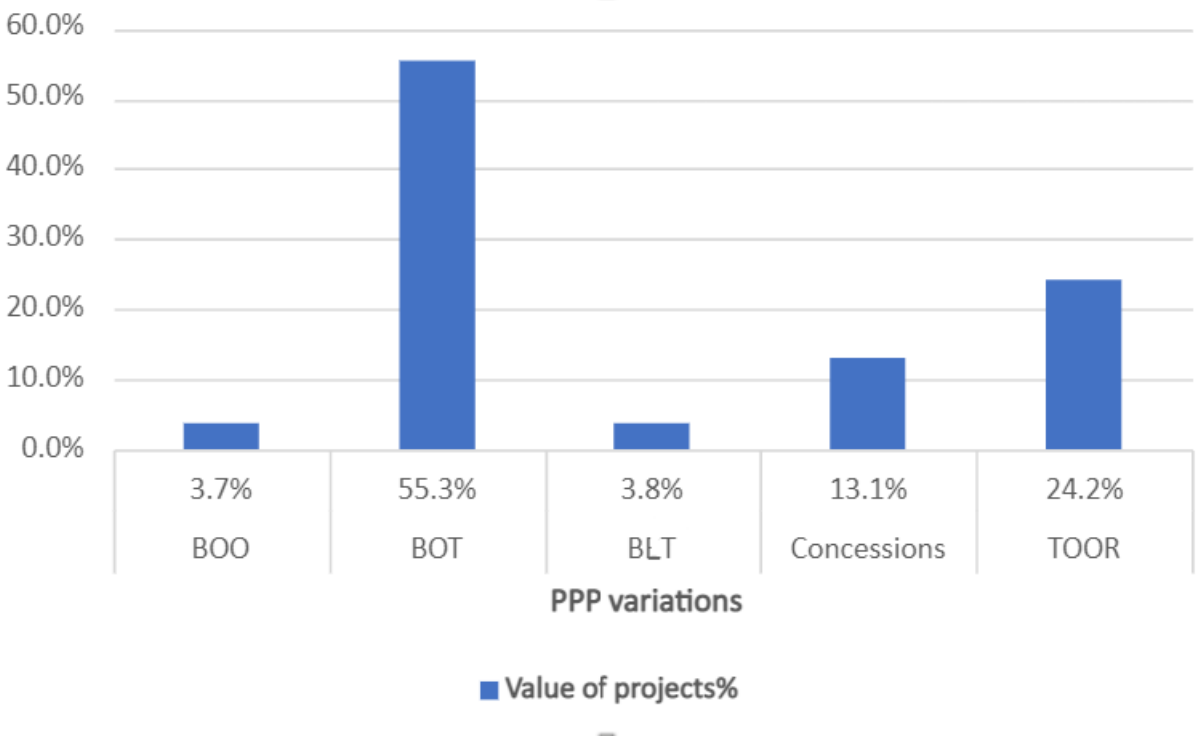

Figure 3.2.2: The share of PPP Variation in the Turkish market(1990-2013).

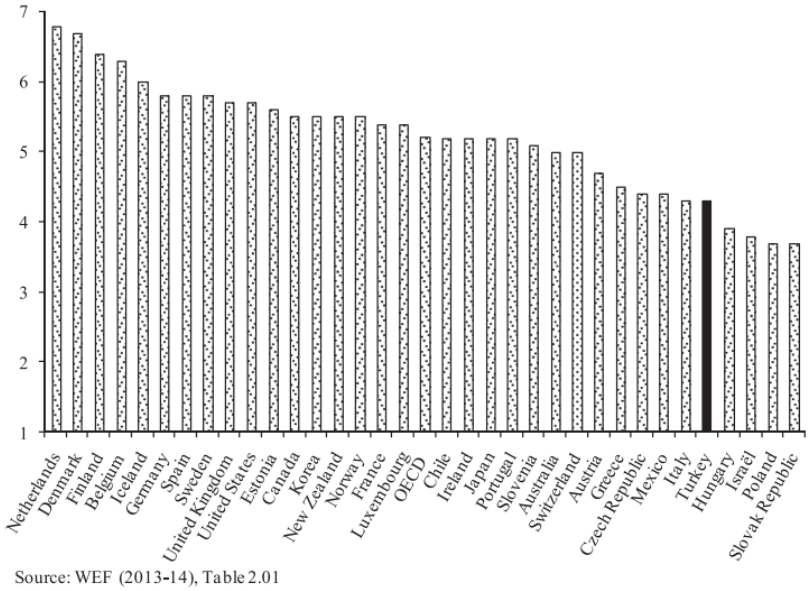

Figure 3.2.3: The quality of infrastructure in OECD countries [51].

3.2.4 Risk Allocation

Eurostat (2010) identifies three key risks in Public-Private Partnerships (PPPs): construction, availability, and demand risks. Construction risks, including cost overruns, delays, and expropriation, are typically assigned to the private party. Demand risks are shifted to the public sector, guaranteeing revenue during the operational phase, irrespective of market demand, as long as the private partner adheres to predefined contract specifications and standards. Availability risks relate to meeting contract standards and specifications (e.g., bridge dimensions in a highway project) and are transferred to the private partner [53]. However, in the case of Turkey, inaccurate service demand forecasting by contract agencies and the use of foreign currencies (USD or Euros) as demand guarantee payments have introduced additional extra risks, such as currency and inflation risks for the public sector. In some instances, the government has had to provide loan guarantees to support the creditworthiness of PPP contracts [26]. Despite the theoretical preference for allocating financial responsibilities to the private party, as outlined by Yescombe (2007), practical considerations often lead governments to become involved in financial matters to ensure the timely provision of public services [22].

3.2.5 Tendering

Public Procurement Law (PPL) in Turkey was initially designed to align with EU directives, particularly for complex projects like those involving competitive dialog in the procurement process. However, PPP contracts in Turkey have often been awarded based on specific institutions' internal rules and directives. There are two distinct regimes for public procurement in the country, one utilizing public funds and the other private funds. To expedite the procurement process for PPPs, Turkey has introduced certain exemptions from parts of the PPL. Unfortunately, this has led to reduced transparency and competition compared to the

standard PPL [26]. Furthermore, the limited number of capable private entities in the PPP market has resulted in low competition for PPP contracts. In fact, the top eight firms held nearly 59 percent of the market share in Turkey's ambitious PPP program from 2007 to 2013 [54]. Guasch (2004) points out that due to their long-lasting nature, PPP contracts may require revision and renegotiation. Renegotiation can be beneficial if it aims to enhance efficiency but can be detrimental if it's principally for the private entities' extra profits [55]. In addition, there are some legal packages in place to motivate private partners. These include loan guarantees for certain projects to encourage private participation in Turkey's PPP program, tax exemption laws that apply to both new and existing PPP contracts, and contractual expectations that allow winning bidders to revise contracts for additional benefits [56].

3.2.6 The Osmangazi Bridge - OGB (Izmit Bay Bridge)

3.2.6.1 General Specification

The first long-span suspension bridge in Turkey, constructed across Izmit Bay near Istanbul, is part of the Gebze-Orhangazi-Izmir motorway project. It significantly reduces travel times on various routes, including a 1.5-2 hour reduction on the Istanbul-Bursa route, 3-4 hours on the Istanbul-Balikesir route, and 4.5-6 hours on the Istanbul-Izmir route [57]. Once completed, it will rank as the world's fourth longest suspension bridge, with a total span length of 2907 meters and a main span of 1550 meters. The bridge's main deck accommodates three traffic lanes on each side and features an aerodynamic box section supported by internal truss elements and diaphragms. The towers, standing at 252 meters in height, are anchored to submerged concrete foundations in the sea [58]. See Figure 3.2.4 for a visual representation of the Osmangazi Bridge.

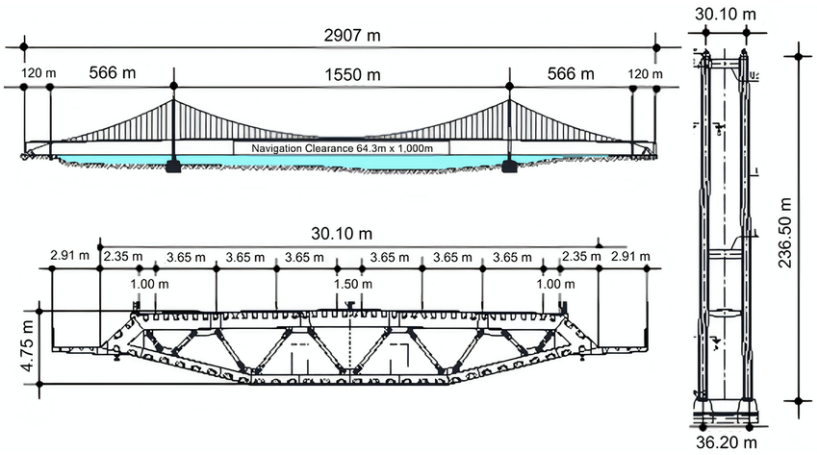

Figure 3.2.4: General layout and dimensions of Osmangazi Bridge [57].

3.2.6.2 Contractual Specification

In April 2009, a joint venture consisting of an Italian company (Astaldi) and five Turkish constructors won a BOT tender for the Gebze-Orhangazi-Izmir Motorway and Osman Gazi Bridge project, between two bidders. The selection criteria were based on the shortest contract period. The contract, signed in 2010, spanned 22

years and 4 months, with 7 years allocated for construction and the rest for operation. Any time saved during construction was intended to extend the operation period, while construction delays would result in deductions from the operation period. The total investment for both projects was approximately 7.6 billion USD [58]. The Osman Gazi Bridge portion of the project, costing around 1 billion USD, was awarded to the IHI-Itochu Consortium, a Japanese infrastructure firm, in July 2011. The Consortium, with prior experience in Turkey's infrastructure projects, were responsible for engineering, Construction, and construction (EPC) based on FIDIC Silver book contract. The project's design was subcontracted to the Danish consultant firm COWI AS. As it shown in the figure 3.2.5, OTOYOL (the national network of controlled-access highways in Turkey) handled project coordination, and NOMAYG represented the joint venture of the six main contractors involved in the highway project. Construction began on March 30, 2013, and concluded on June 30, 2016, with a total cost of 1.3 billion USD [59, 58].

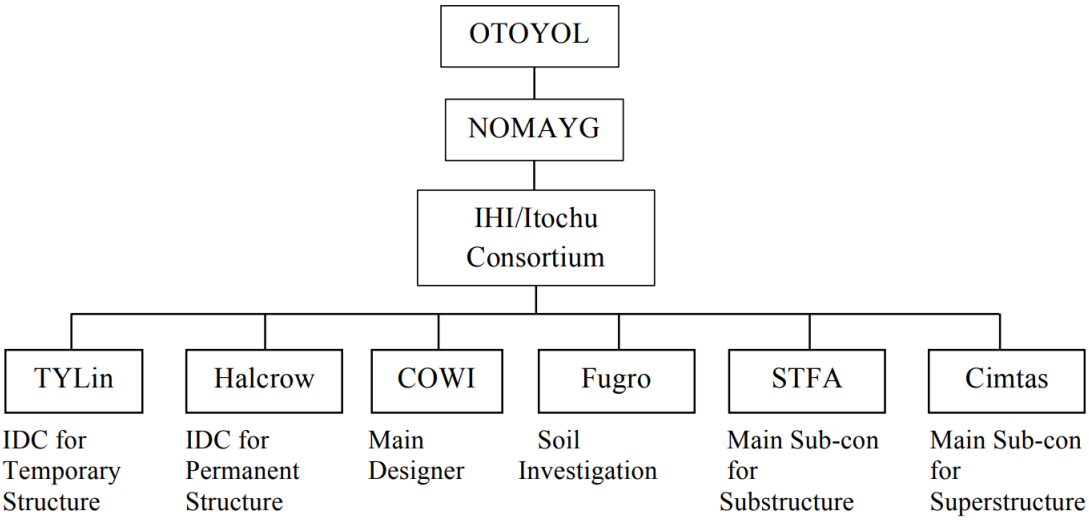

Figure 3.2.5: Organization chart for Osmangazi Bridge project [59]. (IDC: Independent Design Control)

The General Directorate of Highways (GDH) provided a tariff guarantee, in addition to usual traffic guarantees, for the Osman Gazi Bridge project. This tariff guarantee, initially acceptable at the tender stage, faced criticism when the Turkish Lira (TL) depreciated against the USD in 2015. The TL's value dropped significantly, causing the tariff to nearly double. Consequently, if the traffic demand falls below the guaranteed level, any financial losses incurred by the BOT (Build-Operate-Transfer) company must be compensated by the state. This financial burden on the state has raised concerns about the project's ability to achieve its expected economic impacts [58].

3.2.6.3 Main Uncertainties

In a 2015 study by Beliz Ozorhon and Sevilay Demirkesen during the construction of the Osman Gazi Bridge (OGB) project, key individuals from both public and private parties involved in the project were interviewed to identify and assess risk factors. The study aimed to prioritize these risks by considering their impact and

probability of occurrence. The main findings revealed that the highest-priority risk factors for the OGB project fell into three categories: legal, regulatory, and political risks; financial risks; and engineering and construction risks, all of which were considered high-risk factors. Financial risks were expected in such a large project due to potential unexpected costs affecting cash flow. The project's international nature introduced challenges related to compliance with local regulations, political uncertainties, and differences in specifications, codes, and requirements. Technical issues like delays, coordination difficulties, and construction competency were also high-uncertainty factors. While design, environmental, safety, and traffic risks were categorized as medium-level risks, they still needed attention due to their relatively high severity. Other risk factors, although not as significant, had medium impacts and required ongoing monitoring [59].

3.2.7 The Yavus Sultan Selim Bridge - YSS (Third Bosphorus Bridge)

3.2.7.1 General Specification

The Yavuz Sultan Selim Bridge, also known as the Third Bosphorus Bridge, is a hybrid cable-stayed-suspension structure integral to the Northern Marmara Motorway project. Located at the entrance of the Bosphorus River leading to the Black Sea, it was designed to ease traffic congestion in Istanbul, primarily for heavy vehicles and transit freight traffic [58]. As it is demonstrated in figure 3.2.6 this impressive bridge comprises four motorway lanes and one railway lane in each direction, making it the world's widest and longest suspension bridge with a railway system. The total length of the bridge is 2164 meters, with a width of 59 meters and a main span length of 1408 meters. Its distinctive triangular hollow section towers, reaching a height of 322 meters, are constructed from reinforced concrete, while other elements use structural steel [57].

3.2.7.2 Contractual Specification

On May 29, 2012, a private consortium named ICA, consisting of Turkish construction company Ictas and Italian construction company Astaldi, was awarded the BOT (Build-Operate-Transfer) tender for the Third Bosphorus Bridge project. The consortium held a 67% share controlled by the Turkish company and a 33% share by the Astaldi group. The contract had a duration of 10 years, 2 months, and 20 days, with 2 years and 6 months allocated for construction. Any time saved during construction was to be added to the operation period, while construction delays would be deducted from the operation period. Remarkably, the construction of the Third Bosphorus Bridge was completed within three years, finishing on August 26, 2016, which was a record achievement for such a project [58, 28].

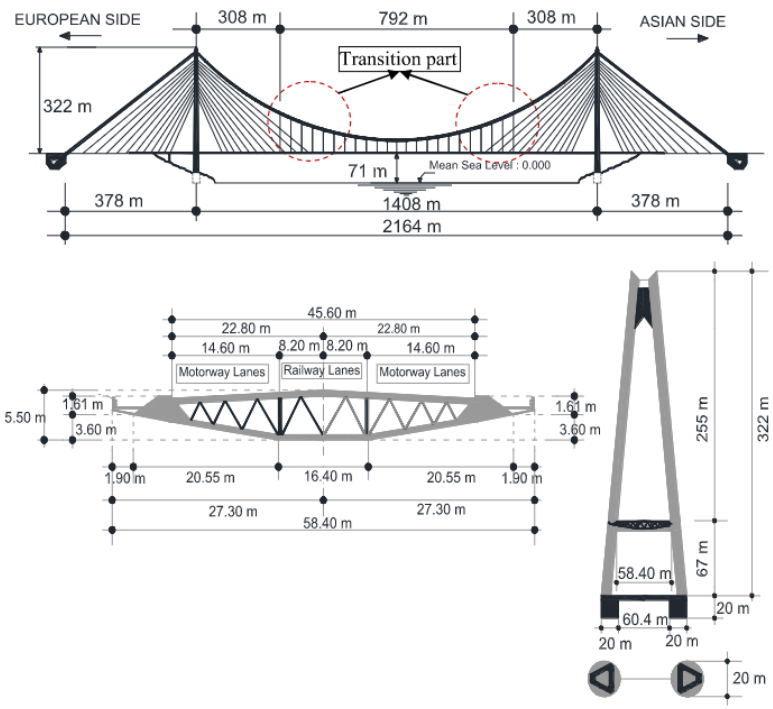

Figure 3.2.6: General layout and dimensions of YSS [57].

In typical BOT projects, governments usually assume responsibility for political and force majeure risks and guarantee product demand. However, in the Yavuz Sultan Selim (YSS) project, the government assumed a broader range of risks, including financial, construction, and availability risks, which is unusual for a BOT project. For instance, the Turkish government provided financial and loan guarantees to secure the necessary project funding. The project cost almost three billion USD, with 2.3 billion USD financed through loans with a 9-year maturity term from Turkish banks, backed by Treasury guarantees. The demand guarantee was set at 135,000 vehicles per day, with the government committing to pay 3.2 USD for each vehicle, resulting in a daily payment commitment of 432,000 USD during the contract period. Due to lower-than-expected traffic in the initial years, the government had to compensate the operator significantly, with payments exceeding 10 million USD in some months. This highlights the importance of precise feasibility analysis and demand evaluation in the early stages of such projects [58, 28].

Given the novelty of the project for ICA, they had to bring together various technical expertise to address numerous technical challenges and find innovative solutions. Several firms and companies with experience in similar bridge projects were involved in the project. Additionally, 74 local and multinational firms from 21 different countries participated in various aspects of the project.

3.2.7.3 Main Uncertainties

In 2020, Yang Liu and colleagues conducted a risk analysis for the Yavuz Sultan Selim (YSS) project, which was almost four years after the completion of project construction. They conducted the study through surveys and relevant documents, categorizing identified risk factors into five main categories, as shown in Figure

3.2.3. These main categories were further developed into ten specific risk factors. To assess these risks, they applied the Analytic Hierarchy Process (AHP) and a fuzzy decision-making method. The results indicated that political, social, economic, and contractual risks were the most significant, with considerable probabilities of occurrence and impacts on the project. In contrast, uncertainties related to laws and regulations, financing, safety, completion, and operation were considered to have a medium level of severity [60].

Number	**Overall risks Of project**	**Specific risks of project**
1	National political risk in Turkey	YSS bridge's financing risk
2	National economy risk in Turkey	YSS bridge's contract risk
3	National legal risk in Turkey	YSS bridge's construction period risk
4	National social risk in Turkey	YSS bridge's completion risk
5	National natural risk in Turkey	YSS bridge's operation risk

Table 3.2.3: Identified risk factors in the YSS project [60].

CHAPTER

FOUR

RESULTS AND DISCUSSION

4.1 Critical Path

4.1.1 Project Financing

At first glance, when it comes to the critical path in a construction project, critical activities on execution process comes to mind. But considering a holistic approach to the PPP projects which a government has given a concession to private companies with the condition that the private companies must secure the finances for the execution of the project, the closure of the finance will be one of the most critical milestones and without providing that, the project cannot be begun. Securing loans from the local and international banks, and financial institutions for such a mega development project is the starting point which directly impacts on the success of the project.

The importance of financing in this project is on par with construction and engineering, as timely funding is essential for the efficient execution of operations [5]. Financing is an essential prerequisite for any construction project. Conversely, financiers require assurance in various aspects such as engineering, production, schedules, and quality before committing to fund the project. The cost estimates, derived from thorough studies conducted by Employer Administrations and producers prior to and during the tender process, need to be highly accurate compared to other projects implemented using alternative models. This precision is crucial because once the financing is finalized, the opportunities for securing additional loans become extremely limited. Investors incur significant expenses when providing supplementary capital [61].

The financing for the 1915 Çanakkale Project stands as a remarkable accomplishment. Addressing the liquidity requirements entailed structuring a financing arrangement involving the participation of seven distinct lender groups, each with their unique prerequisites. These groups included participation banks, export credit agencies, as well as local and international commercial banks. The magnitude of this endeavor necessitated a substantial consortium of financial entities with varying perspectives, all striving to reach a consensus on the structure, documentation, and contracts within a tight time-frame . Turkey witnessed a groundbreaking accomplishment in the financing of the project, as the assembly of project documentation and contracts managed to attract an impressive funding

of nearly 2.3 billion euros in less than a year. This remarkable feat stands as a record achievement within the Turkish context, demonstrating the efficiency and effectiveness of the financing process for the project [8].

Ultimately, a 15-year term loan from 25 banks and financial institutions from 10 different countries was successfully secured for the project, with a grace period of 5 years, amounting to a total sum of 2.265 billion Euros. The loan structure consisted of 70 percent provided by 19 foreign banks and financial institutions, and the remaining 30 percent by 6 Turkish banks. Additionally, the project's shareholders contributed over 900 million Euros of equity investment. The credit package was intricately composed of eight distinct tranches, incorporating elements such as Export Credit Agencies (ECA's) and Islamic financing methods, ensuring compliance with international project financing standards [3].

4.1.2 Design

In Such a huge mega bridge construction project, the starting technical point is always design and engineering activities, so without a certain level of design and engineering, the other department cannot start the work properly. Design activities can be divided into conceptual design and detailed technical design. The former one is needed for getting an environmental permit and some part of the detailed design. On the one hand, this permit and design were incorporated with each other so that to get the environmental permit a certain level of design input is required. On the other hand, the environmental permit and the financial close are incorporated because the banks would like to receive some environmental reports in order to decide to finance the project. Therefore, all these three activities as mentioned are interrelated to each other and delays occurring in each of them will impact on others and the whole project. Detailed design and engineering are the major issues for the execution of the project. It is prerequisite activity to start both the procurement of specific materials and construction works.

In practice, this project followed a fast-track approach, where construction began concurrently with the design process. As each design phase was finalized, construction progressed accordingly, allowing the project to move forward without delay. This methodology is commonly employed in projects of this nature. The overall duration of the project was completed within five years, which served as a significant milestone. To adhere to this timeline, a strict and proactive approach was adopted, ensuring that all tasks were efficiently managed. If the project had insisted on waiting for full completion of the design before commencing construction, it would not have been possible to meet the established time-frame. Therefore, the decision was made to initiate construction or procurement activities while the design phase was still ongoing.

4.1.3 Procurement of specific materials

There are Many specific materials with the long fabrication process in this kind of bridges because everything is in mega size with highest technology. since to keep up the timeline and schedule Certainly very specific materials must be delivered on time, while it almost takes one year or more to fabricate these kinds of items. Therefore, procurement of strategic materials for the project can be another criti-

cal activity. For example, PPWS (Prefabricated Parallel Wire Strand) consisting of high strength wires (1960 MPa) was used on the main cable in Canakkale bridge which has come into use in suspension bridges in recent years. The target is to obtain a high strength main cable with the smallest section. A joint venture including Korean and Chinese companies was responsible for producing this specific material so that wires were produced in Korea then processed into PPWS in China and finally, supplied and installed in Turkey. If by chance during transportation or construction stage one of them to be sunk, it needed to go back again to a very early stage to produce. According to the deputy project director of the project, "Any supply chain problem might cause around 13 months' delay to the project". It was just an example and there were lots of specific items including steel shafts, tower sections, steel deck, hangers, clamps which their on-time delivery play key role in the project success and possible delay has negative impacts in terms of time and cost for the project.

Although some interviewees say that every activity in mega projects is on the critical path, according to most of the interviewees practically it's not acceptable because it is impossible to execute everything at the same time. Therefore, putting some floats for some long progress tasks like procurement activities is vital. Even though starting the design in the early phase of the project put certain amounts of floats for the material procurement activities, occurring some force major like Covid 19 during the project execution changed those activities to the critical and put them on the critical path.

4.1.4 Construction Works

From the EPC (Engineering-Procurement-Construction) point of view there was just one critical path including the construction of Caissons, steel shafts, towers, catwalk, main cables, and steel decks which were the most critical and major items in the construction phase. Following explanation provides a primitive familiarity about what were the Canakkale bridg's critical activities during the construction phase.

4.1.4.1 Caisson Works

In the field of engineering, caissons refer to steel or concrete structures employed in construction sites located either underwater or with water present on the ground. The primary purpose of these structures is to establish a stable foundation within aquatic environments. Caissons are particularly favored for bridge foundations and situations where pile foundations are impractical or insufficient. These caisson foundations, essentially hollow boxes with square or rectangular shapes, are constructed in advance and subsequently lowered into the water depths utilizing cranes [7].

1915Çanakkale Bridge's towers are rising through the water. The caissons (towers' foundations) were built in a dry dock located on the European side, and each had dimensions equivalent to that of a football field, each caisson weighs approximately 50,000 Tonnes. Subsequently the caissons were floated to their designated locations and carefully submerged to precise depths of 37 meters on the European side and 45 meters on the Asian side, with accuracy of eight centimeters and five

centimeters, respectively. Although the design allowed for a horizontal placement tolerance of 20 centimeters, the implementation of guiding poles driven into the seabed earlier ensured that the maximum deviation was successfully limited to just eight centimeters.

To provide a robust foundation, the caissons are positioned on top of three-meter-thick layers of crushed stone that are meticulously placed on the seabed. Prior to this, the seabed was reinforced with steel poles for added strength. In terms of seismic design, the project took into account the impact of an earthquake with a return period of 2475 years. The objective was to minimize the potential damage to the submerged sections of the bridge in the event of such a significant seismic event.

Excavation work for the dry dock, measuring 254 meters by 178.3 meters (equivalent to 4 football fields), and with a depth of 10.5 meters, commenced on August 28, 2017. A total of 318,000 cubic meters of material were excavated to construct the dry dock basin. To enclose the dry dock area, 1328 steel sheet piles were driven into the ground, forming a combined length of 26 kilometers. To prevent the caissons from sinking into soft soil, a layer of 20 centimeters of concrete was applied to the ground. Additionally, concrete canals were created to allow water to flow underneath the caissons during the floating stage, facilitating their lifting process.

The initial concrete pouring for the caissons, occurred on March 19, 2018. A crucial aspect of the concrete used was its durability, designed to withstand a lifespan of 100 years. To meet this high standard, rigorous quality assurance tests were conducted over a span of eight months. Within each caisson, 80 cells were constructed to facilitate a balanced and controlled immersion into the seabed.

Once approximately 80% of the Asian caisson and 76% of the European caisson had been completed, the process of flooding the dry dock commenced on December 15, 2018. Within 36 hours, the caissons began to float, and the flooding process continued for an additional 48 hours. To ensure the caissons were floating in a balanced manner, meticulous observations were conducted using precise GPS devices and markings on both the caissons and the dry dock. The sheet piles, which were installed during the one-month construction of the dry dock, were subsequently removed, and the seabed was dredged. This created an access point on the shore side of the flooded dry dock, facilitating the transfer of the caissons.

The towing of the Asian Caisson commenced on January 16, 2019. In this operation, four tugboats belonging to the Coast Guard General Directorate were utilized. Each of these tugboats had a towing capacity of 88 Tonnes. The caissons were towed to the wet dock, which was situated approximately 400 meters away from the dry dock area. The entire towing process took around 15 hours to complete. The same towing operation was repeated for the European Caisson on January 18, 2019. All in all, the whole process of Caissons' construction and installation took almost 17 months to completion [7].

4.1.4.2 Steel Shafts

Within the scope of the 1915 Çanakkale Bridge and Malkara-Çanakkale Motorway project, steel shafts play a crucial role as essential construction components that establish the link between the caissons and the towers. Similar to the various

stages involved in constructing the bridge, the fabrication, transportation, and installation of these shafts also have a detailed and intricate narrative.

The story of the shafts commenced in December 2017, when a cost report was generated based on the concept design, and the tender process was initiated. The 1915 Çanakkale Project faced numerous challenges throughout its various phases, with time constraints being just one of them. The tender involved the construction of four steel shafts, each measuring 18 meters in diameter. Among these, two shafts were designed to be 26 meters high, while the other two were intended to reach a height of 23 meters. To accommodate the varying water depths on the Asian and European sides of the Çanakkale Strait, the shafts were fabricated at different heights. Out of the total height difference of 8 meters, 5 meters were offset by the caissons, which formed the foundations of the towers, while the remaining 3 meters were accounted for by the height of the shafts installed atop the caissons.

In March 2018, Çimtaş was selected as the fabricator company for the shafts. Weighing 1206 Tonnes on the Asian side and 1052 Tonnes on the European side, production of the shafts commenced in June 2018, following the completion of modeling and preliminary production preparations. The production process was divided into two phases and reached its conclusion nine months later in March 2019. The steel panels, which were fabricated at Gemlik Shipyard, were transported to Gölcük Shipyard, where they were assembled. To safeguard against corrosion, a cathodic protection method known as ICCP was applied to the steel shafts [3].

4.1.4.3 Towers

The rise of the towers was a significant milestone achieved in the construction of the 1915 Çanakkale Bridge. The towers, symbolizing the Çanakkale Victory on March 18th and standing at an impressive height of 318 meters, have been successfully erected. These towers proudly display the Turkish flag with its distinctive red and white colors. The completion of this monumental task required nearly 10 months of dedicated work and marks a crucial phase in the construction process.

The construction of the tower blocks, consisting of panels, took place at the Çimtaş Shipyard. Once the panels were manufactured, the blocks were formed by sequentially carrying out welding and painting processes. The first six blocks were constructed as a single piece, while the 7th, 14th, 24th, and 32nd blocks were divided into four pieces, and the remaining blocks were divided into two pieces. A total of 32 blocks were assembled for each steel tower leg, with three cross beams positioned between each leg. The weight of the blocks varied between 200 and 770 tons, while their dimensions ranged approximately from 7 to 10 meters in width and 7 to 11 meters in height. Except for specific blocks, the typical "L" shaped two-piece blocks had an average weight of 225 tons. Special blocks weighed around 350 tons, and the primary block weighed approximately 770 tons. The total weight of the steel tower, including all the assembled blocks, amounted to 35,514 tons.

Delicate Operation applied to accomplish this challenging work. The completion time for erecting the tower blocks varied due to their different structures and weights. Challenging weather conditions, particularly strong winds, posed difficulties during transportation by boat to the towers. The direction of the wind played a crucial role in determining the feasibility of transportation. Even a slight

difference of one or two points in wind direction between two towers could impact the progress of the work. The Asian tower, situated near ridges on the shore, was relatively less exposed to northerly winds. On the other hand, the European tower faced more intense winds and was generally more affected by adverse weather conditions. Before commencing the erection process, thorough checks were conducted to ensure that the wind speed and wave height remained within acceptable limits. If the wind speed exceeded 43.2 kilometers per hour or the wave height surpassed 0.9 meters, erection operations were suspended, considering the specifications of the tower crane and barge used for transportation [5].

4.1.4.4 Catwalk and Main Cables

Catwalk systems play a vital role in the construction of suspension bridges, particularly due to the long spans involved. These systems serve as temporary structures that provide access to construction works across the bridge. They enable the installation of permanent components such as the main cable (PPWS - Prefabricated Parallel Wire Strands), hangers, clamps, and the bridge deck itself. The catwalk system serves as both a working area and an access pathway, allowing personnel to work above the sea on the permanent structures of the bridge. The completion of the catwalk system marks a significant milestone in the project. Subsequently, the installation of the main cable, which bears the entire traffic load, begins.

When constructing the world's longest mid-span suspension bridge, the dimensions of the structural components naturally surpass standard measurements. In the 1915 Çanakkale Project, the catwalk system comprises 24 steel ropes per span. The cables have a diameter of 50 millimeters, with each meter weighing 12 kilograms. Additionally, the tensile breaking force of each cable is an impressive 214 tons. This immense capacity allows the cables to support the weight of hundreds of cars. The weight of the cables is another noteworthy aspect. The total weight of the catwalk ropes used in the project amounts to approximately 1250 tons, which is an enormous volume to transport from one continent to another. These ropes have been temporarily installed to facilitate the transportation of the main cable. Once the permanent structures are in place, all the catwalk ropes will be dismantled. Despite being described as temporary, the catwalk system is a colossal undertaking due to its size and scale.

The catwalk system operation consists of four key stages. The initial phase involves installing the hauling system, which is utilized to pull temporary ropes and main cables. The second stage focuses on setting up the suspender system on the main span, which supports the catwalk ropes and ensures clearance for ship navigation during the installation of the catwalk ropes. The third stage, which is the most crucial, involves installing the catwalk ropes. This process is divided into three sections: installation of the Asian side span rope (1180 meters), installation of the European side span rope (1090 meters), and installation of the main span rope (2060 meters). The side span catwalk ropes are pulled using a submerging method, employing barges, while the main span ropes are pulled with the hauling system. Once these three stages are completed, the final stage is the installation of the catwalk floor system, which has a width of 4.5 meters. This stage encompasses the installation of the floor, cross bridge, and gallows frame. Following the completion of all these stages, the teams can commence the erection

of the main cables [9].

In the central span of each main cable, there are 144 prefabricated parallel wire strands (PPWS), while the side spans consist of 148 wire strands. Each PPWS is comprised of 127 galvanized steel wires, each boasting a diameter of 5.75 mm. These wire strands extend continuously from the anchor block on the Asia side to the anchor block on the Europe side, with a single wire's average length spanning 4,370 m. The ultimate tensile strength of each wire stands at 1960 MPa. Given that the 1915 Çanakkale Bridge features two main cables, a total of 304 wire strands are employed – 288 for the central spans and an additional 16 for the side spans. The collective cross-sectional area of the finalized main cable measures approximately 0.48 m^2 within the central span. Following the process of being encased with galvanized wire, the main cables undergo an additional coating of elastomeric wrapping. This supplementary layer serves as an impermeable cover, facilitating the application of dehumidification techniques. Dehumidification is implemented to shield the main cables from corrosion and ensure the intended design lifespan is achieved [6].

Hangers, constructed from steel cables, serve the purpose of transferring the deck loads to the main cables within the suspension bridge. In total, the suspension bridge utilizes 314 hangers. Each individual hanger is fashioned from a selection of either 139, 151, or 369 steel wires, all possessing a uniform diameter of 7 mm. The quantity of wires within each hanger is contingent upon its specific placement and the load it bears. These hangers are securely affixed to the deck by means of connection plates and are fastened to the main cable utilizing clamps. The strategic arrangement of hangers on the deck at 24-meter intervals ensures the uniform distribution of the load. To shield the hangers from adverse weather conditions, a protective layer consisting of a minimum 6 mm thickness of HDPE is applied [6].

4.1.4.5 Deck

Within the structure of the bridge, the elements responsible for constituting the roadway are denoted as "decks". In the construction of the 1915 Çanakkale Bridge, the assembly of these decks, which collectively weigh a total of 58 thousand Tonnes, was executed through the utilization of floating cranes and lifting gantries affixed to the main cable. The entirety encompasses 87 decks, comprising 21 single decks and an additional 66 mega decks. The single decks possess dimensions of 45 meters by 25 meters, exhibiting weights ranging from 350 to 500 Tonnes. In contrast, the mega decks boast measurements of 45 meters by 48 meters and carry weights spanning between 740 and 880 Tonnes each. All decks were initially manufactured as individual units; however, to streamline the installation process, they were fused together in the factory to create mega decks. This strategic approach facilitated more efficient and expedited installation procedures.

Right after the completion of the main cable tasks, the decks underwent a sequential loading process onto dynamically positioned vessels. Once loaded, the decks were situated in their designated locations where the installation procedures would take place. Following this, floating cranes or lifting gantries were employed to hoist the decks, marking the initiation of the installation process. Initially, the decks were grouped in sets of five along the land-facing sides of the side spans.

This operation was executed using a floating crane with a lifting capacity of 5000 Tonnes. Concurrently, the lifting gantries, meticulously prepared at Lapseki Fishing Harbour, were affixed onto the main cables. The assembly of these gantry lifts, recognized as a paramount facet of the project, entailed an extensive preparatory phase. The intricate system, necessitating meticulous attention to each individual bolt, was constructed utilizing numerous steel profiles and hydraulic units. These essential components were manufactured in China and subsequently transported to the construction site through approximately 120 cargo containers. Eight lifting gantries, each weighing 360 Tonnes and capable of lifting up to 450 tonnes, were successfully installed on the main cable. Subsequently, the deck installation process exclusively relied upon these lifting gantries.

Following this, a distinct approach was employed for deck placement. Instead of deploying cranes to raise the decks from the sea, they were towed along the main cable of the bridge and meticulously positioned. In order to alleviate the load imposed on the bridge due to the deck's weight, the installation process progressed in two separate directions utilizing the lifting gantries. It advanced from the land towards the towers on the side spans and simultaneously from the midpoint towards the towers in the main span. This methodology ensured a harmonized and controlled distribution of the load throughout the installation process.

These operations are carried out in a sequential manner, implying that any challenges arising during one phase could potentially jeopardize the overall progress. In order to ensure timely completion, the teams involved worked tirelessly around the clock, operating seven days a week and in 24-hour shifts, with the goal of accomplishing all these tasks within an impressively brief span of two months. The success of these endeavors was heavily contingent not solely upon maritime conditions encompassing wave height and currents, but also upon wind velocity, which could significantly influence the advancement. Given that the deck installation relied entirely upon lifting equipment, vigilant monitoring and the utilization of favorable weather windows were of paramount significance. To attain this objective, sensors and anemometers were strategically installed to gauge wind speeds, thereby facilitating real-time data collection and analysis. This strategy contributed to smoother operations and more informed decision-making. Furthermore, the impact of wind was evaluated not only in terms of its implications on the lifting machinery and procedures, but also in relation to its resonating effects on the bridge structure itself. This comprehensive approach ensured that all variables were duly considered to uphold the safety and efficiency of the operations [62].

4.2 Uncertainties

4.2.1 Project Financing

One of the most challenging Item specifically I the initial phases of the project which has a key role to successful delivery of the project is project financing. Securing nearly 2.3 billion Euros from 25 different lenders originating from ten different countries, each with distinct loan agreements, posed a significant challenge given Turkey's financial situation. As previously mentioned, seventy percent of this loan

was provided by 19 foreign banks and financial institutions, and the remaining 30 percent contributed by 6 Turkish banks. This funding was part of a comprehensive credit package, consisting of eight distinct tranches that incorporated various financing methods, including Export Credit Agencies (ECA's) and Islamic finance [3]. The substantial number of stakeholders involved, including 25 lenders, four sponsors, various advisors, and administration, highlights the undeniable uncertainty associated with project finance. This uncertainty is particularly pronounced due to the tight schedule inherent in such projects. The diverse requirements and interests of these stakeholders make project finance a highly complex and challenging undertaking, necessitating careful management and coordination to navigate through the uncertainties effectively [9, 3].

Moreover, given that the majority of the lenders are in foreign countries, the finance team encountered the challenge of working with banks and financial institutions across different time zones. For example, when day begin in Turkey, banks in Asia are already in the midst of their afternoon hours, leaving finance team with a limited time-frame to complete transactions with them during the day. Additionally, some of the banks involved were located in the Middle East where the workweek starts on Sunday, and Friday is observed as a holiday. This intricate structure presents significant challenges to the smooth operation of the financing team. It is worth noting that the difficulty level remains consistent across all transactions, regardless of their scale or complexity [62, 3].

The cost estimates derived from thorough studies conducted before and during the tender process, need to be exceptionally more accurate in PPP projects compared to other projects implemented using different models. This precision is crucial due to the limited possibilities of securing additional loans once the financing is finalized. Providing additional capital becomes a costly endeavor for investors in such cases. On the other hand, cost estimation in this stage while the detailed design and precise investigation is not completed will be along with a lot of uncertainties [61].

In PPP projects, the private partners assume the full risk of financing. Consequently, if they are unable to procure the necessary financial resources within the predetermined time-frame, they not only face substantial financial losses but also risk project cancellation by the authority in the worst-case scenario. Therefore, market competition and delays in project financing are two other uncertainties in this regard.

In the project, inflation emerged as a significant source of uncertainty. According to a deputy project manager involved in the project "the scale of inflation in Turkey far exceeded that of Europe, where inflation already existed. The persistent inflation in Turkey, coupled with the continuous depreciation of the local currency, resulted in significant challenges and complications. In this situation everybody is looking for the inflation compensation, but we are not able to do it as an EPC contractor, because SPV and EPC contractor belong to the same entities and contractor could not get any compensation from the SPV for this kind of things. Consequently, all risks associated with inflation had to be borne solely by the project team themselves".

4.2.2 Design and Technical Complexity

The foundation for the realization of any structure lies in its design. To ensure the success of a project, the design must embody safety, robustness, and efficiency in every aspect. The design team working on the 1915Çanakkale Project faces an additional task of pushing the boundaries of suspension bridge construction. Since 1998, the Akashi-Kaikyo Bridge in Japan has held the title of the world's longest mid-span suspension bridge, but the 1915Çanakkale Bridge surpasses this record. Accomplishing this feat necessitated the utilization of cutting-edge technologies and high-strength materials, as well as the implementation of innovative design and construction methods within a relatively short time-frame. This particular aspect of the project presented one of the most significant challenges to overcome [63].

The design team for the 1915Çanakkale Bridge encountered significant challenges, primarily stemming from the technical complexity of the project. Throughout the design process, they faced a series of hurdles presented by the unique characteristics of the Çanakkale Strait itself. These challenges included managing the intense shipping traffic, addressing the impact of strong winds through appropriate measures, seismic activity, heavy traffic loads, and poor ground conditions. Successfully overcoming these difficulties necessitated a combination of technical expertise and strong teamwork. Successfully overcoming these difficulties necessitated a combination of technical expertise and strong teamwork [63, 3].

In the realm of technical challenges, designers are compelled to push boundaries, achieve new breakthroughs, and find solutions to emerging problems. One such challenge faced by the design team of the 1915Çanakkale Bridge pertained to the heavy traffic flow in the Çanakkale Strait, which is expected to further increase in the future. Recognizing this, the deputy director of administrative and contract, highlighted the potential risks associated with approximately 60,000 ships crossing the Dardanelles Sea annually, including petroleum tankers that may pose a collision threat to the bridge. Therefore, it becomes crucial to develop a secure design that takes into account the possibility of a ship impact and ensures the protection of the bridge. Complicating matter, the bridge traverses a zone classified as "international waters," meaning that the design team had no authority to modify ship routes in this area. Nonetheless, they were tasked with ensuring that the bridge was erected in the most optimal location, considering these challenges and constraints[3].

In large-scale suspension bridges like the 1915Çanakkale Bridge, wind engineering plays a vital role. The undesired effect of uncontrolled dynamic motion in the bridge must be mitigated. To achieve this, a unique design for the deck section was implemented to provide the necessary resistance and ensure the bridge's safety during strong wind conditions. Another significant concern is the risk of earthquakes. To ensure that the foundation structure can absorb the energy generated by seismic motion, special designs for the bridge's foundations were incorporated, along with soil improvement techniques. These measures were essential to enhance the bridge's resilience and stability in the face of potential seismic events [3].

As previously mentioned, a fast-track approach is typically employed in PPP projects, where the design process is a dynamic procedure throughout project ex-

ecution. However, due to the specific site conditions and technical complexities involved, numerous design changes and specification revisions become unavoidable, potentially impacting the project timeline. The deputy contract manager of the project highlighted the challenge posed by the disparity between the actual site conditions and the information obtained from the previous geotechnical survey, leading to the need for redesign and specification adjustments. Similarly, the chief engineer of the project emphasized that despite a detailed design, uncertainties arose during the construction phase due to discrepancies in values or situations. These uncertainties necessitated design adaptations to account for factors such as changes in wind speed and direction, tower movement, and deck vibrations. Consequently, design and technical complexities emerge as two significant uncertainties that can potentially increase project costs and cause delays.

The design firm responsible for the project had extensive experience in designing some of the world's longest suspension bridges, including the Osmangazi Bridge in Turkey. This background enabled them to effectively adapt to the demanding work schedule and provide solutions to various technical challenges. However, what truly set the Çanakkale Bridge apart was its distinction as the world's longest mid-span suspension bridge, featuring exceptionally large structural elements, all within a challenging and risky environment. For instance, the 1915Çanakkale Bridge was nearly twice the size of the Osmangazi Bridge, which was constructed in a location within İzmit Bay where the water and wind conditions were comparatively calmer than those in the Çanakkale Strait [3, 7].

4.2.3 Event Uncertainty (Covid 19)

The most prominent event uncertainty during the project time-frame was Covid 19 pandemic. It began and continued in Turkey and all over the world and had extremely negative impacts on the project particularly in terms of time, cost, and working environment [9]. Expert interviewees in different disciplines who were involved in the project had interesting vision regarding pandemic period and its effects on project performance.

According to the deputy contract at administrative director of the project: "When we were doing the tender, we considered uncertain items and amounts for these risks and based on we managed the budget from the tender stage and our team was handling this. We categorized the risks for the project and of course you cannot avoid the unexpected. We never expected this kind of uncertainty when we were doing the tender in 2016. From 2020-2021 we went to the COVID stage. If this project was like a normal EPC project, Covid 19 was considered as a force majeure issue and we could claim to the client for compensation and the extension of time, but this one was a PPP type project. We had agreements with a fixed period with our lenders. We had no way of extending the period, because if we extended the period, we cannot get money from the government guarantee and we cannot payback loan to the lenders. We must take all the risks inside this PPP model. We are obliged to implement the original project duration. For example, the government closed all Turkish airs space during the Covid period to all kind of commercial flights. What happened? We need to bring some experts from Australia, China, Korea, and from all over the world. We had some experts who were supervising the work in China. When Covid 19 happened, they wanted

to come back. We were forced to take them back, but we needed to manage the work there also, this was a risk. We need a third party from abroad to verify design, specifications, and construction activities. These were problems in the early stages of the project which you were not ever thinking about, but you were supposed to take preventative majores. So, we took all kinds of risks and tried to accelerate the project as much as possible to compensate unexpected event to reach the project's construction target period and this is why project in this size was completed on time".

According to other interviewees who were chief engineer of the project "at the first time for one or two months, when we didn't get the COVID 19 detail information, we didn't feel the Covid and its severity accurately because we were very busy with following the site condition and construction activities. But at that moment we have a chines subcontractor for the cable equipment who should come in the Turkey and stay in here as supervisor. At that time, suddenly the COVID 19 situation deteriorated and changed into a pandemic. Upper management Decide to lock down the project and legislate strict limitations, rules, and quarantine instruction for going out or coming in the construction site. It means some limitation regarding the amount of manpower on the construction site and also problem about procuring the needed manpower, engineers, labors from outside. So that, everyone from the outside must spend two weeks of quarantine period in quarantine hotels nearby the Çanakkale according to the protocols. Automatically, this unexpected event impacted on the project negatively in terms of time, cost, and productivity, so that we often worked with only 50% of our capacity. Almost six months took we could slightly recover with changing the construction method, applying extraordinary equipment, and adding some extra shifts to compensate occurred delay".

4.2.4 Weather Condition

All of the experts including managers who directly contributed to the research and others who their point of views collected in the related documents, strongly believed that the unpredicted harsh windy condition, strong waves, and complex current in the Çanakkale strait were the most prominent uncertainties as well as challenges in design and construction phases of the project which had great impacts on the project performance indicators.

According to one of the interviewees who were project control manager of the project:"The severe weather conditions posed another major challenge during the project. The Çanakkale strait is known for its strong winds and high waves throughout most months of the year. To construct the longest suspension bridge, such as the one in our case with a towering steel tower of 318 meters, height becomes a critical factor. As the structural elements' height increase, so do the negative effects of the wind, including vibrations and movement. In extreme cases, these conditions can force a halt to various offshore activities, including crucial tasks like tower construction, cable installation, deck assembly, catwalk placement, and caisson work. Moreover, heavy lifting operations and marine transportation can also be impacted. While project planning accounts for potential weather conditions and unexpected events with some contingency measures, the exact outcomes remain uncertain. If unfavorable weather persists for an extended period,

surpassing even the anticipated duration, it leads to project delays, which come with associated cost implications. Once a delay occurs, efforts must be made to recover the lost time, and each acceleration to mitigate these delays incurs additional expenses. Both time and money serve as crucial indicators of project performance".

The team responsible for floating caissons and installing them on the seabed from Netherlands consisted of experienced professionals who had previously worked on projects such as the Osmanghazi Bridge, as well as carrying out heavy load operations on bridges and oil exploration platforms worldwide. They also had expertise in handling offshore heavy loads. The manager of the team held an intriguing perspective on the caisson work: "The caisson work was undeniably one of the most crucial aspects of the entire project since the caissons serve as the underwater foundation for the load-bearing towers of the bridge. Essentially, they form the foundation of the entire bridge structure. The design was highly critical, allowing for minimal room for error. The caissons' footprint measured approximately 83.3 m x 74 m, while our allowable settling margin on the seafloor was a mere 20 cm. The primary challenges arose from the sheer magnitude of the caissons and the environmental conditions at the worksite. The area experienced intense and persistent winds, which significantly impacted on our operations. Additionally, there was a strong and complex current that posed further obstacles. While the surface may appear calm, various depths harbor currents flowing in opposing directions, which adversely affected our crane maneuvers. Precise calculations down to the millimeter were always exceptionally difficult to achieve. Despite being a relatively small team considering the project's scale, we collaborated with design, construction, and research teams to ensure accurate installation of the caissons in their designated coordinates. From a professional standpoint, it is an immensely gratifying challenge" [7].

According to the project deputy director from the project control and management (PCM) department: "Due to the highly windy nature of the Çanakkale region, the Project encountered some difficulties due to weather conditions. It is reasonable to assert that the project's most significant challenge had lain in its constant struggle against the wind. Despite August being a summer month, it ironically became the least productive period due to the prevailing winds. These adverse weather conditions restricted our ability to utilize lifting equipment and cranes, leading to delays in the project's timeline. During the whole month of August when we were doing caisson work, we could only perform four heavy lifting operations. As a result, our work schedule keeps changing" [9, 3].

4.2.5 Cultural Uncertainty

The 1915 Çanakkale Project involves four shareholders who collaborate as sponsors and EPC contractors under a Joint Venture structure. Additionally, the project engages construction subcontractors, equipment suppliers, steel fabricators, engineering firms, and lenders from over 10 countries. This collaboration forms an extensive network, making the project noteworthy in terms of its scale. Consequently, managing and accommodating the diverse members from different countries and corporate cultures becomes a particularly challenging task [9].

Based on existing documents and conducted interviews, cultural issues have

been identified as one of the most uncertain aspects throughout the project's timeline, especially in the early stages. These issues have affected various parts of the project in different ways, resulting in different perspectives among managers based on their roles and project experience regarding the impact of cultural diversity on project performance. While the multicultural joint venture presented significant opportunities for the project, it also posed one of the greatest challenges. On one hand, each partner brings their own strengths and weaknesses, and integration helps leverage those strengths and mitigate weaknesses. On the other hand, addressing problems arising from cultural issues consumes time and resources, ultimately impacting project performance negatively. The chairman of board of directors of ÇOKA.Ş. (SPV Company) positively evaluates cultural diversity occurred in the project. According to his perspective: "Every job presents its own set of challenges. Typically, in projects like these, the infrastructure is prepared before the tender process. However, the approach is slightly different in Turkey. We are required to act swiftly. Turks and Koreans share many similarities, and our inclination for quick action is perhaps at the forefront. In Turkey, everything is done "çabuk çabuk," while in Korea, it's "pali pali." This is what sets us apart from the rest of the world. For instance, if this project were in London, it would have taken much longer. We work at a much faster pace. The financing aspect was successfully handled in under a year, which is truly remarkable. Our accomplishments are undoubtedly a result of our knowledge, experience, and partnerships, but primarily, they stem from the character traits shared by Koreans and Turks. "Pali pali, çabuk çabuk" is our shared characteristic, and it's truly wonderful" [7].

According to the one of the interviewees who was the project Deputy manager from the early stages of the project: "The diverse backgrounds and corporate cultures of the managers had the potential to create obstacles in fostering team spirit, a crucial element in the construction industry. Working with individuals from different cultures is not without challenges. We possess varying approaches and work methods. Understandably, it has taken more than a year to develop mutual understanding and effective collaboration, and we are continuously striving to improve in this regard.

To successfully manage complex contracts with various suppliers from different countries, it is crucial to have a highly experienced individual who can coordinate the interfaces between each contract. This main contractor must be capable of handling the integration of different suppliers, such as local, Korean, Chinese, European, and Japanese suppliers. This task is challenging due to the diverse ideas and work methods of each supplier".

Other deputy project manager who was involved in the project shared an interesting perspective on cultural issues and their impacts: "Turkish and Korean companies exhibit some differences in their work approaches. Turkish partners prioritize swift decision-making and overall work direction, whereas Korean partners focus on the decision-making process and detailed analysis. However, I believe these differences contribute to the strength of our joint venture. Hybrids, combining different cultures and members, often outperform homogeneous entities. Our project is truly global, encompassing these diverse cultures. Additionally, I have observed that both Turks and Koreans excel in communication and possess an innate ability to collaborate effectively, even without prior acquaintance. They are diligent, wise, patient, and share a strong sense of responsibility. While corpo-

rate cultures may vary in their perspectives and approaches, rather than hindering progress, these differences have often helped us find optimal solutions for everyone and propel us forward " [3].

4.2.6 Environmental Uncertainty

Mega projects, such as the 1915Çanakkale Bridge and Motorway Project, exert profound effects on the lives and livelihoods of numerous individuals, generating both positive and negative consequences. Additionally, they bring about substantial alterations to the local and regional landscape as well as the natural environment. The interconnecting of these impacts adds a layer of complexity to their assessment. In recent times, heightened emphasis has been placed on guaranteeing that such projects not only mitigate their carbon footprints but are also equipped to endure forthcoming climate changes. Furthermore, efforts are directed at avoiding negative influences on biodiversity and the natural environment [9].

4.2.7 Construction Uncertainty

4.2.7.1 Global supply chain

One of the primary concerns in the early phase of the project as well as during the construction phase of a large-scale infrastructure project revolves around the supply chain. While the EPC contractor can locally provide the main components of materials and equipment, there are numerous specialized materials and equipment, such as main cables, mega cranes, floating cranes, clamps, hangers, and others, which are only available from a limited number of suppliers worldwide. The main uncertainties in this aspect pertain to the timely production of these intricate materials, their quality, and the transportation of these oversized materials from Asia, Europe, and Australia to the construction site. It is essential to have somebody who can stay in the country of origin and inspect the qualities and also schedule which is very difficult to control. These uncertainties were further intensified by unforeseen events like the Covid-19 pandemic, which imposed stringent regulations regarding cargo and human movement.

The deputy director of contract and administrative department who had responsibility to procure this kind of strategic materials and equipment from early stages of the project took some examples to emphasize the importance of global supply chain as a main source of uncertainty within the project which potentially could impact project performance. In this regard he said that "Due to the immense size of everything involved in the project as well as their long production period, we carefully planned our procurement well in advance of the construction phase. Main cables were produced in Korea, then transferred to China, after the prefabricated parallel wire strand (PPWS) process brought them to Turkey. If any of these vessels were to sink, it would take 13 months to recover the materials. In such a situation, we would have to start from scratch, similar to restarting a computer game, and bring everything back up to date, resulting in a 13-month delay. Therefore, any disruptions in the supply chain could potentially cause a 13-month setback. As a result, the insurance aspect of our supply chain becomes highly risky. Furthermore, we faced challenges when Chinese factories and our own factories were closed due to the pandemic, which affected the transfer of materials

from China to Turkey. Additionally, the closure of the Suez Canal caused significant problems, with vessels unable to pass and requiring lengthy transfers around Africa or waiting for the reopening of the Suez Canal, leading to further delays. These types of issues were recurring, highlighting the importance of procurement, especially considering these challenges.

For the tower erection a mega-sized tower crane was required to lift colossal blocks (between 200 and 770 tons). There are a limited number of suppliers around the world which could supply this special tower crane. Finally, Tower cranes were brought from Australia, accompanied by Australian operators, using 50 different ships with various cargo to transport them from Australia to Turkey".

The 1915Çanakkale Bridge, known for having the longest suspension span of 2023 meters, is a groundbreaking project. The main strands of the bridge exceed 4300 meters in length. A joint venture consists of a Korean and a Chinese company jointly participated in the tender and won the project for supplying this high-tech material. The deputy general manager of the chines company and vice president of Korean company shared their point of views regarding the main uncertain aspects of the main cables' supply chain "Handling strands of such size presented challenges, including timely customized production, storage difficulties and transportation complexities. The transportation process involved at least five separate lifting operations, with each coil of Prefabricated Parallel Wire Strands (PPWS) weighing 115 tons. Meticulous planning and stringent safety measures were essential for each lifting operation. Both companies involved were actively engaged in various domestic and international projects, underscoring the importance of timely delivery for all orders. Throughout the process, we were aware that all stakeholders have concerns about our production, technology, inspection capabilities, and other capacities. Meeting these requirements was a crucial aspect of our operations" [61, 5].

4.2.7.2 Safety

The construction of the 1915Çanakkale Bridge presented a highly complex and demanding endeavor. With structures spanning hundreds of meters, there was minimal room for error, often measured in centimeters. This underscores the utmost importance of safety in such a monumental project. When it comes to health and safety, there is zero tolerance for mistakes, as even the slightest negligence or carelessness can result in irreversible consequences. Additionally, weather conditions, including sunny, windy, stormy, or rainy periods, could further amplify the risks involved. Consequently, a rigorous safety protocol governed every aspect of the workers' actions. In addition to standard safety attire like custom-made protective clothing, shoes, and helmets, cutting-edge safety equipment was employed, representing the most advanced technology available. For instance, workers stationed on the caissons, responsible for supporting the weight of the bridge's foundations, had to navigate their tasks with the agility of mountaineers, given their elevation, comparable to that of a six-story building's roof. These workers were consistently secured to steel safety lines using "parachute-style" full body safety harness belts. They traversed security-cleared catwalks and diligently performed regular self-checks and environmental inspections. Workers stationed on pontoons were required to wear automatic inflatable life jackets at all times, prepared for

any potential fall incidents. They remained vigilant of the crane movements, which consistently handled hefty loads. Similar safety precautions were applied to workers operating at the top of the catwalk, who faced comparable risks [7].

Additionally, during the construction of the project, the traffic in the Çanakkale Strait was exceptionally heavy and expected to increase in the future. Considering that a significant portion of the 1915Çanakkale Bridge Project operations took place at sea, there were numerous risks associated with construction elements and equipment, such as towers, tower cranes, and floating boats, being struck by ships. Furthermore, the strait was populated by both small fishing boats and large ships, and fishermen were known to disregard warnings and pursue their fishing activities regardless of the circumstances [3]. The deputy section manager of the project emphasized "the need for comprehensive measures to ensure the smooth and safe execution of operations amidst the bustling traffic in the Çanakkale Strait. The constant surveillance of the busy maritime traffic in the strait was crucial. Numerous critical operations were carried out daily, including heavy lifting, which had the potential to conflict with marine traffic. Therefore, effective and continuous cooperation with the Çanakkale Port Administration was essential to mitigate risks in this regard. The priority was to prioritize safety before commencing any operation. Within the project, there were 36 floating equipment units of various sizes, ranging from cranes to buoys. Safety was given utmost importance, with thorough documentation checks conducted for each piece of equipment. Engineers from the marine operations department and the Health, Safety, and Environment (HSE) department routinely inspected the ships and all the equipment on board. Regular checks were performed on the stability calculations of the floating buoys, health and safety equipment, and electrical systems. Additionally, each vehicle had its own safety protocol. Prior to setting off on the road, the route was inspected to identify and evaluate any potential risks and hazards, ensuring proper precautions were in place".

4.2.7.3 Heavy Lifting

Because of the nature of the offshore mega infrastructure projects, numerous substructure components of substantial weight must be lifted, transported, and assembled during the construction period. As per the occupational safety department of the project, any load weighing over five tons was considered a heavy lifting operation. Certain tower parts that were lifted and installed by cranes weighed 400 tons, while the decks section weighed nearly 750 tons, classifying all on-site loads as critical. Consequently, it was essential to engage a renowned global company equipped with specialized facilities capable of safely handling and transporting these massive components to prevent any potential incidents resulting from a loss of control. To fulfill this purpose, lifting operations both on and off the shore were supported by cranes with a capacity of 2200 tons. Additionally, floating cranes with a capacity of 5500 tons were utilized for operations at sea, along with tower-mounted cranes with a capacity of 330 tons [4]. Furthermore, in addition to the challenging weather conditions, the presence of Covid-19 posed a significant obstacle that could potentially disrupt the heavy lifting operations [61].

The general manager of one the leading companies who was in charge of transportation of steel shafts and decks at the 1915Çanakkale Bridge project mentioned

some of the risks and uncertainties of their work: "We executed the loading operations for four steel shafts constituting the pier foundations. Each shaft weighed between 700 and 750 tons and was 26 meters tall. There was an increased risk of collapse because of the height. In the second phase of the Project, we executed the loading of 87 decks, each with a width of 45 meters, length of 48 meters, weighing 700 tons, from Gölcük. 66 of these decks were mega blocks. Then we unloaded these in Gelibolu and transported them to the stock area. Our work was instrumental in the timely completion of the installation operations on the bridge. The heaviest deck transported as part of the Project weighed 880 tons. Our other struggle was against the weather and the wind. Severe winds and strong waves cause a obstacle for offshore heavy transportation operations" [62].

4.2.7.4 Time

Successfully completing the design and construction of the world's longest mid-span suspension bridge within a tight schedule, despite the challenges posed by the Covid-19 pandemic, is an immense undertaking. In addition to the pandemic, other factors such as unpredictable weather changes and limited preparation time between activities added to the complexities. Delays in mega projects can arise from various sources, including those mentioned earlier, such as weather conditions, pandemics, safety concerns, supply chain issues, design complications, cultural factors, and more. Furthermore, uncertainties surrounding time itself, such as inaccurate time estimation during the project's initial stages, inadequate time estimation and control during construction, and delays in the construction period, can also contribute to delays [9, 3].

One of the interviewees who was deputy project control manager at PCM department of the project emphasized that: "The main issues in the project are time constraints which impacts on cost as another performance indicator. Any extension of the project duration directly affects the budget, leading to increased costs. For example, financial closure is dependent on being mobilized at the site and some primary designs to obtaining necessary permits. Delays in financial closure result in prolonged stays on-site, impacting the budget. Detailed design work is initiated after financial closure, but uncertainties in, for instance geological properties may require additional investigations, leading to design changes and increased time and costs. Weather conditions during project execution, such as bad weather and high waves, can cause delays and additional expenses for recovery.

Moreover, Throughout the project execution, you might encounter situations where the state introduces additional requirements or variations, and you are obliged to comply even if it goes beyond the original scope of work. While you can claim for time extensions and compensation for any costs incurred, not all costs can be fully reimbursed. Sudden instructions from the client or bridge owner during project execution imposes a significant time uncertainty that needs to be managed".

4.3 Critical Path & Uncertainties- Discussion

The completion of the 1915 Çanakkale Bridge project in Turkey represented a significant engineering achievement, but it also highlighted several key uncertain-

ties and challenges that are common in large-scale infrastructure projects. These uncertainties can be grouped into several categories: project financing, design and technical complexity, event uncertainty (such as the Covid-19 pandemic), weather conditions, cultural diversity, environmental considerations, and construction uncertainties. The following is an analytical discussion regarding the main uncertainties of the project faced during the project from signing the agreement to the end of the construction work.

- Project Financing Uncertainty: The financing of mega-projects, especially in the form of public private partnerships (PPP), is inherently complex due to the involvement of numerous stakeholders, diverse financing methods, and international lenders. The challenge of coordinating with multiple banks and financial institutions across different time zones underscores the need for efficient financial management and global communication. Accurate cost estimation is crucial in PPP projects because securing additional loans after financing is finalized can be costly. This underscores the importance of thorough initial cost assessments.

- Design and Technical Complexity Uncertainty: Pushing the boundaries of suspension bridge construction, as seen in the 1915 Çanakkale Bridge, requires cutting-edge technologies and innovative design and construction methods. Overcoming site-specific challenges, such as strong winds, seismic activity, and intense shipping traffic, requires technical expertise and collaborative teamwork. Design changes and specification revisions during construction, often necessitated by unforeseen circumstances, can lead to project delays and increased costs.

- Event Uncertainty (Covid-19): The Covid-19 pandemic, as a force majeure event, introduced unexpected challenges in terms of project timelines, costs, and workforce management. In the context of PPP projects, the inability to extend project periods due to fixed agreements with lenders adds a layer of complexity to managing risks associated with unforeseen events.

- Weather Condition Uncertainty: Harsh weather conditions, including strong winds, high waves, and complex currents in the Çanakkale Strait, posed significant challenges in design and construction. Weather-related disruptions, especially in offshore activities, often lead to project delays and increased costs, necessitating the implementation of contingency measures.

- Cultural Uncertainty: Managing a diverse team of stakeholders from different countries and corporate cultures can be challenging but also offers opportunities for benefiting strengths. Cultural diversity can lead to differing work approaches and communication styles, requiring time and effort to build mutual understanding and collaboration.

- Environmental Uncertainties: Mega projects like the 1915 Çanakkale Bridge have significant environmental impacts, and managing these impacts is increasingly important. Environmental considerations include mitigating carbon footprints, adapting to climate change, and preserving biodiversity.

The construction of large-scale infrastructure projects presents a myriad of uncertainties that demand meticulous planning, careful risk assessment, and strategic management. The 1915Çanakkale Bridge, with its groundbreaking design and monumental scale, exemplifies the complexities and challenges inherent in such endeavors. In the following, the key uncertainties during the construction phase encompassing global supply chain issues, safety considerations, heavy lifting operations, and time management have been discussed.

- Global Supply Chain, Special Material Procurement: One of the primary concerns in the early and construction phases of the 1915Çanakkale Bridge project was the global supply chain. While the project's main components could be sourced locally, specialized materials and equipment, such as main cables, mega cranes, and clamps, were only available from a limited number of suppliers worldwide. The uncertainties in this domain revolved around the timely production of these intricate materials, their quality, and the transportation of oversized components from distant regions such as Asia, Europe, and Australia. The COVID-19 pandemic introduced an unprecedented layer of complexity to the global supply chain. Strict cargo and human movement regulations disrupted material flow, leading to delays and logistic challenges.

- Safety: Safety considerations in the construction of the 1915Çanakkale Bridge were paramount, given the immense scale of the project and the minimal margin for error. Structures spanning hundreds of meters left no room for negligence. Weather conditions, such as wind, storms, and rain, can amplify risks. The construction site's maritime location added additional challenges due to heavy traffic in the Çanakkale Strait, including the risk of ships colliding with construction elements and equipment. To mitigate these risks, advanced safety equipment and rigorous protocols were employed. Collaboration with the Çanakkale Port Administration was crucial to ensuring safety amidst bustling maritime traffic.

- Heavy Lifting: The construction of offshore mega-infrastructure projects necessitates the lifting, transportation, and assembly of substantial substructure components. Heavy lifting operations posed a unique set of challenges, particularly concerning the immense weight and size of the components and windy conditions in Çanakkale strait. The criticality of heavy lifting operations was evident, as any potential accident could result in significant delays and cost overruns.

- Time: Time management was central to the success of the 1915Çanakkale Bridge project, which aimed to complete the world's longest mid-span suspension bridge within a tight schedule. Delays, stemming from various sources such as weather, safety concerns, supply chain disruptions, and inaccurate time estimations, could impact project timelines and budgets. Extensions of project duration directly translated into increased costs, particularly when considering prolonged stays on-site and additional design work. Unforeseen client instructions and unpredictable geological factors also contributed to time uncertainties that required meticulous management.

4.4 Organization Form- Status Quo

4.4.1 Owner Organization

According to the figure 4.4.1,the Project had a multipartite and deeply hierarchical organizational structure, everyone had to fulfill their role in a balanced manner while responding to various expectations [4]. On the top of the organization, there was the concession owners which was the Turkish General Directorate of Highways (GDH). In the context of the BOT model under the framework of Public Private Partnership, the GDH, acting as a representative of the public administration, retained its primary responsibility of overseeing and supervising the services [9].

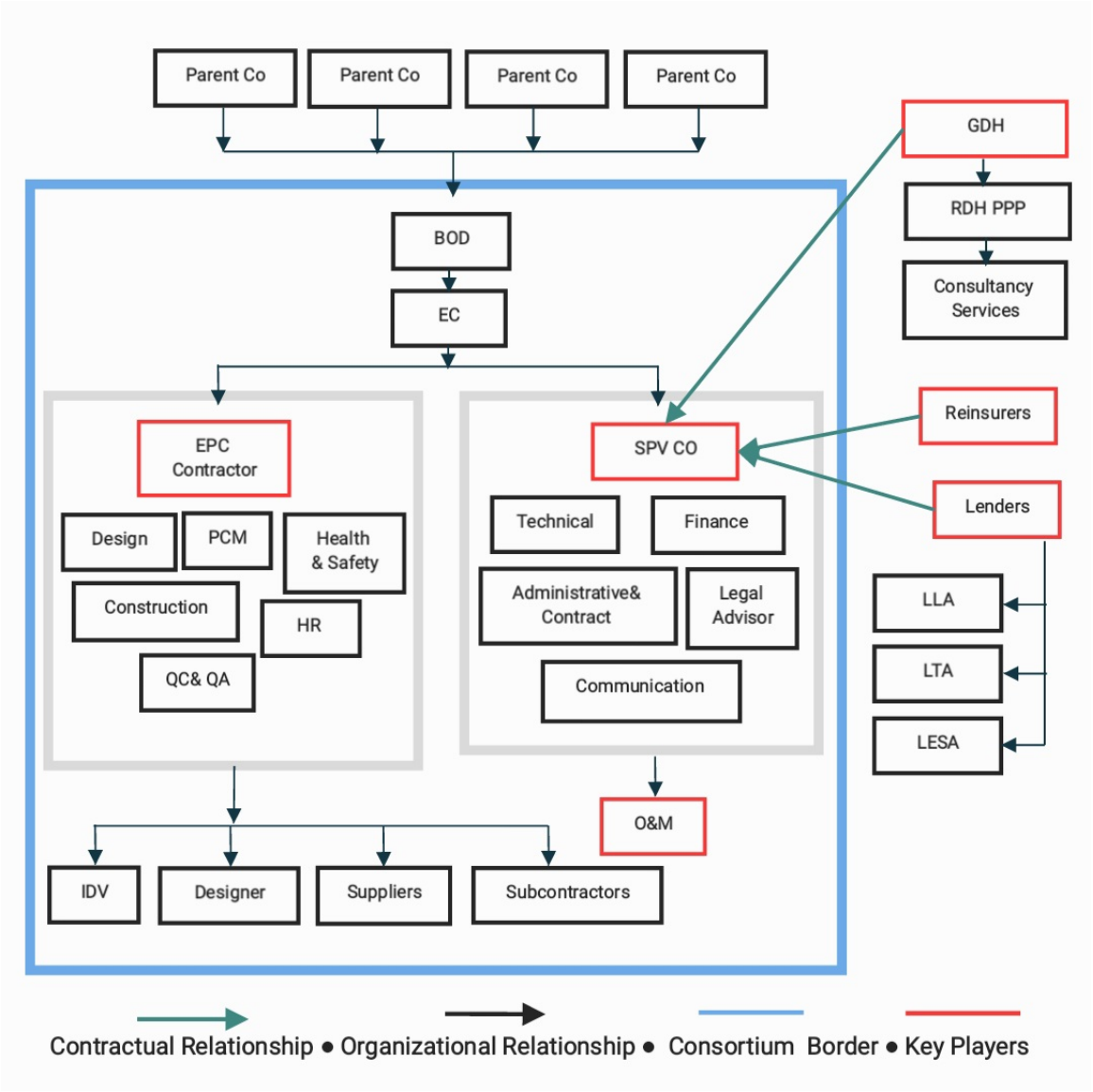

Figure 4.4.1: Organizational Chart of the 1915Çanakkale Bridge Project (BOD: Board of Directors- EC: Executive Committee- PCM: Project Control and Management- IDV: Independent Design Verification- GDH: General Directorate of Highways- RDH: Reagonal Directorate of Highways- LLA: Lenders' Legal Advisor- LTA: Lenders' Technical Advisor- LESA: Lenders' Environmental and Social Advisor

The Regional Directorate of Highways (RDH) for Public Private Partnership which was established in 2011was a segment of the provincial organization, aiming to oversee Production and Operation activities. This entity assembled a specialized team comprising experts from various Regional Directorates. Structurally, the Public Private Partnership Regional Directorate mirrored the layout of other Regional Directorates. Remarkably, it stood as the initial job-specific Regional Directorate within the GDH. Aligning with conventional regional directorates, its responsibilities encompassed project management, execution, manufacturing, supervision, followed by operations, routine maintenance, and traffic safety services. In its capacity as an institution, the RDH Public Private Partnership was designed to apply the insights garnered from the Osmangazi Bridge on the Gebze-İzmir-Orhangazi Motorway to this undertaking [9].

For the 1915Çanakkale Bridge and Motorway Project, the Joint Venture of Tekfen Engineering Co. and T Engineering International SA (JV TT) undertook consultancy and inspection services during the construction phase on behalf of the General Directorate of Highways (GDH). This joint venture acted as an "uninterrupted link" between the Administrative Authority and the Contractor. The consultancy team was composed of a Head of Organization, two Deputy Heads responsible for the Bridge and the Motorway, 15 Chief Engineers, 96 Engineers, 48 Technical Staff, and two Architects. The team's composition could vary periodically based on the level of activity within the schedule [8]. Both the owner and its consultant possessed extensive expertise in their respective fields. Notably, the owner had a proven track record in constructing four long-span bridges and thousands of kilometers of motorways [5]. The main responsibilities JV TT are demonstrated in Appendix-B.

4.4.2 SPV Entity

The project concession was granted to a consortium of four private companies for a specific period. In the 1915Çanakkale Project, four shareholders operate as sponsors and EPC contractors within a Joint Venture structure. Decisions within the joint venture are unanimous, with no designated leader. The collaboration extends to numerous construction subcontractors, equipment suppliers, engineering firms, and lenders from over 10 countries, making the project noteworthy for its extensive collaborative network [9, 5].

The joint venture, comprising SK E&C and Daelim from Korea, and Limak and Yapi Merkezi from Turkey, established a Special Purpose Vehicle (SPV) named ÇOK A.Ş. The SPV's board of directors consisted of the chairpersons from each company within the joint venture. This SPV held the primary contract with the government and got in touch with them all the time, secured financial agreements from banks and financial institutions, and then sublet the project's construction to the Execution Procurement Construction (EPC) contractor company. The EPC contractor, named DLSY JV, were consisted of the same shareholders as the concessionaires [9, 5].

The project was established as a Public Private Partnership, with the private partner being comprised of two entities: ÇOK A.Ş. as the investor and DLSY JV as the EPC Contractor. To ensure effective coordination between these two entities, the Executive Committee (EC) was established. This committee consisted

of eight members, with two representatives from each partner, four with expertise in EPC works and four in financing. The Executive Committee, positioned as a high-level authority after the Board of Directors, had oversight over both EPC and financing activities. Its role was to enhance communication among the four partners, ultimately expediting the decision-making process—an essential factor for efficient project operations [5].

The Special Purpose Vehicle (SPV) was specifically created for this project's management. It played a central role in overseeing the entire project in collaboration with the Administration, the lending group, the Engineering Procurement Construction (EPC) contractor, the Operations and Maintenance (O&M) contractor, as well as other advisors [9]. The SPV entity for the 1915Çanakkale Project comprised four main departments: technical, finance, administrative and contract, and communication departments. Each department was led by a director and deputy director, and staffed with experts as required. The company's structure was unique due to its limited lifespan as an SPV, emphasizing flexibility and versatility over institutionalization. A minimal number of permanent staff were employed, while consultancy services were utilized to address specialized areas that demanded expert knowledge. This structure called for a localized team with capable individuals capable of managing world-class experts [4]. As outlined by the deputy director of the project, the SPV organization operated with a relatively small teams, consisting of approximately 55 individuals. Conversely, during the project's busiest phases, the EPC contractor's workforce swelled to encompass around 6000 personnel.

4.4.2.1 Technical Department

The technical department was composed of three teams, totaling nine individuals: the technical team, the operation and maintenance (O&M) team, and the environmental and social impact assessment (ESIA) team. In Build-Operate-Transfer (BOT) projects, there are distinct phases during the concession period: construction and operation. Ordinarily, the construction phase is briefer than the operation phase. In the case of the 1915Çanakkale Bridge and Motorway Project, the concession period spanned 16 years and two months, encompassing approximately four years for the construction phase and 12 years for the operation phase. Consequently, the technical department established both short-term and long-term objectives for this project. In the short term, in collaboration with the EPC (Engineering, Procurement, and Construction) Contractor, their goal was to successfully conclude the construction phase by the planned deadline, adhering to exceptional construction quality, satisfying the expectations of the Client (General Directorate of Highways-GDH/KGM), and fulfilling the operational requisites of this substantial Project. Looking ahead, the long-term objective focused on the sustained management of the Project, ensuring a secure and comfortable driving experience for motorway users, and the timely execution of all necessary maintenance tasks to prolong the Project's lifespan. As stated by the technical director of the SPV company, "the Technical department held several significant responsibilities, effectively serving as the driving force behind the Project. One of the core duties was to meticulously address all technical requisites outlined in various contracts, including the implementation contract, finance contract, EPC, and

O&M contracts. Navigating these requirements and overseeing ongoing activities entailed collaborating with diverse groups of individuals and companies associated with the Project. Additionally, the department was tasked with managing Lenders' Consultants, encompassing Lenders' Technical Consultants and Lenders' Environmental and Social Consultants. These consultants' certifications were vital for drawing funds from the Lenders. Notably, the department consistently managed to uphold its commitments without encountering delays or shortcomings. Consequently, the team could seamlessly issue the Interim Payment Certificate (IPC) amount to the EPC each month, free from complications. All members of the department were engineers, much like those in the EPC Motorway and Bridge teams, albeit with a different perspective. The department's approach entailed a comprehensive view that considered both the operation and construction phases during design review, construction observation, and investigation" [8].

4.4.2.2 Finance department

The Finance department operated as a highly integrated unit, consisting of subteams such as project finance, accounting and reporting, toll collection, corporate finance, and planning, in addition to a legal team. The core of this department, alongside the technical/engineering teams, was the project finance team. The Project's financing was secured through 25 distinct financial institutions, including 19 from foreign origins. This team meticulously monitored the contractual requirements, encompassing finance and project documents, as well as necessary actions, information, and documentation. They undertook comprehensive financial operations and responsibilities for the Company, while also managing communication with the banks. The project finance and planning teams navigated the complexities of executing such an intricate Project. The corporate finance team constructed and maintained the Project's financial model and corresponding financial projections, diligently tracking the model and preparing for potential future inquiries. To measure market and operational risks linked to the Project, they conducted diverse scenario analyses. The accounting team comprised both a Turkish and a Korean team member. The Turkish team managed accounting procedures aligned with local legislation. The unique attributes of accounting for a Build-Operate-Transfer project demanded intricate document structuring. They remained vigilant about potential legislative changes and maintained relationships with tax advisors and institutions responsible for tax and legal audits. Routine accounting reports were part of their duties. Given the Project's strategic importance and scale, public institutions might seek information, which the team provided promptly. The Korean Accounting Manager catered to information and reporting requests from Korean partners in line with Korean accounting standards. Additionally, the manager supported the team with reports prepared according to international reporting standards, necessary for submission to banks. The toll collection team, although not initially present, was established as the operational period neared [62].

4.4.2.3 Contracts and Administrative Department

An infrastructure investment project typically comprises two central aspects: construction and financing. While the SPV had separate finance and technical teams,

numerous tasks existed that fell outside the limits of these departments, including contractual matters, administrative affairs, client relationships, document control, and insurance, among others. To address these gaps and ensure seamless operation, the Contracts and Administration department was established. Its primary function was to bridge these gaps and facilitate the smooth functioning of the SPV. For instance, during the construction phase, the team organized essential aspects for the SPV, including arranging lenders' meetings, coordinating site visits, and occasionally managing overseas trips involving VIPs. Additionally, throughout the operational phase, the team assumed responsibility for overseeing commercial areas like service stations and fuel stations along the motorway. In fact, the team's mission was to provide comprehensive support across all aspects of the Project [9].

4.4.2.4 Communication Department

The Communications Department focused on cultivating and upholding the corporate image and reputation. This encompassed a range of multidisciplinary tasks including devising communication strategies for both the Project and the brand, orchestrating the development and implementation of corporate identity, engaging with stakeholders and the media, managing events, overseeing digital communication and content, and coordinating campaigns that were covered by national and local media. This department reported directly to the CEO of the SPV entity. As noted by the Corporate Communication Manager of the project, the structure involving a multitude of stakeholders was uncommon globally. This structure involved four equal partner companies with distinct corporate cultures from two countries, affiliations with administrative bodies and institutions, numerous supplier companies spanning Turkey and 15 other countries, a workforce of over 30 thousand employees throughout the Project, creditor finance institutions, local authorities, universities, academic circles, and diverse levels of media—national, international, local — all of whom exhibited significant interest in the Project from its inception [4].

4.4.3 Lenders Consultants

The 1915Çanakkale Bridge and Motorway Project stands as a significant mega-scale transportation and infrastructure investment. Given its status as a PPP endeavor, securing financing for such a grand-scale undertaking was of utmost importance. With a valuation of nearly 3 billion euros, the project stands as Europe's leading large-scale PPP investment, backed by 25 financial institutions from 10 countries. The financial stakeholders' ability to monitor project progress and identify critical work schedule risks was crucial. Mott MacDonald, serving as the Lenders' Technical Advisor (LTA), was enlisted to fulfill this role by providing independent third-party consultation closely aligned with lender representatives to ensure the construction program's feasibility.Mott MacDonald played a vital role in generating regular monitoring reports for lenders. These reports encompassed not only technical aspects but also design, contract compliance, timelines, permissions, health and safety, risk assessment, costs, market dynamics, and supply chain considerations. As the Senior Project Manager of Mott MacDonald highlighted, "the role of Lenders' Technical Advisory is multifaceted. It begins with due dili-

gence on behalf of lenders to distinguish technical risks and reinforce the transaction's bankability before securing financing. This role aids lenders and sponsors in achieving a successful financial closure. Post-financial closure, Mott MacDonald's role evolves to include on-site reporting of construction progress to lenders, certifying completed works, and identifying potential risks that might jeopardize the project's timely and budgeted completion. Importantly, the LTA's involvement extends beyond construction monitoring, encompassing the project's operational phase. In this capacity, Mott MacDonald provides counsel on the preparation and execution of operation and maintenance plans, reviews and provides insights on the O&M budget, and evaluates actual expenditures" [9].

An additional critical component of the Project was the Lender's Environmental and Social Advisor, Arup. This role initially focused on Environmental and Social Due Diligence to facilitate international financing for the Project. Arup's guidance encompassed structuring the Project, its construction, and operational activities to align with the environmental and social policies of the international lenders. This alignment extended across both construction and operation phases, necessitating adherence to Turkish laws and regulations, as well as globally recognized environmental and social standards, including the International Finance Corporation's Environmental and Social Performance Standards and the Good International Industry Practice. From June 2018 onward, Arup undertook periodic monitoring on behalf of the lenders. This ongoing assessment ensured that the Project consistently honored its environmental and social commitments in accordance with the lenders' policies. Throughout this process, Arup provided counsel to the lenders on the advancement of implementation, along with an evaluation of associated risks and opportunities. Collaboratively, they closely engaged with key stakeholders, including ÇOK A.Ş. (the Appointed Company), DLSY JV (the Engineering Procurement Construction (EPC) Contractor), and other implementation partners. In addition, Arup extended its support to communities and various stakeholders, building their capacity and aiding in the fulfillment of the lenders' environmental and social prerequisites [9].

Furthermore, Clifford Chance Law Firm, a legal advisory firm, provided consultancy services to the lenders throughout the project. The domain of project finance demands that each undertaking be economically viable, ecologically sustainable, commercially feasible, technically achievable, and legally robust. Given its extended lifespan, the project necessitated collaborative, long-term partnerships among shareholders, contractors, governments, operators, and creditors. The role of the legal advisors, acting as lawyers, was to meticulously examine the inherent project risks, spanning aspects like land, permits, construction, environment, social factors, country regulations, finance, security, force majeure, and intrinsic risks. Their objective was to structure the deal to render it "bankable," ensuring that contracts and documentation eliminated risks that could undermine the project's successful execution. This intricate process entailed an in-depth comprehension of the pertinent sector, market practices, and the country in which the project would occur. Project finance lawyers needed to understand the bigger picture and comprehend the complexities of a project's cash flow. It was of paramount importance that contracts and documentation accurately mirrored the anticipated cash flow dynamics and drew strategies for managing potential deviations from these projections [8].

4.4.4 EPC Contractor

Within the Engineering, Procurement, and Construction (EPC) realm, the project encompassed various essential disciplines, including construction, design and engineering, project control and management, health and safety, human resources and administration, as well as quality control and assurance. Each of these disciplines operated within distinct departments. Moreover, the project involved several subcontractors and suppliers, forming an intricate interdependent network. Effective coordination among these entities became paramount due to their interdependence.

4.4.4.1 Design Department

The design team was primarily responsible for comprehensive management of detailed design tasks, involving various functions such as overseeing bathymetry surveys and geotechnical investigations, determining key bridge geometry parameters based on these surveys and investigations, managing aerodynamic considerations for deck sections, following up Independent Design Verification's tasks (IDV), supervising the overall design schedule, and providing technical support to other departments like Project Control Management (PCM), Quality Assurance/Quality Control (QA/QC), and Construction. A design manager, along with a deputy manager facilitated communication among different departments of DLSY JV and external partners such as design firm COWI, independent design verification consultant Arup-Aas Jakobsen, and the General Directorate of Highways. To ensure effective collaboration with COWI, design team members were stationed at COWI's office, and vice versa, during the design development phase. Most design team members came from the joint venture companies of the 1915Çanakkale Project, with Korean and Turkish members possessing experience in similar projects like suspension bridges in both countries. As the design matured, certain team members transitioned to roles in the Construction Engineering (CE) and Construction departments [63].

4.4.4.2 PCM Department

PCM's primary responsibility involved the planning and oversight of the Project, ensuring it remained within budget and adhered to the established schedule. The team consisted of 32 individuals, with approximately one-third being of Korean origin and the remainder being Turkish. The PCM could be seen as the central nucleus, the intellectual hub of the Project, structured into four sub-departments [9]:

- planning division: It tasked with closely monitoring the budget and work schedule. This team addressed concerns about which aspects of the project could potentially exceed the budget and devised strategies to mitigate these deficits. They were obligated to track the progress of the work schedule and report any delays that arose. Additionally, they held the responsibility of reporting the advancement billings to the lenders, obtaining their crucial approval-a pivotal duty concerning Project financing.

- subcontractor tendering division: It managed subcontractor tenders, having overseen more than 300 tenders since the project's inception. This division handled all matters related to subcontractors and suppliers, ensuring coordination. They managed all communication, progress billings, payments, associated contracts, and schedules, effectively serving as a bridge between the construction site and the design teams. Facilitating communication of subcontractor requests to relevant parties and conveying responses was another key function they fulfilled.

- Local Procurement Division: It was in charge of local procurement. Over the span of approximately four years, this unit procured thousands of items locally. Given the project's expedited nature and its race against time, minimizing procurement lead time held paramount importance. Furthermore, during the pandemic, this division assumed the responsibility of risk assessment to safeguard the work schedule. As a result, procurement strategies involved both local and international sourcing as dictated by necessity.

- Contracts Division: It managed all affairs concerning contracts between the Owner(GDH) and the consulting organization (TT JV). This entailed all written correspondence with administrative bodies, communication of pandemic-related requests, and interactions with authorities beyond the General Directorate of Highways (GDH) concerning project execution. For instance, instances where bridge operations mandated strait closures necessitated official correspondence conducted exclusively through this department.

4.4.4.3 Occupational Safety Department

Throughout every phase of the 1915 Çanakkale Project, numerous high-risk engineering operations were executed under demanding geographical and weather conditions. Among these operations, the most important priority remained safeguarding the well-being of employees laboring in harsh conditions like elevated environments, a responsibility primarily shouldered by the Occupational Safety Department. Right from the initiation of the 1915 Çanakkale Project, the Occupational Safety Department commenced its efforts. The selection criteria for occupational safety specialists encompassed a prerequisite experience in recognizing heightened risks within projects of similar magnitude, such as Istanbul Airport, Eurasia Tunnel, Yavuz Sultan Selim, and Osmangazi Bridges. As time progressed, and as the roles on-site expanded and diversified, the team proportionately expanded as well [4].

4.4.4.4 Human Resource and Administrative Affairs Department

The Department of Human Resources and Administrative Affairs assumed the vital responsibility of ensuring optimum living conditions for a great number of employees from around the globe. This department, consisting of 120 personnel, was dedicated to providing strong support to Project teams both onsite and within offices, addressing matters concerning employees' individual rights and fundamental needs such as housing, transportation, and livelihood since the project's inception. In a scope centered around human interactions, the efforts of this department left a mark on the lives of each individual engaged in the Project. This

department included a blend of experienced professionals with prior experience in analogous ventures and a dynamic cadre of youthful coworkers. Their concerted efforts ensured that these needs were met within the briefest conceivable timeframes, and processes linked to employees' personal rights, aligning with national regulations, were navigated seamlessly. Almost 37,000 individuals were engaged in both short-term and long-term positions. Accommodations were provided for up to 3,000 individuals simultaneously, with near 20,000 people making use of these facilities [4].

4.4.4.5 Quality Department

The EPC entity also featured a dedicated Quality Control Department. Their central duty encompassed ensuring the project's alignment with all stipulated quality prerequisites. This encompassed not only achieving quality benchmarks but also upholding specifications, standards, and project-specific requisites within the allocated time frame and budget. Their responsibilities spanned a spectrum, from concrete design to factory admission tests, site oversight, and establishing effective communication channels with the General Directorate of Highways. The rhythm of operations was complemented by weekly Quality Management meetings with the Management, coupled with regular site visits. A basis of their approach was meticulous planning of Inspection Test Plans, which subsequently secured Management's approval. The team then systematically conducted on-site assessments for each task, a pivotal process in their quality control endeavors. Confronted with the challenge of harmonizing collaborative dynamics among individuals from different cultures, disciplines, and objectives, the department's significant challenge was navigating this complexity. The department included a workforce of 53 members, each assigned distinct roles including assistant managers, chiefs, senior engineers, engineers, and technicians. To ensure the provision of expert services, they also enlisted the involvement of third-party enterprises. The pivotal role of external inspection, especially for ongoing production processes conducted across various foreign countries, could not be ignored. The pre-arrival assessment of materials and the preparation of quality documentation held paramount importance, tasks for which they depended on third-party inspectors. Third-party inspectors also undertook evaluations of internal operations, confirming adherence to quality standards and ensuring seamless functioning. In fact, the main objective revolved around upholding elevated quality benchmarks while proactively addressing challenges and enabling timely decision-making across the project's duration [61].

4.5 Organization Form- Effects on Performance and Uncertainties

4.5.1 Unique Collaboration Model

The Chief Executive Officer at ÇOK A.Ş., who had previously been involved in the Eurasia Tunnel as a Deputy General Manager, highlighted that the experience gained from the Eurasia Tunnel project had been invaluable to apply skills needed to foster comprehensive coordination and broad consensus [4]. He explained how the managerial chosen approach during the project has impacted on time as the

most important performance indicators and has enabled them to manage uncertainties derived by organizational complexity and cultural diversity within the project.

The project was marked by its complexities in various dimensions. Right after the beginning, the focus was to create a trust-based relationship between all stakeholders. Given the project's multi-parties and hierarchically layered organizational structure, establishing a robust system was essential. A well-structured system ensures smooth functionality, reducing the likelihood of conflicts and setbacks. Clarity in determining authority and responsibility, alongside clear definitions of tasks and timelines, ensured minimal complications within the system [4].

Integrating the corporate cultures of four distinct globally recognized companies, while there was the active involvement of the Executive Committee and the Board of Directors, was a task that required careful navigation. Furthermore, close collaboration with the public administrations was a vital aspect. On that situation, a collaborative management model that aligned with the complex structure was demanded. Thus, a bottom-up approach which is characterized by consensus-building, was accepted and decision-making commenced from the lower layers of the hierarchy. Effective management philosophy, in this context, was based on finding equilibrium among multiple parties involved in the project [4, 5].

Moreover, considering the project's tight schedule and great deal of uncertainties influencing time, an agile structure, and management approach were needed to yield optimal outcomes and minimize discrepancies. The key was to emphasize shared objectives over divergences, enabling prompt decision-making and implementation. In summary, the management philosophy was based on system and order creation, building trust, delegation, democratic decision-making, discipline, justice, resource sharing, continuous development, open communication, and empathy. These principles were integral to navigating the complexities of a project of this scale and nature [4].

4.5.2 Focus on Convergence and Meritocracy, the starting point for Unity and Synergy

According to Executive Committee members of the project, undoubtedly, there was an initial worry about the feasibility of harmonizing a joint venture involving four companies, each with distinct corporate cultures coming from different countries, operating without a specified leader. However, as the primary tasks commenced seriously, a remarkable cohesion emerged organically, uniting the efforts of all involved parties into a cohesive and singular organization [5]. From the beginning of the tender process, all four partners invested substantial time working together, sharing physical hours, and this collaboration continued until completion. This extended communication had allowed us to become intimately familiar with one another. This familiarity not only mitigated cultural uncertainties, but also fostered a sense of unity, facilitating swift decision-making – an imperative advantage for a project of this scale [61].

The foundation for unifying the four companies into a single organizational entity was the strategic benefit of their individual strengths. Each partner brought unique value for the project, based on their specialized experts and extensive

experience, However, to ensure optimal expertise in each role, external specialists were recruited when the internal resources of the partners fell short [4, 61]. These varied features were combined in a harmonious manner, effectively employed to result the partnership's success. Daelim's experience lay in constructing various suspension bridges, while SK E&C contributed expertise from PPP infrastructure projects like the Eurasia Tunnel and the Yavuz Sultan Selim Bridge in Istanbul. Limak, with a history of PPP ventures, had a strong connection with the General Directorate of Highways. Yapı Merkezi, a leading Turkish contractor, offered PPP experience and a solid engineering base. While each company allocated their manpower based on their strengths and experiences, these distinct components converged seamlessly as a unified joint venture, earning the benefits of remarkable synergy [5].

This phenomenon was evident both in the construction and project finance phases. As previously mentioned, financing from 25 diverse global corporations was secured for this project. Consequently, each partner had the chance to collaborate with credit corporations that were new to them. On the other hand, the bridge construction was implemented by individuals from all partnering companies who were distributed across various departments. Through these diverse teams, this wealth of experience and knowledge was converted into a single reservoir, enabling partners to reap the results of the shared endeavor [61].

Moreover, there was a strong commitment to establishing a robust corporate culture from the beginning. This comprised creating a distinct corporate identity, maintaining consistent communication, and documenting progress comprehensively. Due to the project's complex multi-stakeholder and multi-cultural environment, establishing a corporate culture based on common principles and values was both challenging and essential. The base of this culture was professionalism and compassion. Professionalism ensured tasks aligned with the corporation's objectives, principles, and values, while compassion emphasized empathy and understanding when engaging with others [4].

Fundamentally, this diversity served as a catalyst for maintaining our concentration on management objectives while upholding a sense of unity through a shared team spirit. While our collective intelligence occasionally led to delays particularly at the beginning, it consistently resulted in high quality products and efficient processes, due to the presence of an effective control mechanism [4, 61, 5].

4.5.3 Effective Communications, the Key for Design Management

As described by the Deputy Design Manager of the project, the 1915 Çanakkale Bridge Project comprised a set of intricate design challenges. The EPC design department consisted of experts from diverse nations, engaged extensively with other EPC departments and third-party collaborators throughout each workday. This level of constant interaction, which created a dynamic working environment, necessitated a remarkable level of energy to meet tight deadlines while keeping effective communication and coordination with other teams.

Moreover, the design partner, COWI, leveraging their team of specialists with extensive experience in suspension bridge design and a robust organizational structure, swiftly responded to our requirements. Our close collaboration started in

2018, allowing us to create a deep mutual understanding. To optimize communication with COWI, two members of our design team were stationed at their office for over a year. Similarly, two COWI representatives worked at our design team's office during a period of design development. This form of close communication not only ensured the continuous information flow but also served as a significant strategy to manage technical and design uncertainties as well as timely change management. "The 1915 Çanakkale Bridge has served as a symbolic bridge not solely between two continents, but also between individuals, cultures, time within Turkey" [63].

4.5.4 Consensus Based Decision Making and Cultural Diversity; Critical Perspectives

According to the project's subcontract manager, Undoubtedly, this particular arrangement involving collaboration with other partners within a joint venture setting is inherently challenging, particularly when shareholders have the same share in everything. This collaborative approach is rooted in the principle of risk-sharing, which is integral to joint ventures. In this context, risks are distributed among the partners, just as ownership is shared. In this circumstance, the essential requirement is to make decisions through unanimous consensus. This procedure necessitates extensive discussions and is also a time-consuming process. Conversely, when a singular company oversees a project, the company's leader possesses the authority to make determinations, even if they are not entirely accurate. In contrast, in the context of joint ventures, one of the main problems lies in the protracted time required for decision-making. Since each of the four companies must have a comprehensive and common understanding regarding various specific issues, misunderstandings occasionally arise due to different culture as well as corporate culture, leading to further delays. In fact, on one hand, this approach offers benefits to the project by alleviating the financial burden that a single company could not bear. On the other hand, the requirement for unanimous decision-making sometime leads to delays.

One of the project's chief engineers, to illustrate this issue, gave an example. "Due to the unanimous decision-making process, when searching for subcontractors for specific tasks, the need to reach a compromise among numerous options was time-consuming, preventing progress to subsequent stages. However, another challenge occurred when the Executive Committee (EC) members expressed an interest in engaging at the construction site. Initially, the rationale behind their strong interest was not entirely clear, but it seemed related to differing cultural perspectives. Their enthusiasm stemmed from the suspension bridge's world records as the world's longest and its symbolic significance. Although their involvement was initially welcomed, it suddenly escalated beyond expectations. Project progress slowed down as practically every decision required EC members' input. Curiously, when questioned about accountability, their stance was confusing – disclaiming responsibility while claiming decision-making authority. If issues arose, it fell on the project manager to resolve, which was an unusual dynamic and impacted project adversely in terms of time".

4.5.5 Adaptable Approach; expediting the progress

Contracts and administration deputy director of the project emphasized that "Leveraging the extensive experience from several similar PPP projects in Turkey, we opted not to introduce a novel or distinct framework for this specific endeavor. If we were even undertaking for example an undersea tunnel project, a tailored organizational structure would already have been in place. This typically includes dedicated teams for quality assurance, design, construction, control, contract, and procurement. However, in this particular project, the emphasis was on accelerating progress. Therefore, we exhibited greater willingness to collaborate with subcontractors and project owners rather than pursuing disputes. Our strategy was noticeably based on adaptability, and we promptly allocated resources to expedite works, especially during the demanding period of the Covid-19 pandemic".

4.6 Organization Form- Key Lessons

4.6.1 More Slender Organization with a Decisive Leadership Vs Collective Leadership

Across different phases of the project, a workforce of more than 30 thousand employees from over 10 countries contributed. Among them, 17 thousand were involved on the bridge, while 13 thousand worked on the motorway. Consequently, orchestrating a harmonious environment for participants coming from diverse countries and corporate cultures posed notable challenges. A strong form of leadership becomes indispensable in managing the complexity of the organization and ensuring its effectiveness. Remarkably, the project was finalized a full 1.5 years ahead of the appointed deadline. This achievement is particularly noteworthy considering the difficult circumstances posed by the pandemic and the complexities of the global supply chain [4, 9].

Although top managers of the project due to the results of regarding project performance indicators believe that the project already has benefited from collective leadership and its unique collaborative management style, there are different view in middle management level. According to the project's chief engineer one of the key lessons emerged from this experience was the significance of decisive decision making. An efficient process requires swift discussions followed by decision-making which operates seamlessly. Due to the weakness of such a system, the organization's hierarchy prevailed in some cases. Although there were several experiences in Turkey regarding mega infrastructure project in the PPP framework, I guess it was the first-time which shareholders had the same equity and consequently the same share of decision making and risk which caused a novel experience about project organization chart. Frequent reorganization compounded this challenge, hindering the establishment of clear roles and responsibilities. Moreover, During the project's peak, the swift expansion of the organization led to obscurity surrounding individuals' functions. In retrospect, it becomes evident that a slender organizational structure featuring well-defined roles and responsibilities, with decisive leadership at the top, is paramount in such a complex project. This model ensures that decision-making is expedited, and that the hierarchy aligns with the project's magnitude. To summarize, given the magnitude of such a project, a

hierarchical structure becomes imperative. This involves dividing responsibilities based on factors such as cost and risk. As a result, distinct decision-makers emerge – the steering committee, EC members, and project managers. Each of these roles should possess varying levels of responsibility and decision-making authority, aligning with their designated functions. This division of responsibilities will ensure a coherent operational framework.

In this regard the Project control manager also emphasized that, while it's important for all stakeholders to be involved in the project, it is essential that a single leader guides such projects. Since the nature of PPP projects demands swift decision-making, I truly believe that even an imperfect decision would be more advantageous than indecision. The rationale behind this is that until a choice is made, its quality remains uncertain. This underscores the need for a capable and experienced leader for projects of this nature. This leader should possess the strength to shoulder all responsibilities and make pivotal judgments. In the absence of such a unique leadership, although achieving success still is possible, it becomes a more time and energy consuming process.

4.6.2 Trust and Transparency; Basic prerequisites for complex organizations

The complex organizational structure with a great number of stakeholders, all demonstrating considerable interest in the Project from its inception, is a rarity on a global scale. Despite the presence of two distinct entities within the joint venture - SPV company, and the EPC contractor- the collective goal remained at the forefront of our endeavors. Cultivating relationships marked by respect and trust played a pivotal role in facilitating the organizational complexities. This extended to all departments of EPC and SPV, including Administrative Affairs, Human Resources, Occupational Health and Safety, and Construction Site Safety. Trust building and fostering transparent relationships formed a strong base to maintain interdisciplinary communication and effective collaborations throughout the life cycle of the project. Moreover, the project's communication manager emphasized on the role of effective collaboration with the government bodies including the Ministry of Transport and Infrastructure, General Directorate of Highways, and Public Private Partnership Regional Directorate as one of the most exemplary aspects of the project. This collaboration was true throughout every phase of the Project, irrespective of challenges or successes. Their involvement extended beyond just providing instructions and overseeing the main contractor's efforts. Instead, they actively collaborated with us, dedicating their time around the clock, and providing uninterrupted support. Their actions conveyed trust, and a sense of guardianship, making us feel support [4].

4.6.3 Importance of Experienced and Skilled Human Resource

One of the project's Executive Committee Member highlighted the importance of human resources in project success. "The competence and background experience of employees play a vital role in realizing operational efficiency. The quality of a team is inherently tied to the abilities of its individual members. Each partner

conducted a thorough assessment of the available project roles and accordingly delegated their employees to roles that best aligned with their skills. However, to ensure the most suitable profiles for each role, experts were employed around the world, in cases where partners couldn't provide from their in-house resources. This strategic methodology empowered us to establish teams comprised of skilled professionals " [5].

In this regard, the Technical Director of the SPV company emphasized that, "individuals stand as a prerequisite in achieving set objectives. My team comprised skilled engineers specializing in diverse disciplines, encompassing civil engineering, environmental engineering, and other specialized areas. Notably, several team members possessed previous experience in both construction and operational stages of similar Build-Operate-Transfer (BOT) projects such as the Yavuz Sultan Selim Bridge, the Osmangazi Bridge, and the Eurasia Tunnel. Their extensive expertise, combined with a strong sense of teamwork, enabled us to successfully tackle numerous tasks both prior to and during the construction phase. This collective proficiency formed the bedrock of our accomplishments. Personally, I held strong trust in my team's capabilities and their dedication to attaining our project's goals" [8].

4.6.4 Flexibility

According to the Contracts and Administration Director of the SPV entity, the SPV's departments operated with a limited workforce. This led to instances where team members, despite having their own assigned responsibilities, were occasionally required to shoulder additional tasks on behalf of the departments. Furthermore, in situations where a team member was unavailable, the team displayed remarkable cohesion, coming together to distribute the workload and provide mutual support. This dynamic, flexibility and dedication inherent within the SPV played a key role in timely completion of allocated tasks [9].

4.6.5 Continuous Follow up and Friendly ambiance

One of the project's executive committee members underscored that the effectiveness of the operational processes greatly depended on the performance of suppliers and subcontractors. Their ability to efficiently manage their operations while meeting the stringent technical requisites of this distinct project was paramount. Moreover, given the multitude of subcontractors and suppliers, many of whom were interdependent, effective coordination becomes pivotal. We ensured that our in-house team maintains close oversight of these subcontractors and suppliers while fostering strong collaboration. Our selection process also carried significant weight. In choosing third-party service providers, our decision was not solely driven by cost considerations. Instead, we prioritized their track record in similar projects, as well as the caliber of their human resources and the robustness of their quality control measures. A crucial facet of successful subcontractor and supplier management lies in viewing them as integral components of our team. This involves vigilant monitoring and continuous follow-up. Treating them as partners rather than just service providers underscore the essence of effective collaboration [5].

4.7 Organization Form- Discussion

The organizational structure of the 1915 Çanakkale Bridge project reflects its magnitude and complexity. The collaboration between public and private entities with different corporate culture, the engagement of various consultants, and the presence of multiple departments within the EPC Contractor demonstrate the need for effective communication and coordination and provide valuable insights into the interaction between organization and project success. The hierarchical arrangement allows for efficient decision-making and the allocation of specific responsibilities. The structure's flexibility is evident in the establishment of specific departments to address varied requirements, ensuring that all aspects, from technical design to legal compliance and financial viability, are adequately addressed. Each component comprised of specialized teams and fulfilled unique roles, emphasizing the importance of interdisciplinary collaboration. Moreover, the presence of international stakeholders highlights the global nature of large-scale infrastructure projects.

The project's success can be attributed to the unique collaboration model that emphasizes trust-based relationships among stakeholders. For this means comprehensive coordination and consensus-building are essential within the organization. This approach allowed the project to effectively manage uncertainties arising from the organizational complexity and cultural diversity. Clear definitions of authority, responsibility, tasks, and timelines ensured minimal conflicts and complications within the system. The principles of delegation, bottom-up decision-making, and open communication facilitated effective management within the intricate hierarchy. The significance of flexible approach for timely decision making that expedites progress while managing complexities became evident, particularly during the Covid-19 pandemic.

Although the organization was well organized from the upper managers' holistic perspective as it was proved by project performance indicators, there were also some defects from the middle body of management point of view who were involved in the construction site. The project's complex joint venture arrangement with the equal share demanded consensus-based decision-making, leading to time-consuming discussions and occasionally delaying progress. Cultural differences and varying corporate cultures added complexity to the decision-making process. The involvement of Executive Committee members on site's activities, driven by differing cultural perspectives, highlighted the challenges of balancing accountability and decision-making authority. Probably, the requirement for existing a unique leader, or at least decisive decision-making structure based on majority of votes in such a complex organization is essential. However, the need for timely decision-making, accountability, and a clear operational framework underscored the importance of a hierarchical structure, particularly in mega infrastructure projects with shared equity and decision-making.

The project's achievement in matching four companies with distinct corporate cultures together underscored the importance of focusing on shared objectives and utilizing partners' strengths. Although cultural diversity caused some problems particularly in the early stage of the project, the project's cohesion emerged gradually as teams collaborated extensively, building trust, and unity. The combination of varied expertise resulted in a partnership that earned the benefits of remarkable

synergy. This convergence was evident in both construction and project finance phases, which demonstrated the power of collaboration in achieving complex objectives.

The project's success was gained by cultivating relationships based on trust and transparency. Despite the complexity of the joint venture and distinct entities, maintaining a collective goal and fostering transparent relationships played a prominent role in managing interdisciplinary communication and collaborations. The project's design challenges highlighted the significance of effective communication and coordination. Close collaboration of design parties within the organization and with external design firm facilitated deep mutual understanding, enabling swift responses to requirements and effective change management. Effective collaboration with government bodies also further highlighted the significance of trust in achieving project goals.

The role of skilled and experienced human resources is evident as a vital component of organization. The quality of the team is directly tied to the competence and background experience of individual members. A strategic approach applying the best internal resources and employing external experts allowed for the establishment of teams with specialized members, contributing to the project's accomplishments. Moreover, the ability to adapt, distribute workloads, and offer mutual support within the organization became instrumental in achieving project tasks. Effective subcontractor and supplier management, treating them as partners, and continuous follow-up further emphasized the essence of maintaining a collaborative and flexible approach.

4.8 Project Structure- Status Quo

The project structure encompasses the contractual framework and financial dynamics that govern a project's development and operation. Central to this structure is the PPP agreement, also known as the upstream contract, between the authority and the private partner. This agreement outlines the private partner's rights and obligations in managing the infrastructure development. The project's specific scope, financial compensation, risk allocation, and other provisions are all reflected in the project structure. The payment mechanism plays a crucial role in shaping the financial and risk aspects of the PPP contract. However, it's important to note that the project structure may vary among projects within the same sector and infrastructure type [64].

4.8.1 Special Purpose Vehicle (SPV) Company

In the context of this BOT (Build, Operate, Transfer) infrastructure project, the Turkish procuring authority General Directorate of Highways (GDH) enters into a contract with a private agent. This private agent was a consortium comprised of four companies (two Turkish, and two Korean companies) awarded the contract. Following the contract award, the consortium established a specific company called the Special Purpose Vehicle (SPV), in compliance with relevant company formation laws, which was called ÇOK A.Ş., specifically for the development and management of this project. The SPV delegated most of its rights and obligations to downstream contracts, effectively distributing responsibilities, risks, and

cash flows among various private entities through different agreements including Financial or debt agreements, EPC contract, Operation and Maintenance (O&M) contracts, and insurance contracts and guarantees. Although it is common for the EPC and O&M contractors, as well as related investment firms, to also be shareholders of the SPV, in the 1915Çanakkale bridge project, just EPC contractor was from the same entity as the SPV. SPV manages the entire project in coordination with the Administration, lending group, Engineering Procurement Construction (EPC) contractor, O&M contractor, and all other advisors. This multi-layered contractual structure ensured a well-defined and balanced distribution of roles and responsibilities among the private actors involved in the project [8]. figure 4.8.1 briefly, demonstrates the structure of the project and The subsequent paragraphs explains contractual relationships as well as the corresponding streams of obligations and funds between involved parties. After the shareholder agreement was signed and SPV signed the contract with the procuring authority, the private partner assumes comprehensive responsibilities for the infrastructure project's entire life-cycle, from design and construction to financing, operation, and maintenance. After the contract signature, SPV undertook the following actions [64]:

- Entering into guarantee agreements for the performance bond, ensuring the fulfillment of contractual obligations.
- Formulating insurance agreements and policies to mitigate potential risks.
- Executing financing agreements, commonly known as "financial close," including loan agreements to secure necessary funding.
- Delegating Engineering, Procurement, and construction responsibilities to the EPC contractor and establishing "downstream" contracts with Operations and Maintenance (O&M) contractors and the other third parties.

4.8.2 Shareholders, PPP, and Loan Contracts

In this regard, the Contracts and Administration Director of the SPV company who was from Daelim (one of the Korean partners) had an interesting view when he was asked to share some of the most important moments in this Project. According to him, "The journey of this project was marked by three significant moments. The first crucial step was the decision to form a partnership for the project. Despite having limited experience with Turkish companies, we were fortunate to meet suitable partners, Limak and Yapı Merkezi, through SK (the other Korean partner), who had prior experience working in Turkey. We were four companies, all had the same share (25%), and the decision-making process was consensus based. This partnership proved essential in bringing the project to fruition. The second memorable moment was during the official proposal opening in 2017. While there were three other competing consortium, our proposal stood out significantly, surpassing all expectations. Winning the bid against tough competitors made it a remarkable achievement for our company and our country. The third remarkable milestone was the signing of the financial agreements on the 16th of March 2018. It was a significant challenge, considering the tight time-frame for financial closure. Yet, with the relentless efforts of the SPV and sponsor groups, we accomplished

this feat within a year, defying common expectations for such mega projects. Project successfully obtained loans from 25 banks and financial institutions from 10 different countries. For the project's financing, a 15-year term loan was secured, with a grace period of 5 years, amounting to a total of 2.265 billion Euros. Out of this sum, 70% was provided by 19 foreign banks and financial institutions, while the remaining 30% came from well-established Turkish banks. The credit package encompasses eight distinct tranches, which incorporate various financing methods like Export Credit Agencies (ECA's) and Islamic financing, adhering to international project financing standards". [9].

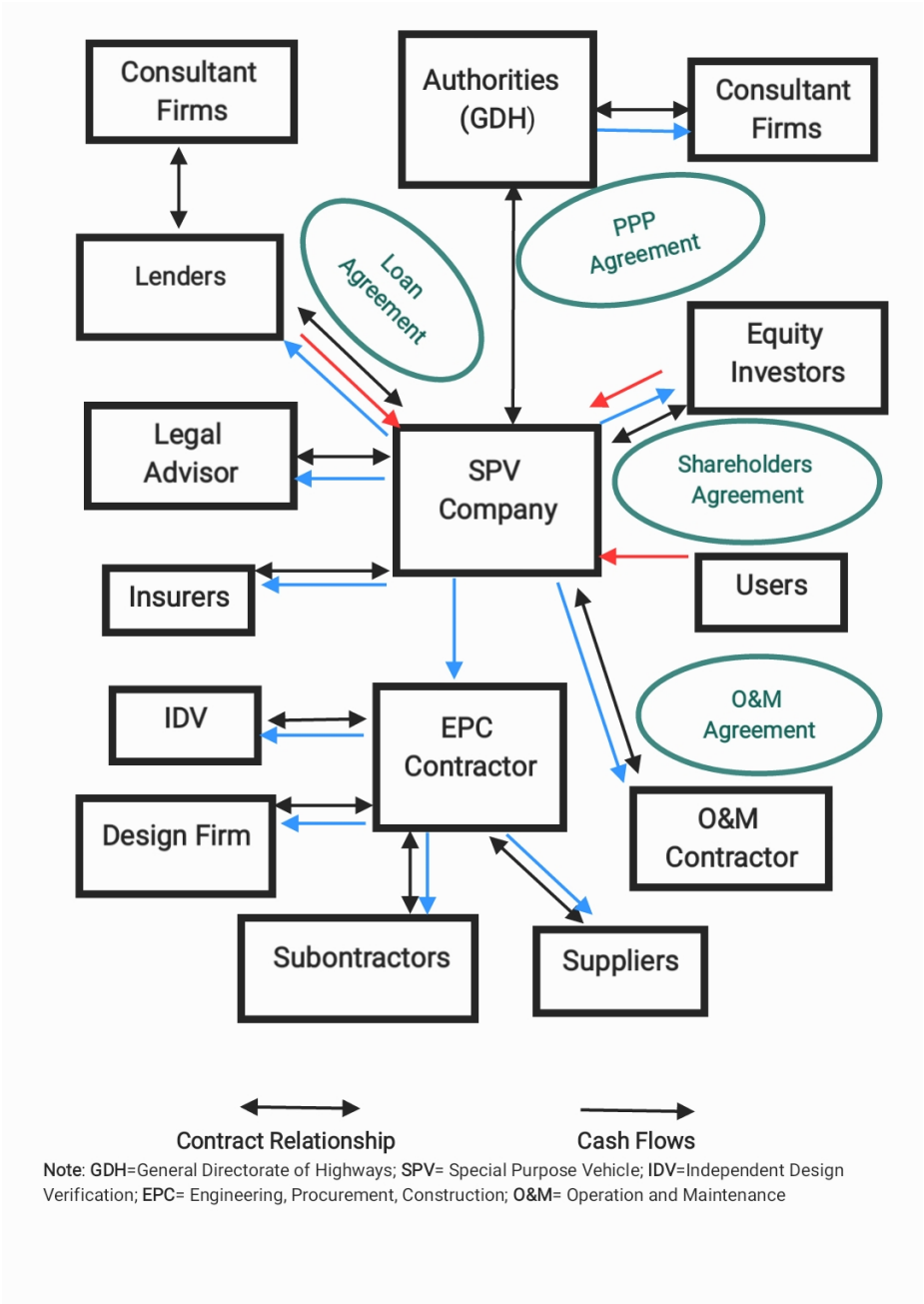

Figure 4.8.1: Contract Structure of 1915Çanakkale bridge project

4.8.3 Insurance Contracts

Moreover, according to the Contracts and Administration Deputy Director of the project, "The 1915 Çanakkale Bridge and Motorway Project faced numerous risks due to its large-scale nature. To mitigate these risks, a variety of insurance policies had been formulated and signed with both local and international insurance companies. Initially, insurance brokers acted as intermediaries, facilitating communication with these insurers and their markets. A comprehensive analysis of the project's requirements and risks was conducted, and this information was shared with the insurance market. The risks and guarantees were then identified. Given the immense scale of the project, it was not feasible for a single insurance company to assume the entire risk burden. This was where re-insurers came in, undertaking specific percentages of the risks. A total of 15 re-insurer firms were involved in the project's most critical insurance policy, which was the CAR (Construction All Risk). In essence, CAR Insurance offers extensive coverage for all materials, structures, equipment, and production activities starting from the project's commencement until the designated completion date. Among the re-insurer firms, the lead re-insurer is the one with the highest percentage of risk undertaken. Munich Re, a prominent player in the global insurance market, assumed as the lead re-insurer and also participated in the TPL (Third Party Liability) policy. This collaboration with multiple re-insurers ensured comprehensive coverage and effective risk management for the project".

4.8.4 Engineering Procurement Construction (EPC) Contractor

As it is mentioned before, the 1915Çanakkale Project was structured under a Public Private Partnership scheme where four different shareholders work together within the framework of the Joint Venture structure in the capacity of sponsors (SPV Co) and EPC contractors. The SPV company, ÇOK A.Ş., delegated all responsibilities regarding EPC works to the EPC contractors [9]. The Project was run by the joint venture established by DL E&C, Limak, SK ecoplant and Yapı Merkezi and named DLSY JV. With its name composed of the capital letters of the companies' names and the term Joint Venture, DLSY JV was an EPC company handling turnkey projects. The Project Management Office comprised Project Managers, and three Deputy Project Managers for each and affiliated teams. The decision-making process was consensus-based because each partner company has representation there. Without the signatures of all four partners, there can't be any purchasing or signing of agreements. Almost ninety-five percent of the personnel were outsourced. In other words, DLSY JV. worked with construction subcontractors, equipment suppliers, steel fabricators, engineering firms, and lenders from over 10 countries also participated in this collaboration [62]. According to the deputy manager of the project, "as an EPC contractor, Initially, we compile the tender documents, presenting our blueprints and specifications. Subsequently, we choose the subcontractor and facilitate their deployment to the site. we were responsible for subcontractor management. we had to anticipate technical problems. We had to make sure that different processes and operations were all running smoothly without overlaps and conflicts and that they were run in

accordance with the design and tender specifications. Within this framework, we address matters concerning design, project monitoring, coordination, and interactions with the employer. Ultimately, the subcontractors hand over their completed work to us, and we, in turn, present it to the employer. Towards that end, we had construction teams, Design team, health and safety teams and quality assurance teams as well as the organizational structure and capacity to bring this turnkey project to its successful completion" [8].

4.8.5 Subcontracts at EPC

The contract and administration deputy director of the project, who has been involved since the early stages, offered an intriguing perspective on task and contract allocation, logistics, and the value of time in a PPP project. "Collaborating with major contractors simplifies supervision and coordination process even though, dividing a project into smaller segments might seem more logical and cost-effective. he illustrated this with an example: "If you secure a major contractor for caisson work and maintain a proactive approach, the process becomes streamlined. Conversely, if you engage three separate firms for concrete, steel work, and caisson transportation, each with numerous subcontractors, the task of supervising and coordinating becomes complex and time-intensive." He emphasized the significance of partnering with reputable companies, cautioning that opting for cheaper alternatives doesn't guarantee optimal outcomes, given the paramount importance of time. "Every day of delay carries potential substantial financial losses. Thus, we possess zero tolerance for delays. While it is our responsibility to drive the contractor, the contractor must also possess the capacity to mobilize, such as deploying a workforce exceeding 1000 individuals if needed for caisson work". He also highlighted the critical role of specialized machinery and large equipment in time-sensitive projects, acknowledging the challenges of advance equipment rental and international coordination, particularly for mega size cranes and lifting gantries. Balancing the cost of additional equipment against the need to accelerate the project becomes a necessity in tight schedules. Lastly, he underscored that the complexity of managing teams and equipment from various countries adds a layer of intricacy to the project.

The deputy subcontract manager of the project explained the critical tasks and the variety of EPC's subcontracts and also main contractor's strategy to managing subcontractors. "however we had more than 300 contracts with different third parties, but the main task of the project which were on the critical path comprised of Design, underground and caisson work, steel towers, Catwalks and main cables, steel deck etc. First, the super structural material elements were fabricated in the related monopolized factories around the worlds and after transporting to the site, the installation were done during a heavy lifting activities by our professional subcontractors. We had a kind of design service provision contract with the design firm, supply contracts with our suppliers and quantity measurement contracts with the subcontractors. This approach required handling multiple subcontractors for each task. Even though we could involve another large company as an intermediary to manage subcontractors, the decision was made to contract the subcontractors directly. This not only eliminated the need to pay additional fees for the intermediary's services but streamlined the communication process

between the parties and enhanced direct control over the subcontractors".

4.8.6 Lenders' Advisors

During the construction phase of the project, subcontractors received progressive payments based on the terms agreed upon in the contract, typically through monthly payments for completed works. The Lender's Technical advisor, Mott MacDonald, and Environmental and social advisors, Arup monitored the work through the whole life cycle of the project to give the best consultancy services to the lenders. For the financiers, keeping track of the project's progress and identifying key risks associated with the work schedule is of paramount importance. Lenders' advisors' responsibilities in this regard, comprised of identifying technical risks and ensuring the bankability of the project before reaching financial closure, reporting the construction progress on-site to the lenders, certifying the number of completed works and highlighting any potential risks that could impact the project's timely and budgeted completion. Furthermore, these advisors were actively involved in the operational phase of the project, continuing to provide their valuable services to ensure its successful implementation [9].

4.8.7 Operation& Maintenance (O& M)

Upon the completion and commissioning of the infrastructure, the procuring authority granted authorization for the commencement of operations phase. In user-pays contracts, which was the case of the 1915Çanakkale bridge project, the Special Purpose Vehicle (SPV) was responsible for charging users. The funds collected by the SPV are allocated as follows: firstly, to cover Operations and Maintenance (O&M) costs, including payments to O&M contractors, as well as the establishment of necessary reserves mandated by law and the contract. The remaining funds are then utilized to pay interest, repay debts, and provide distributions to equity holders. Financial agreements incorporate a predetermined repayment schedule to ensure compliance with the Debt Service Cover Ratio. Additional limitations on equity holder payments are commonly included in these agreements. Consequently, the bulk of returns to shareholders in the form of dividends is typically realized during the later phases of the contract. This strategy prioritizes meeting contractual obligations and securing the project's financial stability before granting significant returns to equity holders. Throughout the Operations Phase, the asset requires periodic investments for renewals or re-investments, often referred to as "major maintenance" or "life-cycle costs". Typically, these works are handled by the O&M contractors under existing contracts, although separate contracts may be sought for renewals if necessary [64].

In the absence of an early termination event, such as a serious default by the private partner, force majeure, or a unilateral decision by the procuring authority, the contract will run its course and naturally expire as per its specified term. Upon contract expiration, the ownership of the infrastructure reverts to the government. Subsequently, the government has several options, including re-tendering the management of the asset in a new contract, engaging in shorter-term agreements for Operations and Maintenance (O&M) outsourcing, or directly assuming the asset's management. This process of returning the asset to public ownership is commonly

referred to as "hand-back." Best practice dictates that the private partner should hand back the infrastructure in a specific condition. To meet these requirements, the private party may need to invest in maintenance and upgrades during the final years (typically 1 to 3 years) leading up to the contract's expiration date. This ensures that the asset is in an appropriate state and condition when it is returned to the government [64].

4.9 Project Structure- Effects on Performance and Uncertainties

4.9.1 Well Project Structure along with Well Suited Strategy

According to the project's deputy director who was involved in the project from the tender stage, PPP project's structure more or less is the same around the world. What makes differentiates is applied strategy to accomplish the works. For the 1915Çanakkale project, the project structure's well-defined roles and responsibilities, along with the streamlined decision-making process within the consortium, facilitated efficient coordination among stakeholders. This contributed to meeting crucial project milestones and tight schedules. The project management approach of direct contracting with subcontractors not only eliminated potential costs to employ third party, but also ensured timely execution and minimized delays. Moreover, the essence of PPP project has been structured based on implementing the construction activities as early as possible which is particular the most important indicator from private partners' perspective to achieve the maximum benefit from the project.

The consortium comprised of reputable companies with the well track of records in PPP projects alongside supportive government played key roles in timely financial agreements which notably ensured the availability of necessary funds for different project phases. The project strategy to collaborate with experienced subcontractors emphasized enhancing the project's overall quality considering the tight schedule. The comprehensive insurance policies, including CAR (Construction All Risks), mitigated a wide variety of risks related to construction uncertainties. Additionally, the presence of multi layers quality control mechanism including GDH's consultancy service, Lenders' Technical and environmental Advisors, and EPC's Internal quality control unit, ensured adherence to quality standards.

4.9.2 Legal Advisors; Beyond the Legal knowledge

The chief lawyer of legal advisor company explained the key role of legal advisors to establish robust financial agreements and their proactive role in foreseeing and managing uncertainties in project life cycle. "Lawyers shoulder the responsibility of navigating a wide-ranging of legal facets. This encompasses an expansive array of legal domains such as public, corporate, construction, commercial, financing, and security law. This extensive understanding is imperative to establish resilient project structures and meticulous documentation.

Furthermore, a project lawyer's understanding should extend beyond legal boundaries. Sufficient knowledge of sector-specific technical complexities and financial cash flow modeling holds significant importance. It is crucial to create a financing framework that systematically addresses all conceivable risks that could potentially influence cash flow dynamics. The convergence of legal expertise, technical knowledge, and financial insight was pivotal for such a complex structure and had a key role in risk management particularly financial and contractual uncertainties within the project" [8].

4.9.3 Transparent Accountability; a solution for the complex structure

The Contracts and Administration Director of the project believes that the tasks proved more challenging than the initial expectations, largely due to the diverse range of stakeholders involved in this Project. He added, this project had an extraordinary importance for Turkey. Thus, considerations extended not only to government officials but also to the Turkish public. Additionally, the project encompassed four sponsor groups and twenty-five financial institutions, along with their respective advisors who were integral to this contract. This essentially made us a substantial entity with numerous components to account for in the decision-making process. Despite the tendency to exceed budget projections, we have consistently succeeded in fulfilling the satisfaction of all our stakeholders. From my perspective, the complexity of the project's structure posed another challenge. Each decision and action can be interpreted diversely depending on their placement within this structure. What might appear advantageous for one party could differ for others. This necessitated an open-minded and sensitive approach that values all viewpoints. To accomplish this, substantial time was dedicated to elucidating the rationale behind issues and the process leading to conclusions for all involved parties. On occasion, a multitude of issues had to be resolved within an exceedingly tight time-frame, often beyond our control. This is primarily due to the distinct internal procedures each stakeholder adhered to. During such instances, our focus lay in striving to provide comprehensive information and deliver messages with maximum clarity [9].

4.10 Project Structure- Key Lessons

4.10.1 Being Proactive, Open Communication, Continuous follow up

At the beginning of the project, decision-making was limited to a small group. However, as time passed, both the SPV and EPC contractor expanded their personnel significantly. This growth led to the need for simultaneous decisions across project areas, posing challenges to effective planning and execution. To address these challenges, contracts and administration department employed key strategies including [9]:

Firstly, Successful planning and execution are significantly influenced by "thorough and proactive thinking". Considering the multitude of stakeholders, con-

tracts, and regulations concurrently, each action can yield diverse effects on different parties. Decisions based on singular viewpoints can lead to unforeseen repercussions, potentially disadvantaging the overall project. Hence, meticulous consideration and anticipation of all possible outcomes in advance are vital for sound decision-making.

Secondly, Communication stands as another pivotal element for effective planning and implementation. Initially, communication was relatively straightforward due to physical proximity; the SPV and EPC JV were in the same building, facilitating clear task allocation. However, as the project expanded, the scenario changed drastically. The workforce grew to thousands, and tasks were dispersed across various teams. As previously mentioned, a single decision could impact both those directly involved and those unaware of the situation. Therefore, effective communication was imperative, involving unbiased response to diverse opinions and views. Regular and open communication channels are equally critical for navigating this complex structure successfully.

Lastly, Continual follow-up is vital for effective planning and execution. Continuous follow-up ensures tasks achieve their intended outcomes. Often, tasks are overlooked until deadlines draw near. A well-structured organization necessitates collaboration rather than working in isolation. Dependency on each other's support is inherent. Waiting without active follow-up can lead to failure, as others may be occupied and forget tasks. In fact, closely monitoring tasks until their completion remains a reliable approach for achieving the desired outcomes.

4.10.2 Importance of Interdepartmental Communication, Backup, Friendly environment

A deputy project manager of the project emphasized the pivotal role of effective communication in managing diverse disciplines. He elaborated, "Our main objective in this venture was to provide robust support to our subcontractors, ensuring the execution of top-quality work within a framework of maximum safety. Essential to achieving this aim is effective communication, which must remain open at all times. Interdepartmental communication serves as a foundation for strong coordination and perfect operations. For instance, multiple temporary structures were constructed on the anchorage block, intricately linked to the cable installation process. This led to a range of issues that required synchronized efforts with the cable teams. In a project characterized by time constraints, intricate considerations, and numerous collaborators, communication falls in the priority. To enhance communication, we initially fostered a friendly environment to cultivate connections among employees. It was crucial that each employee felt a sense of belonging to a unified team. To ensure a secure structure, when we required shift engineers, we not only hired the necessary number but added an extra one, providing comprehensive training for seamless interchangeability among them. This structured approach, with precise staffing and backup levels, fostered a sense of satisfaction among the workforce—an essential element influencing job contentment" [8].

4.11 Project Structure- Discussion

The 1915 Çanakkale Bridge and Motorway Project exemplifies a complex project structure characterized by a Public Private Partnership (PPP) model. This framework encompasses various contractual relationships, including the Special Purpose Vehicle (SPV), consortium members, public sector, lenders, Insurers, EPC contractor, multiple consultancy firms, and other third parties. The SPV company serves as the central entity responsible for coordinating the development, operation, and maintenance of the infrastructure which can be considered as one of the key strengths of the project's structure. This multi-layered structure distributes roles, responsibilities, and risks among the various private entities through the downstream contracts, ensuring a balanced allocation of resources and expertise. Considerably, each contractual relationship within the structure is meticulously defined to reflect financial dynamics, risk allocation, and performance expectations. This strategic structure enables collaboration among diverse stakeholders and enables efficient project execution.

The complex nature of the project structure, involving multiple stakeholders and various contractual relationships, contributes significantly to managing uncertainties. Through proactive planning, open communication, and continuous follow-up, the project management team in cooperation with lenders' technical advisor and client's consultancy services navigate potential uncertainties related design, construction and financial issues. The strategic placement of legal advisors with an expansive understanding of legal, technical, and financial domains ensures the establishment of flexible financial agreements. This comprehensive framework, coupled with the project's multi-layered quality control mechanisms, not only ensures high quality product but also protects the project against a wide variety of unforeseen challenges. The engagement of lenders' advisors, with their expertise in technical and environmental aspects, provides a robust mechanism to monitor the project's progress and identify potential risks, which would be beneficial for both parties.

The success of the 1915 Çanakkale Bridge Project results in valuable lessons for the execution of mega infrastructure project. Proactive planning emerges as a prerequisite, requiring stakeholders to anticipate multifaceted outcomes and implications within the complex structure. which means effective communication is pivotal, especially when dealing with a diverse range of stakeholders. Transparency when it comes to accountability and communication magnifies a shared understanding which will lead to timely collective decision-making. Moreover, the significance of synergistic efforts and coordination among various teams in such a sophisticated structure underscores the key role of interdepartmental communication.

4.12 Specification of the work- Status Quo

The SPV company was contractually obligated to complete the entire construction phase, which encompassed project financing, design, and construction, within 66 months. However, their operational model was based on a 45-month timeline, implying that any delays beyond 45 months would result in financial losses for the private partners, as their budget was structured around this time-frame. Re-

markably, despite the project's vast scale, which set numerous global records, and unforeseen uncertainties such as the Covid-19 pandemic, the SPV successfully concluded the construction phase in just 48 months. This achievement stands as an exceptional feat in terms of adhering to the project's timeline. From standard perspective, there was not in the deep problem since Turkish government had recently completed some mega infrastructure projects comprised of a mega suspension bridge in Istanbul. Therefore, Turkish Highway administration had experience about suspension bridges. They had utilized some of the well-known international consultants for design services as well for the verification. Due to the common positive cooperation in İzmit Bay Bridge, which is now called Osmangazi Bridge, their tendency was COWI, an international company expertise in engineering, environmental science which ultimately was selected as the design firm to prepare detail design and specification for the project.

4.12.1 Design's Specification and Standards

In technical perspective, it was a specific project so there was no design code or a specification that is fully applicable for this project, because those standards, as the name implies are the standards for ordinary projects. But for a specific project like this project, specification both for technical and execution issues need to be organized. The major issues for the specification had been outlined by the client requirements and the SPV company gave the main responsibility to the EPC contractor for proposing a sound specification in line with the client requirements. Therefore, what were Generated here was a combination of many standards. Standard for the road part was very easy, Turkish standard and AASHTO standard were implemented but for the bridge project, COWI was expected to utilized Euro codes to develop the standards and specifications. It was the first time that the specification of a project in Turkey followed Euro Codes deeply. Although Euro Codes was directly used to prepare some general and usual designs like steel and concrete structures, COWI was supposed to create a project specific specification for some critical parts such as the wind design. In this way, a lot of supplementary experiments such as Tower Model Wind Test in Denmark, Deck Section Model Test in Canada, Full Bridge Model Wind Test in China were done to prepare wind specification. All in all, the major issues specified in line with what was provided by the Euro Codes, however some local and other international standards were utilized, for example, the Occupational Safety and Health Administration (OSHA) for the HSE issues.

4.12.2 Design method and its Challenges

The specification of work was generated step by step since it was fast track contract. COWI always prepared the specification while they were preparing the design which means that design did not complete totally before initiating the construction phase. They were developing the design simultaneously with the project execution.

Although COWI knows bridges' issues very well, they were not aware of all aspects of the specific works. They needed some of the subcontractors, fabricators, and suppliers to finalize their specifications which means that they requested us

to select these companies as soon as possible so that they contributed to discuss and finalize the specification. For example, They Prepared the certain level of specification for the steel towers, but They naturally did not know detail as much as the company who will fabricate that one. due to that reason, they requested our technical department to select the fabricator company as early as possible for Supporting them to finalize the specifications. The problem was that the process of finalizing specifications along with specific subcontractors was time consuming. There was another paradox because without those specifications the process of choosing suppliers could not be finalized as well. On one hand, the design company (COWI) required a certain subcontractor to finalize their specification. On the other hand, without those final specifications, it would be very hard to select the subcontractor as well. It is like a problematic issue for the EPC contractor which always impacts time.

4.12.3 Solution Parties

Although basic technical specifications were based on the Euro Codes, there were also certain international standards, especially for things like health and safety issues. In some cases, some of the local standards were imposed to be follow, as basically at the end of the work EPC contractor needed to get the approval from the government side. Finally, there was a mixture of standards and instruction as a source of the project specifications. It was the standard like a Bible And sometimes It can be Followed while for Some items it was not possible to follow 100% and it was required to adjust based on the existing ability and then have been explained to the client's representatives.

If the local standards were not compatible with the global standards and specifications, after precise studies, proposed modifications should had been issued to the third party for getting approval. There was a consultancy services during the construction phase on behalf of General Directorate of Highways (GDH) which was established by the Joint Venture of Tekfen Engineering Co. and T Engineering International SA consultant (TT JV) and their role was maintaining close contact with the Contractor as well as performing consultancy services like specification clarifying.

Moreover, the design process was an interactive process particularly for the great number of temporary structures in bridge project where Designers would create a draft and share it with the contractor for review and feedback, and this collaborative cycle repeated several times until the final output was achieved. Once COWI completed the final design and specifications, certain elements, such as temporary structures, underwent grading. Based on these grades, some items required assessment by the client representative (JV TT), which often resulted in a significant time delay. Notably, the EPC contractor had a dedicated design and engineering department responsible for identifying design and specification discrepancies, assessing constructability and design risks, and providing constructive feedback to both JV TT and COWI.

All in all, the bridge's design underwent thorough scrutiny at multiple stages, encompassing four distinct levels of examination. These encompassed the EPC contractor's design department, design firm (COWI), independent design verification (IDV) firm, and administration consultancy firm (TT JV) [6]. In addition

to them, as the main solution partners of the project, two other external parties were involved in addressing specification and quality matters at different project stages. These entities were Mott MacDonald, serving as the Lenders' Technical Advisor (LTA), and Arup, fulfilling the role of Lenders' Environmental and Social Advisor. According to the senior project manager at the LTA company, they operated a fully integrated business management system. This system guaranteed the provision of services in alignment with requisite quality standards and client expectations, while also fostering a culture of continuous enhancement. The system was web-based and accessible to all staff members. Its implementation ensured that all deliverable adhered to the following criteria: • ISO 9001: 2015 Quality management systems • ISO 14001:2015 Environmental management systems • OHSA 18001:2007 Occupational health and safety management systems • ISO 27001:2013 Information security management systems • BS 10500:2011 - Specification for an anti-bribery management system • BS 11000-1:2010 -Collaborative business relationships- Part 1: A framework specification [9].

Arup also served as the Lenders' Environmental and Social Consultant for the Project. Initially, their role encompassed conducting Environmental and Social Due Diligence to facilitate the Project's funding from international lenders. This advisory process included outlining how the Project, along with its construction and operational activities, should be structured to ensure alignment with the environmental and social policies of the lenders across all phases of the Project's lifecycle. These policies mandated adherence to Turkish legal regulations as well as globally recognized environmental and social standards, such as the International Finance Corporation (IFC)'s Environmental and Social Performance Standards and the Good International Industry Practice. These standards encompass rigorous criteria for evaluating and addressing social and environmental impacts and risks [9, 7]. The Project's Chief Financial Officer (CFO) emphasized the increasing significance of environmental and social impact studies in projects with international financing. This importance is particularly pronounced for foreign banks and export-import institutions. In the realm of international financing, emphasis on sustainability and environmental consciousness has surged. The global interest in environmentally sustainable financing models is on the rise. Financial institutions required our team to engage in pre-financing planning and specific studies. Additionally, they demanded that these studies undergo review by their designated international consultants. The 1915Çanakkale Project fell under the category A classification in terms of environmental and social impact assessment. Consequently, adherence to the International Finance Corporation (IFC) standards was obligatory. We were tasked with conducting environmental and social impact assessment studies adhering to international benchmarks. This commitment extended beyond the financing phase, and initiatives included actions such as stopping piling activities in the Çanakkale Strait during dolphin crossings and relocating Pinna Nobilis mussels discovered at the marine works construction site to more suitable habitats to ensure their survival. Furthermore, we administered a Community Level Assistance Program aimed at resolving grievances stemming from the Project's impact on local communities. In the sphere of safety and health, numerous expert teams were deployed on-site. Comprehensive monthly occupational safety reports were submitted to both the banks and company partners, reflecting a strong emphasis on this aspect. The partners displayed a high level of

sensitivity toward this issue as well [62].

4.12.4 Outstanding Specification

Although there were a lot of innovative and high-tech components in such a mega project, the project's executive committee (EC) member underscored some of the project's main innovative engineering and technological solutions. He believed that "The design of the 1915Çanakkale Bridge seamlessly blended historical sensitivity with cutting-edge engineering methods, forging a symbolic connection that extended beyond continents. This connection also bridges Turkey's past, its current era (1915 to 2023), and the future that awaits" [5]. According to him, following is a concise representation of the distinctive design specifications of the 1915Çanakkale Bridge:

4.12.4.1 GENERAL DESIGN

The total length of the 1915 Çanakkale Bridge spans 3,563 meters. This measurement specifically pertains to the suspended steel deck of the Suspension Bridge. It comprises two symmetrical side spans, each stretching 770 meters, and a central main span spanning 2,023 meters. Consequently, the configuration of the bridge qualifies it as a 3-span suspension bridge. However, the bridge's scope extends beyond this central expanse. Anchoring the suspension bridge, reinforced concrete approach viaducts are positioned at both ends. These viaducts stretch for 680 meters on the Asian side and 365 meters on the European side. When these integral viaducts are factored in, the comprehensive bridge system extends over a distance of 4,608 meters (as depicted in Figure). The bridge's design accommodates the need for navigation clearance, allowing for a height of 70 meters over a width of 1,600 meters. This specific ratio has been chosen as an economically optimal decision, particularly for a suspension bridge of such magnitude, setting the stage for the achievement of a world record main span [5, 3, 6].

4.12.4.2 CAISSONS

Two massive caissons, utilizing a substantial volume of 65 thousand cubic meters of concrete, each the size of a football field, were built in a dry dock. Once composite shafts were erected in the wet dock, these caissons were floated to their designated spots and carefully lowered to depths of 37 meters on the European side and 45 meters on the Asian side, demonstrating exceptional precision at eight centimeters and five centimeters respectively. It's worth noting that despite a 20cm horizontal placement tolerance in the design, advanced guiding poles driven into the seabed limited any potential deviation to just eight centimeters [5]. To achieve this, a unique approach was employed that had not been previously utilized for structures of this scale. Notably, each caisson was composed of 80 individual cells. By deliberately filling these compartments with water, a controlled process was initiated to gradually submerge the caissons. Additionally, a significant modification was introduced to the upper portion of the caissons. This transformation involved transitioning from a rectangular prism shape to a graduated cube configuration. This alteration aimed to mitigate the potential impacts of vessels colliding with the caissons, enhancing overall stability and durability [7]. For a robust base, the

caissons were positioned on three-meter-thick layers of crushed stone, placed over a seabed reinforced with steel poles. The seismic design strategy considered an extremely rare earthquake with a 2475-year recurrence interval, aiming to mitigate potential underwater bridge damage during such an event [5].

4.12.4.3 TOWERS

The steel tower structures of the 1915 Çanakkale Bridge serve a crucial role in supporting dynamic forces, including wind and seismic effects, along with live traffic loads and various dead loads. These towers consist of steel pillars and crossbeams, with 128 steel tower blocks and 18 crossbeam segments meticulously assembled. To ensure stability, strict quality control and precise geometry monitoring were enforced during construction. The towers were designed with chamfered edges to reduce wind-induced vibrations. The assembly process involved lifting and joining steel blocks using a combination of bolts and welding. The tower blocks were transported to the site and assembled with high-capacity floating and tower crane systems. Given the substantial forces at play, accurate assembly was crucial for the bridge's overall structural integrity [6].

To counteract vibrations resulting from the unique tower geometry under windy conditions, active mass dampers (AMDs) were utilized throughout both construction and operation. These AMDs were intentionally relocated twice during construction and eventually maintained in their second position to avert harmful vibrations. TE Solution as one of the leading global companies in wind engineering and vibration control technologies, was actively involved in the 1915Çanakkale Project, contributing through the provision of advanced technologies, wind tunnel testing, wind and vibration analyses. Given the Çanakkale Strait's reputation as one of Turkey's windiest locations, and the 1915Çanakkale Bridge's distinction as the world's longest mid-span bridge, susceptibility to wind-induced vibrations was a notable concern. This company took charge of managing vibrations in the bridge's towers and cables. This endeavor included the installation of cutting-edge technology, namely four AMD units, each weighing 30 tons, with a 1.2-meter stroke, for tower vibration control during both construction and operation. Furthermore, 500 Stock-bridge dampers were implemented to mitigate wind-induced vibrations in hanger cables. Comprehensive analyses and control measures were also designed for hand ropes and pull-back ropes in the main cables. They conducted wind tunnel tests to assess the aerodynamic stability of the main girder during the basic design phase, as well as to evaluate tower panel stability during lifting operations. Vibration measurements and analyses were performed for the tower top crane, along with corresponding measures to minimize vibration [62, 5].

The division manager of the project drew a comparison between the current project and the Yavuz Sultan Selim Bridge, "In the previous project, four concrete towers, each measuring 322 meters in height, were constructed using around 65 thousand cubic meters of concrete for the anchorage cable attachment points. This concrete placement process spanned 17 months. However, in Çanakkale, a similar amount of concrete, approximately 65.5 thousand tons, was used solely for the towers, completed in a much shorter period of around ten months. This achievement was a notable feat given the challenging geographical conditions in Çanakkale. Overcoming such challenges required the implementation of advanced

technologies and methods. For instance, the installation of the steel towers employed a tower crane with a capacity of 300 tons, significantly larger (ten times) than the one used for Yavuz Sultan Selim. Additionally, active mass dampers were utilized to mitigate the impact of wind forces [7].

Moreover, comprehensive investigation was undertaken to assess the potential consequences of ship collisions spanning 50 years, considering trends in shipping traffic and diverse ship dimensions. The objective was to guarantee minimal harm to the submerged segments of the bridge, even when subjected to substantial impacts from ship collisions [5].

4.12.4.4 DECK

Research and studies for five decades and the construction of suspension bridges with spans exceeding 1500 meters have validated the effectiveness of deck designs using multiple boxes to withstand wind loads within budget constraints. The 1915Çanakkale Bridge, with a 2023-meter main span, overtook Japan's Akashi Kaikyo Bridge by 32 meters, a record holder since 1998, while using 33 percent less steel (including cables, suspension ropes, towers, and decks). The 1915Çanakkale Bridge's 3.5-meter-high "multi-box" deck design, unlike Akashi's 14-meter-high truss deck [5], and its innovative twin deck arrangement, with separate East and West traffic lanes connected by a nine-meter gap, contribute to its uniqueness [63]. To install deck's mega blocks each one weighed between 740 and 880 highest-capacity cranes and lifting equipment such as 8 lifting gantries each with a lifting capacity of 450 tons and floating crane with a capacity of 5000 tons were employed [4, 62]. Thorough aerodynamic evaluations were conducted to verify the stability of the bridge deck against wind influences. Assessments determined a crucial wind speed of 226.8 km/hour through deck tests. Additionally, the largest wind tunnel laboratory globally, located in China, examined a 1/190 scale model of the 1915Çanakkale Bridge, subjecting it to winds reaching 299 km/hour. The results showcased the bridge's robustness, even in the face of such extreme conditions [5, 7].

4.12.4.5 MAIN CABLES and Saddles

In addition to its aesthetic significance, the bridge's main cable serves a vital function by transmitting all loads to the anchorage structures. Achieving a balance between strength and minimal wind resistance required an iterative process to define the cable's section. Utilizing Prefabricated Parallel Wire Strand (PPWS) with a high tensile strength of 1960 MPa for the main cable ensured durability while minimizing its overall dimensions. In the execution of the 1915Çanakkale Project, SPCC, a Chinese manufacturer of PPWS (Prefabricated Parallel Wire Strands) cables, partnered with KISWIRE as key suppliers responsible for fabricating and overseeing the main cable manufacturing for the bridge construction. Their approach involved a sophisticated workflow that integrated research, design, manufacturing, and installation consultation, tailored to address specific challenges within the project. To commence, they established a dedicated team to assess design prerequisites, manufacturing standards, and inspection protocols, subsequently formulating a comprehensive research and development strategy. Following these preparations, enhancements were made to their production and inspec-

tion facilities. The initial focus was on innovative automatic wrapping equipment, meticulously designed to ensure the productive efficiency of PPWS manufacturing. This equipment enabled a production team to generate 1.5 PPWS units daily, a vital factor as both companies at the same time were involved in various domestic and foreign projects. Equally noteworthy were the prefabricated specialized tools and testing apparatuses, independently developed by SPCC. Historically, manual intervention during cable production on construction sites led to inefficiencies and compromised quality control. Through dedicated research and development, specialized equipment was devised to eliminate the need for such labor-intensive tasks on-site, enhancing efficiency, preserving labor resources, and guaranteeing product excellence. These innovations stood as the most distinctive features of cable production endeavors [61, 5].

Gruppo Cividale, a leading European foundry with an annual production of 190 thousand tonnes, played a crucial role in the construction of the 1915Çanakkale Bridge by producing tower saddles and splay saddles.The CEO of the company briefly explained the key technical aspects of the design process. "These components are essential for transferring vertical loads and guiding cable directions. The company's expertise and advanced equipment, including Vacuum Oxygen Degassing and precision machining, ensured the components met costumer's rigorous technical standards such as Euro codes. Also, Close collaboration with the customer's engineering teams led to optimized designs and successful production" [9].

4.12.4.6 DURABILITY

The 1915 Çanakkale Bridge is meticulously designed to ensure a minimum 100-year service life through careful consideration of maintenance needs. Focus on resilience against environmental factors, particularly marine conditions, is evident in the design of the suspension bridge and approach viaducts, with a performance-based approach taken for the concrete structures. To prevent corrosion, advanced measures include a dehumidification system integrated into key components like the main steel structures, towers, twin box deck girders, main cables, and anchor blocks' back chambers. To further guarantee longevity and evaluate its behavior against various forces such as earthquakes, storms, and potential ship collisions, a sophisticated structural health monitoring system is implemented. This system plays a pivotal role in achieving and extending the intended service life of the bridge while ensuring its robustness [6].

A Structure Health Monitoring System (SHMS) was utilized to consistently observe how the bridge reacts to different influences over its entire lifespan. This system permits real-time evaluation of dynamic reactions, confirmation of design presumptions, assessment of maintenance metrics, and well-informed decision-making when confronted with seismic or climatic occurrences [5]. To ensure the targeted 100-year service life, consistent upkeep and replacement of components are pivotal. Information gleaned from the SHMS will guide decisions regarding maintenance and replacement strategies. Moreover, the SHMS will provide crucial insights into the irreplaceable elements, such as concrete features, towers, decks, main cables, and saddles. These elements will continue to perform seamlessly throughout the bridge's extended service span. The 1915 Çanakkale Bridge and its associated

approach viaducts have been equipped with over 1000 sensors, encompassing corrosion sensors within concrete structures. These sensors are actively engaged in real-time monitoring, diligently recording measured data. These recorded readings serve as valuable information for subsequent analysis [6].

4.12.4.7 Lifting Equipment

Although on and off the shore operations of the 1915 Çanakkale Bridge project were supported by a great numbers of tower cranes, floating cranes, and other lifting equipment, some of them were globally unique and impacted project performance considerably. Notably, two floating cranes, with capacities of 2200 tons and 5500 tons, played a vital role in transporting mega blocks between onshore and offshore locations. Additionally, two tower-installed cranes, each with a capacity of 330 tons, along with eight lifting gantries for deck erection, stood out as particularly remarkable components of the construction process [4].

DLSY JV's achievements in constructing the 1915 Çanakkale Bridge include two groundbreaking feats during tower erection. First, the M2480D Heavy Lift Luffer (HLL) crane, weighing 600 tons and lifting capacity of 330 tons, was assembled, lifted, and transported to the worksite in Çanakkale Strait. This marked the world's largest tower crane, had been used for placing tower mega blocks. Notably, it was the first time such a large crane was lifted fully assembled. These cranes were put together onshore and transported offshore using the Taklift 4 floating crane, capable of lifting 2200 tons [61] (This floating crane from the Netherlands, had also aided in caisson shaft installation previously [3]). Second, The M2480D HLL cranes achieved another remarkable feat by performing the world's heaviest (155 tons) and highest (318 meters) craneage lift during the installation of the upper cross beam (UCB) on the bridge tower. Positioned at 328 meters above the water, the crane successfully raised the UCB to its final position 318 meters above sea level. This significant achievement marked a major milestone in the construction of the 1915 Çanakkale Bridge and represented a world-first accomplishment [61].

Additionally, the floating crane named Asian Hercules III, with a lifting capacity of 5000 tons, was brought from Australia to facilitate the transportation of mega deck blocks, each weighing between 740 and 880 tons. Ensuring safety, the crane could transfer 5 blocks simultaneously. Lifting gantries, meticulously prepared at Fishing Harbour, were strategically positioned on the main cables as a critical step in the project. This complex process, involving the assembly of gantries using components from China transported in over 120 freight containers, marked a significant milestone. Eight lifting gantries, each weighing 360 tons and capable of lifting 450 tons, were set up on the main cables to facilitate efficient deck erection. Installation was strategically carried out in two distinct directions to reduce the load exerted on the bridge due to the weight of the decks [62].

The 1915 Çanakkale Project involved challenging engineering tasks in tough geographical and weather conditions, with a strong focus on worker safety. Occupational Safety Department managers detailed the comprehensive measures taken to ensure the well-being of employees throughout the project.

4.12.5 Safety Instruction and Measures

The 1915 Çanakkale Project involved challenging engineering tasks in tough geographical and weather conditions, with a strong focus on worker safety. Occupational Safety Department managers detailed the comprehensive measures taken to ensure the well-being of employees throughout the project. Occupational safety was prioritized from the hiring stage, with experienced specialists chosen. The Occupational Safety Department collected information from construction teams, conducted risk analysis, and ensured safety filters were applied to all methods before implementation. Onsite operations needed occupational safety specialists' approval via work permits system. Applications were reviewed early, and if approved, work began; inadequacies led to suspensions. Daily checks and immediate pauses for life-critical issues were done. Hazards were swiftly addressed to prevent accidents. Nonconformities were documented and shared for corrective action. This approach enhanced risk perception and ensured safe operations. A wireless radio system was used for instant updates on work permits, operations, and safety measures. Meetings were held regularly to maintain a smooth information flow. Monthly safety committee meetings addressed measures and concerns, while weekly meetings with subcontractors resolved issues quickly. Both subcontractors and the main contractor's experts reviewed activities for safety measures, which means twice inspection. Civil engineers also received specialized training for onsite safety [4].

A comprehensive set of 56 emergency drills were carried out to prepare for potential crises, complementing the preventative measures in place. These drills covered a range of scenarios, such as falls from heights and into the sea. Specialized exercises involved rescuing simulated casualties from water or elevated positions, utilizing human-weight crash test dummies. Sea rescue simulations timed the response of rescue boats and casualty transportation to the infirmary. Moreover, five infirmaries were established, including one on the Bridge during welding operations. An on-call team of 11 health officers, ambulances, drivers, and doctors was available 24/7, supported by an emergency rescue boat and captains. The infirmaries handled emergencies and minor health concerns, treating around 2000 patients per month, with 99 percent of cases resolved on-site without hospital referrals. Clear and continuous communication was essential due to the site's growing distances [4].

Daily informative meetings known as "Toolbox Talks" were conducted by health and safety managers as part of the project's safety procedures. Originating in the USA, these talks earned their name because they occurred right beside toolboxes, just before commencing work. During these sessions, workers were briefed on health and safety concerns prior to beginning their daily shifts. The potential risks associated with specific tasks for the day, along with all potential adversities, were comprehensively explained. Active participation from workers was encouraged during these gatherings, where they could share their observations and previous experiences. This collaborative approach helped identify potential hazardous situations. Furthermore, these meetings fostered a collective brainstorming process to devise precautionary measures. Moreover, within these colossal structures of the 1915Çanakkale Bridge, the margin for error was confined to mere centimeters. This underscores the paramount importance of Toolbox

Talks [7]. Moreover, an occupational safety system was established that rewarded 20 employees monthly as "role models" with gift certificates. Instead of fines, a warning-based approach was used for penalties, starting with verbal warnings for safety violations such as not wearing a safety belt. The goal was to ensure safety compliance and encourage a safer work environment [4].

As mentioned before, daily operations on-site included vital tasks like heavy lifting, for which a diverse range of floating equipment, including cranes and buoys, was employed. The stability, safety equipment, and electrical systems of these equipment were regularly inspected. Each vehicle adhered to its own safety protocol, with route assessments conducted beforehand to identify and assess potential risks and hazards [3].

In matters of health and safety, there is no margin for errors, as even the slightest negligence or oversight could result in irrecoverable damage. Additionally, weather conditions, varying from sunny to windy, stormy, or rainy, depending on the season, could escalate the associated risks. Consequently, every phase of the project adhered to a rigorous safety protocol. On the construction site, any load exceeding five tons was classified as a heavy lifting operation. Tower components weighing up to 400 tons and decks nearly 750 tons fell into the critical category, necessitating careful handling. Rigorous planning took place during dedicated meetings for operations involving over 100 tons. These plans covered every detail, from personnel arrangement and equipment selection to guide rope operation. Working at sea altitude posed challenges influenced by wind conditions. Operations stopped if wind speeds exceeded 12.5 meters per second, and work on the catwalk ceased at over 15 meters per second. Sea-based heavy lifting stopped when wave heights surpassed half a meter. At the European Anchorage where work occurred 12 meters underground. A ventilation system and continuous oxygen monitoring were implemented to ensure worker safety. Limited work duration of 40 minutes with mandatory breaks further enhanced safety measures for those working underground [4].

4.13 Specification of Work- Effects on Performance and Uncertainties

4.13.1 Professional Business Partners, No Risky Design

According to the Contracts and administrative director of the project, Despite the 1915 Çanakkale Bridge being the longest suspension bridge, its numerous components had previously undergone testing, albeit on a smaller scale. For instance, elements like caissons and the cabling system, which were utilized in this project, shared similarities with those used in other suspension bridge projects previously undertaken by our partners. Consequently, our initial advantage lay in not needing to take risks by experimenting with novel concepts across various scenarios.

Additionally, in the last ten years, Turkey successfully completed several of the world's largest suspension bridges, including the Osman Gazi and Yavuz Sultan Selim bridges. Given this backdrop, we made the strategic decision to collaborate with COWI, a globally renowned bridge designer, which had also played a pivotal role in designing the Osman Gazi Bridge in Turkey. This familiarity with large-

scale suspension bridges and the inherent natural risks in Turkey enabled them to readily align their expertise to our project. They adeptly integrated considerations such as windy conditions and seismic factors stemming from our proximity to seismic zones.

Moreover, apart from the experienced experts in EPC contractor's design and technical department, both the owner and private partners separately engaged third-party consultants to independently evaluate and verify all aspects of COWI's proposed design and specifications. Additionally, Lenders' technical and environmental advisors undertook similar roles for their respective clients. Consequently, the key point was that our designer had an excellent track record in Turkey's PPP project, considered all possible risks generating project specifications, and there were a multi-layer verification and inspection system for the design which meant that nothing was left to chance.

However, as it previously mentioned the project design followed fast track approach. Therefore, based on the design schedule we were adjusting the construction schedule. From the design stage, some problems arose from the third party (TT JV). Although they had to check the design and it was one of their responsibilities, in many cases long bureaucracy imposed delays to the project, while we were submitting required documents on time.

In the endorsement of the preceding paragraph, the project's deputy manager highlighted that: Sometimes, inconsistencies occurred between the employer's requirements and project specifications as well as the conflicts between the various specifications. In the former case, we raised a great number of RFI's (request for information), which was the main act that we were doing as contract management in order to clarify the inconsistencies between the requirements of the clients and what is specified. In this case, these RFI's needed to be answered by the owner's representative. That was their main role to clarify the specifications, but sometimes this process took a long time due to some unknown reasons which negatively impacted project performance.

4.13.2 Robust Design, Innovative technology and methods

Each phase of the project came with its unique set of challenges, yet perhaps the most demanding aspect was the need to complete the design, production, and assembly processes within a relatively short time-frame. This challenge becomes more apparent when considering a comparison with the Akashi Kaikyo Bridge in Japan, which had the same scale, completed over a span of nine years. The 1915Çanakkale Bridge was targeted to achieve completion within four years. Overcoming this challenge was facilitated primarily by applying innovative technologies and efficient design that enables rapid production, and meticulous planning. Additionally, the remarkable commitment, unity of purpose, team spirit, and selfless dedication exhibited by all teams on site greatly contribute to overcoming this demanding task [63].

The CEO of SK E&C provided a concise overview of the importance and technological characteristics of the 1915 Çanakkale Bridge, as well as how these attributes influenced project performance indicators and uncertainties throughout the construction stage. The Çanakkale region posed a notable seismic risk, compelling us to fortify the bridge to a greater extent than typical projects, ensur-

ing earthquake safety. Addressing wind sensitivity, wind stability was validated through wind tunnel tests during construction and operation stages. A dynamic mass damper system was integrated to manage wind-induced vibrations in the world's tallest steel tower. We employed higher-strength materials for the main cable, tower, and decks, yielding a sturdier and more streamlined structure. The main cable incorporated PPWS (Prefabricated Parallel Wire Strand) with high-strength wires (1960MPa). Various components, such as tower, deck, and cable structures, boasted elevated grades compared to standard bridge projects. Our approach embraced advanced techniques like BIM and real-time measurement for weather, minimizing errors via detailed 3D models and ensuring precise geometric control [63, 5, 7]

The construction plan, especially meeting the schedule, proved a formidable challenge. To mitigate weather-related impacts, strategic measures were taken. Plinth and tie beam structures initially planned for marine operations shifted to Large-Block Erection after land prefabrication. For tower and bridge deck erection, we adopted a similar approach, leveraging higher-capacity cranes and lifting devices. Tower blocks were hoisted as full or half blocks with a 300-tonne tower crane, while bridge decks were erected as mega blocks using supplementary lifting equipment. Every project encounter risks within a VUCA (Volatility, Uncertainty, Complexity, Ambiguity) setting. Our robust design, inventive construction methods, and cutting-edge technology allowed us to manage and mitigate a spectrum of uncertainties—technical, design, weather, and construction—while adhering to schedules and quality requirements [62, 63, 61].

4.13.3 Safety, Paramount on Land and at Sea: Zero Tolerance for Mistakes

According to some managers of the Occupational Safety Department, a great number of preventive measures were applied by occupational safety department to execute safety specification appropriately, from multiple check for issuing the work permit, to Toolbox system, to possible suspension for the case of life-critical nonconformity issues, to 56 conducted drills. Although these precautions might have appeared to hinder progress, they actually yielded the opposite effect. In reality, these measures aimed to avert potential accidents that could lead to lengthy work stoppages. These mandatory safety breaks, indirectly, played a crucial role in preventing delays and ensuring the project adhered to its designated timeline [4].

For instance, the primary objective of implementing the Toolbox system as a hands-on initiative for safety instruction was to empower every onsite employee to exhibit the mindset of an occupational safety specialist. Within a construction site characterized by a frequent rotation of personnel due to diverse tasks, cultivating a robust culture of occupational safety stood as a prominent goal. Within the context of the 1915Çanakkale Project, the paramount concern was ensuring that every employee held the status of "trained personnel." In essence, the overarching endeavor was to elevate occupational safety from being solely the responsibility of supervisors or specialists to becoming the collective concern of all employees. This not only motivated each onsite worker to embrace an occupational safety perspective, but also laid the foundation for a sturdy safety culture—a pivotal

objective within the dynamic environment of a construction site. This approach was pivotal in mitigating safety-related risks [4, 7].

Moreover, throughout the construction phase, the utilization of robust equipment played a crucial role in averting adverse incidents resulting from loss of control. As an example, Marr Contracting International, a specialist in design and delivery of heavy lift tower cranes, played a vital role in the 1915Çanakkale Bridge project. The company's innovative craneage solution, developed in collaboration with the DLSY JV project team, significantly reduced construction time and risks. By employing the M2480D HLL crane's high capacity to lift larger modular components, the traditional approach of lifting and welding smaller components individually was replaced. This approach condensed the construction schedule, minimized on-site activities, and enhanced safety. The M2480D HLL crane's exceptional lifting capacity marked a potential game-changer for bridge construction. Despite challenges posed by factors like wind, water, seismic conditions, and the unexpected impact of Covid-19, the DLSY JV effectively managed the project, maintaining both the timeline and safety standards [61].

4.14 Specification of Work- Key lessons

4.14.1 Early Business-Partners Involvement

One of the noteworthy aspects of the 1915Çanakkale Bridge project was the robust collaboration among various partners during the design process. Beyond the involvement of the Design firm, verification third parties, and the EPC's design team, the early engagement of subcontractors and suppliers in the design of caissons, cables, towers, deck, and craneage played a pivotal role in minimizing uncertainties and ensuring project success. This approach directly influenced the mitigation of risks associated with these components.

For instance, Marr's Director, from an international company specializing in heavy lifting design and delivery, provided insights into this collaborative effort. "The EPC contractor demonstrated a clear vision while remaining receptive to unconventional solutions. Their acknowledgment of Marr's expertise in heavy lifting paved the way for a fruitful partnership that allowed the tower stage of the project to be completed in a remarkably short time-frame. The key to this achievement lay in the early involvement of Marr in designing a solution tailored to DLSY JV's goals. By collaboratively addressing challenges and opportunities in the initial design phase, a bespoke solution was formulated that aligned with DLSY JV's objectives. This approach focused on reducing program time, cost, and enhancing safety – factors that drove the project's success. The collaborative spirit between Marr and the DLSY JV team was paramount in achieving these objectives. Through direct interaction and joint efforts in the design phase, a solution that met all requirements was crafted, leading to remarkable progress in the project. The proactive engagement of partners in the early stages of design emerged as a critical factor in the project's overall success" [61].

4.14.2 Significance of Proactivity and Collaboration

The 1915Çanakkale Bridge Project has faced significant challenges due to the region's strong winds, which have proven to be its primary obstacle. Even during the summer months, wind-related issues persisted, leading to reduced productivity and delays in the project's schedule. These adverse weather conditions render the use of lifting equipment and cranes unfeasible. To address this challenge, two primary solutions have been employed. The first involves preassembling bridge components and subsequently lifting them into place. The second approach involves conducting operations concurrently whenever possible. Both strategies were complex to execute and manage, demanding careful coordination.

Perhaps the most valuable lesson learned from this project was the significance of proactivity. In fast-tracked projects, time constraints can limit the attention given to planning. Paradoxically, insufficient planning time can lead to substantial time losses and increased costs. Effective and thorough planning proves essential in preventing unfavorable outcomes within tight time-frames and in a cost-effective manner [9].

In this regard, one of the control manager of the project added: "despite meticulous planning, challenges can arise during the actual construction phase due to designers lacking awareness of on-site uncertainties as we do. Design, given its inherent nature, doesn't always perfectly mirror reality, carrying a multitude of uncertain factors, particularly for temporary substructures. These uncertainties frequently result in complications during execution. Once the design and specifications are finalized, making changes to the specifications becomes a time-consuming endeavor. Therefore, it is vital for the EPC contractor's design team to possess a solid grasp of the specifications right from the beginning. Collaboratively, they should interact with the design firm, dedicating ample time to comprehensively assess all specifications and pinpoint aspects that might not be feasible, along with their underlying reasons. Concurrently, they should actively search for feasible alternatives to propose".

4.15 Specification of Work- Discussion

The 1915 Çanakkale Bridge project represents a significant achievement due to its scale and complexity. The project's completion within 48 months, surpassing the 66-month timeline despite the Covid-19 pandemic disruptions, reflects efficient management. The adherence to and even surpassing of the timeline derives from the dedication and effectiveness of the project's stakeholders. Creating specifications for a unique project like the 1915Çanakkale Bridge required combining multiple standards to address technical and execution complexities. Utilizing Euro Codes for the first time in Turkey demonstrates a commitment to global best practices. Adaptations, such as wind tests in different countries, show a thorough approach to ensuring structural integrity under various conditions.

The fast-track nature of the project required collaborative efforts with subcontractors and suppliers to finalize accurate specifications. Balancing this interdependence between subcontractor selection and specification finalization is complex which highlights the challenges of managing multifaceted dependencies in a fast-track project. Early involvement of various partners in the design process played a

crucial role in minimizing related uncertainties and risks. Moreover, on one hand, the fast-track design approach leads to challenges stemming from inconsistencies between employer requirements and project specifications. On the other hand, the reliance on Request for Information (RFI) to fill these gaps results in delays due to prolonged response times. This highlights the significance of efficient communication channels and prompt resolution of discrepancies to maintain project acceleration.

The initial advantage of utilizing components with similarities to previous suspension bridge projects reduced the need for risky experimentation. Collaborating with experienced design firm with a well track records in similar Turkish PPP project was another advantage for the project. Collaboration among solution partners ensured adherence to international, local, and client-specific standards. Multi-layered verification system realized by various independent entities, not only guaranteed comprehensive and robust design and specifications but also Involvement of external partners enhanced project quality and eligibility for international funding. The project's alignment with environmental and social standards, and its impact assessments, demonstrates a careful approach to sustainability. This also aligns with the trend of sustainable financing models, reflecting global awareness of environmental implications in large-scale projects.

The project for the construction of the 1915 Çanakkale Bridge was a complex and ambitious undertaking and the project's success depended on strategic planning, cutting-edge engineering solutions, adaptive construction methodologies, and meticulous attention to safety measures to ensure the well-being of workers and the durability of the final product. By applying advanced techniques like BIM and real-time measurement, errors were minimized, and precise geometric control was achieved. The integration of seismic safety measures, wind tunnel tests, and dynamic mass damper systems demonstrated the proactive approach taken to manage uncertainties. The transition from marine to land prefabrication and the utilization of higher-capacity lifting equipment demonstrated adaptive strategies to mitigate weather-related impacts. The project's challenges with strong winds underscored the importance of proactivity and effective interdisciplinary collaboration. Comprehensive planning to address complexities and uncertainties that arise during construction along with ongoing communication between the design team and contractors to ensure that design specifications are practical and feasible is pivotal.

4.16 Procurement Route- Status Que

4.16.1 Procurement Route for the Main Contract

The Chairman of the Board of Directors at ÇOKA.Ş. (SPV company), which is a subsidiary of SK E&C, one of the Korean partners, recounted the procurement journey of the PPP project during the tender phase. "Upon learning of the tender, its significance for Turkey was promptly acknowledged. Previous involvement in public-private sector partnerships in Turkey, including the Eurasia Tunnel, motivated the decision to pursue this undertaking. Additionally, Daelim, another experienced Korean bridge construction company, was enlisted alongside SK E&C, and Yapı Merkezi, a partner in the Eurasia Tunnel project. The reliabil-

ity and competence of Limak were also instrumental in forming this partnership" [7].

Before the involvement in the 1915Çanakkale Project as an investor, SK E&C has participated in several international PPP projects, such as the Eurasia Tunnel in Turkey and the Almaty Ring Road in Kazakhstan. This positioned them as pioneers among Korean companies in the global PPP market, including Turkey and the UK. Their significant experience also extended to various mega projects across the world. Additionally, their motivation for participating in the 1915Çanakkale Project was amplified by the prospect of deploying their skilled workforce, which had gained valuable expertise in both EPC and finance through their work on the Eurasia Tunnel and the Yavuz Sultan Selim Bridge in Turkey [61].

Over the last two decades, Daelim (DL E&C) has constructed five suspension bridges and 13 cable-stayed bridges. Daelim is a corporation that is especially known for its main cable installation and cable reinforcement technologies applied in suspension bridges and has registered many patents with its work in Suspension Bridge Equipment and Construction Engineering is becoming one of the world's greatest actors in the field of R&D. for DL E&C this Project was extremely unique from two perspectives. Firstly, it was the world's longest mid-span suspension bridge which is common knowledge for everyone. Secondly, it was DL E&C's first PPP road project overseas realized through a joint venture of four different companies [9, 61].

Yapı Merkezi, one of the four partners in the international consortium invested the 1915Çanakkale Project, holds a distinctive position as a Turkey-based general contractor that integrates technology and design to execute mega projects, primarily focused on railway and road construction on a global scale. With a robust engineering foundation, they operate across nine different countries and boast a workforce of over 20,000 employees. Having gained experience in several PPP projects, Yapı Merkezi's collaboration with SK Engineering & Construction in the Eurasia Tunnel project is notable. This project, executed under the Build-Operate-Transfer model, was successfully completed and operationalized in December 2016 [63, 5, 7]. In addition to project prestigious itself, the corporate ambitious strategy to entrance to the new market areas such as marine construction and suspension bridges construction was one of the main motivational reasons for Yapı Merkezi partnering to the project [63].

Limak is a prominent company that has actively undertaken numerous PPP infrastructure projects both domestically in Turkey and internationally. They possess extensive experience collaborating with the General Directorate of Highways. Limak's influence extend worldwide, with a conglomerate of companies operating across diverse sectors and a global workforce exceeding 60,000 employees. Their distinguished track record in the construction industry spans a wide spectrum, encompassing projects such as airports, seaports, dams, irrigation facilities, motorways, and oil and gas pipelines. In more recent times, their contributions have extended to sectors like cement, energy, and tourism, enhancing their reputation as a dependable partner. Beyond their business accomplishments, the Limak Group's noteworthy efforts to translate their commercial success into meaningful social investments further distinguish them [5].

The Contracts and Administrative Director from Daelim, the other Korean partner, highlighted that, when we made the decision to form a partnership for

this Project, my sponsor company lacked direct prior experience collaborating with Turkish companies. Furthermore, the industry boasted a multitude of companies, each specialized in various aspects, rendering our choice of an ideal partner challenging. Fortunately, our interaction with SK, which had prior experience operating in Turkey, facilitated our introduction to Limak and Yapı Merkezi. This paved the way for us to establish a consortium. Given our time constraints, the decision-making process and subsequent signing of the partnership agreement were expedited, thanks to the valuable input and guidance from all parties involved [8]. Forming a partnership involving two Korean and two Turkish companies presented its challenges due to differing cultures and systems. However, diligent efforts were made to unite and foster a team spirit through mutual understanding, even necessitating a fresh start at times. This endeavor was an experimental struggle, which was managed despite its complexity [7].

The tender itself commenced in 2016, utilizing data from the feasibility study for the 1915Çanakkale Bridge project conducted in the same year. Swift changes occurred following the tender announcement, requiring the estimation of construction costs, financial analysis, and bidding strategy to be promptly prepared [8]. During the tender process, intense competition was evident, particularly from an ambitious Japanese rival. The planning reassured the team's capability to successfully handle the project [7]. In 2017, the official opening of proposals took place in Ankara, with three other consortium submitting their bids. ÇOKA.Ş. emerged as the winner on January 26, 2017, surpassing other bidders' proposals by a significant margin. The uniqueness of the winner's announcement on the same day as the bid reception added to the project's distinct experience.

4.16.2 Procurement Route for the Loan Agreements

Subsequent to winning the bid, the sponsors directed their attention towards swiftly establishing the SPV and diligently planning for the construction phase, giving immediate priority to critical financial considerations. One of the most remarkable milestones occurred when the financial agreements were finalized on March 16, 2018. Despite the PPP agreement stipulating this deadline, based on global understanding and experience, it appeared nearly unattainable. It was very rare for any other mega projects that had managed to secure financial closure within a year. However, thanks to the dedication of our SPV colleagues and sponsor groups, it was successfully accomplished within the specified time-frame [8, 7].

As recounted by a member of the project's Executive Committee, the banks initially leaned toward basing their decisions on project progress. However, a significant shift occurred during the fourth creditors meeting when their attention and enthusiasm for the project notably increased. "At the fourth meeting, a gathering of 23 banks and nearly 200 individuals from various countries including Korea, China, Denmark, Kuwait, Germany, France, Italy, and Turkey took place. The atmosphere resembled that of a G20 summit," he recalled. Suddenly, the remarkable level of interest increased by the substantial support from the Turkish government and the profound symbolic significance associated with the 1915Çanakkale Project [3]. Convincing several local and international financial institutions with different approaches and interest to be involved in the project was a demanding process.

Several financiers have shared their insights regarding the reasons that influenced their decision to participate in the financing of the 1915Çanakkale Project, along with the specific aspects of the project that resonated with them the most. The results, as reflected in the Appendix- C , are remarkable.

Involvement in this project carries inherent prestige for financial institutions, investors, professionals, consultants, and subcontractors associated with it. Beyond its prestige, the project held strategic significance for Turkey, aligning with their 2023 Vision. Its status as a publicly supported project greatly appealed to foreign investors, offering a sense of confidence and stability regarding the feasibility of the project during the financing process. Moreover, one of the most significant issues for lenders was that the Debt Assumption Regulation to be supported by the government. These regulations enable banks to offer loans to the Project at favorable rates and outlining a balanced distribution of specific risks between the public and private sectors. The support of the Ministry of Treasury and Finance, the Ministry of Transport and Infrastructure, and the General Directorate of Highways was distinctly conveyed to foreign banks, fostering an environment of trust and support [62, 9].

Similarly, the project's shareholders with excellent experience of completing similar mega projects demonstrated uninterrupted support at every phase. Notably, the participation of Korean EXIM banks, KEXIM, and KSURE, in providing a one billion euros loan—the largest they've ever extended to a single project—served as a significant motivation for other foreign banks. Consequently, lenders expressed an astonishing level of interest, submitting requests for loans that amounted to one and a half times more than the originally required loan amount [62, 9].

Furthermore, the project's funding structure showcased remarkable diversity, leveraging a range of international resources. So that a portion of the loan was provided by the internal synergy of the project. For instance, a separate loan package was secured from the Danish EXIM bank EKF due to their previous common experience with KEXIM, KSURE, and COWI. This diverse blend of international resources underscored the project's strategic approach to optimization. In summary, the 1915Çanakkale Project not only garnered financial support but also demonstrated effective resource diversity, optimal funding structure, and a strong lender profile. It served as an exemplar of successful project financing with far-reaching implications for multiple stakeholders [62, 9].

One of the most formidable aspects of the project was creating alignment among all stakeholders implicated in the loan agreement. This encompassed 25 creditors, 4 partners, legal, financial, and technical advisors, as well as relevant official authorities. Managing the expectations of these diverse groups of creditors posed another challenge, particularly given their dispersed locations across various time zones. Teamwork played a pivotal factor in such a great achievements. Project finance team was comprised of experts from various domains, including law, project finance, corporate finance, auditing, and treasury who had been converged of four distinct corporate cultures. This diversity of expertise played a crucial role in fostering synergy and establishing a shared perspective that proved instrumental in overcoming barriers and achieving our objectives [3].

4.16.3 Procurement Route for the Subcontracts

According to the contracts and administrative deputy director of the project, there were very limited companies who can provide design and specifications for the project with high level of complexity as well as uncertainties, produce certain material with a rigorous specification like PPWS for cables 1960 mega pascal capacity, and also accomplish precise operations of heavy lifting and transportation. Therefore, negotiations stages were done with very limited companies. Moreover, the high variety of lenders' group caused some kind of limitation in different stages of the project. For example, sometimes we were required to use Korean currency while we needed to use European products for certain periods. There were just limited big worldwide companies who can tolerate the situation. Therefore, we were limited to starting negotiation with the 3-4 companies, getting the consultant confirmation as early as possible, contract to one of them, and then production could be started. In this situation, the important thing is adequate resources of money. If sufficient resources have been provided timely, with paying in advance, materials and services can be asked and provided as early as possible. Otherwise, private partners had to bear a great deal of financial loss due to considerably delay until finishing the project finance process. Fortunately required financial resource in early stages had been provided by the private partners of the project since based on PPP contract between SPV company (ÇOK A.Ş) and the General Directorate of Highways (GDH), shareholders of the Project were supposed to invest more than 900 million Euros of equity for the project.

Moreover, SPV's main strategy was working with well-known companies with the lowest risks. If you are going to buy a car, you face a lot of car brands in the market, If you know that Mercedes is a good car, or if you are going to high hills, If you believe that Range rover is the best for mountains, then you use Range rover not another brand, so, We did not take that risk and employed the best well-known companies with well track records, preferably with previous shared works. For saddles, we used an Italian company, Gruppo Cividale is a leader of the European foundry sector. If you go to the internet and search for saddle, you can find this company, there are not so many alternatives. Also, for the main cables, there were not so many alternatives, we brought them from Korea. Daelim and SK (Two Korean partners) knew them beforehand due to the several previous common collaborations. If you need to save time, if you need high quality as they are the most prominent things in PPP projects, automatically it costs you! Following to the no-risk strategy for employing the project's different executive parties which mentioned before, document studies and interviews' result demonstrated that a great number of subcontractors, suppliers, experts, and human resources who had been involved in the 1915Çanakkale bridge Project had at least one favorable track record in Turkish PPP projects. Table demonstrates just some of the leading companies who were involved in the 1915Çanakkale bridge Project. The table also comprises the information regarding the companies' responsibilities in the project as well as their previous experience in Turkey's mega road infrastructure projects which were done in form of PPP.

The deputy Subcontract manager of the project emphasized that There are not many vendors around the world for this kind of suspension bridge construction work. With those was certain specific companies, pre-qualification comprised

of asking them about their track records, and financial status. in addition, we preferred to invite to the tender the companies who had done similar works previously. Normally people in the Project Control and Management (PCM) department always tended to select companies with the lowest prices. Although price is one of the most important criteria for selecting subcontractors, it definitely could not be the sole sufficient reason. All in all, there was a consensus to a long-term approach to select the most economical advantage choices considering subcontractors' experience, technical capacity, financial status, as well as their track records. for sure, we tried to employ them down to the lowest price, if possible, but it did not work always. Anyway, even though some of them were not the lowest price companies, they were awarded due to their other advantages which were match with the specific tasks and ensured accomplishing works within the schedule and also high quality.

The project control manager of the project believes that in such PPP projects, the most important thing is to complete the work as early as possible as well as the quality according to the specification and requirement in the contract. Although the operation period is fixed, there is flexibility for bidders which means that as long as the private party finishes the construction works earlier than the contract due date, the saved time would be added to the minimum operation duration which means the extra profit for shareholders. So, from a procurement perspective although the most prominent things are cost and quality simultaneously, delivery schedule could be a key determinant parameter. For example, sometime selecting an expensive company between some companies with the same technical capacity would be much more beneficial considering the company's lower delivery time. The saved time not only could be added to the operation phase, but also can be considered as a time contingency to balance delays derived by possible uncertain events. It even provides sufficient time for some of the required tests for the QC and QA. as a result, the main policy for the procurement route was based on looking for the optimized Supplier In the market which provided the most economic advantage for the shareholders considering mentioned criteria. The procurement route also depends on what you need to procure whenever. For example, if you just need to buy the normal steel, you might have like 20 candidates but if you want to provide the cable for the suspension bridge these candidates become like 5 or less. So, the number of potential candidates can be varied depending on the specification of the material prepared by the design firm. The ideal thing was preparing everything comprising suppliers and subcontractors locally. The local market was known and accessible which could ease monitoring and control process for inspectors Otherwise, it could be problematic to stay everywhere to control everything around the world. Unfortunately, lots of strategic materials or expertise subcontractors served in the project had to be provided from abroad due to lack of required competency in the local market.

One of the chief engineers of the project also gave a supplementary explanation regarding procurement route particularly for the on-site subcontractors. in the initial stage we were trying to do the competition tender for the subcontracting or procurement of our materials. But sometimes limited subcontracts for some items will lead to better results. Normally, we were making a list of capable subcontractors or suppliers in advance, and then they were giving the RFQ (Request for quote). This list usually was prepared based on conversation with experts or

common previous experience with the project's shareholders. Then, based on their suggested price and methods and also their technical competency subcontractors were chosen. but regarding specific material like cables, steel towers and decks etc. which were on the critical path, due to their long production process, contract process had begun in the early stages of the project when construction phase had not started yet which means that when the construction phase were initiated, those suppliers had been chosen and were producing those special items. Except for these special items, the competition was held based on the RFQs as usual and then subcontractors have been selected often based on the lowest price.

4.17 Procurement Route- Effects on Performance and Uncertainties

4.17.1 Acceleration of Early-Stage Progress

The unbelievable fast pace progress in early stage of the project from establishing the joint venture company to conducting feasibility analysis to holding and announcing the result of PPP tender to finalizing the loan agreements, positively affected on project performance in terms of cost and time. which were derived by accumulative collaboration between different parties and showcased their commitment. Moreover, partners strategy for the procurement route of the 1915 Çanakkale project impacted to manage uncertainties in various aspects of the project. As it mentioned earlier, one of the main project strategy emphasized completing the project as early as possible which affected on procurement route policy as well. Partnering with experienced companies with the complementary features that enabled them to deliver the project on time helped manage uncertainties related to project schedules. The focus on time savings aligned with the PPP contract's flexibility for early project completion, which could lead to increased profits for the private partners.

4.17.2 Strategic Project Financing and Safe Procurement

Project financing for such a mega infrastructure project was one of the most milestone of the project which could decrease anxieties when the number of uncertain items were high. The successful achievement of financial closure within a specified time-frame demonstrated effective financial management which mitigated financial concerns in early stage of the project. Apart from the loans, the private partners also in the project were required to invest significant equity, which helped ensure adequate financial resources early in the project to start negotiation for procuring strategic materials with a long production duration like cables before starting the construction phase. The importance of this strategy was determined when the Covid 19 Pandemic occurred and caused various problem to global supply chain and transportation issues and to great extend played positive role to managing Covid 19 side effects. The procurement route strategy also focused on partnering with well-known companies with established track records and reputations. This reduces the risk of supply chain disruptions by selecting suppliers and subcontractors with proven expertise and capacity to deliver critical materials and services.

The emphasis on working with reputable suppliers minimizes uncertainties related to material quality, timely delivery, and production capabilities.

4.17.3 Managing Complexity through Expert Collaborations

The project involved high level of complexity and engineering challenges during the construction phase. Following to the no-risk strategy for employing the project's different executive parties which mentioned before, document studies and interviews' result demonstrated that a great number of subcontractors, suppliers, experts, and human resources who had been involved in the 1915Çanakkale bridge Project had at least one favorable track record in Turkish PPP projects. Table4.17.1 demonstrates just some of the leading companies who were involved in the 1915Çanakkale bridge Project. The table4.17.1 also comprises the information regarding the companies' responsibilities in the project as well as their previous experience in Turkey's mega road infrastructure projects which were done in form of PPP. Collaborating with subcontractors experienced in similar projects in Turkey like the Eurasia Tunnel, Osmangazi Bridge, and Yavuz Sultan Selim Bridge, enhanced the partners' ability to handle design and construction challenges effectively.

4.17.4 Securing Sustainability through the Environmental and Social Impact Assessment

Finally, a crucial prerequisite for finalizing the financial agreement was the preparation of an environmental and social impact assessment report. This requirement was significant for banks, especially foreign ones and EXIM institutions. The report was collaboratively developed with international consultants and subsequently evaluated by international consultants appointed by the lenders . Although this may have appeared as an additional challenge given the project's tight timeline, the outcomes of these studies not only streamlined the financial agreement process but also served to identify and mitigate environmental uncertainties associated with the project [N2].

4.18 Procurement Route- Key Lessons

A deputy project manager who has been engaged in the project from its initial tender stage emphasized the one-sided nature of the PPP procurement process, which resulted in limited communication between the owner and private partners. Consequently, the private partners were obligated to accept all uncertainties stipulated in the contract. Assessing uncertainties like geotechnical conditions during the tender period posed a challenge, as it was tough to accurately incorporate these risks into our proposal. In my opinion, the procurement process should transition into a more interactive framework to extract the utmost advantages from the project. Introducing a dialogue phase before or during tender stage would allow for proactive management of uncertainties before they transform into obstacles during the construction phase. This approach benefits both the client and the contractor, facilitating smoother project execution and contributing to its timely advancement.

Company	**Origin**	**1915Çanakkale bridge Project**	**experience in Turkey**
COWI[3]	Denmark	Design Services	OGB
SPCC& KISWIRE JV[61]	China& Korea	Supplying Main Cables	YSS Bridge
ÇİMTAŞ[3]	Turkey	Steel Shafts Fabrication	OGB
GRUPPO CIVIDALE[9]	Italy	Supplying tower saddles	OGB,YSS Bridge
STROS[62]	Czech Republic	Supplying hoists and elevators	YSS Bridge
SAMYOUNG M-Tek[9]	Korea	cable clamps and steel products	YSS Bridge
MAURER SE[4]	Germany	Expansion Joints and Mass Dampers	OGB,YSS Bridge
FREYSAS[63]	Turkey	Viaducts and Anchorages	YSS Bridge
TT JV[8]	TURKEY& SWISS	Consultancy Services on Behalf of(GDH)	YSS Bridge
MUNICH Re[8]	Germany	Reinsurer's Leader	Eurasia tunnels
Mott MacDonald[9]	International	Lenders' Technical Advisor (LTA)	YSS Bridge
Yayla Altufan Konuku(YAK)[8]	Turkey	SPV's Legal Advisor	OGB, Eurasia Tunnel

Table 4.17.1: List of involved companies in 1915Çanakkale bridge Project who had experience in Turkish PPP project. OGB: Osmangazi Bridge, YSS Bridge:Yavuz Sultan Selim Bridge, JV: Joint Venture, GDH: General Directorate of Highways

The viewpoint of the contracts and administrative deputy director of the project is that in a PPP project marked by intricate technical requisites and a compressed timeline, particularly when the local market lacks the capacity to adequately provide specialized materials, the negotiation with globally acclaimed suppliers becomes a crucial strategy. Ideally, these suppliers should possess prior collaborative experience in PPP projects, aiding in mitigating risks associated with

punctual product delivery while adhering to the stipulated quality standards in the contract. Conversely, even though the project organization included quality inspectors and allocated limited resources for material verification, the significant number of worldwide suppliers that needed concurrent inspection posed a challenge for the organization. This challenge was intensified when the project encountered unpredictable events such as the Covid-19 pandemic, resulting in stringent border-crossing restrictions. In situations where heavy reliance on suppliers is inevitable for quality control, quality assurance, transportation, and other factors, the significance of the adopted subcontracting strategy becomes evident. He also emphasized the importance of cultural issues when a private partner is evaluating appropriate partners to make joint venture company. "Flexibility and proactive planning were pivotal in the success of our project. Collaborating with Korean partners highlighted the value of flexibility and adaptability, unlike the more rigid approaches of some other nationality who I experienced working with them. For instance, Koreans swiftly responded to challenges like the Covid-19 pandemic, showing the importance of immediate preventive actions and decision making in unpredictable situations to complete the project on schedule".

One of the chief engineers who were particularly involved in substructures and temporary structures of the project provided insights, stating that significant challenges weren't encountered with major suppliers due to a corporate strategy focused on low-risk contracts with reputable companies for specific materials. These suppliers underwent regular assessments from dedicated technical and commercial teams, both during the tender process and after the contract was signed. While issues did arise with groups of construction subcontractors who had been chosen based on the lowest-price criteria for less critical tasks. Although their experience and capability had been assessed, certain aspects might have been overlooked. Moreover, despite subcontractors being directed to consider all specifications and contract conditions when pricing their bids, instances arose where deliberate underestimations were made to secure the bid. Quality wasn't compromised during this period due to robust quality control measures overseen by multiple layers of inspection, but there were occasional timeline issues with this group of subcontractors.

4.19 Procurement Route- Discussion

The procurement route for the 1915 Çanakkale Bridge project was a crucial factor in shaping the project's overall success, managing uncertainties, and achieving desired performance outcomes.The procurement route for the main contract involved an international consortium of companies from Korea and Turkey, each with distinct expertise and track records. The strategic composition of the consortium laid a solid foundation for a cooperative environment. The decision to form this partnership was driven by previous experience in public-private partnerships (PPP) and the desire to leverage the skills gained from projects like the Eurasia Tunnel and Yavuz Sultan Selim Bridge.

The chosen procurement route had several positive effects on managing uncertainties and enhancing project performance. The consortium's strategy of completing the project as early as possible aligned with the PPP contract's flexibility

for early project completion, positively impacted time and cost management. Partnering with experienced companies enabled effective management of uncertainties related to project schedules, design complexities, and technical challenges. The financial closure achieved within the specified time-frame demonstrated effective financial management and while this strategic project financing and procurement approach ensured resource availability, mitigating financial and supply chain uncertainty during COVID 19. Emphasizing reputable suppliers and with established track records in Turkish PPP projects minimized uncertainties related to material quality, timely delivery, and production capabilities. Collaborating with subcontractors experienced in similar projects further enhanced the consortium's ability to handle design and construction challenges.

Although the completed met almost all the criteria for project success in terms of time, cost and quality, there is a potential for improved communication and interaction between the owner and private partners in the PPP procurement process. The idea of introducing a dialogue phase before or during the tender stage could help proactively manage uncertainties. Creating alignment among diverse stakeholders, exemplified by the financial agreements' negotiation process, underlines the importance of establishing a supportive environment to attract lenders. The significance of negotiation with globally acclaimed suppliers is emphasized, especially when specialized materials are required and the local market lacks capacity. Flexibility, adaptability, and proactive planning were found to be pivotal in project success, particularly in responding to unpredictable situations such as the Covid-19 pandemic. Additionally, the importance of assessing subcontractors thoroughly and considering cultural compatibility in forming partnerships is highlighted.

4.20 Agreement Format- Status Quo

4.20.1 Contract format

The General Directorate of Motorways commissioned the 1915Çanakkale Bridge and Motorway Project, within the framework of the public private partnership model, to a Turkish-Korean consortium in 2017. Limak and Yapı Merkezi from Turkey and Daelim and SK E&C from Korea were the companies that made up this consortium which in turn established a joint-venture company that is specific to the project, under the name of Çanakkale Otoyol Köprüsü İnşaat Yatırım İşletme A.Ş. (Çanakkale Motorway Bridge Construction Investment Management Inc.) [3, 7]. Four shareholders had the same share of investment and risks in the project according to the PPP and Shareholder's agreements. There was no leader for this joint venture and all decisions were made in consensus based [5]. For the 1915Çanakkale Bridge and Motorway Project, the concession period was 16 years and two months which consisted of nearly four years of construction phase and 12 years of operation phase [8].

According to the PPP contract, the private sector was responsible for securing the financing in addition to design development, procurement, construction works and operations until the end of the concession period [9]. The legal advisor of SPV company ascertained that, "Project finance is not just based on assurances offered by project sponsors or shareholders. The pivotal aspect is creating a financing structure that guarantees all contracts and documents could consider all

probable risks which can impact on the cash flow. Project finance entails handling an extensive array of contracts and documents. Unlike certain other transactions, these documents are not archived and referred to solely when complications arise. Instead, they establish a project's enduring framework, specifying essential procedures, stakeholder dynamics, and protocols for addressing unforeseen deviations from the plan. Hence, meticulous effort was made for each document to ensure seamless coherence and uniformity across all documents, enabling effective implementation of their prescribed requisites. Ensuring the contracts and documentation accurately depict the projected cash flows and outlining contingency measures for instances when they deviate from expectations is of paramount importance" [8].

Finally, the loan agreements for this huge project were signed and financial closing was done within a year with 25 banks and financial institutions from 10 different countries. For the financing of the project, a 15-year term loan, with a grace period of 5 years, for a total sum of 2.265 billion Euros was secured (the rest of the investment equal to 900 million Euro was provided by the shareholders of the project). Seventy percent of this loan was provided by 19 foreign banks and financial institutions, and 30 percent by Turkish banks. The credit package, which is composed of eight different tranches including Export Credit Agencies (ECA's) and Islamic financing methods, was structured in accord with the international project financing standards [3].

Responsibility of design (engineering), procurement, and construction of the project were allocated to the EPC contractor (DLSY JV) by the SPV company (ÇOK A.Ş.). Both of the companies for this project were from the same entity and had been established by shareholders of the project. EPC contractor followed the formal agreements like FIDIC (International Federation of Consulting Engineers) and other global standard agreements to contract project's various tasks to the subcontractors and suppliers. The main responsibility of EPC contractor was control, manage, and lead all subcontractors and suppliers to fulfil their task according to the contract and its specifications.

4.20.2 Guarantees and Risk sharing

According to the project control manager of the project, In PPP type projects, the main and biggest purpose of the SPV company is providing financing from the lenders. It is not possible for shareholders to construct such a mega project just by their own investment. SPV company need to convince lenders this investment has very low risks. Therefore, inevitably SPV leaves many risks for EPC contractor entity. Otherwise, they cannot secure such huge finances. Basically, in the PPP type project, after financial close, EPC contractor must bear rest of the risks. That is why EPC contractor's planning, engineering, and design capabilities becomes very important. Risks are not shared within the EPC entity, which means that risks are not shared with the subcontractors, although there are certain limits in their contracts. They are just shared by the project's main partners. There's no subcontractor or supplier who is willing to take the project's risks.

On the other hand, in PPP projects, it is quite common for the government to guarantee the minimum revenues. Otherwise, the PPP becomes very risky. The 1915Çanakkale bridge is away from big cities, it is more of the monumental

project to celebrate the First World War, I think without that kind of guarantee from the government nobody would have participated. But regarding other kinds of guarantees, although big support from the government side was clear and it motivates lenders for investment, there were not any financial guarantees from the government.

The deputy subcontract manager of the project emphasized that, Contracts' guarantees within the EPC entity mostly had comprised of the advance payment guarantee, the performance guarantee, and defect liability guarantee. subcontractors need certain money to start the work anyway, so they reasonably request 10% or 15% of contract amount as an advanced payment. For this means, they are required to prepare a bank guarantee to receive advance payment. Performance guarantees also normally are 10% or 15% of the contract amount to force subcontractors to accomplish the work according to the contract, on time, within the agreed price. After taking over the work from the subcontractor, depending on the contract, a two- or three-years defect liability period is considered. Defect liability guarantee ensures subcontractors will fix possible defects During defect liability period.

4.20.3 Changes

After the technical team, construction team, or design team come up with the change items, it requires to be assessed in terms of the scheduling impact, cost impact and finally requires every parties' agreement to Unanimous decision. Everybody who was in charge of this change, whether the construction manager or the design manager, or the Budget control manager, always must be prepared to explain to all the partners. The process of preparing relevant documents to get approval for variation orders (VO) was a time-consuming process.

4.20.4 Conflict Resolution and compensation Format

As mentioned, changes are inevitable in such mega projects. If those changes came from the Turkish Government side, Then EPC contractor claimed for it for sure. And If contractors' documents were convincing for the public partner, they compensated us with the certain amounts of operation period time instead of compensating by money. For example, In the tender stag when the bidding was submitted to the Turkish Government, there was some fault data regarding the earthquake criteria in their specification. After signing the PPP agreement, they realized that the number was not correct. as a result, they decided to Apply the revised data Which caused enlarging caissons size and towers size as which, negatively impacted on private partners in terms of time and cost. SPV company asked for compensation, and they accepted and paid it in the form of a 130-day operation period extension.

There was a certain mechanism for the claim management according to the FIDIC Silver book with some minor changes. When an event occurred, the subcontractors had to inform the EPC contractor about their claims, for a certain period of 28 days. If they did not inform the EPC on time, they lost their Right and they were not entitled to claim anymore. After upon receipt of that notice the EPC contractor had to response within a certain time according to the contract

content with the brief Analysis or explanation or request additional information to verify the claim. Claims could be rejected due to certain reasons or be verified. After that, during a meeting the decision was made either to settle the figure or go to arbitration. Therefore, there was the procedure for execution of the claims and there was a procedure of how these claims will be mediated. There was an amicable settlement mechanism and if nothing could be settled, it went to arbitration. There were some claims between private sector and public sector and lots of claims from subcontractors to the EPC contractor during the project. Fortunately, all of them were solved as amicable settlement between parties without the necessity to carry them to the arbitration and court.

4.21 Agreement Format- Effects on Performance and Uncertainties

4.21.1 A Holistic Approach to Quality, Budget, and Timely Delivery

The chairman of the board at one of the shareholder companies offered an interesting perspective on the advantages of the PPP format, which resulted in numerous positive outcomes for project performance. "We placed great importance on the quality and durability of the materials we employed, as we were also tasked with operating and maintenance of the bridge in the future according to the contract. Given the long-term nature of our responsibility, we consciously opted for alternatives that would extend the bridge's lifespan. This approach was mirrored in subcontracting tasks, from design to construction activities, resulting in an exceptional work quality. Furthermore, PPP projects, due to their financing structure, are typically completed either within the budget or with only marginal budget deviations. Costs are meticulously determined through comprehensive studies conducted by both the Employer Administrations and producers, both before and during the tender process. This precision is paramount, as once the financing is secured, obtaining additional loans becomes highly restricted. Additional capital infusion is an expensive proposition for investors. Hence, it is rare for a PPP project to experience budget increases of double or triple proportions. The maximum cost escalation during construction generally remains in the range of 10% to 20%. The distinct financing mechanism of PPP projects implies that any construction delays would inflict significant damages on investors. Consequently, these projects are usually executed either on schedule or ahead of time. The combined efforts of the public administration and private partners diligently work to prevent delays. The project owners, including the Ministry and the General Directorate of Highways (GDH) authorities, played a pivotal role in achieving timely completion through prudent decision-making, dedicated endeavors, and particularly valuable contributions during the project financing phase" [61, 5].

4.21.2 Inherent Flexibility of PPP Project Vs Event Uncertainties (COVID 19)

The contracts and administrative deputy director of the project emphasized the specific nature of PPP agreements as a contractual format that effectively navigated uncertainties and force majeure events during the project's construction phase. "We encountered the unprecedented global impact of the Covid 19 pandemic that affected not only our nation but also our ambitious Project. In addition to the already demanding workload, we were confronted with an extraordinary situation of a scale previously unseen in this projects' context. When the Covid-19 pandemic emerged, numerous factors like factory closures, disrupted global supply chains, grounded airlines, and restricted borders necessitated a halt in construction activities.If this was a government-funded project, it might have been straightforward to declare a force majeure, cease construction, and initiate a compensation claim for incurred losses. Consequently, the project's timeline might have been extended by approximately three years or so. However, the loan agreements' structure dictated a fixed repayment period for repayment of loans to lenders, presenting a distinct challenge. Even though we did pursue a force majeure claim with the government, the compensation framework within the PPP agreement was tied to an extended operational period package, rather than a direct financial compensation. Consequently, we had to adhere closely to the contractual obligations. Although we couldn't avoid the impacts of the pandemic entirely, we implemented a wide range of emergency measures to mitigate its adverse effects on project performance. For instance, strict rules, quarantine protocols, and limitations on site access were enacted. Even though our construction site had sufficient accommodations, sharing rooms was no longer feasible, leading us to rent 12 different hotels for accommodations, including a quarantine hotel near the site. To ensure safety, individuals were transported daily via company buses. Substantial resources were invested to prevent the entry of Covid-19 onto the construction site. Innovative construction methods, equipment, and additional shifts were employed to counter delays. Despite the numerous challenges faced by operations and construction projects during the pandemic, our Project remained uninterrupted. This determination and proactive response which was derived by the nature of PPP contract enabled the on-time and within the budget completion of a project of this magnitude".

4.21.3 Timely Financial Close a Key for Navigating Uncertainties and Enhancing Project Performance

The SPV company's legal advisor emphasized the critical role of achieving a timely financial close, and loan agreements in enhancing project performance and effectively managing uncertainties. "The remarkably swift financial close of the 1915Çanakkale Project stood as a remarkable feat, not only ensured adherence to the project's schedule but also effectively addressed and mitigated financial uncertainties that initially had posed significant concerns. Assembling the project documentation and contracts to secure a substantial 2.3 billion euros from seven distinct lender groups within a year was an unprecedented achievement in Turkey. Managing a diverse consortium of creditors with varied perspectives and inter-

ests necessitated swift consensus on a structural framework, documentation, and contracts in a remarkably short span. This endeavor demanded meticulous coordination and dedicated project management efforts, involving comprehensive communication and alignment of instructions from all finance parties. Negotiating agreements among the finance parties, borrowers, sponsors, the General Directorate of Highways (GDH), and the Turkish Treasury further added to the complexity. The key success factor to deal with complexities was the unwavering commitment of all stakeholders and a seamless teamwork approach across all fronts" [8].

4.21.4 Fast-Track Approach in Design and Its Side-Effects

The project's control manager underscored the dynamic nature of the PPP project, where changes occur daily due to the fast-track approach employed in the design process. While the ideal scenario would be completing a project with no changes, it would be impossible in reality. These change processes initiate from variation orders, proceed through multiple critique sessions, and ultimately require the approval of the owner's representative. Unfortunately, these changes often have a negative impact on the project, particularly in terms of time and cost. Around 20% of changes may yield positive impacts, whereas a significant 80% result in adverse consequences. Despite the necessity to allocate additional funds and time, these changes are always rooted in meetings with a specified quality threshold. While consistently identifying the most cost-effective solution which leads to frequent changes is a challenging endeavor, in a PPP project characterized by tight timelines, expediting the engineering and design phases is imperative. This approach aims to minimize the potential repercussions and ensure a timely completion.

As per the insights shared by the deputy subcontract manager of the project, the conflict resolution process typically had impacts on the project's cost aspect. Subcontractors holding claims were aware that, contractually, they were obligated to proceed with the work despite these claims. The resolution procedure centered around negotiation and mutual satisfaction. Consequently, we consistently aimed to adhere to the timeline, in spite of the claims, while claims often had cost effects for the project.

4.22 Agreement Format-Key Lessons

4.22.1 PPP; Tailored to Turkey's Needs for Infrastructure Development

The project's contract and administrative deputy director, believe that the PPP format has been well-suited to Turkey's circumstances over the years. Specific rules have been developed gradually to facilitate the PPP process. GDH has also established a specialized unit to transfer information and experience from previous PPP projects in Turkey to future ones. On one hand, Turkey requires significant investment in its infrastructure projects. On the other hand, the PPP format allows the government to leverage private capital for infrastructure development, which aligns with Turkey's economic situation. Additionally, due to successful

experiences, particularly in the road infrastructure sector, it is unlikely that an alternative to the PPP format will be found in Turkey, at least in the near future.

A crucial aspect for our parties is the concession period, during which the SPV company is responsible for project operation and maintenance. This means that if any issues arise during this period, the SPV company needs to bring in experts for repairs. Certain cases, such as Electrical and Mechanical (E&M) materials, are even more important. Instead of seeking services from another company, it's preferable for the subcontractor company who was responsible for construction of an item to provide the necessary services. Therefore, particularly in electro-mechanical works and all visible components, adopting a long-lasting service approach within the defect's liability period would be most advantageous for the SPV entity. However, for certain tasks like caisson work, even having a two-year defect liability period from the subcontractor might not be very beneficial for the SPV company. This is because the caisson is submerged beneath the sea, making it challenging to inspect it frequently.

4.22.2 Government Guarantees and Currency Fluctuations; Criteria for the feasibility

The deputy subcontract manager of the project highlights the significance of a minimum guaranteed revenue from the government. This guarantee is pivotal in assessing the feasibility of contributing to a PPP project and plays a decisive role in determining participation in the bidding process. Furthermore, the project's vulnerability to currency fluctuations is considerable, given the absence of any governmental currency guarantees. This factor, particularly the stability of currency over the project's extended duration, necessitates careful consideration. Consequently, when viewed from the PPP standpoint, countries like Turkey are currently perceived as high-risk environments. Hence, the preference is to engage in endeavors within more economically stable nations.

4.22.3 Strategic Contract Management; A Pillar of Success in Complex Projects

The deputy project manager underscored the significant role of contract management as a fundamental driver of success in a project of such intricate nature. "The FIDIC Silver Book and other standard contracts used for subcontracting provide a well-defined methodology for the execution of such projects. Adhering to the contract and its specified approach can help prevent the emergence of unmanageable challenges. It is imperative to maintain a constant awareness of project developments. For instance, a diligent understanding of the scope of work is crucial, and any changes must be addressed promptly through the appropriate claims process within the designated time frame. Failure to do so would result in a loss of entitlement. Effective project management is vital in handling projects of this nature. While the design and construction aspects are essential, achieving the harmonious convergence of all elements within constrained budgets and timelines underscores the critical role of project management. I firmly believe that a significant portion of successful project management is devoted to adept contract management".

He also highlighted the importance of a more diligent selection process when it comes to subcontracting tenders. "Typically, when submitting a tender to choose a subcontractor, we provide them with comprehensive information and request that they carefully review all specifications and contractual terms before submitting their final price. Regrettably, there are instances where they intentionally overlook certain aspects or deliberately underestimate costs in order to secure the bid. This practice is especially prevalent in smaller-scale tenders. While the contract size might be modest, the mutually linked of tasks means that the inability of subcontractors can lead to disruptions in other areas and result in delays. These considerations must be taken into account for future projects".

4.23 Agreement Format- Discussion

Mega projects demand expertise and proficiency not just in engineering, but also across financial, legal, social, economic, and organizational management domains. The realization of the 1915Çanakkale Project involves four sponsors and the backing of 25 financial firms while numerous public institutions had diverse and extensive interests in the project. A project of such global magnitude can only come to result through the consensus and collaborative efforts of all involved parties. The private sector undertook responsibilities like financing, design, procurement, construction, and operations. One of the most significant features of PPP is applying the private sector's innovative and competitive dynamic to secure swift and efficient investments [5]. A significant emphasis was placed on meticulous documentation and ensuring coherence across all contracts and documents to align with projected cash flows. The financing involved complex arrangements with multiple banks and institutions from various countries. The structure of financing was largely in line with international project financing standards. The alignment of financing with the project's life cycle indicates a forward-looking approach to ensuring the project's viability.

projects utilizing Lump Sum contracts, especially in international bids, are usually favorable for public sectors due to their lower risks. However, unclear project scopes can pose lots of risks for Contractors. Conversely, unit rate projects allow Contractors to claim costs for all on-site work, altering the original estimate considerably. While, the PPP model emerges as a fairer approach, effectively distributing risks between Administrative Authorities and Contractors [8]. The risk allocation within the PPP model is a critical aspect of the Agreement format. The principle of risk allocation, as outlined in the project, signifies the strategic distribution of risks between the SPV company and the EPC contractor. The nature of PPP projects necessitates the SPV company's endeavor to assure lenders of minimal risks, thereby placing a significant burden of risk on the EPC contractor. Guarantees such as advance payment, performance, and defect liability guarantees within the EPC entity demonstrate the multi-tiered approach to risk management. The concept of government guarantees for minimum revenue illustrates the symbiotic relationship between public and private sectors in PPP projects. The absence of such guarantees might prevent private sector participation, causing projects to be economically unfeasible due to increased risks. While government revenue guarantees mitigate some risks, the absence of other financial guarantees like currency

and inflation from the government underlines the complexity of risk assessment within PPP projects.

The dynamic nature of the project lead to changes in design and construction methods that needed to be carefully assessed for their impact on scheduling, costs, and stakeholder agreement. The change management process involved precise evaluation and stakeholder communication to ensure alignment and minimize disruptions. To do that, the project was monitored by the government's representative continuously. This procedure not only reassured all stakeholders regarding quality of final product but created confidence for attracting long-term international investments [62]. Conflicts and claims were managed through negotiation and settlement mechanisms, emphasizing the importance of adhering to contractual obligations. In this regard, the FIDIC Silver Book was utilized as a basis provided a framework for managing claims and disputes, with an emphasis on timely communication and response to claims.

The PPP format brought advantages to the project's quality, durability, time and budget management which mostly derived from the long-term nature of PPP projects. The financing structure of PPP projects led to disciplined cost management and timely completion. The COVID-19 pandemic posed unprecedented challenges, highlighting the adaptability of PPP contracts in addressing force majeure events, given the project's requirement for a fixed loan repayment period. This exemplifies the alignment between contractual commitments and project realities. Moreover, as private partners are also responsible for operation and maintenance stage, they placed significant importance on the robustness, resilience, and endurance of the structure they erected for the 1915 Çanakkale Project. This situation highlights the convergence of the private sector's motives with the public sector's concerns, resulting in a product of exceptional quality [61].

The swift financial close and robust loan agreements were crucial to managing uncertainties. In fact, we are discussing a model focused on extensive, long-lasting public benefits rather than individual, short-term gains. These projects must first prove their financial viability through economic analysis, ensuring a satisfactory balance between cash inflows and outflows for stakeholders. Projects failing this test cannot proceed using this method. Unlike commercial value, the other advantages of project with this level of transformation for the economy are less measurable due to intangible factors like political value. Even infrastructure projects that might be financially unfeasible in the present could gain commercial value over time and eventually become viable. Ultimately, these projects substantially contribute to the economy over the long term, aiming to enhance public welfare and well-being [4, 5].

Finally, If the choice to implement the PPP model is in harmony with the economic circumstances, priorities, and developmental strategy of the nation, the execution will become more effective [5]. PPP projects were well-suited to Turkey's infrastructure development needs, allowing the government to leverage private capital. Successful experiences in road infrastructure suggested that PPP would remain a preferred approach. The essence of PPP contracts required the SPV company to ensure long-lasting service approaches, especially in defective liability periods, to ensure operational efficiency and maintenance. Government guarantees for minimum revenues were pivotal for assessing the feasibility of participation and managing risks associated with large-scale projects however it seems that

they should find a solution for currency and inflation issues for the next projects. Adhering to standardized contract methodologies like FIDIC Silver Book was crucial to manage complexities and prevent unmanageable challenges. The selection process for subcontractors must be more diligent, ensuring they fully understand specifications and contractual terms to prevent disruptions and delays.

CHAPTER

FIVE

CONCLUSIONS

5.1 Main Uncertainties

The completion of the 1915 Çanakkale Bridge project in Turkey was a remarkable engineering achievement, but it also underscored several key uncertainties and challenges common to large-scale infrastructure projects. These uncertainties fall into various categories: project financing, design and technical complexity, event uncertainty (as demonstrated by the Covid-19 pandemic), weather conditions, cultural diversity, environmental considerations, construction uncertainties (which includes global supply chain issues, safety concerns, heavy lifting operations, and time management).

The financing of mega-projects like the 1915 Çanakkale Bridge is a complex endeavor that involves multiple stakeholders and diverse financial methods. Effective financial management and accurate initial cost assessments are vital to the success of such projects. Proper coordination with international lenders and banks, along with efficient global communication, is essential to navigate the complexities of public-private partnerships (PPPs).

Pushing the boundaries of engineering with innovative design and construction methods is necessary for projects of this scale. However, site-specific challenges, such as severe weather conditions considering fast-track approach applied for design of the project, can lead to design changes and specification revisions, potentially causing project delays and increased costs. Technical expertise and collaborative teamwork are essential to overcome these challenges.

The Covid-19 pandemic, classified as a force majeure event, introduced unexpected challenges to the project, affecting timelines, costs, and workforce management. Managing risks associated with unforeseen events in the context of fixed agreements with lenders is a complex issue in PPP projects.

The harsh weather conditions in the Çanakkale Strait, including strong winds, high waves, and complex currents, presented significant challenges during design and construction. Weather-related disruptions often lead to project delays and increased costs, necessitating the implementation of contingency measures.

Managing a diverse team of stakeholders from different countries and corporate cultures is a challenge that requires time and effort to build mutual understanding and collaboration. Cultural diversity can lead to differing work approaches and communication styles.

Large-scale infrastructure projects like the 1915 Çanakkale Bridge have substantial environmental impacts. Addressing these impacts, including mitigating carbon footprints, adapting to climate change, and preserving biodiversity, is crucial in modern infrastructure development.

Supplying specialized materials and mega equipment globally caused logistical challenges, especially during the COVID-19 pandemic. Ensuring timely production, maintaining quality, and transporting oversized components from distant regions were significant uncertainties that required careful management.

Due to the immense scale of the project and minimal margin for error, safety considerations were of paramount importance. Weather conditions and maritime location added complexity, necessitating advanced safety equipment and rigorous protocols.

The lifting, transportation, and assembly of substantial substructure components required meticulous planning due to the massive weight and huge size of these components. Heavy lifting operations were critical to project success but also caused significant risks in terms of potential accidents and delays.

Time management was central to project success, with delays deriving from various sources, including weather, safety concerns, design change, supply chain disruptions, and inaccurate time estimations. Delays could lead to increased costs, making meticulous time management imperative.

In conclusion, the 1915 Çanakkale Bridge project serves as a valuable case study in the challenges and uncertainties inherent in large-scale infrastructure projects. Addressing these uncertainties demands meticulous planning, risk assessment, and strategic management across various domains, from finance and design to environmental impact and safety. The successful completion of such projects depends on effective coordination, collaboration, and adaptability in the face of unforeseen events and challenges.

5.2 PDM Elements in 1915Çanakkale Bridge Project

The Turkish government awarded the 1915Çanakkale Bridge and Motorway Project to a Turkish-Korean consortium, employing the public-private partnership (BOT) model. This project brought together four distinct shareholders under the Joint Venture framework, acting as sponsors (SPV) and EPC contractors. Additionally, the collaboration extended to construction subcontractors, equipment suppliers, steel fabricators, engineering firms, insurers, and lenders from over 10 countries, making it an international endeavor with a diverse range of stakeholders. In the PPP model, the SPV company played a pivotal role in overseeing the entire process, particularly in the project's initial stages, handling various agreements ranging from PPP agreements to financial and insurance contracts, supply agreements, and design contracts. Meanwhile, all construction responsibilities and risks were assumed by the EPC contractor. Both the EPC and SPV companies in the 1915Çanakkale Project were part of the same entity, featuring specialized internal departments that facilitated effective interdepartmental communication and collaboration throughout the project. While the SPV company operated with a smaller team of experts, the EPC contractor was a relatively large organization. The project implemented multi-layered quality control and quality assurance pro-

cesses to ensure a high-quality final product, albeit occasionally causing delays.

Despite benefiting from cutting-edge technologies, stronger materials, and refined design and construction methods, the primary design strategy for the 1915Çanakkale Bridge project was risk mitigation. Consequently, COWI, a renowned global company specializing in suspension bridge design with a proven track record in Turkey (Osmangazi Bridge), was selected for the bridge's design. This approach extended to the procurement route, emphasizing the use of subcontractors and suppliers within the EPC company. The project's design specifications and standards combined local and international norms, with a focus on Euro codes. However, certain aspects, such as wind design, required tailored specifications generated by COWI. The fast-track approach was applied to bridge design, a common practice in PPP projects but one with its own set of challenges. The design process involved an interactive collaboration between multiple parties, including the design firm, owner's consultancy services, the EPC's design team, supply firms, and lender's technical and environmental advisors within the project. While this approach typically results in high-quality design, it also had the potential to cause project delays.

The consortium for the 1915 Çanakkale Bridge project was carefully selected to bring together a mix of international and Turkish companies with extensive experience in large infrastructure projects. This approach helped benefit the expertise of each partner and mitigated risks associated with the project's complexity. All partners, had prior experience in international PPP projects, including the Eurasia Tunnel in Turkey. Moreover, some of them had common previous experience in infrastructure projects. This experience positioned them favorably in the global PPP market and helped them navigate the uncertainties such as the global supply chain, design, and construction. The successful financial closure of the project within the specified time-frame is noteworthy. Achieving this milestone required dedication and collaboration among the project sponsors, lenders, and government. The involvement of various international financial institutions derived by the support of the Turkish government contributed to the timely financial agreements. The project's procurement strategy focused on minimizing risks by selecting well-known companies with proven track records, even if it meant higher costs. This approach is especially critical in a PPP project where quality, timeliness, and reliability is paramount. The selection of subcontractors was based on a combination of factors, including technical capacity, financial stability, and previous experience. The emphasis on timely delivery and quality is crucial in a project with potential financial benefits for early completion. Some materials and expertise had to be sourced globally due to the lack of local competency. This highlights the importance of global supply chain management in complex infrastructure projects. The procurement strategy considered the importance of time as a key determinant parameter since the early completion of construction works could lead to additional profits for shareholders, highlighting the significance of delivery schedule in PPP projects.

The project was structured as a public-private partnership (PPP), where the private sector consortium (SPV) was responsible for securing financing, design, development, procurement, construction, and operation of the project throughout the concession period. The financing for the project involved a complex structure, with a significant portion secured through international banks and financial institutions. A 15-year term loan was obtained, and the financial closing was

achieved with the participation of 25 banks and financial institutions from 10 different countries. This financing structure followed international project financing standards. In PPP projects, the SPV leaves many risks for the EPC (Engineering, Procurement, and Construction) contractor, as securing financing requires convincing lenders of low project risks. Risks were primarily allocated to the EPC contractor, emphasizing the importance of their planning, engineering, and design capabilities. While the Turkish government, as it common in PPP projects, provided guarantees for minimum revenues to make the PPP project less risky, there were no financial guarantees beyond this. However, the supportive role of government in convincing financial institutions to contribute to the project was considerable. Within the EPC entity, guarantees typically include advance payment guarantees, performance guarantees, and defect liability guarantees. These guarantees aimed to ensure subcontractors' compliance with contract terms and the quality of their work. Changes in the project, whether initiated by the Turkish Government or other parties, were subject to assessment of their scheduling and cost impacts. A unanimous agreement among all parties involved was required for any changes. As a result, the process of preparing documents for variation orders (VO) was time-consuming. The project employed a mechanism for claim management based on the FIDIC Silver Book with some modifications. Subcontractors were required to inform the EPC contractor of their claims within a specific period, and a formal process for review and resolution was followed. Claims could be settled in a friendly manner or, if necessary, through arbitration. Notably, the project managed to resolve all claims, including those between the private sector and the public sector, and numerous claims from subcontractors to the EPC contractor, through amicable settlement between parties without resorting to arbitration or court proceedings. The agreement format and risk-sharing mechanisms in the 1915 Çanakkale Bridge and Motorway Project illustrate the complexity and careful planning required in large-scale infrastructure projects, especially in the context of public-private partnerships. The successful resolution of disputes and effective risk allocation contributed to the project's overall success.

5.3 PDM's Effects on Performance and Uncertainties

In the scope of mega infrastructure projects, the 1915 Çanakkale Bridge project in Turkey stands as an example to the interactive relation between organizational form, project structure, specification of work, procurement route, and agreement format. This case study offers a wealth of insights into the dynamics that shape the success of such endeavors and the effective management of uncertainties inherent in them. Following the impact of PDM's elements on project performance and their role to managing uncertainties in different stages of 1915Çanakkale bridge project has been briefly investigated:

- Organization Form: The project's organizational structure facilitated effective communication and coordination among diverse stakeholders. Clear definitions of authority, responsibility, tasks, and timelines minimized conflicts and complications. Although the hierarchical structure allowed for

timely decision-making which was critical in addressing uncertainties, consensus based decision making derived by same share of shareholders sometimes led to delay in progress. The unique collaboration model exhibited by the project emphasizes shared objectives and the benefiting of partners' strengths. This unity gradually emerged despite initial cultural diversity, leading to a partnership that resulted in remarkable synergy in both construction and project finance phases.Trust-based relationships among stakeholders and transparent relationships played a prominent role in managing interdisciplinary communication and collaborations. Skilled and experienced human resources, both internal and external, were instrumental in addressing uncertainties effectively.

- Project Structure: The complex project structure, involving multiple stakeholders and various contractual relationships, contributed significantly to managing uncertainties. Proactive planning, open communication, and continuous follow-up within this structure enabled the project management team to navigate potential uncertainties related to design, construction, and financial issues. The strategic distribution of roles, responsibilities, and risks among various private entities ensures a balanced allocation of resources and expertise. Legal advisors with expertise in legal, technical, and financial domains played a crucial role in establishing flexible financial agreements. Multi-layered quality control mechanisms ensured high project quality and resilience to unforeseen challenges.

- Specification of Work: the specification of work proved to be a critical facet in achieving the project's timely completion and surpassing initial expectations. Creating specifications for a unique project like the 1915 Çanakkale Bridge required a meticulous approach. The use of advanced techniques like BIM and real-time measurement mitigated errors, applying innovative Methods and mega equipment for heavy lifting activities accelerated work in windy conditions, and proactive seismic safety measures and several wind tunnel tests demonstrated the project's endeavors to managing uncertainties effectively. Early involvement of partners in the design process minimized uncertainties related to design changes. Collaborative efforts with subcontractors and suppliers in finalizing accurate specifications were essential. Comprehensive planning to address complexities and uncertainties during construction, along with ongoing communication between the design firm and contractors, ensured project acceleration and minimized disruptions.

- Procurement Route: The chosen procurement route, involving an international consortium with complementary expertise, effectively managed complexities and enhanced project performance particularly at the early stage of the project. Partnering with experienced companies allowed for the efficient management of uncertainties related to project schedules, design complexities, and technical challenges. Emphasizing reputable suppliers and establishing clear communication channels reduced uncertainties related to material quality, timely delivery, and production capabilities. Flexibility, adaptability, and proactive planning were pivotal in addressing uncertainties, especially during unpredictable events like the Covid-19 pandemic.

- Agreement Format: The 1915 Çanakkale Bridge project illuminated the significance of aligning financing with the project's life cycle and comprehensive risk management.The distribution of risks between the SPV company and the EPC contractor, coupled with a multi-layered approach to risk management, displayed the project's commitment to achieving stability and reliability. The presence of government guarantees for minimum revenues was crucial for assessing the feasibility of participation and managing risks. Timely decision-making, accountability, and a clear operational framework were essential in addressing uncertainties. The adherence to contractual obligations, the use of standardized contract methodologies, and the creation of alignment among diverse stakeholders played pivotal roles in managing uncertainties and delivering a high-quality product.The alignment of contractual commitments with project realities, exemplified during the Covid-19 pandemic, underscored the importance of robust and adaptable agreement formats.

5.4 Key Lessons

The construction and successful delivery of the 1915 Çanakkale Bridge project represent a remarkable achievement in the field of large-scale infrastructure development. Throughout the course of this endeavor, a multitude of uncertainties were encountered, and strategies were employed to navigate them effectively. These uncertainties encompassed project financing complexities, design and technical challenges, event-related disruptions, weather conditions, cultural diversity, environmental considerations, and construction-related uncertainties. In light of these challenges, several key lessons can be derived from the delivery process of the 1915 Çanakkale Bridge project, offering valuable insights for future large-scale infrastructure endeavors.

- Thorough Risk Assessment and Planning: Comprehensive risk assessment and meticulous planning are essential prerequisites for the successful execution of mega-projects. The project's ability to anticipate and plan for various uncertainties, including financial, technical, and environmental risks, proved instrumental in mitigating potential disruptions. This underscores the importance of thorough risk assessment at the project's inception and the development of robust risk management strategies to address contingencies effectively.

- Effective Collaboration and Communication: Collaborative and transparent communication among stakeholders is critical for project success, especially in culturally diverse environments. Managing a diverse team of stakeholders from different countries and corporate cultures demanded effective cross-cultural communication and collaboration efforts. The project's success was built on trust-based relationships among stakeholders, highlighting the significance of fostering transparent and open communication channels.

- Flexibility and Adaptability: Flexibility and adaptability are paramount in responding to unforeseen challenges, such as the Covid-19 pandemic and

supply chain disruptions. The project's ability to adapt to changing circumstances, whether due to unforeseen events or design modifications, played a pivotal role in maintaining project timelines and budgets. Future projects should prioritize flexibility in their delivery models and contingency plans to address unexpected developments effectively.

- Interdisciplinary Collaboration: Interdisciplinary collaboration is crucial for addressing the complex nature of mega-projects. The project's success was achieved through close collaboration among various teams, including technical, financial, legal, and environmental experts. This highlights the importance of fostering a culture of interdisciplinary collaboration and creating mechanisms for effective coordination among different departments.

- Proactive Procurement Strategies: Strategic procurement routes, including partnering with experienced companies and ensuring robust supplier relationships, can mitigate uncertainties related to material quality and timely delivery. The selection of an international consortium with complementary expertise and a track record of PPP projects contributed to efficient management of uncertainties. Future projects should consider the strategic composition of project consortia and place emphasis on reputable suppliers and clear communication channels.

- Robust Agreement Formats: Well-structured agreement formats that allocate risks strategically and align with project realities are crucial for large-scale infrastructure projects. The 1915 Çanakkale Bridge project's Agreement Format, characteristic of PPP projects, distributed risks effectively between stakeholders. The alignment of contractual commitments with the project's dynamic nature, as exemplified during the Covid-19 pandemic, underscores the importance of adaptable agreement formats.

- Commitment to Sustainability: Integrating sustainability considerations, including environmental and social standards, enhances project quality and eligibility for international funding. The project's alignment with global environmental and social standards demonstrated a commitment to sustainability. Future large-scale infrastructure projects should prioritize sustainability as part of their core objectives, considering long-term impacts on the environment and society.

- Proactive Change Management: Proactive change management processes, including precise evaluation and stakeholder communication, are essential to minimize disruptions caused by design changes. The project's management of design changes and discrepancies through proactive change management processes emphasized the significance of efficient communication channels and prompt resolution of discrepancies. Future projects should prioritize change management to maintain project acceleration.

In conclusion, the delivery process of the 1915 Çanakkale Bridge project offers valuable lessons that extend beyond the domain of infrastructure development. It underscores the importance of strategic planning, interdisciplinary collaboration, effective risk management, and adaptability in addressing uncertainties and

achieving project success. These key lessons serve as a road-map for future mega-projects, guiding stakeholders toward more efficient, resilient, and sustainable infrastructure endeavors that benefit both the public and the broader economy. The success of the 1915 Çanakkale Bridge project serves as a evidence to the power of innovation, collaboration, and strategic thinking in overcoming the numerous challenges of large-scale infrastructure development.

5.5 Potential Future Works

Since present research has followed a holistic approach to investigate the impacts of different elements of PPP on the whole process of the project execution, following text offer a more Atomistic approach as potential studies for the future.

- Government Perspective: As mentioned, present research scope was limited to the main contractor's perspective. how ever the main player in PPP delivery model are private partners until the end of concession period, conducting a research from the government' lens as a project owner could be a potential fruitful research.

- Comparative Analysis of PPP Models: Given the success of the 1915 Çanakkale Bridge project in Turkey, future researchers can explore and compare different Public-Private Partnership (PPP) models used in large-scale infrastructure projects across various countries. Analyzing the strengths and weaknesses of different PPP approaches and their impact on project performance can provide valuable insights for policymakers and project managers.

- Cultural Diversity and Collaboration: Building on the cultural diversity aspect mentioned in the conclusion, researchers can explore how diverse teams can effectively collaborate in international mega projects. This research can focus on best practices for cross-cultural communication, conflict resolution, and building trust among stakeholders from different backgrounds.

- Innovation and Technology Adoption: The conclusion highlights the use of advanced technologies in the Çanakkale Bridge project. Future studies can investigate the role of innovation and technology adoption in improving project efficiency and performance, with a focus on specific technologies such as Building Information Modeling (BIM) and real-time measurement.

- Legal and Contractual Aspects: Researchers can conduct in-depth analyses of the legal and contractual aspects of PPP projects, including dispute resolution mechanisms, contractual obligations, and risk-sharing arrangements. Understanding how these legal frameworks impact project success can provide valuable guidance for future PPP ventures.

- Supply Chain Management in Global Projects: Given the challenges faced during the procurement of materials and equipment from global sources, future research can explore supply chain management strategies in mega projects. This could include case studies on how disruptions (e.g., the COVID-19 pandemic) affected supply chains and how projects adapted to these challenges.

- Lessons for Project Governance: Investigating the governance structures and decision-making processes within mega projects can be a attractive area of research. Understanding how project roles and responsibilities are allocated among stakeholders, and how decisions are made, can offer insights into effective project governance.

- Risk Management in PPP Projects: The conclusion highlights the importance of risk management in PPP projects. Future research can delve deeper into the strategies and tools used for risk assessment and mitigation in mega infrastructure projects. This can include case studies of how specific risks (e.g., COVID-19 pandemic, weather-related disruptions) were managed and how risk allocation between public and private partners affects project outcomes.

- Environmental Impact of Mega Projects: As large-scale infrastructure projects often have significant environmental impacts, future research could focus on assessing and mitigating these impacts. Researchers can investigate innovative and sustainable practices in construction, design, and operation to reduce the environmental footprint of such projects.

- Comparative Study of Suspension Bridge Projects: Researchers can conduct a comparative study of various suspension bridge projects worldwide, considering factors like different PDMs, design approaches, construction methodologies, and project management models. This can help identify best practices and lessons learned from similar projects.

- Long-term Project Performance: It would be valuable to study the long-term performance of mega infrastructure projects like the 1915 Çanakkale Bridge. Assessing how well these projects continue to function and meet their intended goals over time can provide insights into the sustainability and durability of such investments.

These research directions can contribute to the ongoing improvement and success of mega infrastructure projects, helping project stakeholders make informed decisions and achieve better outcomes in the future.

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APPENDICES

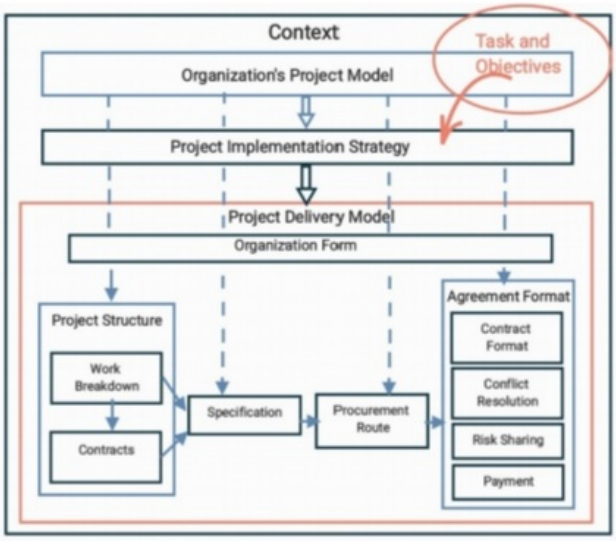
A - INTERVIEW GUIDE

.0.1

Project delivery model in 1915Çanakkale Bridge Project

Introduction

This interview guide has been developed by Siamak Akbarnezhad, a master student of Project Management at NTNU as a representative of research group, for a study that is being carried out in cooperation with the Norwegian Public Roads Administration (NPRA). The NPRA is currently planning the delivery of E39 Stord-Os (Hordfast), which is an important part of the development of a Coastal Highway Route E39. This project includes the construction of some of the largest and most innovative bridges and tunnels ever made. In this connection, NTNU and NPRA seek to study experiences with project delivery models (PDMs) in complex projects. Here, a project delivery model is understood as a collection of formal elements implemented for the project to achieve its strategic aims (Klakegg 2017) and whenever is pointed to project performance indicators, it means the time, cost, and quality of activities in the project's critical Paths.



The study seeks to explore the following research questions:

1) How was the Project Delivery Model (PDM) in the project?

2) How did PDM's elements impact project performance indicators? To what extent did they contribute to managing uncertainties in the project?

3) What were the key lessons regarding the PDM within the project?

Interview process

Audio recordings of the interviews will be taken to ensure better dialogue and data analysis. The interviewees will be given a summary of the interviews for verification of the findings and will have the opportunity to be rendered anonymous. It can be agreed upon to make certain information from the interviews confidential. The interviews will take approximately one hour

Figure .0.1

.0.2

and can be carried out both physically and digitally. The interviewee has the right to not answer one or some questions for any reason.

0.Interviewee

What is your role in the project?

When did you enter the project and how long were you involved in it?

What is your professional background/education?

1.General

a) Which were the critical paths connected to project performance?

b) How were the project performance indicators for the activities on the critical paths?

c) Which were the 3-5 uncertainties which had the greatest impact on the project performance?

2.Organization Form

a) How was the Organization Form in the project?

b) How did Organization Form impact Project performance? To what extent did it contribute to managing the uncertainties in the project?

c) what were the key lessons regarding the organization form?

3.Project Structure

a) How were the tasks and contracts in the project divided?

b) How did Project Structure impact project performance? To what extent did it contribute to managing the uncertainties in the project?

c) what were the key lessons regarding the Project Structure?

4.Specification

a) How were the works in the contracts specified?

b) How did Specification of Work impact Project performance? To what extent did it contribute to managing the uncertainties in the project?

c) what were the key lessons regarding the Specification in the project?

5.Procurement Route

a) How were the Procurement Route in the project?

b) How did the Procurement Procedure impact Project performance? To what extent did it contribute to managing the uncertainties in the project?

Figure .0.2

.0.3

c) what were the key lessons regarding the Procurement Route in the project?

6.Agreement Format

a) What were the Agreement Format in the project?

b) How did Agreement Format impact project performance? To what extent did it contribute to managing the uncertainties in the project?

c) what were the key lessons regarding the Agreement Format in the project?

End

-Are there other aspects you think should be discussed?
-Are there any project documents that you would recommend looking at?
-Are there any people you would recommend us to interview?
-Would it be okay for us to contact you if we have any further questions?

Thank you for your contribution!
Best regards,
NTNU

Figure .0.3

B - TT JV'S RESPONSIBILITIES

	Owner's Consultant Responsibilities
1	overseeing contracted tasks by the Appointed Company, following BOT Contract guidelines. The Head of the Organization acts as the Administrative Authority's representative, serving as the Project's "Engineer" during construction.
2	Ensuring that the tasks are advancing according to the terms of the construction contract.
3	Evaluating and recommending approval for business plans and modifications, reviewing financing programs, and reporting to the Administrative Authority about these matters.
4	Checking the conformity of materials and work done by the Appointed Company with regulations and international standards, and requesting replacement of non-compliant materials.
5	Examining construction methods to ensure work progresses as planned, suggesting more efficient methods if needed to expedite the process.
6	Assessing extension requests from the Appointed Company from both technical and contractual viewpoints, and conveying the evaluation's outcome to the Administrative Authority.
7	Creating and monitoring the infrastructure for "Change Orders" related to modifications in technical and practical scope.
8	Compiling and maintaining inspection and engineering reports and records to ensure thorough documentation of work progress and completed productions.
9	Overseeing safety measures implemented to protect life and property
10	advising the Contractor in case of deviations from the program, investigation of measures to compensate for the delay and reporting of these to the Administrative Authority.
11	Creating an Administrative Authority committee to assess project completion, identify deficits before final acceptance, and manage the process in line with contract terms through an Acceptance Protocol.

Table .0.1: Responsibility of TT JV (Owner's Consultant) within the project [8].

C - LENDERS' MOTIVATIONAL REASONS FOR CONTRIBUTING TO THE PROJECT

Financial Institution	Motivational reasons
KEXIM	1)Importance of Project itself-2)the significant role of Korean firms-3)Government strong support
K-Sure	1)low risk of completion due to Sponsors' excellent track records-2)secured source of the loans' repayment-3)Project' contribution in Turkey's socio-economic, and tourism development
EKF	1) KEXIM, K-Sure, and COWI attendance as previous partners-2)government strong support-3)contribution to another type of transaction
ING	1)low risk of completion due to Sponsors' excellent track records-2)secured source of the loans' repayment-3)government strong support
Garanti BBVA	1)Importance of Project itself-2)Project' contribution in Turkey's socio-economic, and tourism development-3)low risk of completion due to Sponsors' excellent track records-4)Government strong support
ICBC	1)Importance of Project itself-2)low risk of completion due to Sponsors' excellent track records-3)Project' contribution in Turkey's socio-economic, and tourism enhancement-4)Government strong support
Deutsche Bank	1)low risk of completion due to Sponsors' excellent track records-2)strong support provided by KEXIM and K-sure
QNB FİNANSBANK	1)Project' contribution in Turkey's socio-economic, and tourism development-2)low risk of completion due to Sponsors' excellent track records-3)Diversity of involved international financial institutions
Kuveyt Türk Participation Bank	1)Diversity of involved international financial institutions-2)Diverse structure of the loan packages-3)the guarantees given by international insurance institutions

Table .0.2: Financial Institutions' Motivational reasons for contributing in 1915Çanakkale Project Loan Agreements [9]. (KEXIM:Export-Import Bank of Korea, K-Sure:Korea Trade Insurance Corporation, EKF:Export and Investment Fund of Denmark, ING:Global Financial Institution, Garanti BBVA:Banco Bilbao Vizcaya Argentaria)