Towards a More Flexible Project Management Approach in Complex Construction Projects from the Scheduling Perspective

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DELFT, THE NETHERLANDS

Faculty of Civil Engineering and Geosciences

Towards a More Flexible Project Management Approach in Complex Construction Projects from the Scheduling Perspective

Post-Doctoral Research Report

In

Engineering Project Management

By

Önder Ökmen

January 2021

Bursiyer ve Programa Ait Bilgi Formu

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RESEARCH REPORT APPROVAL PAGE

I have examined the research report entitled

TOWARDS A MORE FLEXIBLE PROJECT MANAGEMENT APPROACH IN COMPLEX CONSTRUCTION PROJECTS FROM THE SCHEDULING PERSPECTIVE

presented by

ÖNDER ÖKMEN

and hereby certify that it is worthy of acceptance.

25/01/2021

Co-Advisor

Dr. Ir. Marian BOSCH-REKVELDT

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Integral Design & Management

Engineering Project Management

Dedicated to my wife, Çiğdem Sayın Ökmen

& to my daughters, Masal and Derin

CONTENTS

LIST OF ABBREVIATIONS

CME	Construction Management and Engineering
CPM	Critical Path Method
CSRAM	Correlated Schedule Risk Analysis Model
EF	Early Finish Time
ES	Early Start Time
EVM	Earned Value Management
FA	Flexibility Agent
FF	Finish-to-finish
FS	Finish-to-start
FSMA-CPM	Flexible CPM-Based Schedule Management Approach
IFCRM Procedure	Integrated Flexible Complexity/Risk Management Procedure
LF	Late Finish Time
LOB	Line of Balance Method
LPS	Last Planner System
LS	Late Start Time
LSM	Linear Scheduling Method
MCS	Monte Carlo Simulation
PERT	Program Evaluation and Review Technique
PMBOK® Guide	Project Management Body of Knowledge
PMI	Project Management Institute
RBS	Risk Breakdown Structure
SF	Start-to-finish
SS	Start-to-start
TF	Total Float Time
TOE Framework	Technical, Organizational, External Framework
TU Delft	Delft University of Technology
WBS	Work Breakdown Structure

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I would like first to express my thanks and gratefulness to my co-advisor Assist. Prof. Dr. Marian Bosch-Rekveldt for her invaluable guidance and giving me the opportunity to complete this research. It has been a great honour to work with her and to learn from her academic experience. I would like to present my sincere gratitude to my advisor Prof. Dr. Marcel Hertogh for accepting me as a postdoctoral researcher and motivating me for this research. I would also like to introduce my special thanks to Prof. Dr. Hans Bakker for supporting my works and for his invaluable contributions. Along the way, many people have contributed in a variety of ways to this research. I would like to thank our department secretary Ms. Sandra Schuchmann-Hagman for all her helps since the beginning of this journey. I also would like to send my thanks to the executive secretary of our department Mr. Jaap Meijer and to the staff of the Human Resources Department of the TU Delft for their helps. I would like to thank my colleague Mr. Leon Hombergen for his collaboration during the preparation of our conference paper. I would also like to thank my colleagues in our research group for their contributions to my knowledge during the colloquiums and literature review meetings. My special thanks are to the M.Sc. students Lise Andringa and Theodora Stratton for their patience against my suggestions as a supervisor. I would also like to thank Dr. Martijn Leijten for his collaboration within the supervising committees of the theses of Lise and Theodora. I am as ever, especially indebted to my wife Çiğdem Sayın Ökmen, whose love and support made this work possible. And my lovely daughters, Masal and Derin, your presence gave me the strength that I need to achieve this research. I also would like to thank to the members of our grand families for not withholding their loves from us. Moreover, I would like to thank the Jean Monnet Scholarship Program and its esteemed staff working in the Directorate of the European Union of the Ministry of Foreign Affairs and the Central Finance and Contracts Unit. Lastly, I would like to present my special thanks to the Ministry Authority, my ex-director and Presidential State Supervisory Council Member Mr. Sami Kalaycı, my friends and colleagues Cahit Şahin Bulut, Dr. Tarık Buyruk, Önder Meşe and Ahmet Veli Tekin, staff of the Human Resources Department and my colleagues from the Directorate of Internal Auditing Unit of the Ministry of Transport and Infrastructure for their supports and friendships.

SAMENVATTING

Dit postdoctorale onderzoek is uitgevoerd in de Onderzoeksgroep Engineering Projectmanagement van de sectie Integraal Design & Management van de Faculteit Civiele Techniek en Geowetenschappen van de Technische Universiteit Delft (TU Delft), Nederland, tussen 17.02.2020 en 15.02.2021 in het kader van een Jean Monnet Scholarship. Dit Scholarship is onderdeel van het Jean Monnet Programma, gefinancierd door de Europese Unie in het kader van pretoetredingssteun voor Turkije. Het onderzoek is ook officieel ondersteund door het Ministerie van Transport en Infrastructuur van de Republiek Turkije. Dit rapport presenteert het onderwerp, de inhoud en de bevindingen van het onderzoek alsmede de andere uitgevoerde academische activiteiten.

Het belangrijkste doel bij bouwprojecten is om te voldoen aan de verwachtingen op het gebied van kwaliteit en veiligheid, de tevredenheid van de stakeholders te waarborgen en de projecten op het geplande tijdstip, binnen het vooraf bepaalde budget en scope te voltooien. Dit doel kan worden bereikt door, onder diverse weers- en grondomstandigheden, tal van onderling samenhangende activiteiten te voltooien volgens vooraf opgestelde planningen. Om een dergelijke complexe structuur van het activiteitennetwerk, bestaande uit onderling samenhangende activiteiten, te beheersen wordt projectmanagement toegepast, meer specifiek de Critical Path Method (CPM). In hoeverre is CPM echter in staat om in te spelen op de dynamiek en complexiteit van huidige bouwprojecten?

Het doel van dit onderzoek is om een hybride benadering voor te stellen met zowel traditionele als flexibele kenmerken die kunnen worden gebruikt bij het beheersen van projectplanningen gebaseerd op de Critical Path Method. Op basis van een literatuurstudie wordt een aanpak voorgesteld en geëvalueerd. De voorgestelde aanpak wordt beschouwd als een belangrijke stap in de richting van de ontwikkeling van een flexibelere projectmanagementmethodologie die kan worden gebruikt bij het beheersen van planningen van complexe bouwprojecten.

ÖZET

Bu doktora sonrası araştırma, Hollanda Delft Teknoloji Üniversitesi (TU Delft) İnşaat Mühendisliği ve Yerbilimleri Fakültesi'nin Bütünleşik Tasarım ve Yönetim Bölümü Mühendislik Proje Yönetimi Araştırma Grubu'nda, 17.02.2020 ile 15.02.2021 tarihleri arasında Jean Monnet Bursu desteğiyle gerçekleştirilmiştir. Jean Monnet Bursu, Avrupa Birliği tarafından katılım öncesi yardım aracı çerçevesinde finanse edilen Jean Monnet Programı'nın bir parçasıdır. Araştırma, ayrıca Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı tarafından resmi olarak desteklenmiştir. Bu araştırma raporu; araştırmanın konusunun, içeriğinin, bulgularının ve araştırma süresince gerçekleştirilen akademik faaliyetlerin sunulması amacıyla hazırlanmıştır.

İnşaat projelerinde temel amaç, kalite ve güvenlik ile ilgili beklentileri karşılamak, paydaş memnuniyetini sağlamak ve projeleri planlanan zamanda, öngörülen bütçe ve önceden belirlenen kapsam dahilinde tamamlamaktır. Bu hedefe, çeşitli hava ve zemin koşullarında işçilik, ekipman ve malzeme gibi farklı kaynakların kullanıldığı birbiriyle ilişkili çok sayıda faaliyetin önceden hazırlanmış iş programları doğrultusunda tamamlanmasıyla ulaşılabilmektedir. Birbiriyle ilişkili çok sayıda faaliyetten oluşan böylesine karmaşık bir faaliyet şebeke yapısını yönetebilmek için proje yönetiminin, daha özgül olarak Kritik Yol Çizelgeleme Yönteminin (CPM) uygulanması gerekmektedir. Bununla birlikte, CPM mevcut inşaat projelerinin dinamiklerine ve karmaşıklığına ne ölçüde cevap verebilmektedir?

Bu araştırmanın amacı, günümüzün karmaşık inşaat projelerinin maruz kaldığı karmaşık, belirsiz ve dinamik koşullar altında CPM ile hazırlanmış iş programlarının yönetilmesinde kullanılabilecek hem geleneksel hem de esnek özellikler taşıyan hibrit bir yaklaşım önermektir. Bu bağlamda, kapsamlı bir literatür çalışmasına dayalı olarak bir yaklaşım geliştirilmiş ve değerlendirilmiştir. Elde edilen bulgular dikkate alındığında, önerilen yaklaşım, karmaşık inşaat projelerinin iş programlarının yönetilmesinde kullanılabilecek daha esnek bir proje yönetimi metodolojisinin geliştirilmesine yönelik önemli bir adım olarak kabul edilmektedir.

ABSTRACT

This postdoctoral research has been carried out in the Engineering Project Management Research Group of the Integral Design & Management Section of the Faculty of Civil Engineering and Geosciences of Delft University of Technology (TU Delft), The Netherlands, between 17.02.2020 and 15.02.2021 through the support of Jean Monnet Scholarship. Jean Monnet Scholarship is the part of the Jean Monnet Program, funded by the European Union within the framework of the instrument for pre-accession assistance. The research also has been officially supported by the Ministry of Transport and Infrastructure of the Republic of Turkey. This research report has been prepared in order to present the subject, content and findings of the research as well as the academic activities carried out during the research period.

The main objective in construction projects is to meet the expectations regarding the quality and safety, to ensure stakeholder satisfaction, and to complete the projects at the scheduled time, in the prescribed budget and within the pre-determined scope. This objective can only be achieved by completing numerous interrelated activities through using different resources such as labour, equipment and materials under various weather and land conditions in accordance with the work schedules prepared in advance. Project management, more specifically the Critical Path Method (CPM), needs to be applied in order to manage such a complex network of activities consisting of many interrelated activities. However, to what extent is CPM able to respond to the dynamics and complexity of current construction projects?

The aim of this research is to propose a hybrid approach with both traditional and flexible features that can be used in managing the work schedules prepared by the CPM under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to. In this context, an approach has been developed and evaluated based on an extensive literature study. Given the findings, the proposed approach is considered an important step towards the development of a more flexible project management methodology that can be used in managing the work schedules of complex construction projects.

1 INTRODUCTION

This report has been prepared by the Researcher to introduce the achievements and results of a post-doctoral research carried out in the Engineering Project Management Research Group of the Integral Design & Management Department of the Faculty of Civil Engineering and Geosciences at the Delft University of Technology (TU Delft) between the dates 17.02.2020 and 15.02.2021 through the support of the European Union under the Jean Monnet Scholarship Program implemented through the agreements established between the Republic of Turkey and the European Commission, and funded by the European Union within the scope of the Instrument for Pre-Accession Assistance. This research also has been supported officially by the Ministry of Transport and Infrastructure of the Republic of Turkey.

This chapter introduces the research topic, research problem, aim and objectives, scope, research methodology, and outline of the report.

1.1 RESEARCH TOPIC

The topic of the research was determined in agreement with the Researcher's co-supervisor Dr. Ir. Marian Bosch-Rekveldt and supervisor Prof. Dr. Ir. Marcel Hertogh and in parallel with the subjects currently investigated by the Engineering Project Management Research Group. First, it was focussed on the subject of "flexibility" in project management. Next, the topic was narrowed down the "complexity" problem in project management for which flexibility is assumed to be a solution. Finally, the topic was reduced to how the scheduling processes in complex construction projects should be established and managed in a (more) flexible way in order to achieve success under highly uncertain, frequently changing, and quite dynamic conditions of today's construction projects. In today's construction projects, various stakeholders intervene in the project and in turn, the stakeholder satisfaction evolves as another success criterion to be achieved besides the major success criteria of project management, i.e. time, cost, and scope. The narrowing process of the research topic is illustrated in Figure 1.1.

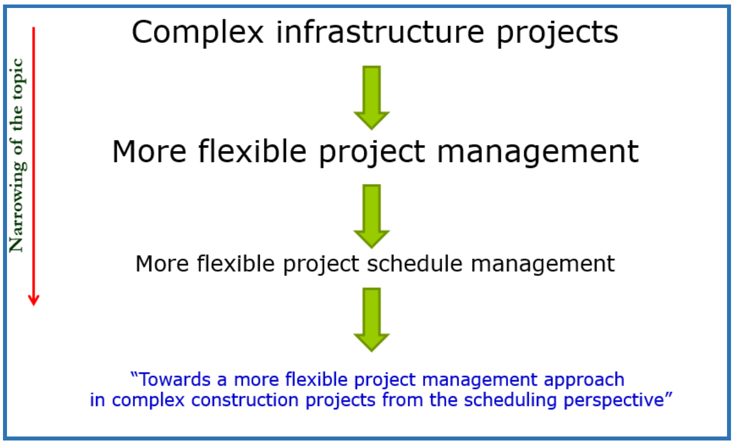

Figure 1.1 Illustration of narrowing process of the research topic

1.2 PROBLEM STATEMENT

Construction projects are generally realized under challenging weather and ground conditions through a great many interrelated activities carried out with the usage of various resources such as labour, equipment and materials. In order to regulate such a complex working environment and thereby deliver the construction projects on time, within budget, within scope, and in compliance with the contract conditions and other relevant legislation especially related to safety and environment, it is inevitable to apply the main knowledge areas and the related processes of project management including, but is not limited to, project schedule management and project risk management, as the Project Management Institute (PMI)'s “PMBOK® Guide (Project Management Body of Knowledge)” proposes (Project Management Institute, 2017). In case of large-scale infrastructure projects such as railway and highway projects, which can be considered as complex construction projects, the working environment gets more complicated and the uncertainty effect rises up (Hertogh & Westerveld, 2010).

In the construction sector, the requirements of the public or private owners are covered by the primary actors of the sector such as the designers, consultants and contractors in collaboration with the secondary parties such as the suppliers through different type of projects determined to be feasible and rentable mainly in terms of technical, economic and environmental aspects. Taking into consideration the general well-known meaning of the term ‘project’, a ‘construction project’ can be specifically explained as;

> *The production of a facility according to the requirements of the owner, society and other stakeholders in a systematic and disciplined way through consuming various resources like money, material and labour under unique and highly uncertain conditions in compliance with a contract and a plan showing the desired start and finish dates along with a predetermined budget and scope*.

Perhaps, such a long definition is enough alone to describe how challenging is to manage and successfully deliver the construction projects in compliance with the contract conditions and compatible with the requirements of the owners and various stakeholders. However, the real situation is much more complicated than this definition proposes, which can be considered as a relatively traditional definition.

The relevant literature frequently emphasizes the increasing low success rates observed world-wide in the completion of large-scale and complex construction projects within planned time and cost together with the deficiencies in terms of scope, quality and stakeholder satisfaction (Flyvbjerg *et al.*, 2003a; Chapmen, 2016). For instance, Flyvbjerg *et al.* (2004) analysed 258 transportation projects and detected that nine out of ten among the transportation projects overrun the planned budget and for the case of railway projects, the budget was overrun by 45% on average. The situation is not different for the other type of projects. Therefore, it can be said that cost overruns and time delays are common in projects and this situation leads to project failure (Hall, 1981; Thamhain & Wilemon, 1986; Morris & Hough, 1987). Bosch-Rekveldt *et al*. (2011) claim that one of the reasons that lead to failure in projects is the project complexity and the increasing trend observed in the complexity levels (Williams, 2002; Williams, 2005), or the underestimation of the project complexity (Neleman, 2006). Furthermore, in the literature, there is a wide opinion that the complexity level in construction projects is increasing and this causes difficulties in the management of these projects (Wideman, 1990; Baccarini, 1996; Gidado, 1996; Williams, 1999; Walker, 2002; Loosemore *et al.*, 2003; Flanagan & Jewell, 2005; Hillson & Simon, 2007; Vidal & Marle, 2008; Hertogh & Westerveld, 2010; Braglia & Frosolini, 2014). The literature pointing out the importance of complexity in projects also brings a discussion on the inadequacy of the traditional project management methods and tools depending on the fact that as the projects are getting more uncertain and complex, the traditional project management becomes incapable of sufficiently providing the needed tools to cope with these challenges (Baccarini, 1996; Hobday, 1998; Williams, 1999). Mainly, the aim of the traditional project management is to reach to the predetermined goals (Aritua *et al*., 2009), most of the time defined based on budget, time, and performance (Koppenjan *et al*., 2011). It is basically assumed that it would be possible to define the goals at the beginning of a project (Atkinson *et al*., 2006). However, the project complexity and uncertainty turns the upfront planning to a less proper task (Williams, 2005). As a result, recent researches intend to develop new methods for the purpose of coping with complexity and uncertainty and in turn to manage risk and improve the project performance (Blom, 2014). In other words, new approaches to increase ‘flexibility’ in project management are aimed to be developed (Atkinson *et al*., 2006; Koppenjan *et al*., 2011).

Through the explanations put forward up to now, it can be stated that while traditional project management puts the emphasis on rigid planning and control to achieve success in projects, the modern project management considers the flexibility as a requirement for success. However, it should be mentioned that complexity and uncertainty are both included in both of the aforementioned approaches but they differ in dealing with the problem. In more clear terms, in dealing with complexity and uncertainty, while the traditional project management strongly puts emphasis on identifying the relevant risks in advance and controlling them, the modern project management rather gives importance to being flexible in any circumstance (Koppenjan *et al*., 2011). The literature about project management widely emphasizes this conflict. While some researchers point out that projects need rigid planning and control, others consider that projects mainly require flexibility. However, Koppenjan *et al*. (2011) claim that the practitioners are aware of the shortcomings of the two differing approaches and therefore they generally try to combine them. They also point out that project success might not be obtained in case the practitioners do not succeed in meeting the requirements of both of the approaches in terms of control and flexibility (Koppenjan *et al*., 2011). Furthermore, in their study, while the traditional management approach was represented by the “predict-and-control” perspective, which is assumed to be mechanic, the modern management approach was represented by the “prepare-and-commit” perspective, which is assumed to be organic (Koppenjan *et al*., 2011). Cuppen *et al*. (2016) states that since the predict-and-control approach mainly depends on narrow task definition, hierarchical type of steering, inflexibility towards change, and limited, or standardized, information exchange, it is of mechanistic character and on the other hand, since the prepare-and-commit approach encompasses broad task definition to increase cooperation, network type of steering, flexibility towards change as needed, and open, unstructured information exchange, it is of more organic character.

The problem investigated in this research has been constituted within the above context, i.e. without disregarding the methods of traditional project management, searching the ways of flexible project management in complex construction projects from the scheduling perspective. Obviously, today’s applications of project schedule management in practice are dominantly based on control (Shenhar & Dvir, 2007). Only a small part of the projects is compatible with the traditional approach and most of them have become too much uncertain and complex to be managed by an straight forward planning depending on the increased project dynamics, technology and markets (Shenhar & Dvir, 2007). In this regard, complex and dynamic conditions of today’s construction projects require the exploration of the flexible features of the existing scheduling methods and investigation of the means of expanding those managerial flexibilities through a risk-based approach by benefitting from the principles of flexible project management methodologies such as the “Agile Project Management” (Crowder & Friess, 2015; Agile Manifesto, 2020) and from the models developed to tackle with the dynamic structure of complex projects such as the “Detail-Dynamic Project Management Model” of Hertogh and Westerveld (2010).

1.3 AIM & OBJECTIVES

The aim of this research is to propose a hybrid approach (i.e. carrying both flexible and traditional features) that can be used in the management of Critical Path Method (CPM) based schedules under the complex, uncertain and dynamic conditions to which today's complex construction projects are exposed. In this context, the objectives have been determined as;

1. To investigate the managerial flexibilities inherent in the traditional method of construction scheduling, the CPM, and in the processes of traditional project schedule management proposed by the "PMBOK Guide" (Project Management Institute, 2017).
2. To investigate the expansion of managerial flexibilities in CPM scheduling under uncertainty in case the deficiencies of CPM evolving depending on its deterministic features are eliminated up to an extent through the incorporation of the risk simulation capability by the means of the "Correlated Schedule Risk Analysis Model (CSRAM)" (Ökmen & Öztaş, 2008).
3. To investigate the processes of traditional project risk management proposed by the "PMBOK Guide" (Project Management Institute, 2017) from the scheduling and flexibility perspectives.
4. To incorporate the complexity assessment into the project risk management to be implemented on CPM-based schedules through the utilisation of the "Technical, Organisational and External (TOE) Complexity Assessment Framework" (Bosch-Rekveldt *et al.,* 2011), the "Correlated Schedule Risk Analysis Model (CSRAM)" (Ökmen & Öztaş, 2008), and "Detail-Dynamic Project Management Model" (Hertogh & Westerveld, 2010). By this way, to develop a complexity assessment incorporated schedule risk management procedure applicable on CPM-based schedules.
5. To propose a hybrid approach (i.e. carrying both flexible and traditional features) utilisable in the management of CPM-based schedules under complex, uncertain and dynamic conditions based on;
    a. the complexity assessment incorporated schedule risk management procedure developed,
    b. the processes associated with the project schedule management and project risk management knowledge areas of project management proposed in the "PMBOK Guide" (Project Management Institute, 2017),
    c. and the principles of flexible project management methodologies such as "Agile" (Agile Methodology, 2014; Crowder & Friess, 2015; Agile

Manifesto, 2020) and “Lean” (Lean Construction Institute, 2020; Ballard, 2000; Blom, 2014; Jalali-Sohi, 2018, Jalali-Sohi *et al.*, 2019a), and “Dynamic Scheduling Method” (Vanhoucke, 2012).

1.4 SCOPE

The complex construction projects constitute the outer territory of the research topic. Complex projects typically contain so many reciprocal ties in unpredictable and continuously changing economic, political, and social conditions and besides, stakeholders exist in such projects who insist on extraordinary changes and without respect who might even object to the already established agreements, schedules, policies or strategies (Chapman, 2016). In this research, complexity concept was not perceived as a distinguishing feature that could be used to categorise the construction projects as complex or noncomplex. Rather, it is assumed that every construction project may have complexities less or more. Only, the scope and level of responses to manage these complexities would differ depending on the volume of complexities. In this regard, the elements falling into the inner part of this territory, i.e. complex construction projects, and that are within the scope of this research are listed below and illustrated in Figure 1.2:

- Project schedule management
- Project risk management
- Critical Path Method (CPM)
- Technical, Organisational and External (TOE) Complexity Assessment Framework
- Monte Carlo Simulation (MCS) technique
- Correlated Schedule Risk Analysis Model (CSRAM)
- Fit-for-Purpose Project Management Strategy
- Detail-Dynamic Project Management Model
- Dynamic Scheduling Method
- Principles of flexible project management methodologies such as Agile and Lean

As it can be observed on Figure 1.2, other scheduling methods used in construction projects such as the “Linear Scheduling Method” (Harmelink & Rowings, 1998), “Repetitive Scheduling Method” (Harris & Ioannou, 1998), “Line of Balance Method” (Lumsden, 1968), and “Critical Chain Method” (Goldratt, 1997) are out of the scope of this research. In other words, only CPM is taken into consideration. The investigation of these methods have been kept out of the scope and could be recommended as a future work.

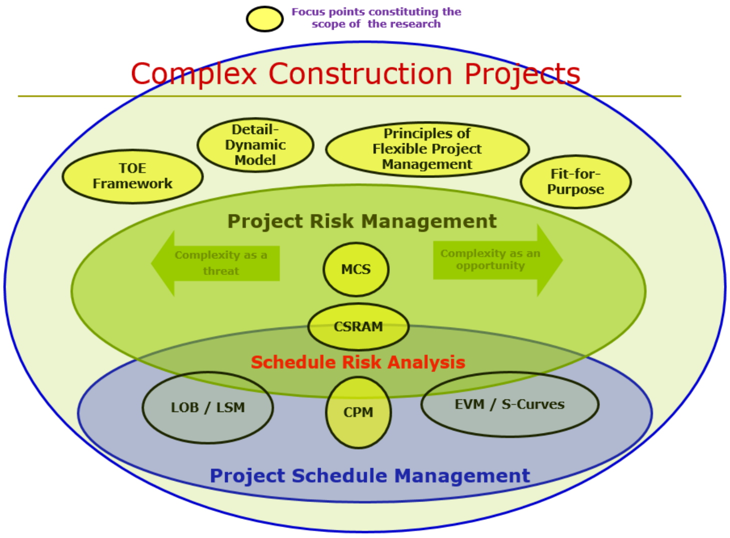

Figure 1.2 Illustration of the scope

In this study, the complexity term was not perceived as the title of a distinctive project category, rather the complexity has been taken into account as a macro-level risk-factor. This macro-level risk factor contains several micro-level risk-factors that may affect the projects in any size in spite of the fact that the complexity is frequently attributed to large-scale infrastructure projects or to so-called major or mega projects (Chapmen (2016), Bosch-Rekveldt *et al.* (2011), Koppenjan (2011), and Hertogh & Westerveld (2010)). However, complexity can also be associated with the small size projects. For instance, Kraus (2012) showed the need for also the small size engineering projects to be managed through a flexible fit-for-purpose management strategy.

Besides the project schedule management, another knowledge field of project management, which is assumed to be in close relation with complexity, i.e. the “Project

Risk Management" (Project Management Institute, 2017), is also taken as the primary concern within this research. The reason of this scope expansion is that in order to establish flexibility in terms of schedule management in the complex construction projects, it is needed to take the influence of uncertainty and risk-factors into consideration because these are the main causes of complexity (Bosch-Rekveldt *et al.*, 2011). It should be mentioned that there are several studies confirming the connections between the project complexity and project risk management. For instance, Ackermann *et al.* (2007) consider the project risks as a network of interrelated possible events based on the thought that a holistic view between the complexity and risk assessment is required in order to provide realistic results. A research by Senescu *et al.* (2013) measured data from 69 test projects that supports the assumption that higher values in risk demonstrate higher complexity intervals. Cristóbal *et al.* (2018) highlight that as today's projects are becoming more complex, a concern evolves with regard to the project complexity as a concept and in terms of the implementation of the traditional tools. The same study further claims the necessity of extending the risk to complexity from the conceptual and practical perspectives (Cristóbal *et al.*, 2018). A study performed by Hartono (2018) also supports the conceptual enhancement of 'complexity' to 'risk'. Vidal *et al.* (2011) demonstrates a way of dealing with risks from a project complexity-based perspective by presenting a framework that connects the uncertainty and complexity to the risk and by this way capturing the indirect effect of the complexity on project risk management.

As illustrated in Figure 1.2 and explained up to now, in this research, the effects of complexity-risk relationship will be investigated from the perspective of CPM scheduling. After incorporating complexity assessment into schedule risk identification and analysis, the managerial flexibilities of CPM scheduling will be explored first in its traditional form, then through CSRAM, which is a schedule risk analysis model based on MCS, and eventually the ways of flexible schedule management in complex construction projects will be queried by using the explored managerial flexibilities and benefitting from the principles of flexible project management methodologies.

1.5 RESEARCH METHODOLOGY

There are two main approaches (methodology or paradigm) that direct the scientific researches. One is “deductive”, the other is “inductive” (Imenda, 2014). While deductive research approach tries to move from the general to the specific dominantly through a quantitative type of research, inductive research approach tries to move from the specific to the general mainly based on qualitative research (Liehr & Smith, 1999; Imenda, 2014). In other words, while the deductive research approach tests the previously developed theories and hypotheses by the conduction of empirical observation, the inductive research approach develops hypotheses and theories by making empirical observations on reality (Lancaster, 2005). However, the usage of these two research approaches may change place during the different stages along a research (Lancaster, 2005). Lancaster (2005) further identified three different types of research methodologies specifically for the field of management that depend on the objective or the major focus of the research. These are the “theory building research”, “theory testing research”, and the “problem centred/practical research” (Lancaster, 2005). While the first two types correspond to inductive and deductive research approaches respectively, the last one is in between deductive and inductive. The third type, i.e. the “problem centred/practical research” does not aim to establish or test the theories differently from the first two types, rather it aims at examining an existing real-life problem about management within the framework of a specific management approach and finally recommending an action plan (Lancaster, 2005, Jalali-Sohi, 2018). Within the context of the aforementioned literature, this research mainly follows the inductive research approach as well as the problem centred/practical research methodology through synthesizing relevant concepts from various sources based on a qualitative research problem.

In this regard, previously developed frameworks, methods or models to be utilized (refer to Figure 1.2), will be synthesized after performing an extensive literature review and exploring the already existing features of CPM scheduling that would lead us to a more flexible project management in accordance with the scope of the research. Since the scheduling subject will be evaluated within the framework of CPM scheduling, the hybrid approach (i.e. carrying both flexible and traditional features) that is aimed to be proposed at the end of the research will be utilizable in the management of CPM-based schedules based on the principles of both traditional and flexible project management methodologies under complex, uncertain and dynamic conditions.

As previously mentioned, this study has been performed in a one year post-doctoral research. Accordingly, it does have some connections with the Researcher's doctoral thesis (Ökmen, 2008) from the point that the CSRAM (Ökmen & Öztaş, 2008), which will be one of the models that will be used in this research, is a product of this thesis. Furthermore, the TOE Complexity Framework (Bosch-Rekveldt *et al.* 2011) and Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010), which will be used in the research, have been developed by the Researcher's co-advisor Dr. Ir. Marian Bosch-Rekveldt in her doctoral thesis (Bosch-Rekveldt, 2011) and by the Researcher's advisor Prof. Dr. Ir. Marcel Hertogh in his doctoral thesis (Hertogh & Westerveld, 2010), respectively.

1.6 OUTLINE OF THE RESEARCH REPORT

In order to achieve the abovementioned aim and objectives of the research, the outline of the research report has been constituted as follows:

- Chapter 1: Introduction
  The topic, problem statement, aim and objectives, scope, methodology of the research and outline of the research report are introduced.
- Chapter 2: Literature Review & Theoretical Background
  Theoretical background on the subjects constituting the scope of the research is presented through a literature review (refer to Figure 1.2).
- Chapter 3: Managerial Flexibilities in CPM and Flexibility in Project Schedule Management Processes
  Managerial flexibilities inherent with the traditional method of construction scheduling, the Critical Path Method (CPM), are evaluated and the project schedule management processes proposed by the PMBOK Guide (Project

Management Institute, 2017) are discussed from the flexibility perspective, respectively.

- Chapter 4: Managerial Flexibilities of CPM under Uncertainty and Project Risk Management Processes
  The expansion in the managerial flexibilities of CPM schedules under uncertainty is evaluated through the utilisation of CSRAM (Ökmen & Öztaş, 2008) and the project risk management processes proposed by the PMBOK Guide (Project Management Institute, 2017) are discussed from both the scheduling and flexibility perspectives, respectively.

- Chapter 5: Incorporation of the Complexity Assessment into the Project Risk Management
  The TOE Complexity Assessment Framework developed by Bosch-Rekveldt et al. (2011) is incorporated into the project risk management to be implemented on CPM schedules through the utilisation of CSRAM developed by Ökmen & Öztaş (2008), Detail-Dynamic Project Management Model developed by Hertogh & Westerveld (2010) and relevant processes of the PMBOK Guide (Project Management Institute, 2017). By this way, a complexity assessment incorporated schedule risk management procedure is proposed.

- Chapter 6: Proposal of a Hybrid Approach for the Flexible Management of CPM Schedules in Complex Construction Projects
  A hybrid approach for the flexible management of CPM schedules in complex construction projects to be utilised under complex, uncertain and dynamic conditions is proposed based on;
    - the complexity assessment incorporated schedule risk management procedure proposed in Chapter 5,
    - the processes associated with the project schedule management and project risk management knowledge areas of project management proposed in the PMBOK Guide (Project Management Institute, 2017),
    - d. and the principles of flexible project management methodologies such as Agile (Agile Methodology, 2014; Crowder & Friess, 2015; Agile Manifesto, 2020) and Lean (Ballard, 2000; Blom, 2014; Jalali-Sohi,

2018, Jalali-Sohi *et al*., 2019a), and Dynamic Scheduling Method (Vanhoucke, 2012).

- Chapter 7: Discussion of the Results and Limitations of the Research
  The results and limitations of the research are discussed in detail.

- Chapter 8: Conclusions & Recommendations for Future Research
  Conclusions drawn up and recommendations for future research are presented.

After Chapter 8, the sources benefitted in the research report are listed under the heading "Bibliography". Throughout the research period, i.e. the period between 17.02.2020 and 15.02.2020, the Researcher has been assigned as a supervisor within the supervising committees of two different Master of Science (M. Sc.) Thesis Projects realised under the Construction Management and Engineering (CME) Master Program of TU Delft. The titles and authors of these theses are as follows:

- "Investigation of relationship and interactions between complexities and risks in complex construction projects for usage during the risk management process" by Lise Andringa
- "Using critical success factors and Q Methodology to discover perspectives on project risk management within a construction organisation" by Theodora Stratton

In Appendix A, the cover pages and executive summaries of the abovementioned M. Sc. Theses are presented. Afterwards, in Appendix B, the academic activities that the Researcher has participated throughout the research period are listed.

2 LITERATURE REVIEW & THEORETICAL BACKGROUND

This chapter introduces the theoretical background associated with the scope of this research through a literature survey. The resources used in the literature survey in this chapter and also throughout the report have been primarily obtained from the TU Delft Library, internet and resource inventory gathered during the Researcher's previous academic studies.

The literature review in this chapter has been carried out under the following headings:

- Complexity assessment in project management
- Project risk management
- Project schedule management
- Flexible project management

This chapter aims to reveal the theoretical background associated with the research topic and also that will help achieve the main goal of the research, i.e. proposing a hybrid approach carrying both traditional and flexible features that can be used in management of the schedules prepared by the Critical Path Method under complex, uncertain and dynamic conditions that today's complex construction projects are exposed to.

2.1 COMPLEXITY ASSESSMENT IN PROJECT MANAGEMENT

Flyvbjerg *et al.* (2003a) states that while globally the number of large-scale infrastructure projects is increasing, the performance recorded in these projects is low. Commonly, these projects end up with budget overrun, schedule delays and/or deficiencies in terms of the scope and quality (Flyvbjerg *et al*., 2003b). For instance, Flyvbjerg *et al.* (2004) analysed 258 transportation projects and detected that nine out of ten among the transportation projects overrun the planned budget and for the case of railway projects, the budget was overrun by 45% on average. As a result, the new researches in the literature focus on the development of methods aiming at lowering the uncertainty, managing the risk and enhancing the project performance (Chapmen, 2016). The UK National Audit Office (NAO, 2013) claims the existence of a direct cause-effect type of relationship between the shortage of understanding of complexity in projects and the low project performance, a situation which is frequently encountered especially in the UK's public projects (NAO, 2013; Chapmen, 2016). The unsuccessful results obtained in projects in terms of time delays and cost overrun is a common practice (Hall, 1981; Thamhain & Wilemon, 1986; Morris & Hough, 1987). Bosch-Rekveldt *et al*. (2011) claims that one of the major reasons of the project failure is the increasing level of project complexity (Williams, 2002; Williams, 2005), or not sufficiently taking into account the project complexity (Neleman, 2006). Furthermore, the complexity level among the construction projects is increasing, a situation that causes great difficulties in the management of these projects as Hertogh & Westerveld (2010) states. In addition, in the extent literature, a common perception prevails in the sense that the level of complexity is rising up in construction projects (Wideman, 1990; Baccarini, 1996; Gidado, 1996; Williams, 1999; Walker, 2002; Loosemore *et al*., 2003; Flanagan & Jewell, 2005; Hillson & Simon, 2007; Vidal & Marle, 2008; Braglia & Frosolini, 2014).

2.1.1 Definition of Complexity

The definition of complexity in Collins English Dictionary (2020) has been made as "the state of having many different parts connected or related to each other in a complicated way" (Collins English Dictionary, 2020) and the definition of "complex" has been stated as "the situation of having many different parts, and is therefore often being difficult to understand" (Collins English Dictionary, 2020). However, no consensus seems to exist on what the definition of complexity should be among the researchers who investigated this subject during their researches such as Baccarini (1996), Parwani (2002), Bosch-Rekveldt *et al.* (2011), Vidal *et al*. (2011), Ochieng *et al*. (2013), and Fitsilis & Damasiotis (2015). For instance, while Baccarini (1996) considers the complexity as the situation of having many and various parts interrelated in between which can be explained based on their differentiation degree and interdependency, Vidal & Marle (2008) make another proposal such that the complexity is a characteristic of a project which converts it to a difficult form to comprehend, predict and control its complete behaviour, even if complete and reasonable information is given about the project (Vidal & Marle, 2008). Besides, the drivers of the project complexity are the factors related to the project's size, variety, interdependence and context (Vidal & Marle, 2008).

On the other hand, it is worth pointing out the difference between the "complicated" and "complexity". A large-scale complicated project might be comprehendible and manageable so that such a project may be considered as highly foreseeable and progresses properly (Chapmen, 2016). In contrast, a complex project contains a continuously changing and also unforeseeable economic, political, and social structure composed of so many reciprocal interrelations, and besides, stakeholders exist in such projects who insist on extraordinary changes and without respect who might even object to the already established agreements, schedules, policies or strategies (Chapmen, 2016). Maylor *et al*. (2008) and Whitty & Maylor (2009) claims that a project can be considered as the complex only in case the uncertainties prevail, otherwise, the project would be categorised as the complicated to a great extent (Maylor *et al*., 2008; Whitty & Maylor, 2009; Bosch-Rekveldt *et al.*, 2011).

Generally, practitioners also may have different perceptions on complexity just like the researchers. People, even working within the same organisation, on the same projects, and with comparable roles, can identify entirely different elements of complexity within the same project. This phenomenon is called as "*perceived complexities*" or "*subjective character of complexity*" (Bosch-Rekveldt *et al.* 2014). Different perceptions on the complexity may affect the project performance negatively in case they are not managed, however they make positive contribution to the project performance if they are managed properly (Bosch-Rekveldt *et al.*, 2014). The management of perceived complexities is called as the "perception-based management" (Bosch-Rekveldt *et al.*, 2014). Bosch-Rekveldt *et al.* (2014) claim that perception-based management should be taken into account as one of the core aspects during the management of project complexity in large-scale construction projects (Bosch-Rekveldt *et al.*, 2014). In accordance with the research findings conducted on 5 different case studies, Bosch-Rekveldt *et al.* (2014) point out three basic features that make contribution to the implementation of perception-based management, which are the maturation the suitable preconditions, the establishment of a shared mental model, and the focussing on learning (Bosch-Rekveldt *et al.,* 2014). The implementation of the perception-based management and establishment of a shared mental model are important to benefit from the differences between the perceived complexities (Bosch-Rekveldt *et al.,* 2014). After the establishment of a shared mental model, it is needed to be owned, activated, and applied by all the relevant staff involved in a project through building the trust between the individuals, which is the key issue for the success of the process (Bosch-Rekveldt *et al.*, 2014).

2.1.2 Project Complexity Models

In the literature, traditionally two different approaches are observed with regard to the project complexity. While the first approach considers the complexity as subjective within the framework of perceived complexity, the second approach sees the complexity as a descriptive characteristic of a system and in turn takes it as measurable (Marle & Vidal, 2016; Obdam, 2016). Furthermore, the literature contains two major schools to deal with project complexity, which are the control approach and the hands-off approach (Bosch-Rekveldt *et al.* 2014). In case of the control approach, projects are conceived as the endeavours which can be predicted, planned and controlled (Bosch-Rekveldt *et al.* 2014). On the contrary, in case of the hands-off approach, it is assumed that it is not possible to forecast the projects in advance and thus it is not possible to keep them under control (Bosch-Rekveldt *et al.* 2014). However, the relevant literature discusses another third approach about whether a combination of the two aforementioned approaches may lead to a more effective approach to cope with the project complexity (Bosch-Rekveldt *et al.* 2014). As previously mentioned in Chapter 1, this research mainly follows the aforementioned combined or hybrid approach. Table 2.1, which was adopted from Bosch-Rekveldt *et al.* (2014), lists and compares the project management approaches proposed in the literature within this context to deal with complexity.

Table 2.1 Categories for different project management approaches to cope with the project complexity (Bosch-Rekveldt *et al*., 2014)

Source	*Control-approach*	*Hands-off-approach*	*Combined-approach*
Baccarini (1996)	Integration	-	-
Williams (1999)	Traditional approach	Soft techniques	-
Austin et al. (2002)	ADePDO	-	-
Hertogh and Westerveld (2010)	Systems management	Interactive management	Dynamic management
Thomas and Mengel (2008)	Traditional approach	Management based on understanding	Combination
Koppenjan et al. (2011)	Predict-and-control	Prepare-and-commit	Combination
Leijten (2012)	-	Centralise risks in decision making	-
Favari (2012)	Plan and control	PM-2	-
Bértholo (2013)	-	The shadow of projects	-
Best et al. (2013)	Controlling	Connecting	Actuating
Davies and Mackenzie (2013)	Integration	Flexibility	Disciplined flexibility
Locatelli et al. (2013)	Systems engineering	-	-

Hertogh & Westerveld (2010) developed a framework for the practitioners containing five complexity elements, i.e. technical, social, organisational, legal and time complexity. The first three elements, i.e. the technical, social and organisational, are based on the research of Baccarini (1996). In the study of Hertogh & Westerveld (2010), it was shown that complexity exists in all phases of the projects. While traditionally complexity level is high during the early project phases, the complexity seems not disappearing over time (Hertogh & Westerveld, 2010). Bosch-Rekveldt (2011) developed a framework, named as TOE Framework (Bosch-Rekveldt *et al.* 2014), to be used in the project complexity assessment, which include 47 complexity elements under 3 categories, i.e. technical, organisational and external. The utilisation of the TOE Framework provides the complexity footprint of the projects specifically in the infrastructure sector (Bosch-Rekveldt *et al.* 2014). As abovementioned, Bosch-Rekveldt *et al.* (2011) consider the project complexity as a subjective, dynamic and uncertain matter in line with the perceived complexity concept.

Obdam (2016) investigated the project complexity assessment models in the literature and made a three headed categorisation with taking into account 27 detected models such that the conceptual models or frameworks depending on the literature to a great extent and not put into practice, the practice-based models based on the sectoral experiences, and the science-based models again depending on the literature, but validated up to a certain extent (Obdam, 2016).

In this research, as previously stated in Chapter 1, the TOE (Technical, Organisational and External) Project Complexity Assessment Framework (Bosch-Rekveldt *et al.* 2014) developed by Bosch-Rekveldt (2011) is utilised. Table 2.2 shows the complexity elements identified by the TOE Framework under three main categories. Detailed explanation on TOE Framework will be presented in Chapter 5.

Table 2.2 Complexity elements in the TOE Project Complexity Assessment Framework (Bosch-Rekveldt, 2011)

Technical Complexity (17 elements)	Organizational Complexity (17 elements)	External Complexity (13 elements)
High number of project goals	High project schedule drive	Level of competition
Non–alignment of project goals	Lack of Resource & Skills availability	Instability of project environment
Unclarity of project goals	Lack of Experience with parties involved	Company internal strategic pressure
Uncertainties in scope	Lack of HSSE awareness	Lack of experience in the country
Strict quality requirements	Interfaces between different disciplines	Remoteness of location
Project duration	Number of financial sources	Interference with existing site
Size in CAPEX	Number of contracts	Required local content
Number of locations	Type of contract	Lack of company internal support
Newness of technology (world–wide)	Number of different nationalities	Political influence
Lack of experience with technology	Number of different languages	Dependencies on external stakeholders
High number of tasks	Presence of JV partner	Variety of external stakeholders' perspectives
High variety of tasks	Involvement of different time zones	Number of external stakeholders
Dependencies between tasks	Size of project team	External risks
Uncertainty in methods	Incompatibility between different pm methods / tools	
Involvement of different technical disciplines	Lack of trust in project team	
Conflicting norms and standards	Lack of trust in contractor	
Technical risks	Organizational risks	

2.2 PROJECT RISK MANAGEMENT

The projects are open to the impact of various uncertainties and risk factors. These may not only affect the timely completion of the projects within the budget, but also influence the projects in some other aspects like the safety and the quality. In this regard, project risk management becomes the standard methodology of systematically identifying, classifying, and analysing the project risks to eventually identify the risk mitigation strategies to deal with risks and ensure the achievement of the desired project objectives to a certain extent (Öztaş & Ökmen, 2004). In the construction sector, each project possesses unique features. No construction project is absolutely the same with another. Even though the projects can be categorised around similar characteristics, each project should be evaluated, planned and executed in a different way in compliance with its own conditions. Depending on this, risk management in construction projects turn into a challenging task in which the risks have to be tackled compatible with the uniqueness property of construction projects. This property necessitates the utilization of systematic management procedures such as the project risk management in order to achieve the primary project objectives as listed below (Halphin & Woodhead, 1998; Atkinson, 1999; Toor & Ogunlana, 2010; Oberlender, 2014):

- Completing the projects within schedule.
- Completing the projects within cost.
- Completing the projects within scope.
- Completing the projects within quality, safety and environmental requirements along with ensuring stakeholder satisfaction.

The ‘risk’ term has been discussed conceptually and practically utilised since 1940’s especially in the insurance sector (Kangari, 1995; Elmas, 1996). By the beginning of 1980’s, the ‘risk’ terminology has also entered into the construction sector. A great volume of scientific research has been carried out on construction risk management and analysis since 1990’s. Furthermore, during the period between 1991 and 1997, the number of survey-based researches aiming at searching the perceptions of the practitioners towards the risk concept and the risk management practices among the clients, consultants and contractors in the construction sector (Edwards & Bowen, 1998). This need has evolved due to the inherent risky structure and conditions of construction projects, not less but more than other business sectors. Inevitably, the need for the implementation of the risk analysis and management has increased over time because of the increasing complexity, size, competition, client and end-user requirements, politic and economic problems, difficult physical conditions and etc. Therefore, by time, risk management has become an essential key factor in completing the projects successfully. Currently, a common opinion prevails on that the project risks can only be mitigated through the utilisation of the project risk management processes throughout the whole project (Ökmen, 2008).

PMBOK Guide (A Guide to the Project Management Body of Knowledge) developed as a general project management framework by the Project Management Institute (PMI) located in the USA proposes 49 processes under 5 different process groups in relation with the 10 knowledge areas to achieve success in project management (Project Management Institute, 2017). The process groups and knowledge areas in question are as follows (Project Management Institute, 2017):

"*Process Groups*

- Initiation
- Planning
- Execution
- Monitoring & Control
- Closure" (Project Management Institute, 2017, pp. 23)

"*Knowledge Areas*

- Project Integration Management
- Project Scope Management
- Project Schedule Management
- Project Cost Management
- Project Quality Management
- Project Resource Management
- Project Communications Management
- Project Risk Management
- Project Procurement Management
- Project Stakeholder Management" (Project Management Institute, 2017, pp. 23-24)

The Project Management Institute additionally proposed two other knowledge areas specifically for the construction projects in its another guide called the "Construction Extension to the PMBOK Guide" besides the knowledge areas listed above: "Project

Health, Safety, Security, and Environmental Management" and "Project Financial Management" (Project Management Institute, 2016). The above list discloses the importance of project risk management and project schedule management, which are also the focus points of this research (refer to Figure 1.2). Then what is risk, what is uncertainty and how can we define risk specifically for projects? The following section clarifies this issue.

2.2.1 Definition of Risk and Uncertainty

In the literature, some of the resources propose the meaning of the word "risk" from the managerial point of view as follows:

- Risk is the occurrence probability of an outcome, which is undesirable (Evans & Olson, 1998).
- Risk is a possibility of a deviation from an outcome, which is expected (Vaughan, 1997).
- A project risk is an uncertainty which might influence the implementation of the project in the negative direction as a threat or in the positive direction as an opportunity (Ökmen, 2008).

All of these definitions share two common aspects, i.e. indeterminacy and loss (Vaughan, 1997). In other words, the existence of risk is associated with firstly the existence of two possible outcomes at least and secondly, at least one of these outcomes is undesired (Vaughan, 1997). In case it is definitely known that a loss would occur, the risk cannot be the issue (Vaughan, 1997). The fuzzy environment in construction projects is also qualified by the adjectives "risky" or "uncertain". However, some researchers claim that these terms have different meanings (Flanagan & Norman, 1993; Vaughan, 1997; Evans & Olson, 1998). Uncertainty generally occurs as a result of risk. For example, the completion time of a construction project is uncertain. However, the reasons leading to this uncertainty are the risks that affect the project aspects. On the other hand, risk can also be considered as a result of uncertainty in any factor that impact the project such as the weather conditions. The final effect may be a positive or negative variation in the impacted project aspect such as the activity duration. For instance, the uncertainty in weather conditions will create the risk of variation in activity durations either in positive or negative direction. In other words, the actual activity durations may finally evolve as more or less than the expected durations (Ökmen, 2008). Instead of sticking into different definition nuances as such, this research focuses on the effect of risks and uncertainties on construction projects, specifically on projects schedules, and on the relation between complexity and risk.

Different types of risk lists are available in the literature because of the different procedures followed in risk classification such as the risk list proposed in the Construction Extension to the PMBOK® Guide (Project Management Institute, 2016). However, the content of these lists are almost the same and all of them may be complementary in setting up a risk management system. Furthermore, they indicate the same point when the consequences of the construction risks are concerned (Ökmen, 2008). The following section introduces a brief literature investigation on the general procedure of risk management.

2.2.2 General Procedure of Risk Management

Risk management mainly contains the risk identification, risk analysis, and risk response tasks and is defined as a procedure of systematically controlling the identified risks in a project or an investment (Dikmen *et al.*, 2004). It can be applied to the whole project life cycle and like every systematic procedure, it has a stepwise structure consisting of risk management planning, risk identification and classification, risk analysis, risk mitigation (response) planning, monitoring & control, and feedback & updating tasks (Flanagan and Norman, 1993; Edwards, 1995; Chapman & Ward, 2006; Project Management Institute, 2000). The flowchart of a general application of risk management is given in Figure 2.1 (Flanagan and Norman, 1993; Project Management Institute, 2000; Ökmen, 2008). While the risk identification and classification is associated with the detection of the risks, the risk analysis is about qualitatively and/or quantitatively analysing the risks. At the risk response step, the results of the previous steps are evaluated and suitable risk response actions are determined before the occurrence of the risks (Ökmen, 2008). The implementation of project risk management brings a number of organisationals advantages in construction projects and therefore it is essential handle the risk management as an integral component of an organization's management practice in the construction sector (Zou *et al.*, 2010). In the following sub-sections, risk identification, risk analysis and risk response steps constituting the general procedure of risk management are briefly introduced.

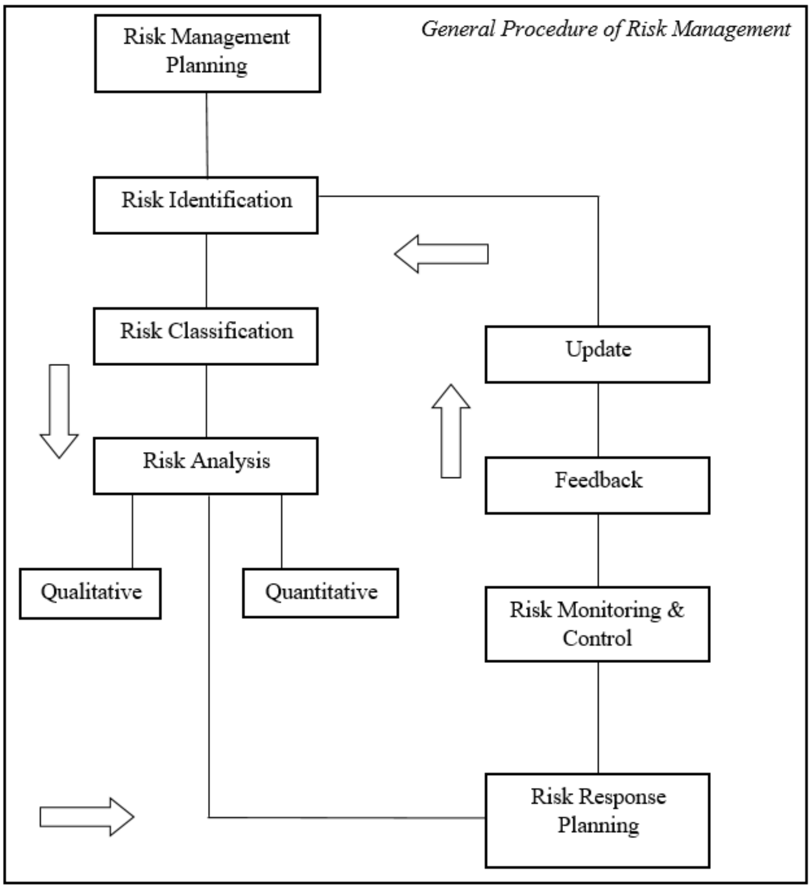

Figure 2.1 Flowchart of a general application of risk management (Flanagan and Norman, 1993; Project Management Institute, 2000; Ökmen, 2008).

<u>Risk Identification</u>

Risk identification can be considered as the initial step in a risk management process if the preceding preparatory tasks such as risk management planning, allocation of responsibilities and staffing are not taken into account. It can be considered together with risk classification task although some researchers like Flanagan and Norman (1993) approaches the risk classification as a separate step. Risk identification is an important step in the sense that capturing all the risks possibly affecting the projects is required in order not to skip any in the risk analysis and while deciding on the risk mitigating actions. Main risk identification methods are listed below (Flanagan & Norman, 1993; Edwards, 1995; Vaughan, 1997; Project Management Institute, 2000; Hillson, 2002; Chapman & Ward, 2006; Hallowell & Gambatese, 2010):

- Risk identification questionnaires: These are the tools developed to discover the risks by the means of a series of questions prepared in detail.
- Exposure checklists: These are the lists containing the common risks encountered. It can be used effectively in combination with the other risk identification tools as a final check to lower the probability of skipping an important risk.
- Insurance policy checklists: These can be provided from the insurance companies. Such lists include a catalogue of insurance types. Risk managers consult such a list in order to pick out the policies applicable to the company or the business.
- Expert systems: The expert systems incorporate different functions of the risk identification questionnaires, exposure checklists, and insurance policy checklists with a single risk identification software based on expert knowledge. Expert systems help the user identify the risks specific to a project through a series of knowledge-based questions.
- Risk mapping (Probability x Impact Scoring): They are the two-dimensional scaled graphs prepared for identifying the occurrence probability of a risk and its potential impact. The potential impact and probability of a risk help the practitioner decide whether it is an important risk or not. In practice, risk mapping is also used as a qualitative risk analysis method. The predicted probability of occurrence of a risk and its potential impact are multiplied and the calculated score is used to find the influence degree of the risk in question (high, medium or low) through a predetermined risk scoring model.
- Brainstorming: Brainstorming is simply discussing a problem within a group in order to produce a solution. It can be useful during both the risk identification and qualitative risk analysis tasks.
- Cause and Effect Diagramming: This is a diagramming technique utilized to establish the links between the effects and causes associated with the identified risks in a visualized manner.

- Interviews: Interviews made with key personnel within an organization generally provide important information that can be useful during the risk identification.
- Risk category summary sheet: This is prepared after identifying the risks with the attendance of all the team staff.
- Risk Breakdown Structure (RBS): It is similar to the Work Breakdown Structure (WBS) and decomposes the potential sources of the risks hierarchically into layers of increasing level of detail. The RBS might be an effective risk identification, risk assessment and risk reporting tool, and provide new considerations about the risk exposure on a project (Project Management Institute, 2000; Project Management Institute, 2001).
- Delphi Method: It is a systematic and interactive technique used for gathering the judgmental views of a group of experts for the purpose of converging to a consensus to identify the risks. The experts are selected according to some predetermined criteria and are requested to attend two or more structured survey rounds for ensuring the convergence of opinions.

Nevertheless, the most widely used techniques are the risk checklists compiled from the previous data and based on experience, interviewing with senior project personnel, brainstorming with the project team, and risk mapping (Thompson & Perry, 1992).

Risk Analysis

The next step after risk identification is the risk analysis in a risk management process. Risk analysis is carried out by at least one of quantitative, qualitative or mixed (semi-qualitative) techniques. While pure qualitative techniques utilizes qualitative data gathered through questionnaires, brainstorming, interviews, and etc., pure quantitative techniques utilizes quantitative data generally gathered through recordings of previous works. On the contrary, semi-qualitative techniques generally utilizes the quantitative data converted from qualitative data. However, most of the quantitative tools and techniques used in the risk analysis also contain subjectivity to some extent. Probability and statistics, fuzzy set theory, simulation, and spreadsheet modeling are among the frequently used methods and techniques in risk analysis. The importance of risk analysis lays in the fact that it shows what happens in case the project does not progress in line with the project plan because of the identified risks and it warns the user about the responses needed to mitigate with risks (Flanagan & Norman, 1993).

Some of the widely used risk analysis techniques are enumerated below (Flanagan & Norman, 1993; Edwards, 1995; Vaughan, 1997; Project Management Institute, 2000; Chapman & Ward, 2006):

- Sensitivity analysis
- Monte Carlo Simulation (MCS)
- Decision-tree analysis (stochastic or deterministic)
- Fuzzy-set theory
- Utility Theory
- Probability theory
- Scenario analysis

The quantitative risk analysis techniques are classified as deterministic and stochastic (probabilistic) techniques. The stochastic methods such as MCS and stochastic decision tree analysis produce probabilistic solutions instead of assuming complete certainty for decision variables as in the case of deterministic analysis techniques. Deterministic techniques such as deterministic decision tree analysis produce fixed single-value results. In contrast, the variables in a stochastic risk analysis model can be represented by probabilistic terms or distributions so that the uncertainty surrounding the project is assessed. For these reasons, stochastic risk models and analysis techniques are becoming more popular among project managers and decision-makers (Ökmen, 2008).

Risk Response

Risk response is a stage of the project risk management during which the risk analysis results are evaluated and in turn, the strategies to mitigate with risks are determined. The risk response strategies can be categorized in four groups (Thompson & Perry, 1992; Flanagan & Norman, 1993; Edwards, 1995; Vaughan, 1997; Chapman & Ward, 2006):

- Risk retention (absorption)

Risk retention or risk absorption is the action of risk acceptance. The party who is aware of the risks and desires to take the responsibility usually applies risk retention. This procedure will eventually load residual risks over the risk retaining party whether it is capable of controlling them or not.

- Risk reduction (prevention – mitigation)

  Risk reduction (prevention-mitigation) is another way of risk acceptance. It can be achieved by reducing the intensity of risk if it occurs (mitigation) or reducing the probability of risk (prevention) in advance of its occurrence.

- Risk transfer

  Risk transfer is the action of transferring the responsibility of risks to another party using a contract, insurance, an indemnity, a bond or a surety. It is a widely utilized risk response strategy but important point to be cared about is that the party to whom the risks are transferred must be capable of controlling and affording the risks. Otherwise, the whole project may be affected negatively.

- Risk avoidance

  Risk avoidance is the risk refusing action unlike the risk retention or risk reduction. The best examples are the refusal of the whole project or avoiding only its risky parts.

2.3 PROJECT SCHEDULE MANAGEMENT

As it was stated in the previous section, PMBOK® Guide considers the project schedule management as one of the ten knowledge areas of project management (Project Management Institute, 2017). It defines the project schedule management as a series of processes needed to implemented for the completion of projects in time. These processes are introduced as the “activity definition, activity sequencing, activity duration estimating, schedule development, and schedule control” (Project Management Institute, 2017, pp. 173).

These processes are connected with each other and with the other processes of the other knowledge areas. Furthermore, each process generally occurs at least once in each of the project management process groups, i.e. "initiating, planning, executing, controlling, and closing" (Project Management Institute, 2017, pp. 23). In this research, the emphasis is put on the interaction of project schedule management with the project risk management to explore the means of providing flexibility in construction project management from the scheduling perspective under complexity and uncertainty. Furthermore, as discussed in Chapter 1, the topic will be investigated based on the CPM scheduling. Depending on this, the following sections first introduces brief information about the main features of CPM and then, the schedule control methods mainly based on CPM, i.e. the S-Curve Analysis and Earned Value Management (EVM), are briefly explained respectively.

2.3.1 Critical Path Method (CPM) Scheduling

Planning, scheduling and controlling are the three interrelated tasks that should be appropriately fulfilled for a successful project management. Although, PMBOK Guide considers the planning as one of the five main process groups of projects management, and appreciates the scheduling and controlling under the project schedule management, which is one of the knowledge areas of project management (Project Management Institute, 2017, pp. 23-24), these three tasks are systematically influence and continuously update each other throughout a project life cycle. While the planning is mainly associated with 'What to do?' and 'How to do?', scheduling is rather associated with 'When to do?' and 'Who will do?'. Similarly, controlling can be considered as related to 'Is the completed compatible with the planned and scheduled?'

Alternatively, a schedule can be perceived as the matured form of a project plan from the front-end engineering and design (FEED) phase (i.e. initiation or feasibility phase) towards the execution phase. In this regard, scheduling is being used as a term covering also the control activities and a schedule is being perceived as a maturated form of a project plan throughout this report.

CPM was developed in 1957-58 in the USA by the E. I. Du Pont Nemours Co. to schedule a large-scale project (Olson, 1969). However, the US Navy about the same time developed a similar method which was a probabilistic one different from the CPM called the Program Evaluation and Review Technique (PERT) (Olson, 1969). Since then, CPM has achieved wider acceptance and popularity with respect to PERT because of its advantages, simplicity and low cost of application (Olson, 1969). In some aspects, CPM can be considered as one of the greatest advancements during the evolvement of modern management era at 1960s, especially in the construction sector although it found application areas also in the other project-driven sectors (Olson, 1969). Prior to CPM, the sector was completely dependent on bar (Gantt) chart scheduling which has several insufficiencies with respect to CPM, although it is still used in simple projects or to provide the illustration of the complicated parts of CPM schedules at the worker level due to its simplicity and comprehensibility. CPM stands as a revolutionary step in project management when compared to bar chart scheduling. CPM enables scheduling the activity networks through specific algorithms called forward and backward pass calculations that require the activity durations and network dependencies entered as an input. When compared with the bar chart scheduling, CPM can be considered as a superior method as it reveals including, but not limited to, the critical activities, activity float times and the shortest possible project completion time with taking the assigned network interdependencies into account (Ammar, 2013). Furthermore, it is possible to modify and regulate the schedules established with CPM through resource levelling, fast tracking and schedule crashing (Project Management Institute, 2017; Oberlender, 2014; O'Brien & Plotnick, 2015). Besides, CPM enables the utilization of project control methods such as the EVM and S-Curve Analysis. Updating the schedules and revising the estimations on project completion by the actual data gathered from construction site is easier with CPM. An example CPM schedule shown on an activity-on-node network diagram is given in Figure 2.2.

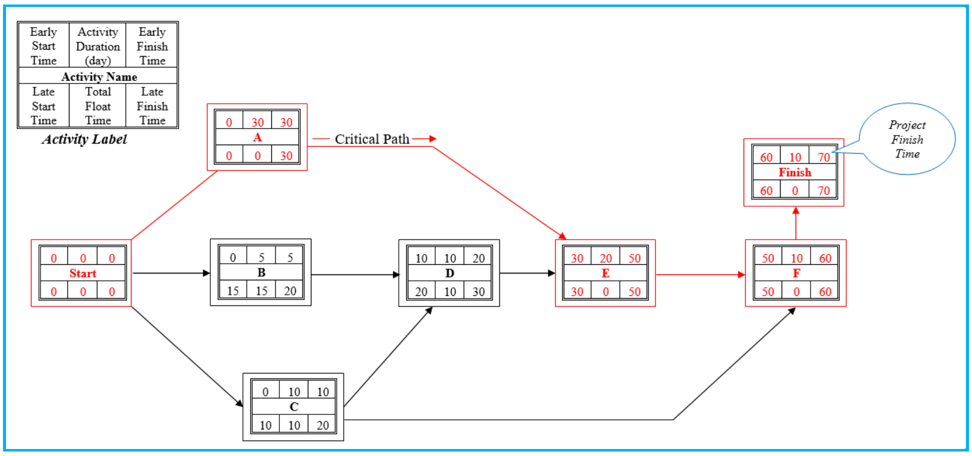

Figure 2.2 An example CPM schedule in the form of an activity-on-node network diagram

The success and popularity of this relatively traditional activity network scheduling method is probably related to the information it provides to its users, like project managers, owners, contractors, engineers, foremen, workers or even lawyers. The information that CPM provides includes, but are not limited to (Newitt, 2009; Oberlender, 2014);

- *Shortest possible project completion time*

  CPM calculates the shortest possible project completion time based on determined activities, estimated activity durations and assigned inter-activity relationships. This data is entered as input into its algorithm at the front-end of a project and CPM applies the so-called forward/backward pass calculations to find out the shortest possible project completion time.

- *Critical path(s), critical activities*

  CPM explores the critical path(s) and the critical activities lying on these paths. Critical activities are those having no float times, which can be used in case of delay during the execution of these activities. In other words, critical activities are those activities in a network having no flexibility in terms of execution dates envisaged for them. In accordance with this, critical activities possess zero tolerance towards time extension because any delay that will occur on these activities would directly lead to delay on the shortest possible project completion time calculated by CPM.

- *Noncritical path(s), noncritical activities*

CPM explores the noncritical path(s) and the noncritical activities lying on these paths. The noncritical activities do have float times in varying amounts different from the critical activities. In other words, noncritical activities have some flexibility and tolerance against delays up to a certain extent because in case a delay occurs during the execution of these activities, it would be absorbed in amounts proportional to their float times until they turn to critical. By this way, the shortest possible project completion time is not be affected.

- *Activity float times*

CPM reveals the activity float times in different types such as *total*, *free*, *shared*, *independent*, and even *negative*. Float times, which only noncritical activities possess, can be consumed during the project execution for the purpose of levelling the resources, switching the resources from the noncritical activities to critical activities whenever required by affording some absorbable delay in noncritical activities, and ensuring the timely completion of the project without any delay.

- *Relationships between the activities*

CPM discloses the relationships between the activities in terms of finish-to-start, start-to-start, finish-to-finish and start-to-finish, and also allows the allocation of lag or lead times between the activities.

- *Early/late start/finish times of activities*

CPM calculates the early start and early finish times of the activities together with the late start and late finish times. These are the specific points on the schedule that determines when an activity could be performed earliest or latest without affecting the project completion time.

PMBOK Guide describes the CPM as follows (Project Management Institute, 2000, pp. 200):

"*CPM is a network analysis technique used to predict project duration by analysing which sequence of activities (which path) has the least amount of scheduling flexibility (the least amount of float). Early dates are calculated by means of a forward pass, using a specified start date. Late dates are calculated by means of a backward pass, starting* *from a specified completion date (usually the forward pass' calculated project early finish date). CPM calculates a single, deterministic early and late start and finish date for each activity based on specified, sequential network logic and a single duration estimate* (Project Management Institute, 2000, pp. 200)*"*

The above definition gives the clues of the fact that CPM, although it represents a revolution in project management by the beginning of the 1960s and still is being used at a world-wide scale, has also some limitations. The following are of these limitations which frequently have received criticism in the literature so far (Jaafari, 1984; Ökmen & Öztaş, 2008; Ammar, 2013; Koskela *et al*. 2014; Zhou *et al*., 2013):

- *CPM is deterministic.*

  The real conditions in projects are stochastic, not deterministic. CPM requires deterministic input data and in turn, provides solely deterministic results such as fixed project completion time, unchanging critical paths, constant float times, and etc. Unfortunately, the things are not idealized as such for the reason all these values almost always tend to vary throughout a project. CPM cannot reflect the variable nature of projects, which is the result of various risk factors and uncertainties. In short, CPM does not take into account the variations in activity durations caused by risk factors. Depending on this, the project completion time predicted by CPM at the front-end generally follows a different course throughout the execution. In order to pull the project on alignment in such cases, playing with resources may be required in expense of cost overruns.

- *CPM ignores the correlations that might exist between activities and between risk-factors, which cause greater uncertainty on activity durations and in turn on project duration.*

  The correlation effect may lead to amplification and propagation of the uncertainty effect along the activity paths and increase the uncertainty on the project completion time in an accelerated fashion. Therefore, possible correlations between specific activities caused by the same risk-factors affecting those activities and possible correlations between the risk-factors should not be ignored during scheduling. Otherwise, the results provided by CPM would be misleading.

- *CPM assumes unlimited availability of resources.*

  Resources are almost not unlimited in any case for any type of project. CPM mainly focuses on time and the precedence relationships between activities but ignores the limitations on resources. It disregards the resource continuity constraints needed to avoid idle times and maximum allowable resource constraints executed to avoid resource over usages.

- *CPM has limited flexible features, therefore it is not adaptable enough to changing conditions and it is unable to reflect the ever changing dynamic nature of projects.*

  CPM allows for the schedule update with real data coming from site during execution but it is not capable of showing the probabilistic nature of projects in advance.

- *CPM has limited capability in scheduling linear or repetitive type of projects.*

  CPM is more suitable for projects that can be scheduled in activity networks. In case of linear projects such as highway, pipeline or high-rise building constructions, CPM becomes insufficient to schedule all the project parts due to the resource continuity needed to be established in such type of projects. Alternatively, CPM is preferred to be used in combination with linear scheduling methods in these projects.

Literature also contains studies proposing the ways of overcoming the CPM's aforementioned shortcomings. These studies mostly focus on the application of probabilistic methods, risk analysis procedures and optimisation methods on traditional CPM (Pohl & Chapman, 1987; Ökmen & Öztaş, 2008; Khamooshi & Cioffi, 2013; Zhou *et al*., 2013) . Besides, the literature includes studies that propose the integration of CPM with the linear scheduling methods (Ammar, 2013; Ökmen, 2013a). None of these studies disregards CPM, but it is tried to extend and improve the CPM in compliance with the uncertain, complex and dynamic conditions of the construction projects. The reader is referred to Newitt (2009), O'Brien & Plotnick (2015), and Oberlender (2014) for detailed explanations on the algorithm (forward-backward pass calculations) and diagramming methods (activity-on-node vs. activity-on-arrow) of CPM.

Finally, the primary project information that is provided through CPM can be summarized as the activity criticalities (critical or non-critical activities), path criticalities (critical or non-critical paths), float types (total, free, shared or independent floats), float times (generally calculated in *days*), and the possible shortest time to complete a project. These are explored through the forward and backward calculations of CPM based on the dependency relationships allocated to the project activities constituted in the form of a network. The relationship types assigned between the activities might be one of the finish-to-start (FS), start-to-start (SS), finish-to-finish (FF) and start-to-finish (SF) (Newitt, 2009; O'Brien & Plotnick, 2015; Oberlender, 2014). The critical path(s) found out through CPM are the longest activity chains. At the same time, they disclose the shortest time needed to complete a project. The activities on the critical path(s) constitute the critical activities. Critical activities do not have any float time or in other words, the float amount is zero for these activities. Therefore, they cause delay in project completion if extended. In contrast, non-critical activities have float values greater than zero and therefore have some flexibility of extension proportional to the float time and type they possess without causing a delay in project completion or giving disturbance to the succeeding activities coming after them. Another important feature of CPM is that updating the baseline plan depending on the recorded schedule performance and revising the time and cost forecasts envisaged for the end of the project turn into easy tasks as far as the CPM is implemented through a project planning software. Furthermore, it is possible with CPM to distribute the resources in an optimum way through resource levelling by using the float times of non-critical activities and to shorten the project through project compression or schedule crashing at the expense of cost increase (Newitt, 2009; Oberlender, 2014).

2.3.2 S-Curve Analysis

S-Curve (Progress Curve) Analysis is a graphical method used for progress control in project schedule management. S-Curve Analysis is frequently used in conjunction with EVM, and the results produced by EVM can be converted to graphs via cumulative S-Curves (Project Management Institute, 2000). The S-Curve Analysis displays the achieved progress at any specific time of a project through graphs called S-Curves.

These graphs represent cumulative data as such the horizontal axis represents the time and the vertical axis shows the cost, man-hour, or the percentage of completed work. Since it is a graphical method, it might be more difficult to use compared to EVM for the reason EVM offers analytical solutions. A common aspect of S-Curve Analysis with EVM is that both of the methods needs schedules prepared with CPM for correct and proper applications of them. In practice, first, early start and early finish times of activities and late start and late finish times are explored by CPM calculations and then planned S curves are drawn up by using these data. Another alternative approach is to determine the baseline S-Curve at the beginning of the work, and then draw the actual S-Curve that is realized at any point in the project through actual values obtained after setting up the target S-Curves. It is concluded that the project progresses in accordance with the schedule, as long as the actual S-Curve remains between the planned early and late S-Curves, or as long as the actual S-Curve is in line with the target S-Curve. Likewise, in case the actual curve deviates out of the early and late curves in negative direction or fall behind the target curve, it can be concluded that the project does not progress in line with the schedule (Del Pico, 2013). The illustration of a simplified S-Curve Analysis is given in Figure 2.3.

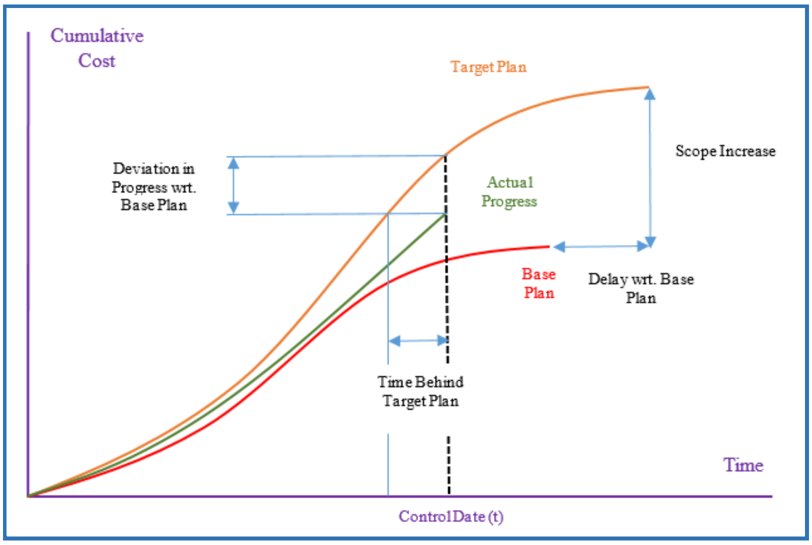

Figure 2.3 General illustration of S-Curve Analysis

2.3.3 Earned Value Management

Since its first introduction in the USA in mid-1960s, researchers have performed various studies on Earned Value Management (EVM). EVM is utilized to measure the project performance in terms of cost and time with respect to the baseline plan and to predict the time and cost to complete the project as of a specific date during the project execution (Fleming, 1998; Fleming & Koppelman, 2005). EVM, which is a project control tool, requires the utilization of comprehensive schedules prepared with scheduling methods such as the CPM to enable measuring the cost and time performances in an easy and correct way at any moment during the project execution (Czemplic, 2014). In this manner, the time and cost predictions envisaged by EVM regarding the end of the project based on the past performance would be more realistic. Therefore, there is a strong relationship and dependency between CPM and EVM in practice. However, this dependency is not two sided. Only that the properly application of EVM depends on well-prepared and professionally executed CPM schedules. However, CPM does not generally require a method like EVM unless it is required to provide measures showing the past performance through simplified metrics (e.g. variances and performance indexes based on cost and time) which are easily understandable and to revise the time and cost forecasts envisaged for the end of the project in a practical way without needing to analyze the remaining activities.

It is possible to measure the physical and monetary progresses through the EVM metrics. Nevertheless, the important feature common with all of these EVM calculations is that the performed work and the actual costs expended must be tracked and recorded correctly during the implementation of projects in order to enable EVM produce accurate results. This is of course possible with the usage of schedules prepared carefully and loaded with necessary resources such as “cost”.

The logic behind the EVM calculations is illustrated in Figure 2.4 through S-Curves drawn on graphs showing the time on the x-axis and the cumulative cost on the y-axis. The graphical representation of EVM through S-Curves along with the arithmetic calculations conducted through formulae simplifies the comprehension of the evaluation process.

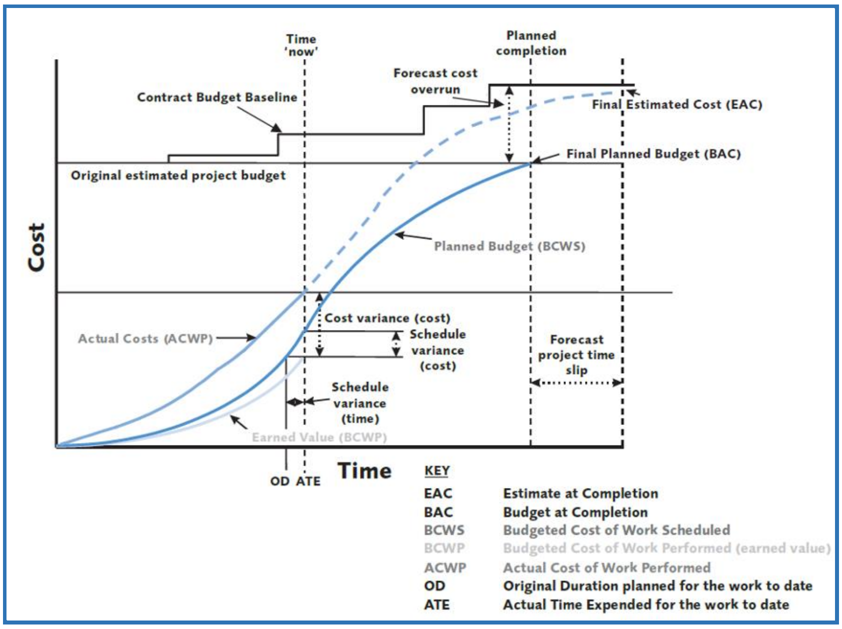

Figure 2.4 EVM Graph (APM Guidelines, 2008)

In spite of its wide acceptance as a project control tool in project management, EVM also has been criticized due to its deficiencies. In order to eliminate these deficiencies, some extensions or modified versions of it have been developed such as the Earned Schedule Method (Lipke, 2003), Earned Duration Method (Jacob, 2003), and Planned Value Method (Anbari, 2003). Furthermore, some researchers have tried to improve EVM to enable its usage also under uncertainty through a stochastic manner by taking the project risks into account instead of following a traditional deterministic approach (Babar *et al*. 2017; Bonato *et al*. 2019).

2.4 FLEXIBLE PROJECT MANAGEMENT

Projects arise out of unmet needs. “A project is a sequence of unique, complex, and connected activities that have one goal or purpose and that must be completed by a specific time, within budget, within scope” (Wysocki, 2013, pp.4) and according to a number of specifications associated with such as quality, safety, environment, and etc. This is the standard definition of ‘project’ according to Wysocki (2013). However, Wysocki (2013) claims insufficiency in this definition and proposes a “better business-focused” definition as such: “A project is a sequence of finite dependent activities whose successful completion results in the delivery of the expected business value that validated doing the project” (Wysocki, 2013, pp.7). In this definition, the key concept is the “value”. Projects are undertaken mainly to create some expected values for the involved parties or stakeholders such as the society (end-users), owners (clients) and contractors.

Project Management Institute (2013) defines the project management as “the application of knowledge, skills, tools and techniques to project activities to meet the project requirements” (Project Management Institute, 2000, pp. 205). Wysocki (2013) criticizes this traditional definition from some aspects and by putting emphasis on the created value once more as in the case of the definition of “project”, he brings a different definition to project management; “Project management is an organized common-sense approach that utilizes the appropriate client involvement in order to meet sponsor needs and deliver expected incremental business value” (Wysocki, 2013, pp.29).

Project management methodologies are categorised under two main groups nowadays: Traditional (also called Waterfall, Linear, Plan-Driven or Conventional) and Flexible (also called Agile, Change-Driven, Adaptive or Modern) (Wysocki, 2013; Jalali & Wohlin, 2012; Moe *et al.*, 2010; Van-Kralingen, 2017). The traditional project management was initiated in the defence and aerospace industry in the 1950’s, during which limited knowledge existed about flexibility and project complexity (Jalali-Sohi *et al.*, 2016). The traditional project management approach contains several different plan-driven methods including the well-known waterfall method (Van-Kralingen, 2017). In waterfall approach, a number of well-defined subsequent steps are applied from project initiation to execution and to the project completion (Buresh, 2008). In traditional project management, the tasks are completed subsequently in a predefined order (Moe *et al.*, 2010) as shown in Figure 2.5 (Wysocki, 2013).

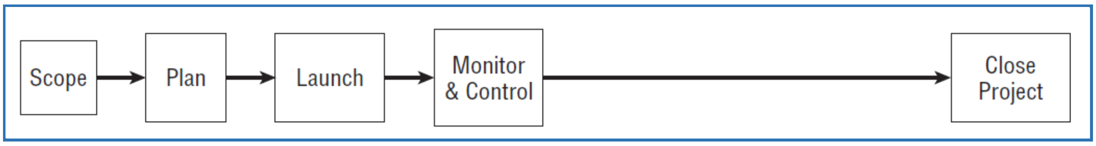

Figure 2.5 Life-Cycle model for traditional project management (Wysocki, 2013, pp. 45)

In traditional project management, a plan is prepared and this plan is applied during the execution phase (Nicholas & Steyn, 2012). Main tools used in traditional project management are the work breakdown structure, bar (Gantt) charts, CPM, S-Curves and EVM.

The complex and changing conditions of today's projects makes it impossible to predict in advance in a reliable way, thus instead of trying to predict and avoid changes, changes are required to be processed during a project (Priemus *et al.* 2013). Several researchers (Atkinson *et al.*, 2006; Geraldi, 2008; Geraldi *et al.*, 2008; Koppenjan *et al.*, 2011; Perminova *et al.*, 2008) put forward the need for the project management to evolve in this direction. According to Geraldi (2008), the projects need for integration of traditional and modern approaches. For this purpose, a certain level of flexibility is required to circumvent the complexity and uncertainty (Geraldi, 2008; Koppenjan *et al.*, 2011).

The flexibility in project management is the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions. Throughout this research, the flexibility in project management is terminologically used in line with this perception.

Different methodologies and techniques have been developed to tackle the increasing complexity in projects. A methodology that directly responds to the complexity problem and covers the need for flexibility in project management is the Agile Project Management (APM) (Jalali-Sohi, 2016; Van Kralingen, 2017). APM is based on the agile approach (or philosophy) or agile way of thinking (or working) (Agile Manifesto, 2020). The agile approach first was imlemented in the software sector but so far the other sectors have also adapted it in projects such as the construction sector. As opposed to a traditional approach, APM has been developed to create flexibility and increase efficiency in the management of software engineering projects. In 2020, it was seen that 95 percent of the organizations are practicing the agile approach (State of Agile Report, 2020).

Although there exist different types of approaches under the heading of agile methodologies, all the types share the following basic objectives (Cooke, 2012; Johansson, 2012; Jalali-Sohi, 2016):

- Instead of upfront planning, the implementation of incremental planning so that the most recent information is available and can be processed,
- Establishment of a better upfront planning and identification of technical risks as early as possible in order to lower the influence of changing project requirements,
- Delivering the expected business value in a frequent and continuous manner to the organisation,
- Establishment of trust among staff and provide development opportunities to the staff,
- Encouragement of continuous communication between the stakeholders and team staff in the project,
- Provide the means of increasing the involvement of the client into the processes.

A typical traditional project management life-cycle model was previously illustrated in Figure 2.5. For the purpose of comparison, this time a general APM life cycle model is given in Figure 2.6. When the two models are compared, the main difference between the two approaches, i.e. linear character of traditional vs. iterative character of agile, can be easily observed.

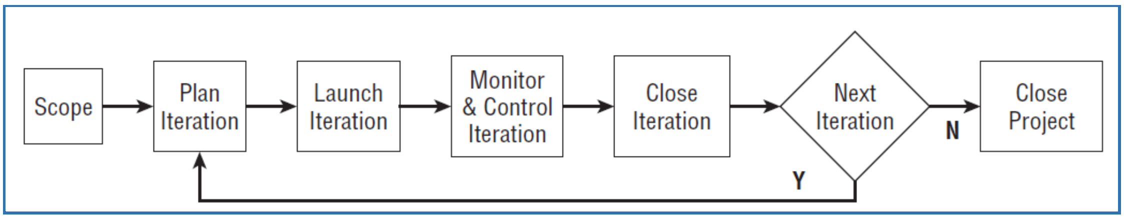

Figure 2.6 Life cycle model for Agile Project Management (Wysocki, 2013, pp. 51)

An iterative approach is used in delivering a project in case of APM throughout the project's life cycle as shown in Figure 2.6. Iterative life cycles are constituted with several iterations or incremental stages to complete a project. Iterative life-cycle implementation have been frequently used in software development projects up to now to increase the progress velocity and adaptability to changing project conditions since by this way it becomes possible to take the appropriate position an adjust along a project when compared to the implementation of linear type of life cycle. In this sense, one of the main aims of implementing iterations in APM is to deliver the benefits and value to the customer or client throughout the project instead of delivering it at the end of the project. However, the most important issue in APM is the central values along with flexibility, trust, empowerment, and collaboration (APM, 2020).

Lean approach in management started to be applied in the early 1900's at the Toyota Company plant in Japan (Blom, 2014). The implementation of the lean approach in project management aims at decreasing the waste, creating higher client satisfaction and increasing the profit. As a result, it is aimed at reducing the costs, lead-time and increasing the quality (Moujib, A., 2007). Last Planner System (LPS) has been developed for the achievement of these purposes by the Lean Construction Institute (Lean Construction Institute, 2020). In other words, LPS has been developed as a lean planning tool to be used in construction projects.

Dynamic Project Scheduling or Dynamic Scheduling has been developed and introduced by Vanhoucke (2012) in his book entitled "Project Management with Dynamic Scheduling" (Vanhoucke, 2012). In dynamic scheduling, the scheduling process is considered as a dynamic event which generates in a continuously changing environment along the life cycle of a project. For this reason, dynamic scheduling puts emphasis on project control based on the usage of Earned Value Management and the project performance. Furthermore, it gives special importance to the baseline schedule in order to provide a proper integration of the schedule with the schedule risk analysis and by this way, to ensure efficiently controlling of the project (Vanhoucke, 2013). This brief description shows that Dynamic Project Scheduling tackles the scheduling problem through a hybrid, i.e. both control and flexible (dynamic) approach and puts emphasis on baseline schedule, schedule risk analysis and project control. These three points are defined as the three dimensions of dynamic scheduling.

In Dynamic Scheduling, the ultimate goal of baseline scheduling and schedule risk analysis is considered as to gather information of the project to support the project control phase during the project's progress. It is different from static scheduling in the sense that it recognizes that the first two dimensions, baseline scheduling and risk analysis, are only supportive steps to gain information that can be later used during the project control step in order to steer the corrective actions in case of problems to bring the project back on track. Dynamic scheduling leads to a careful balance between optimizing the baseline schedule to obtain efficiency of resources and awareness of uncertainty that can dramatically change the initial expectations as stipulated in the baseline schedule (Vanhoucke, 2013). In this approach, the baseline schedule dimension is represented with the "complexity", the risk analysis dimension is represented by the "uncertainty". The main limitation of dynamic scheduling lies in its perception of complexity (Vanhoucke, 2013). Complexity only has been tackled within the narrow frame of schedule complexity by ignoring the complexity factors affecting the projects and in turn, the schedules. Another limitation with Dynamic Project Scheduling is that it does not suggest the means of managing the schedules flexibly although it accepts the necessity of bringing dynamism to the scheduling process.

Detail-Dynamic Project Management Model or Framework has been developed and introduced by Hertogh & Westerveld (2010). In Detail-Dynamic Project Management Model, project complexity is modelled by two different dimensions: detail and dynamic. While the detail complexity is associated with a high number of components, a high degree of interrelatedness, the dynamic complexity is associated with the potential to change over time, the limited comprehensibility and predictability (Hertogh & Westerveld, 2010). When detail complexity is high, it is considered that the system is complicated, when dynamic complexity is high, it is considered that the system is complex (Hertogh & Westerveld, 2010). When both are high, it is both complicated and complex, i.e. dynamic (Hertogh & Westerveld, 2010). The model is shown in Figure 2.7

(Hertogh & Westerveld, 2010, pp.228). The building blocks in this figure is based on the systems (control) management and interactive (interaction) management and different management strategies are proposed to cope with detail and dynamic complexity (Hertogh & Westerveld, 2010).

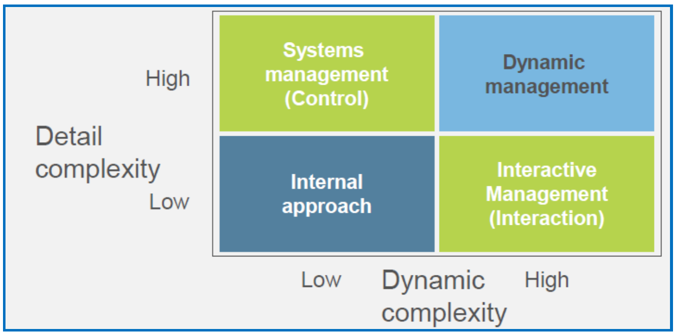

Figure 2.7 Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010, pp. 228)

Detail-Dynamic Project Management Model distinguishes 4 types of management approaches as given below (Hertogh & Westerveld, 2010):

- Internal approach
- Control approach
- Interactive approach
- Dynamic approach (both control and interaction)

For managing today's projects, although the traditional or waterfall approach is still the starting point, such an approach might not be perfectly suited most of the time when the project becomes increasingly complex. As a solution, without avoiding the utilisation of traditional approach and thinking about what to additionally apply or how differently to apply certain activities or tools from the traditional approach, some elements of flexible project management methodologies such as agile project management might be applicable. In case a managerial solution cannot be brought to the complexity by this way, the approaches should be fit to the situation. This is named as the fit-for-purpose project management (Van de Loo, 2015) or adaptive project management (Shenhar & Dvir, 2007). This approach is depends on the idea that since each project is unique, the projects should be managed by different approaches or styles to achieve the project objectives (Ehrman & Holzmann, 2012; Klein *et al.*, 2015).

The current projects carry high uncertainty and complexity. Therefore, an ordinary project planning becomes insufficient due to the increased project dynamics (Shenhar & Dvir, 2007). For this reason, instead of approaching the projects in the same direction as the traditional project management dominantly does, the modern project management approaches consider the projects as differing endeavours and claim the necessity to adapt the managerial practices to the specific purpose of each project (Bakker *et al.* 2016) as the fit-for-purpose project management proposes.

The project complexity is a subjective matter. What one project manager might consider complex will not be automatically perceived as complex by another project manager. This is also valid among the practitioners at different levels within the same company. For example, people who are working within the same organisation, on the same projects and with comparable roles, can identify entirely different elements of complexity within the same project. This phenomenon is called as the "perceived complexities" by Bosch-Rekveldt *et al.* (2014). The "perception" is defined as the way an organism interprets its environment. In this context, a management approach for the benefit of the project, called the "perception-based management" has been developed (Bosch-Rekveldt *et al.* 2014). Instead of considering the complexity as a threat, a different positive approach, i.e. embracing the complexity by seeing it as an opportunity is required. In order to create such a change on the views, the utilisation of perception-based management and the establishment of a shared mental model become important (Bosch-Rekveldt *et al.* 2014).

2.5 CONCLUDING REMARKS

In this chapter, the theoretical background related to the subjects entering into the frame of this research (refer to Figure 1.2) has been introduced through a literature survey. The subjects in question were clustered under four main headings: Complexity Assessment in Project Management, Project Risk Management, Project Schedule

Management, and Flexible Project Management. The purpose of following such a pattern is to align the theoretical background with the aim and objectives of this research, which have been stated in Chapter 1.

Complexity assessment is a relatively new task in project management. Therefore, the models and frameworks reviewed from the literature regarding the project complexity are in general associated with the studies claiming the need for a paradigm change in project management, i.e. from traditional and plan-driven towards flexible, adaptable and change-driven. Among these models, the TOE Complexity Assessment Framework developed by Bosch-Rekveldt *et al*. (2011) is utilised in this research (Bosch-Rekveldt *et al.* 2011). Chapter 5 includes a detailed explanation of the TOE Complexity Assessment Framework (Bosch-Rekveldt *et al.* 2011).

Succeeding the complexity assessment in project management, the project schedule management (Project Management Institute, 2017) and project risk management (Project Management Institute, 2017) have been introduced respectively in two different sections. Since these have been accepted among the main knowledge areas of project management (Project Management Institute, 2017) for a sufficiently long time, a high volume of studies have accumulated in the literature regarding these two subjects. For this reason, the resources have been filtered as much as possible to enable the usage of only the resources that are believed to contribute to the general purpose of this research.

Finally, at the end of the chapter, the modern approaches recently developed in project management to tackle with the new conditions of projects, i.e. complex, highly uncertain and dynamic, have been reviewed with giving brief explanations from the relevant literature. Since, in this research, the 'flexibility' in project management is taken into account as the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions, both the subjects reviewed within this chapter and that will be studied throughout the next chapters have been determined in accordance with the three main attributes of today's projects, i.e. complex, uncertain and dynamic, which need to be to be mitigated by using flexible project management. In other words, while the section regarding the complexity assessment is associated with the ‘complexity’ component, the sections regarding the project risk management and flexible project management are associated with the ‘uncertainty’ and ‘dynamic’ components, respectively. On the other hand, the section regarding the project schedule management is associated with the core focus of the current research, i.e. scheduling.

3 MANAGERIAL FLEXIBILITIES IN CPM AND FLEXIBILITY IN PROJECT SCHEDULE MANAGEMENT PROCESSES

In this chapter, firstly, managerial flexibilities inherent with the traditional method of the activity network scheduling, the Critical Path Method (CPM), will be evaluated. Next, the flexibilities in the "A Guide to the Project Management Body of Knowledge (PMBOK® Guide)"s view on project management will be examined from the scheduling perspective (Project Management Institute, 2017). The "Construction Extension to the PMBOK® Guide" (Project Management Institute, 2016) and the "Practice Standard for Scheduling" (Project Management Institute, 2017) are also taken into consideration during the evaluation. PMBOK Guide conceives the Project Schedule Management as one of the main knowledge areas of project management. Accordingly, the processes assumed to be related with this knowledge area has been identified in the Guide. Since CPM is a traditional scheduling method and the general view on project management in the PMBOK Guide is dominantly of a traditional character, this chapter in a way represents the discussion of the so-called traditional plan-driven project management, which is mainly based on "predict & control" approach (Koppenjan *et al.*, 2011). The aim is to understand the existing flexibilities in traditional approaches, both at method-level, i.e. based on CPM and at process-level, i.e. based on the processes proposed in the PMBOK Guide (Project Management Institute, 2017), and by this way, to become aware of the areas open to development for obtaining a more flexible project management from the perspective of scheduling.

The evaluation is performed in two subsequent sections. The first section starts with a conceptual discussion part with regards to the managerial flexibilities provided by the CPM. In the succeeding part, the subject is evaluated in detail through illustrative example applications. Afterwards, in the second section, the discussion is elaborated from method-level to a process-level. In other words, this time the flexible features of the project management processes associated with the "project schedule management", which is identified as one of the knowledge areas of project management in the PMBOK Guide (Project Management Institute, 2017), are evaluated around the general principles of flexible project management. In this context, Chapter 3 constitutes the discussion of the research problem, which was introduced in Chapter 1, from the viewpoint of traditional project management. The purpose of such an effort is to get aware of the existing flexibilities in the traditional method of scheduling, i.e. the CPM, and traditional project management, based on the PMBOK Guide (Project Management Institute, 2017). By this way, it is desired to detect the points open to development in order to propose a hybrid approach carrying both traditional and flexible features to be used in managing the schedules of complex construction projects. Finally, the chapter ends with the concluding remarks.

3.1 EVALUATION OF MANAGERIAL FLEXIBILITIES IN CPM

Schedules are important tools in the management of construction projects from the point that a project schedule puts forward the project duration, start and completion dates, and the resources needed for each activity in the project. Depending on this, inappropriate schedules may lead to the allocation of the resources to the wrong tasks or to the tasks at the wrong time or might cause the wrong conclusions about the progress (Ackley *et al.* 2007). Schedules also give information about the usage of cost. For instance, the renting cost of a big crane can be very high per unit time. Thus, if the durations of the activities for which the usage of the crane is needed in a project are miscalculated, the contractor can quickly consume the profit to the rental charges. In addition, the contractor's overhead also increases due to the fact that the overhead costs are dependent on the project duration (Gould 2005; Menesi, 2010).

Scheduling in construction projects is important for not only delivering the projects within the so-called iron triangle constraints, i.e. time, cost and scope (Toor & Ogunlana, 2010), but also for bringing claims about the compensation of time and cost in case of delay (Arditi & Pattanakitchamroon, 2006), and for distributing the float times fairly among the project parties (Al-Gahtani, 2009). In case some problems occur, the schedules help reschedule the project activities and rearrange the resources for the achievement of the primary project objectives in terms of time and cost under budget and resource limitations (Menesi, 2010).

The standard or traditional method of scheduling the construction projects has been the CPM for the reason that no previously developed methods such as the bar (Gantt) chart diagramming, as the most known among others, contain capabilities including, but are not limited to, scheduling of the activities through networks (as illustrated in Figure 2.2) by assigning different relationships (in the form of Finish-to-Start, Start-to-Start, Finish-to-Finish, and Start-to-Finish as illustrated in Figure 3.1) between the activities, showing the early and late start and finish times of each activity in an activity network, assigning lag and lead times between the activities, showing the critical, near critical and noncritical activities and paths in the network, disclosing the activity in different types (total, free, independent, shared, positive, and negative) and path float times, and the possible shortest project completion time given the expected activity durations, milestones and resource constraints. Basically, the algorithm used in the CPM analysis, which is called the forward and backward pass calculations, enables the fulfilment of the aforementioned capabilities (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015). The increasing trend regarding the usage of CPM in the construction sector has been disclosed by the researchers like Kelleher (2004) and Hawkins (2007) in their studies (Menesi, 2010). Furthermore, the importance of CPM has been pointed out in the Construction Extension to the PMBOK Guide (Project Management Institute, 2016) with stating that the construction industry predominantly uses the CPM for its scheduling practice and the usage of CPM often stands at the centre of the claims raised by the contractors based on the delays (Project Management Institute, 2016).

In spite of its popularity, like every method, model or procedure, CPM has also limitations that have taken criticism by the researchers and practitioners as discussed in Chapter 2. However, a quite few researches also have been carried out in the literature to overcome these limitations. Besides, the commercial project planning software, which almost all is based on CPM analysis (Menesi, 2010), have been donated with advanced technical and user-friendly features in order to make it available to perform analyses based on the CPM including, but are not limited to, schedule update, progress analysis, earned value analysis, what-if analysis, delay analysis, resource allocation, resource levelling, schedule compression, multiple calendar analysis, and optimisation (time-cost trade-off analysis). These additional capabilities not only expand the managerial flexibilities of CPM but also make contribution to the managerial flexibilities associated with the processes of project schedule management, which will be discussed in the second section.

In this section, managerial flexibilities of CPM are evaluated with respect to the activity, path, and project levels compatible with the three different dimensions inherent in the activity networks. The links that could be possibly set up between the management flexibility and characteristic features of CPM are discussed first conceptually and then evaluated through illustrative example applications. It should be mentioned that the study introduced in this section has been presented at the 8th IPMA Research Conference held online in 2020 (Ökmen *et al.*, 2020).

3.1.1 Flexibility at Activity-Level

Flexibility at activity level in a CPM schedule can be evaluated based on float times belonging to noncritical activities. Activity float times provide various potential flexibilities during managing a CPM schedule. Basic definitions of activity float types are given below (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015). Furthermore, the flexibilities associated with these floats are discussed.

Total float time is the difference between the activities' late start time and early start time or late finish time and late start time (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015). It represents the amount of total flexibility of an activity that can be consumed in case of any possible delay or disruption in that activity. A delay in an activity as far as the amount of delay stays within the limits of total float time does not cause delay on the envisaged project completion time. However, total float should not be considered as an absolute flexibility for an activity because some portion of it may be shared by some of the successor activities (Newitt, 2009). As a result, total float times do not provide full flexibility and therefore they should be consumed consciously. Furthermore, it should be emphasized that unlike the noncritical activities, critical activities have no flexibility with respect to total float time because the critical activities have no float time by definition.

Free float time is the float amount up to which an noncritical activity can be delayed without causing any delays on the early start times of any of its successor activities (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015). Furthermore, the consumption of the free float does not cause a delay on the project completion time if it does not contain any shared float (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015). In that sense, free float represents a kind of partial flexibility in CPM schedules.

Shared float time is the float amount up to which an noncritical activity can be delayed after consuming the entire independent float that it possesses (Newitt, 2009). In other words, shared float constitutes the portion of float within the total float of an activity after its independent float is consumed. The usage of the shared float causes the consumption of some of the float that also belongs to successor or predecessor activities, as its name implies "shared". One may argue that shared float therefore does not provide full flexibility like free float.

Independent float time is perhaps the most comfortable flexibility that CPM provides at the activity level as it only belongs to the activity which possesses it. The usage of it will neither steal from the float times of the successor or predecessor activities that may share some portion of the float with that activity nor affect the early start times of the successor activities and the project completion time as well. In that sense, independent float can be perceived as the absolute and core flexibility agent of CPM.

In a CPM schedule, the noncritical activities might not possess free, shared and independent floats at the same time, but by definition, each activity has some float. The strategy that should be followed when managing a CPM schedule starts with the notion of float. A manager should not fall into mistakes by using the total floats carelessly as if they are only under pure possession of noncritical activities. In short, the usage of flexibility unconsciously may lead to further inflexibility in CPM schedules. This issue will be elaborated in the upcoming example applications.

And what about the critical activities? Don't they have any flexibility from a management viewpoint? In the end, they have no float of any kind. The awareness CPM brings to a project manager through the information “those activities are critical, so be careful while executing them, take the necessary precautions in advance” can also be considered as a kind of managerial flexibility. Furthermore, the critical activities, along with the noncritical activities that may turn into critical during execution of the project, can be utilised for shortening the project duration through the project compression (crashing and fast tracking) capability of CPM (Project Management Institute, 2016) and this gives flexibility of changing the predetermined project duration if required, but in expense of increase in project costs.

Detailed explanations regarding the forward-backward pass calculation algorithm and other specific features of CPM can be found in relevant publications such as Newitt (2009), Oberlender (2014), and O’Brien & Plotnick (2015). Since it is out of scope, such details are not given in this report. However, in Figure 3.1 (Menesi, 2010, pp.11), the types of relationships that can be assigned to the activities together with lag times in a CPM schedule network that is established based on activity-on-node diagramming (precedence diagramming) technique are illustrated for the sake of comprehensibility of the example applications carried out in this section.

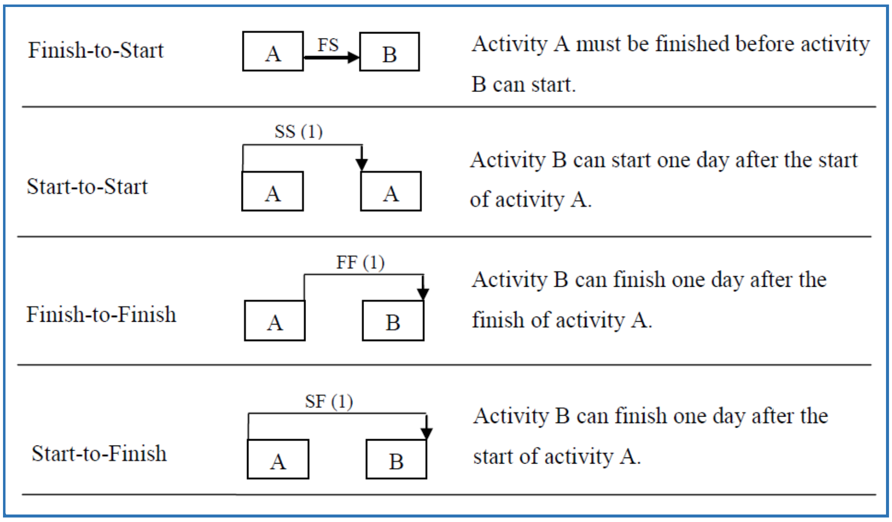

Figure 3.1 Types of activity relationships (Menesi, 2010, pp.11)

3.1.2 Flexibility at Path-Level

CPM, as its name implies, is a scheduling method that operates through activity paths. It discloses the critical path(s), and noncritical path(s) to show the required work flow through related activities.

The flexibility of CPM at the path level comes from the path floats occurring due to the float times of noncritical activities lying on the paths. However, once more, conscious usage of the path floats as in the case of activity floats is a requirement because path floats are not independent from the activity floats. In other words, the type of the floats that the noncritical activities on a path possess determines the degree of comfort regarding the usage of flexibility for that path. Therefore, flexibility at path level should not be a luxury of a manager to be used arbitrarily any time.

3.1.3 Flexibility at Project-Level

CPM provides the shortest possible project completion time of a project, which is very important from the managerial viewpoint. Is there any flexibility on the calculated completion time? Traditional application of CPM can calculate only one single project duration at a time because of its deterministic nature. However, CPM's updating capability creates flexibility at this point up to an extent. As far as accurate data is provided with regard to the completed parts of projects and the estimations for the remaining parts are updated realistically taking into account the actual data, completion times of projects would be calculated more precisely each time through a more flexible approach. Depending on the outcomes, project managers could take precautions in order to overcome deviations from the project completion duration envisaged in the baseline or target schedule.

However, the flexibility of CPM at project-level is not associated with only the updateability of project completion time, there are also some other flexibilities such that CPM can also be used as a cost schedule, labour schedule or equipment schedule. In other words, a CPM schedule provides further flexibilities when it is used as a resource schedule in terms of cost, labour or equipment and in that case CPM can also be used for:

- levelling resources through consuming activity float times in order to keep under the maximum available resource limit,
- skipping resources from noncritical activities to critical activities in order to avoid schedule overruns,
- optimising time against costs, i.e. time-cost trade-off analysis (Newitt, 2009; Oberlender, 2014; O'Brien & Plotnick, 2015).

All of these capabilities increase the flexibility of CPM. However, proper and conscious usage is required throughout the project in order to fully benefit from CPM at project-level as in the case of activity and path levels.

3.1.4 Example Application 1

So far, the notion of flexibility is described on three levels from a theoretical perspective: activity level, path level and project level. This section and the next one introduce a more detailed evaluation of the managerial flexibilities of CPM at these three levels using two different example applications. Firstly, a sewer line project is used to evaluate the flexibility at activity and path levels. Subsequently, the flexibility of CPM at project level is discussed in terms of its resource levelling capability through another example project specifically constituted for the sake of simplicity.

Example application 1 has been implemented on a hypothetical sewer pipeline construction. The purpose of the application is to show the flexibilities provided by CPM at activity and path levels from a managerial point of view. Table 3.1 shows the data used in the application, i.e. activities, activity numbers, activity durations, predecessor activities, lag times, and network relationships between activities. This data has been constituted by taking the basic requirements in constructing a simple sewer pipeline.

The time schedule of the project was prepared through CPM's forward/backward pass algorithm. The reader is referred to Newitt (2009), Oberlender (2014), and O'Brien & Plotnick (2015) for detailed explanations on the algorithm and computation procedures of CPM. The resulting activity-on-node network diagram is shown in Figure 3.2. The representation of the data in the quadrilaterals is indicated by the "activity notation" in Figure 3.2. The CPM application revealed that:

- Activities 1, 2, 6, 8, 9, 11 and 12 are the critical activities having no float times,
- Activities 3, 4, 5, 7 and 10 are the noncritical activities having float times,
- Path 1 (1–2–6–8–9–11–12) and Path 2 (1–2–6–8–11–12) are the critical paths,
- Path 3(1–2–6–8–10–12) and Path 4(1–2–3–4–5–7–9–11–2) are the noncritical paths.

The total, free, shared, and independent float times of the activities, float sharing activities, float times of the paths, and the criticality of the activities and the paths are given in Table 3.2. As shown in Figure 3.2, the late finish time of the last activity represents the resulting project completion time, which is 62 days.

Evaluation of Flexibility at Activity Level

When the float times given in Table 3.2 are examined, it is observed that each noncritical activity does not have to possess free, shared and independent float necessarily at the same time. However, by definition, each activity has a total float time. This is important for the determination of the appropriate management strategy. As previously mentioned, a manager who is not fully aware of the flexibilities that CPM provides in terms of float times at activity level might mistakenly use the total floats carelessly as if they were only under the pure possession of noncritical activities. This is clarified below.

For instance, the activity 10 has a 11 days of total float, which is relatively high when compared to the project completion time, which is 62 days. More important is that this total float is also the free and independent float for this activity. In other words, activity 10 does not share any portion of its float with any of its predecessor or successor activities. Therefore, activity 10 carries a large amount of flexibility for itself and for the path on which it lays. Furthermore, the activity-level flexibility that "activity 10" possesses creates not only path-level flexibility but also project-level flexibility.

Table 3.1 Activities and network information of example application 1

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship
1	Workplace delivery and mobilization	3	-
2	Sewage line route application	15	1 (Finish-to-Start)
3	Manhole excavation	6	2 (Finish-to-Start)
4	Inserting manhole formworks	10	3 (Start-to-Start,+3 days lag time)
5	Pouring manhole concrete	10	4 (Finish-to-Start, -3 days lag time)
6	Sewage line trench excavation	20	2 (Finish-to-Start)
7	Removing manhole formworks	5	5 (Finish-to-Start)
8	Installation of sewer pipes	25	6 (Start-to-Start, +2 days lag time)
9	Control of manholes	3	7 (Finish-to-Start), 8 (Finish-to-Start)
10	Handling of trench excavation equipment	4	8 (Finish-to-Start)
11	Sewer line trench filling	12	8 (Finish-to-Start), 9 (Finish-to-Start)
12	Testing the work, handing it over to the employer (completion of work)	2	10 (Finish-to-Start), 11 (Finish-to-Start)

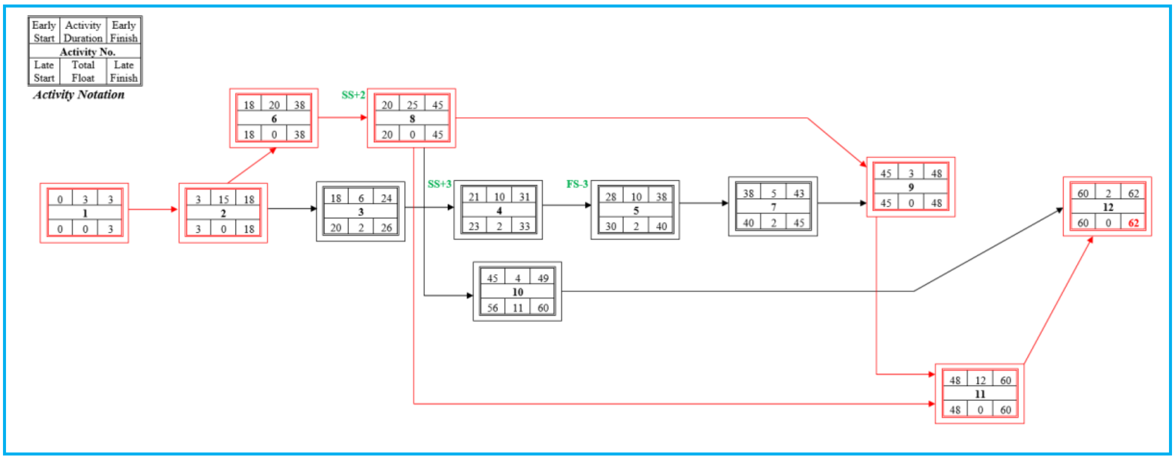

Figure 3.2 Activity-on-node network diagram of example application 1

Table 3.2 Float times and criticalities of the activities and paths of example application 1

Activity/Path No.	Free Float Time*	Shared Float Time	Independent Float Time	Total Float Time	Float Sharing Activity	Path Float Time	Criticality
Activity 1	0	0	0	0	-	N/A	Critical
Activity 2	0	0	0	0	-	N/A	Critical
Activity 3	0	2	0	2	4, 5 & 7	N/A	Noncritical
Activity 4	0	2	0	2	3, 5 & 7	N/A	Noncritical
Activity 5	0	2	0	2	3, 4 & 7	N/A	Noncritical
Activity 6	0	0	0	0	-	N/A	Critical
Activity 7	2	2	0	2	3, 4 & 5	N/A	Noncritical
Activity 8	0	0	0	0	-	N/A	Critical
Activity 9	0	0	0	0	-	N/A	Critical
Activity 10	11	0	11	11	-	N/A	Noncritical
Activity 11	0	0	0	0	-	N/A	Critical
Activity 12	0	0	0	0	-	N/A	Critical
Path 1	N/A	N/A	N/A	N/A	N/A	0	Critical
Path 2	N/A	N/A	N/A	N/A	N/A	0	Critical
Path 3	N/A	N/A	N/A	N/A	N/A	11	Noncritical
Path 4	N/A	N/A	N/A	N/A	N/A	2	Noncritical

Next to the flexibility created by the activity 10, the flexibilities belonging to the other noncritical activities, i.e. the activities 3, 4, 5, and 7, should be discussed together because these activities are located subsequently on the same path. As given in Table 3.2, these activities have 2 days of total float each. However, the float they each possess is the shared float at the same time. In other words, they share the 2 days of float. Therefore, the cumulative flexibility of these four activities sequentially lined up as shown in Figure 3.2 is as much as their shared float amount, i.e. 2 days, rather than the cumulative of their total floats, i.e. 8 days.

Evaluation of Flexibility at Path Level

The flexibility of CPM at path-level depends on the path floats, which is composed of the float times of the noncritical activities on the paths. However, once more, conscious usage of the path floats as in the case of activity floats is required because path floats relate to the activity floats. In other words, the type of the floats of the noncritical activities on a path determines the level of comfortable usage of flexibility for that path. For instance, the path 1-2-3-4-5-7-9-11-12 (Path 4) may seem to have 8 days of float in total (due to the cumulative floats belonging to activities 3, 4, 5, and 7) although it actually has only 2 days of float (due to shared float among activities 3, 4, 5, and 7).

Let's assume that the project has progressed up to activity 5. If activity 5 is completed with 2 days of delay by consuming its total float, no float will remain for activity 7 which is the successor of the activity 5 because the 2 days of float were shared among the activities 3, 4, 5, and 7. In other words, consuming the 2 days of float for each activity on Path 4 will cause "8 (*cumulative of the floats belonging to the activities 3, 4, 5, and 7*) – 2 (*float shared among the activities 3, 4, 5, and 7, i.e. the real float value of the Path 4*)" = 6 days of delay in terms of the project completion. This example shows the importance of utilising the flexibility in the CPM schedules in an appropriate way.

When we examine Path 3, it is a different situation because it has a float of 11 days depending on the independent flow of the single noncritical activity on that path, i.e. "activity 10". In other words, the flexibility existing with "activity 10" is directly creating flexibility on the path on which it stands. Therefore, each path on a CPM schedule should be analysed separately based on the flexibilities that the activities on them provide by taking the float types into account.

3.1.5 Example Application 2

In this section, the flexibility of CPM at project level is discussed in terms of its resource levelling capability through another example illustrative project. The project data used in this application is given in Table 3.3. The activities of the project are represented with letters and all the network relationships between the activities are taken as finish-to-start (FS) without any lag times. Table 3.3 also includes the information about the activities, activity durations, predecessor activities, network relationships between the activities as well as the number of workers required by each activity. This data was used in the implementation of CPM, in the preparation of time and labour schedules, and in levelling the labour requirement. For the sake of simplicity, only one type of resource was taken into account.

Firstly, in line with the information in Table 3.3, a time schedule was created with forward/backward CPM calculations. The schedule is given in Table 3.4 and shown as an activity-on-node network diagram in Figure 3.3. According to the schedule;

- The activities A, C, F, I, and J are the critical activities having no float times,
- The activities B, D, E, G, and H are the noncritical activities having float times,
- The path A–C–F–I–J is the critical path,
- The paths A–B–F–H–J, A–C–F–H–J, A–D–J, A–E–J, and A–G–J are the noncritical paths.
- The completion time of the project is 24 days.

Subsequently, labour charts showing the labour requirements along the project were prepared by the data given in Tables 3.3 and 3.4. It was assumed that the maximum number of workers that can be employed throughout the project is 9. In other words, there is a workforce of 9 workers available for this job. Therefore, a labour shortage is assumed to occur when more than 9 workers are needed on any working day, and some of the workers will remain idle when less than 9 workers are required.

Labour requirement schedules can be prepared by a stepwise procedure consisting of three stages. In the first stage, a labour schedule is prepared according to the early start and early finish times of the activities. In this schedule, it is determined on which dates labour shortage and on which dates excess labour problems will occur. Then, a second labour schedule is prepared according to the late start and late finish times of the activities. In this schedule, again it is determined on which dates labour shortage and on which dates excess labour problems will occur. Then, by using these two labour schedules and shifting the required activities over the total float times of the uncritical activities, a levelled or optimized labour schedule is constituted. This process is called “resource levelling” (Newitt, 2009; Oberlender, 2014; O’Brien & Plotnick, 2015). In this final labour schedule, the need for labour generally increases at the beginning of the project, follows a regular course in the middle and starts to decrease as the end of the project approaches. The number of workdays with labour shortage or excessive labour problems is minimized or eliminated.

Using the values in Tables 3.3 and 3.4, taking into account the maximum allowable labour assumption, i.e. maximum 9 workers daily, and following the three-stage resource levelling procedure described above, the labour requirement charts (i.e. labour schedules) of the example project were prepared. The charts are given in Figures 3.4 - 3.6. Figure 3.4 and Figure 3.5 show that we are facing an over-requirement problem in terms of labour force. This problem can be resolved through benefitting from the flexibilities provided by CPM at project level, as described below.

Table 3.3 Activity network information and labour requirement of Example Application 2

Activity	Activity Duration (day)	Predecessor Activity	Network Relationship	Labour Requirement (worker)
A	2	-	-	4
B	4	A	FS	6
C	5	A	FS	2
D	4	A	FS	3
E	2	A	FS	7
F	6	B C	FS	8
G	3	A	FS	5
H	4	F	FS	2
I	9	F	FS	2
J	2	D E G H I	FS FS FS FS FS	3

Figure 3.5 illustrates the labour requirement chart prepared according to the early start and early finish time. It shows that 23, 23, 16 and 11 workers are needed on the 3rd, 4th, 5th and 6th days, respectively. Hence, a labour shortage due to the need for more workers than the maximum worker capacity of 9 is observed. The need for workers increases rapidly at the beginning of the 24-day total work period, and the need drops suddenly before the project reaches the end. In other words, the need for labour does not follow a regular course. Accordingly, we need some flexibility to overcome this labour shortage.

Table 3.4 CPM solution of Example Application 2

Activity	Early Start Time*	Early Finish Time	Late Start Time	Late Finish Time	Total Float Time	Criticality
A	1	2	1	2	0	Critical
B	3	6	4	7	1	Uncritical
C	3	7	3	7	0	Critical
D	3	6	19	22	16	Uncritical
E	3	4	21	22	18	Uncritical
F	8	13	8	13	0	Critical
G	3	5	20	22	17	Uncritical
H	14	17	19	22	5	Uncritical
I	14	22	14	22	0	Critical
J	23	24	23	24	0	Critical

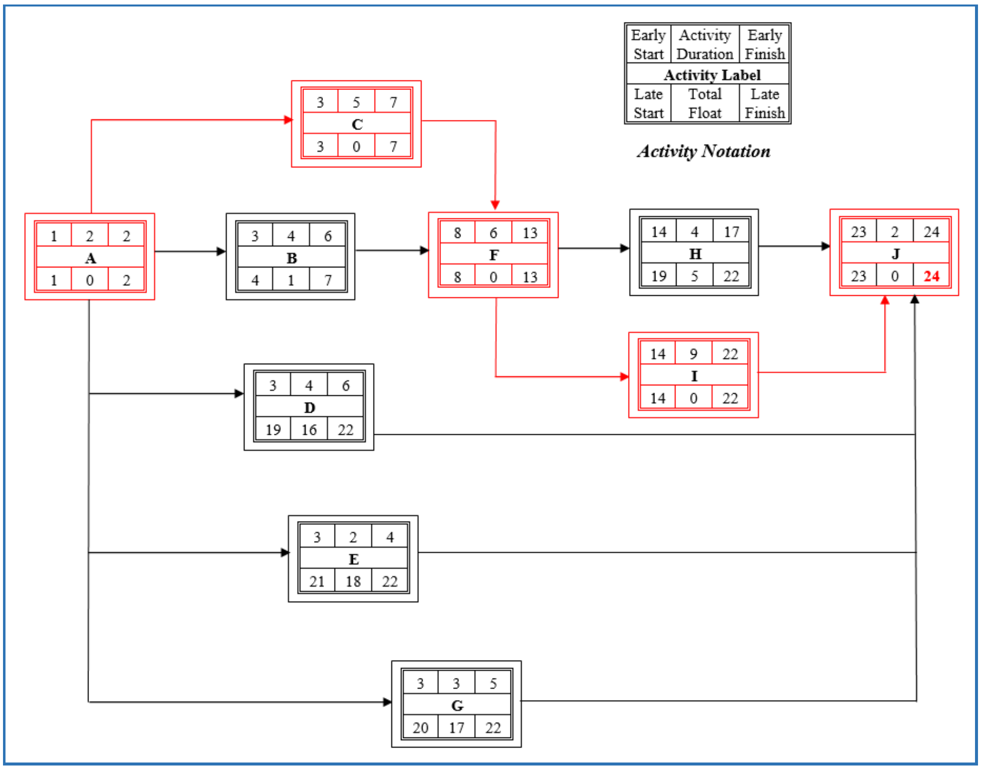

Figure 3.3 Activity-on-node network diagram of Example Application 2

Figure 3.6 illustrates the labour requirement chart prepared according to the late start and late finish time values. Now only 12 workers are needed on the 21st and 22nd days. In other words, labour shortage will still occur due to the need for more workers than the maximum worker capacity of 9, but the number of days with labour shortage has decreased from 4 to 2 compared to Figure 3.6. Also the number of extra workers needed has decreased significantly. Apart from this, the need for workers increases slowly at the beginning of the 24-day total work period, the need drops rapidly with a sudden leap towards the end, after following a regular course. In other words, the labour schedule prepared according to the late start and late finish times still needs to be levelled due to the sudden leap after the 21st day though it is superior with respect to the labour schedule prepared by the early start and early finish times. We need additional flexibility.

In order to overcome this problem, we can benefit from the resource levelling capability of CPM. The labour requirement chart obtained by resource levelling is given in Figure 3.6. According to the levelled chart, there is no day left with labour shortage. The need for workers follows a regular and balanced course throughout the 24-day period. In order to create this levelled schedule, uncritical activities were shifted over their total float times for eliminating the days of labour shortage, hence creating more balanced labour requirements. In other words, we actually did benefit from the flexibility capacity of CPM to overcome the aforementioned over-requirement problem in terms of labour.

Activity	**Day**																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	4	4																						
B				6	6	6	6																	
C			2	2	2	2	2																	
D																			3	3	3	3		
E																					7	7		
F								8	8	8	8	8	8											
G														5	5	5								
H																	2	2	2	2				
I														2	2	2	2	2	2	2	2	2		
J																							3	3
Total Labour Requirement	4	4	2	8	8	8	8	8	8	8	8	8	8	7	7	7	4	4	7	7	**12**	**12**	3	3

Figure 3.4 Labour requirement chart prepared based on early start and finish times

Activity	Day																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	4	4																						
B			6	6	6	6																		
C			2	2	2	2	2																	
D			3	3	3	3																		
E			7	7																				
F								8	8	8	8	8	8											
G			5	5	5																			
H														2	2	2	2							
I														2	2	2	2	2	2	2	2	2		
J																							3	3
Total Labour Requirement	4	4	**23**	**23**	**16**	**11**	2	8	8	8	8	8	8	4	4	4	4	2	2	2	2	2	3	3

Figure 3.5 Labour requirement chart based on late start and late finish times

In this section, the managerial flexibilities provided by CPM were evaluated at three levels, i.e. activity, path, and project, first conceptually, then through two different example CPM applications. The results have introduced three important findings. Firstly, CPM, in spite of its criticized deterministic features, contains various flexible aspects from a managerial viewpoint. Secondly, potential flexibilities in CPM are mainly associated mainly with the noncritical activities, noncritical paths, activity float times, activity float types and float times of noncritical paths, and also through its additional capabilities like resource levelling. Thirdly, CPM contains full flexibility through independent type of floats and resource levelling capability. The example applications have shown that trying to manage the CPM schedules without being aware of the managerial flexibilities will not contribute to the aim of successfully completing the construction projects. CPM is not as rigid as it is assumed as far as the manager using it is aware of the means of benefitting from its flexible features. For instance, it is important to make the distinction between the activity float types in a CPM network schedule, i.e. total, free, shared, and independent. While total float times belonging to noncritical activities are probably the most well-known aspect of CPM to the practitioners, the free, shared and independent floats that the total floats contain should be regarded with utmost care during the schedule applications to avoid any wrong usage of the activity float times. Otherwise, the number of critical activities would increase and the schedules would face the risk of overrunning the target durations. Such critical points regarding the correct utilisation of the flexibilities provided by CPM also have been discussed in this section.

Activity	Day																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	4	4																						
B				6	6	6	6																	
C			2	2	2	2	2																	
D														3	3	3	3							
E																		7	7					
F								8	8	8	8	8	8											
G																				5	5	5		
H														2	2	2	2							
I														2	2	2	2	2	2	2	2	2		
J																							3	3
Total Labour Requirement	4	4	2	8	8	8	8	8	8	8	8	8	8	7	7	7	7	9	9	7	7	7	3	3

Figure 3.6 Levelled labour requirement chart

3.2 DISCUSSION OF FLEXIBILITY IN PROJECT SCHEDULE MANAGEMENT PROCESSES PROPOSED BY PMBOK GUIDE

In this section, flexible features of the processes associated with the Project Schedule Management knowledge area, which is indicated by the “A Guide to the Project Management Body of Knowledge (PMBOK® Guide)” (Project Management Institute, 2017) as one of the main knowledge areas of project management, are investigated together with taking into account the “Construction Extension to the PMBOK® Guide” (Project Management Institute, 2016), and the “Practice Standard for Scheduling” (Project Management Institute, 2017). When compared to the previous section, the current section elaborates the discussion from the method-level, i.e. based on CPM, to the process-level, i.e. based on project schedule management. The purpose is to explore the managerial flexibilities in project schedule management proposed by PMBOK Guide. It should be pointed out that, in this section, CPM continues standing at the centre of the discussion like in the previous section. However, the subject is handled from a wider perspective, i.e. at process-level.

As previously mentioned in Chapter 2, throughout this research, the ‘flexibility’ concept in project management is perceived as the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions. Depending on this, the project schedule management proposed by the PMBOK Guide is evaluated in line with this context.

3.2.1 General View of PMBOK Guide on Project Management

PMBOK Guide has been prepared to show good project management practices (Project Management Institute, 2017). Therefore, it should not be considered as a project management methodology. However, in spite of the fact that flexible and adaptable project management approaches like agile, iterative and incremental are acknowledged and pointed out up to an extent in the PMBOK Guide (Project Management Institute, 2017) and Construction Extension to the PMBOK Guide (Project Management Institute, 2016), the focus is mainly kept on traditional and plan-driven project management. In order to clarify this point, the typical project life cycle taken into consideration in the PMBOK Guide is illustrated in Figure 3.7 (Project Management Institute, 2017, pp.18). The interrelations between the project phases of this plan-driven life cycle are also illustrated in Figure 3.7 along with the related project management process groups, each containing various project management processes. The list of project management process groups and knowledge areas were given in Chapter 2. As it can be observed on Figure 3.7, the project life cycle model proposed in the PMBOK Guide shows a linear or waterfall character.

A project life cycle provides the basic framework for managing a project and therefore its structure gives clues about the project management methodology or philosophy followed. The project life cycle proposed in the PMBOK Guide, which is shown in Figure 3.7 (Project Management Institute, 2017, pp.18), is basically a predictive plan-driven model based on “predict & control” or waterfall approach. However, the general approach in the latest version of PMBOK Guide, which is the 6^{th} Edition (Project Management Institute, 2017), is not as rigid as it is assumed with respect to its older versions. PMBOK Guide, in its latest version, acknowledges the fact that the project phases may be sequential, iterative, incremental, hybrid, overlapping, predictive or adaptive (Project Management Institute, 2017). In some manner, it recognises the current need for a flexible and agile approach in project management (Project Management Institute, 2017).

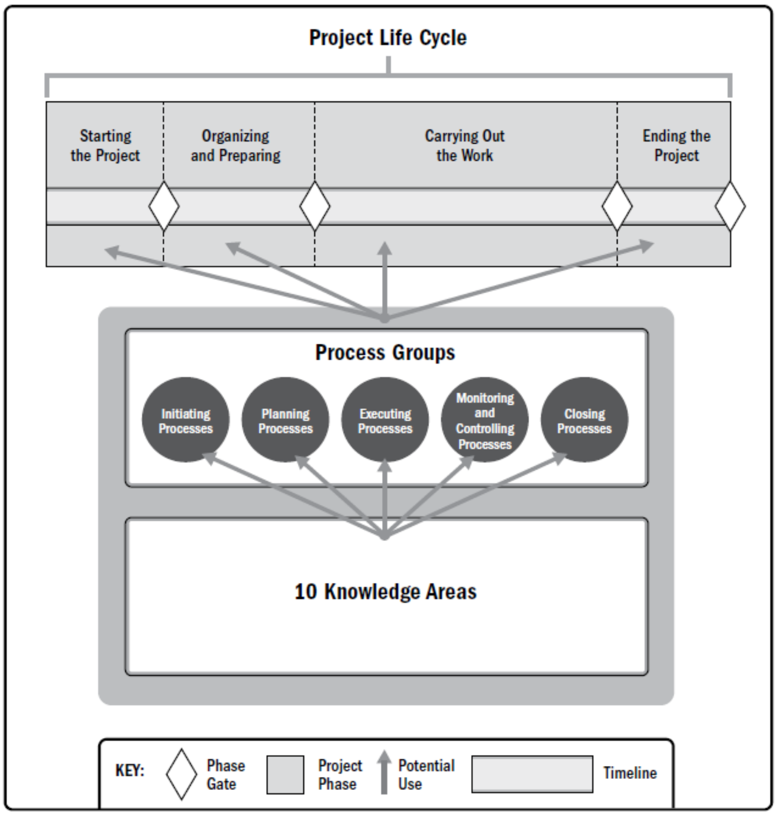

Figure 3.7 Interrelationship between the key components of the PMBOK Guide (Project Management Institute, 2017, pp.18)

In spite of the positive view on the newly evolving approaches on project management, the reflections of the general view observed throughout the PMBOK Guide, which is essentially predictive and plan-driven, are also observed on the processes associated with the project schedule management knowledge area (Project Management Institute, 2017). It can be said that PMBOK Guide considers the project schedule management as a knowledge area which contains a series of processes needed to be applied to complete the project in time (Project Management Institute, 2017).

In the latest version of PMBOK Guide, i.e. the 6th Edition (Project Management Institute, 2017), doors have been left open for a flexible project management although the ways of how to achieve this were not sufficiently clarified. For instance, the Guide emphasizes that the determination of the most appropriate life cycle for any project is up to the project management team (Project Management Institute, 2017). More important, the flexibility issue in project management has been opened to discussion at least within the narrow framework of project life cycle (Project Management Institute, 2017).

In the “Construction Extension to the PMBOK Guide” (Project Management Institute, 2016), the aforementioned common view of the PMBOK Guide does not vary too much. However, the subject has been handled from the perspective of construction projects. Furthermore, the importance of CPM has been pointed out in the Construction Extension to the PMBOK Guide with stating that the construction industry predominantly uses the CPM for its scheduling practice and for also other purposes such as bringing claims in case of delay (Project Management Institute, 2016). However, the questions raised at this point are ‘Will the managerial flexibilities provided by the CPM be sufficient to establish a flexible project management from the scheduling perspective?’ and ‘In case the answer of this question is no, which is assumed to be, how can we expand the flexibilities of CPM and how can we establish flexible project management processes from the scheduling perspective to be implemented in complex construction projects?’. The effort put forward throughout this research carries the intent of finding out the means of this problem. In this regard, it is considered as being valuable firstly to evaluate the flexibilities inherent with the processes identified within the project schedule management knowledge area of PMBOK Guide (Project Management Institute, 2017) prior to the next chapter, which is aiming at discussing the expansion of managerial flexibilities in CPM through the incorporation of risk analysis capability.

3.2.2 Flexibilities in Processes Related with Project Schedule Management

Figure 3.8 visualises the general overview of the PMBOK Guide on scheduling (Project Management Institute, 2017, pp.176). When the figure is examined, the general traditional view of the PMBOK Guide on project management, which was discussed in the previous section, can also be noticed here. However, the "schedule model" approach it brings to schedule project management is worth of emphasizing. On the contrary of this general traditional overview, the Guide points out that whenever it is possible, the schedule prepared in detail at the beginning of the project should be kept sufficiently flexible during the project in order to adjust it according to the newly gathered knowledge, increasing risk perception as well as the value-added activities (Project Management Institute, 2017).

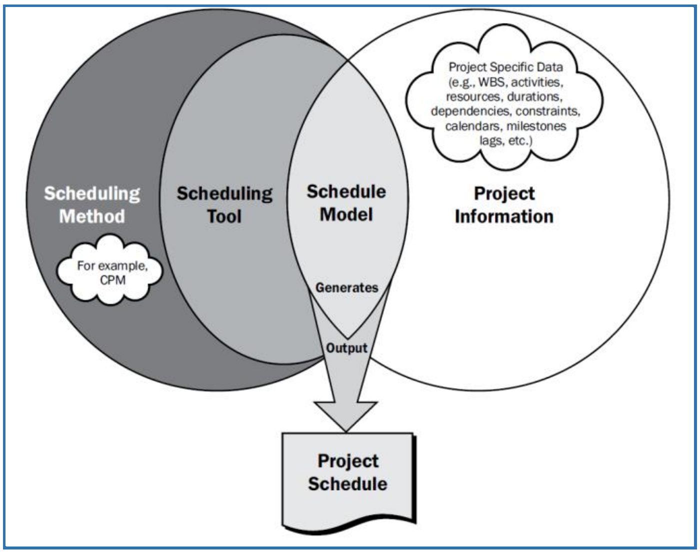

Figure 3.8 The overview of the PMBOK Guide on scheduling (Project Management Institute, 2017, pp.176)

The noticeable point in the above explanations is the high number of variety in the used terms. *Agile, adaptive, iterative, incremental, hybrid, predictive, plan-driven, change-driven, lean, on-demand, alterative, pull-based, highly predictive, highly adaptive* terms are used throughout the Guide (Project Management Institute, 2017) and this situation creates confusion. In this regard, the applications or approaches not included within the traditional project management are considered as *flexible* in this study. This issue was also pointed out in Chapter 2.

Figure 3.9 shows the overview of the PMBOK Guide on project schedule management (Project Management Institute, 2017, pp.174). The processes related to the project schedule management knowledge area can be observed in the form of “input-tools & techniques-output” on this figure. It should be mentioned that the inputs and outputs belonging to these processes have connections with the other processes included into other knowledge areas. In some manner, the PMBOK Guide draws a network that is composed of various project management processes in order to establish an actual picture of the complicated structure of project management as much as possible.

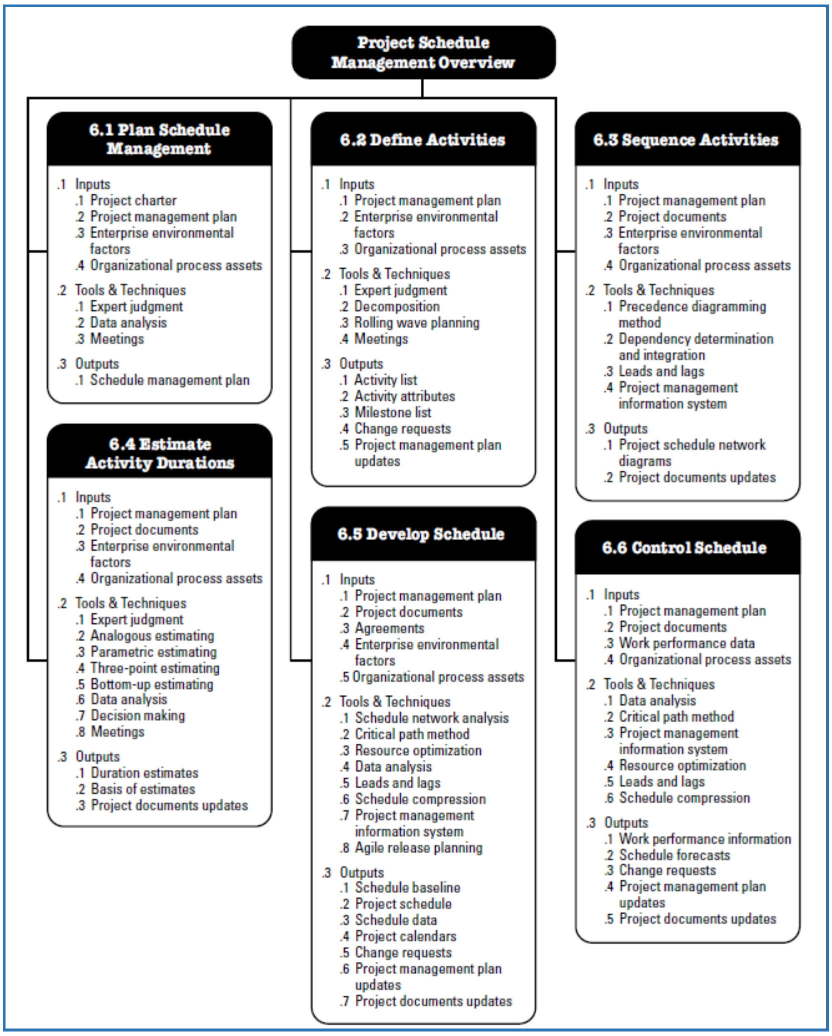

Figure 3.9 The overview of the PMBOK Guide on project schedule management (Project Management Institute, 2017, pp.174)

When the Figures 3.8 and 3.9 are examined together, it can be observed that the overview illustrated in Figure 3.8 is almost a summary of the systematic followed in the overview given in Figure 3.9, except for the “plan schedule management” and “control schedule” processes. This is the key point that differentiates the scheduling illustrated in Figure 3.8 from the schedule management illustrated in Figure 3.9. In other words, scheduling with an advanced method like CPM only leads us to a schedule model. However, we need to manage the schedules produced from this schedule model in the optimum way for achieving success in a project. The question at this point is ‘what kind of management methodology should be applied?’. The answer given to this question in the PMBOK Guide is a step-by-step procedure composed of six successive processes as shown in Figure 3.9. It is obvious that this is a traditional plan-driven approach and may not be appropriate to be implemented in construction projects having complex, uncertain and dynamic conditions. A new different approach is required.

PMBOK Guide points out the importance of the style of life cycle implemented in a project for the reason that the management style applied in a project, which may be traditional, (pure) flexible or hybrid, becomes clear essentially through the implemented life cycle style (Project Management Institute, 2017). Figure 3.10 shows the various ways recommended by the PMBOK Guide in this manner (Project Management Institute, 2017, pp.666).

Predictive	Iterative Incremental	Agile
Requirements are defined up-front before development begins	Requirements can be elaborated at periodic intervals during delivery	Requirements are elaborated frequently during delivery
Deliver plans for the eventual deliverable. Then deliver only a single final product at end of project timeline	Delivery can be divided into subsets of the overall product	Delivery occurs frequently with customer-valued subsets of the overall product
Change is constrained as much as possible	Change is incorporated at periodic intervals	Change is incorporated in real-time during delivery
Key stakeholders are involved at specific milestones	Key stakeholders are regularly involved	Key stakeholders are continuously involved
Risk and cost are controlled by detailed planning of mostly knowable considerations	Risk and cost are controlled by progressively elaborating the plans with new information	Risk and cost are controlled as requirements and constraints emerge

Figure 3.10 The Continuum of Project Life Cycles (Project Management Institute, 2017, pp.666)

3.3 CONCLUDING REMARKS

In this research, CPM is located at the centre of the topic and it is aimed at finding out the ways of flexibly managing the CPM-based schedules in complex construction projects under uncertain and frequently changing dynamic conditions. As a step towards the achievement of this purpose, Chapter 3 firstly introduced the potential managerial flexibilities inherent with the traditional CPM scheduling. It should be mentioned that the study introduced in this section has been presented at the 8th IPMA Research Conference held online in 2020 (Ökmen *et al.,* 2020). Next, the chapter continued with expanding the subject from method-level to process-level, i.e. from CPM to Project Schedule Management. This second part of the discussion was performed based on the processes proposed related with the project schedule management in the last and 6th edition of the PMBOK Guide (Project Management Institute, 2017). The reason of handling the PMBOK Guide as the main reference is that it is widely recognised as a primary source of project management both in the literature and also in almost all the project-driven sectors including the construction industry. The purpose of evaluating the flexibility concept first at method-level based on the CPM and then at process-level based on the project schedule management processes proposed in the PMBOK Guide (Project Management Institute, 2017) is to explore the managerial flexibilities already existing in the so-called 'traditional' agents of the project scheduling. It is believed that the findings and the literature knowledge obtained through this chapter will open a window as a first step towards the development of a hybrid approach to be used for the management of CPM schedules in complex construction projects under uncertainty.

The managerial flexibilities provided by CPM were evaluated at three levels, i.e. activity, path, and project, first conceptually, then through two different example CPM applications. The results of the study have introduced three important findings. Firstly, CPM, in spite of its criticized deterministic features, contains various flexible aspects from a managerial viewpoint. Secondly, potential flexibilities in CPM are mainly associated with its features including, but are not limited to, resource levelling, uncritical activities, uncritical paths, activity float times, activity float types, and float times of uncritical paths. Thirdly, CPM contains complete flexibility through independent activity floats and resource levelling capability. However, the managerial flexibilities of CPM are not limited with these features. Some of the other capabilities of CPM creating flexibility from the managerial perspective are project compression (schedule crashing and fast-tracking), time-cost trade-off analysis (optimization), delay analysis, float allocation, dispute resolution, schedule risk analysis, what-if analysis, updateability via CPM based scheduling software, monitoring and control (Earned Value Method and S-Curve analysis), integration with linear scheduling method, multi-calendar analysis, preparation of reports at various detail levels by means of scheduling software, and etc. The discussion on CPM also has revealed that CPM is not as rigid as it is assumed as far as the manager using it is aware of the means of benefitting from its flexible features. For instance, it is important to make the required distinction between the activity float types in a CPM network schedule, i.e. total, free, shared, and independent floats. While total float times belonging to noncritical activities are probably the most well-known aspect of CPM to the practitioners, the free, shared and independent floats that the total floats contain should not be disregarded and overlooked during the schedule management so that any wrong usage of the activity float times is avoided. Otherwise, the number of critical activities would increase and the schedules would face the risk of overrunning the target durations. Such critical points regarding the correctly utilisation of the flexibilities of CPM also have been discussed.

The second part of the chapter, in which the PMBOK Guide was examined from the scheduling perspective, also provided important findings that will be benefitted in the upcoming chapters. Firstly, it is concluded that the general view of the PMBOK Guide on project schedule management, which has been disclosed as being dominantly of a traditional, predictive and plan-driven character, can be taken as a pivot point on which the final product of the research can be built upon, i.e. a more flexible CPM-based schedule management approach to be used under complex, uncertain and dynamic conditions. Unexpectedly, the most important finding related with the PMBOK Guide has been the fact that, in spite of the criticism it attracts from the literature for being too traditional, the PMBOK Guide indeed acknowledges the need for a flexible paradigm change in project management in its 6th edition (Project Management Institute, 2017) and alternatively recommends the implementation of the life cycle phases of a project through an agile (adaptable), iterative, incremental, overlapping or hybrid approach depending on the project conditions (Project Management Institute, 2017). In some manner, PMBOK Guide recognises the current need for an adaptable (agile) and change-driven approach in project management based on the "prepare and commit" principle even though the means of how to achieve it were not sufficiently clarified. As a result, the project schedule management processes and the recent recommendations made regarding the adaptable approaches in the PMBOK Guide have flexible features worth of being benefitted in the remaining parts of the research.

4 MANAGERIAL FLEXIBILITIES OF CPM UNDER UNCERTAINTY AND PROJECT RISK MANAGEMENT PROCESSES

Throughout this research, the ‘flexibility’ in project management is conceptually perceived as “the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions”. In Chapter 3, the research problem stated in Chapter 1 has been handled from the viewpoint of the traditional project management, firstly by evaluating the managerial flexibilities provided by the traditional CPM scheduling, and then by discussing the processes put forward in the PMBOK Guide with regards to the project schedule management knowledge area of project management. Now, in Chapter 4, the research problem will be handled from the framework of ‘uncertainty’, which is one of the components in the abovementioned definition of flexibility. The questions raised are;

- in what way the uncertainties and project risks influence the CPM based schedules,
- how the managerial flexibilities provided by CPM can be expanded to be utilised under uncertainty,
- and how the schedule risks will be managed within the scope of project risk management.

In order to bring up answers to these questions, firstly, in the first section, CPM will be applied within the framework of the Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen & Öztaş, 2008). By the implementation of CSRAM and comparing the results obtained against the results of CPM, the expansion of managerial flexibilities in CPM will have been evaluated. Next, in the second section, the processes defined within the project risk management knowledge area of project management in the PMBOK Guide (Project Management Institute, 2017) will be examined from both the scheduling and flexibility perspectives in order to explore the means of connecting the traditional project schedule management to the complexity incorporated project risk management over which a more flexible project schedule management could be built.

The subject of incorporation of the ‘complexity’ into the risk management will be discussed in the next chapter. Furthermore, another purpose in the current chapter is to show the fact that the implementation of standard risk analysis procedures such as probability-impact matrices (Project Management Institute, 2017) become inappropriate and insufficient to analyse the impacts of risks on the schedules and in turn, especially complex construction projects scheduled by CPM require the utilisation of advanced risk analysis models that simulate the complex and uncertain conditions of real life as much as possible. Main argument is that the usage of simulation based schedule risk analysis models would help manage the schedules of complex projects more flexibly.

4.1 EVALUATION OF EXPANSION IN MANAGERIAL FLEXIBILITIES OF CPM UNDER UNCERTAINTY

Scheduling of a construction project in which the project activities can be combined with each other in the form of an activity network by the utilisation of the relationships given in Figure 3.1 along with the assignment of lag or lead times between activities in case of any requirement can be done by using the traditional method of construction scheduling, i.e. the Critical Path Method (CPM) (Newitt, 2009; Oberlender, 2014). In construction projects, various resources are used to realise the tasks. These resources can be categorised in terms of time, cost, labour, materials, and equipment. On the condition that it is used in full manner, a CPM schedule may turn into a tool not only for managing the *time* but also for managing the other resources. In other words, a CPM schedule can be used either as a time, cost, labour or equipment schedule depending on the requirements. Furthermore, it turns into a project control tool when used together with project control methods such as the EVM and S-Curve (Progress) Analysis (Del Pico, 2013).

In spite of the advantages that CPM provides to manage the projects properly, it has a distinct shortcoming. It is not capable of reflecting the influence of uncertainty on the schedules due to its rigid deterministic nature (Ammar, 2013; Jaafari, 1984; Koskela *et al.* 2014; Ökmen & Öztaş, 2008, Zhou *et al.* 2013). In reality, all the information generated by CPM are open to variation due to the risk-factors impacting the projects.

In other words, the information such as the project completion time, activity/path criticalities, activity float times, and early/late start/finish times of activities obtained by CPM indeed follow a stochastic pattern and therefore they may vary during the execution of a project. In order to overcome this shortcoming, a quite few studies have been conducted by the researchers. A great majority of these studies tried to insert risk analysis capability onto CPM by using probability and statistics, fuzzy set theory, and simulation techniques (Woolery & Crandall, 1983; Ahuja & Nandakumar, 1985; Pohl & Chapman, 1987; Wang & Demsetz, 2000; Öztaş & Ökmen, 2005; Ökmen & Öztaş, 2008; Ökmen & Öztaş, 2014). However, the importance of CPM has never been disregarded in these studies, rather CPM has been tried to be improved to cope with the uncertain, complex and dynamic conditions existing in the construction projects.

Today's construction projects need for methods and tools, which are relatively more flexible from the managerial point of view in order to achieve success in complex, dynamic and highly uncertain project conditions. In this context, this section aims at investigating the expansion of the managerial flexibilities of CPM in case it is integrated with Monte Carlo Simulation (MCS) for the purpose of converting it to a schedule risk analysis tool. This will be achieved by means of a previously developed CPM and MCS based risk simulation model called the Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen, 2008; Ökmen & Öztaş, 2008). Succeeding an explanation of the CSRAM, how the flexibility capacity of CPM can be improved through implementing this model is discussed conceptually. Subsequently, an illustrative CSRAM application will be introduced in order to evaluate the expansion in managerial flexibilities of CPM scheduling under uncertainty.

Prior to introducing the details of CSRAM, it is worth remembering the managerial flexibilities inherent with the traditional CPM scheduling shortly, which was discussed in the previous chapter at three different levels, i.e. activity, path, and project levels. In this section, the same multi-level approach will be followed to evaluate the expansion in flexibilities of CPM.

Activity-level flexibility is associated with the floats or float times of the noncritical activities in a CPM activity network. The floats can be categorised as total, free, shared and independent. The float time of an activity represents the flexibility associated with that activity in terms of the time interval for which the execution of this activity can be skipped or extended without causing any delay on the project completion time as well as on the early start times of the successors of that activity.

Path-level flexibility is associated with the float times of the noncritical paths in a CPM activity network. Noncritical paths possess float times due to the noncritical activities lying on these paths. Accordingly, the float of a path could be consumed in agreement with the float times and float categories of the noncritical activities on that path.

Project-level flexibility is associated with the various capabilities of CPM including, but are not limited to, resource levelling, resource transferring, project compression (schedule crashing and fast-tracking), time-cost trade-off analysis (optimization), delay analysis, float allocation, dispute resolution, schedule risk analysis, what-if analysis, updateability via CPM based scheduling software, and monitoring and control through techniques like Earned Value Method and S-Curve analysis.

4.1.1 Correlated Schedule Risk Analysis Model (CSRAM)

CSRAM is a schedule risk analysis method that can be used in the risk management process of construction projects (Ökmen & Öztaş, 2008). The method was built upon the integration of MCS into CPM. MCS is a simulation technique, which is used to carry out quantitative risk analysis by means of spreadsheet software specifically developed for this purpose such as @Risk® and Crystal Ball®. It becomes possible to model different project aspect such as the cost estimations and time schedules by simulating the real life conditions in a stochastic way through MCS by means of such software, which otherwise would be almost impossible to do analytically (Ökmen & Öztaş, 2008).

MCS produces random variables in agreement with the statistical characteristics of the input data by the help of the algorithms embedded within CSRAM. At the end of each MCS run containing a sufficiently high number of successive CPM applications, a series of statistical data is obtained regarding the variations on different project aspects, presumably which might happen during the project execution due to uncertainty. In this regard, MCS was integrated to CPM in order to gain the capability of simulating the uncertain conditions of real life through running the CPM algorithm as many as needed by randomly produced data, for example tens of thousands times or even more. Each CPM run generated through MCS within CSRAM reflects a different situation for the project. In other words, risk-factors that are assumed to affect a project follows a different impact trend in each CPM run during the simulation. However, the data used in each CPM run is selected randomly by CSRAM by concurrently taking the correlations between the activities and between the risk-factors into account through using qualitative data entered to enable CSRAM capture the correlations indirectly, i.e. without directly requesting correlation coefficients, which are generally difficult to determine accurately due to the insufficiency of data belonging to previously completed projects possessing similar features (Ökmen & Öztaş, 2008).

While the correlations between activities occur in case a specific risk-factor influences more than one activity in a CPM network, correlations between risk-factors occur when more than one risk-factor influence that CPM network in agreement with each other. For instance, an unexpected situation associated with weather conditions may affect some of the activities, which will be performed outside on a construction site. In this case, we can discuss about the existence of correlation between these activities with respect to the ‘weather conditions' risk-factor. For instance, in case it is assumed that the ‘labour productivity’ risk behaves in line with the ‘weather conditions’ risk (which is an expected situation most of the time, i.e. as the weather conditions gets worse, labour productivity drops down on a construction site), then we can also talk about the existence of a correlation between these two risk-factors. Such two-sided correlations may amplify the intensity of uncertainty on CPM schedules. Therefore, neglecting the correlations between the activities and between the risk-factors would lead to inaccurate results with regard to the effects of uncertainties on a CPM schedule (Ökmen & Öztaş, 2008).

In accordance with this fact, CSRAM has been donated with the capability of modelling the aforementioned two-sided correlation effect. As mentioned above, the model utilises the qualitative data entered in order to randomly select the activity durations that will be used in each CPM run. Since CSRAM is a stochastic extension of CPM, the activity durations are identified to CSRAM in the form of three duration estimations, i.e. most likely, minimum (optimistic) and maximum (pessimistic), instead of single duration estimates as in the case of CPM, so that CSRAM selects the activity durations randomly from the time intervals constituted in between these estimated three duration values in agreement with the submitted risk and correlation information (Ökmen & Öztaş, 2008).

Figure 4.1 illustrates the input-output chain of the CSRAM to clarify the descriptions introduced up to now (Ökmen & Öztaş, 2008). Subsequently, the flowchart of a typical CSRAM simulation is illustrated in Figure 4.2 (Ökmen & Öztaş, 2008). As it can be observed on these figures, CSRAM simulation is an iterative schedule risk analysis process based on CPM and MCS converging to statistical results in the end.

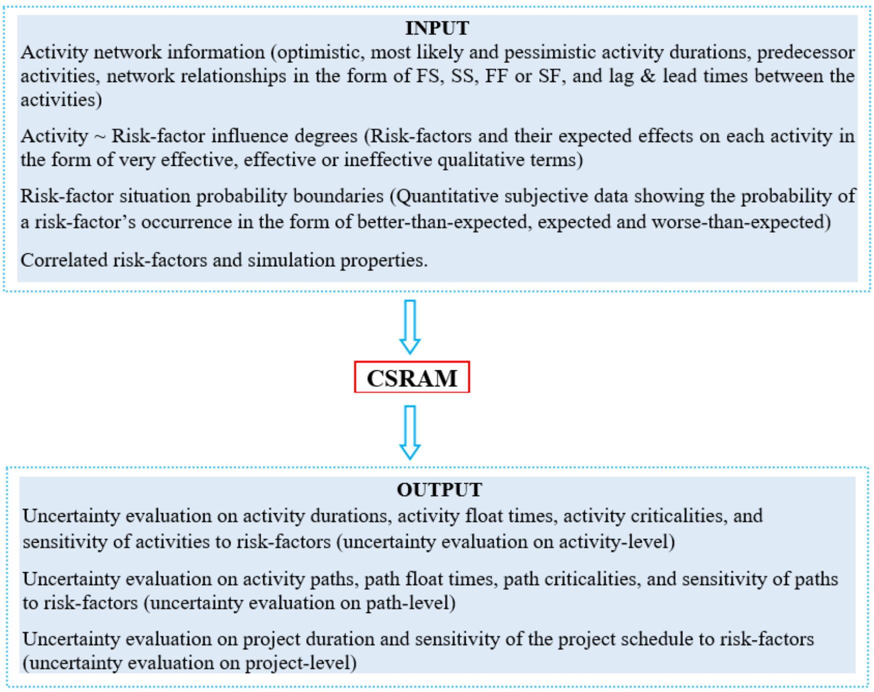

Figure 4.1 Input-Output chain of CSRAM (adapted from Ökmen & Öztaş, 2008)

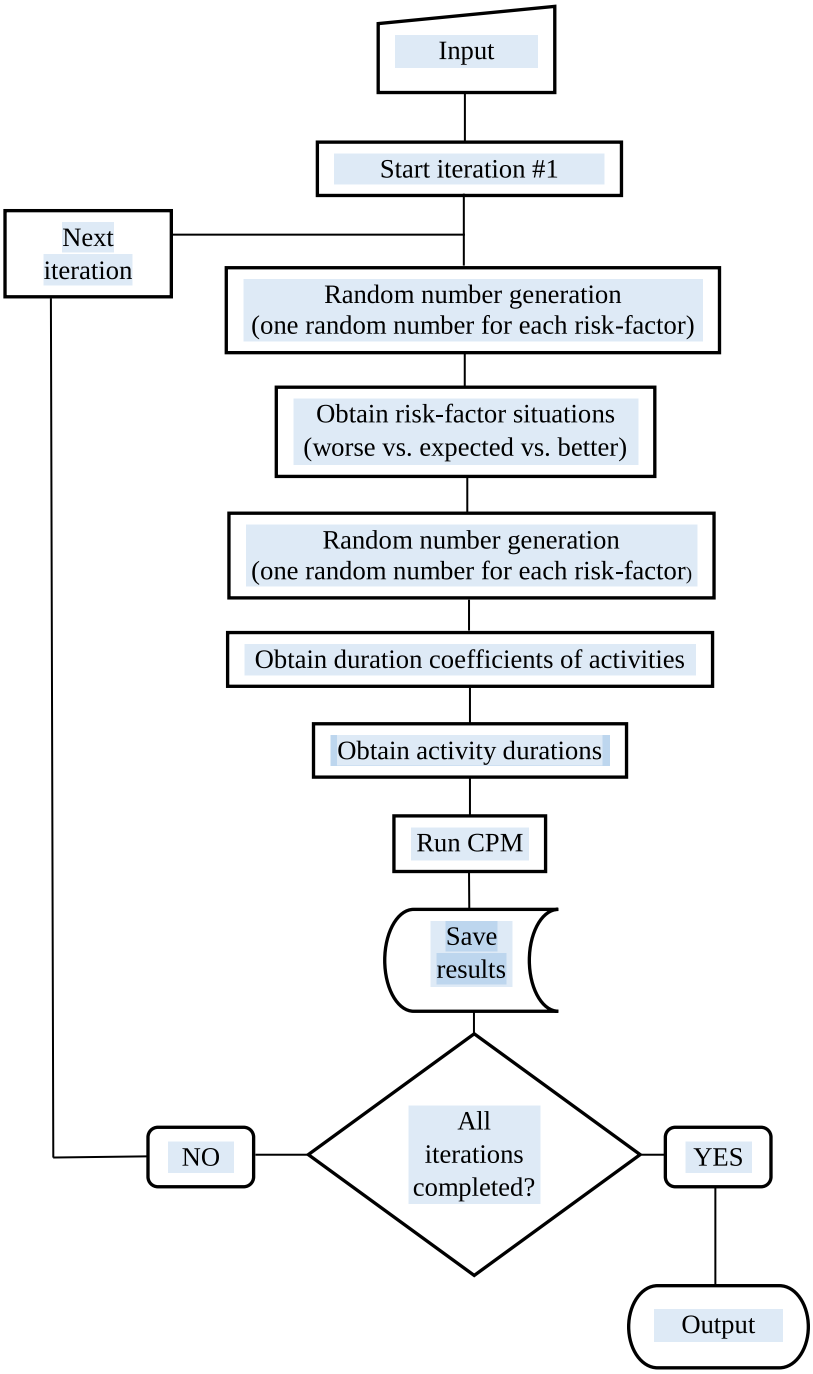

Figure 4.2 Flowchart of CSRAM (adapted from Ökmen & Öztaş, 2008)

A view of the spreadsheet prepared for the computerisation of CSRAM by using MS Excel and @Risk software programs is shown in Figure 4.3 (Ökmen, 2008). Detailed information about the CSRAM and its computerisation can be found in Ökmen & Öztaş (2008) and Ökmen (2008).

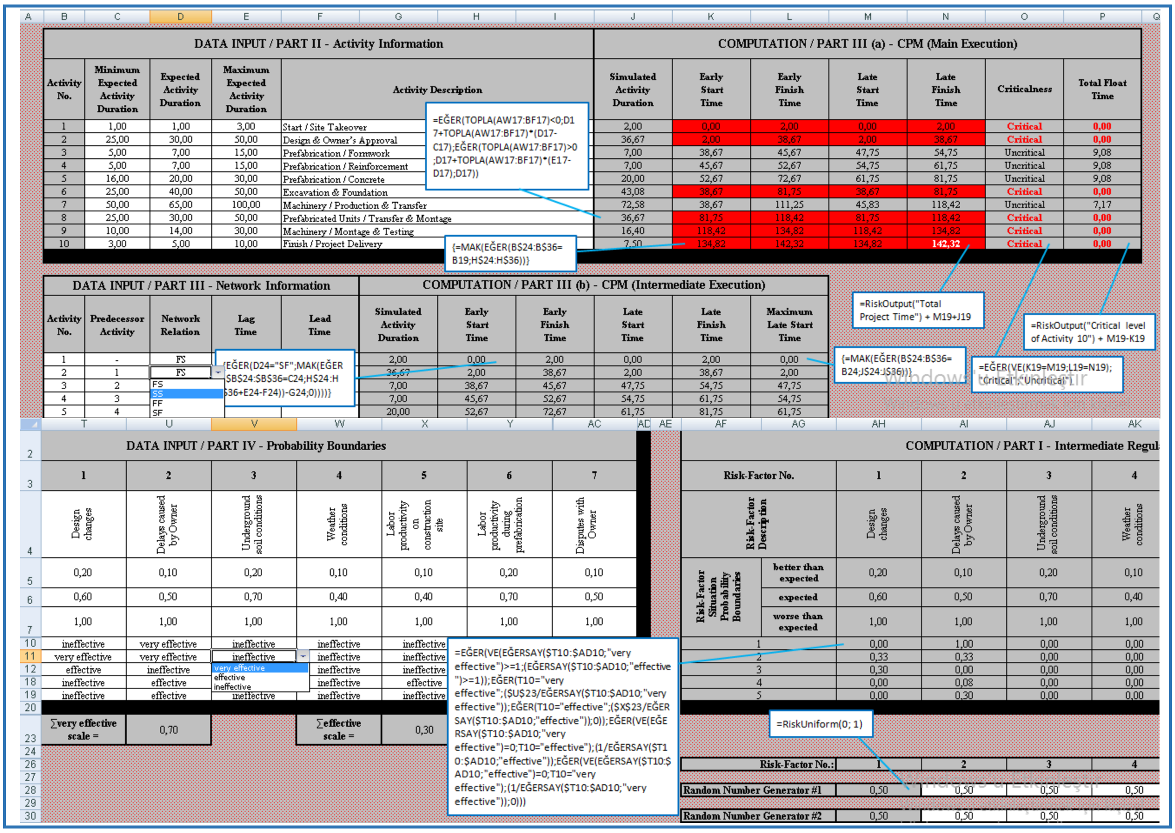

Figure 4.3 A view from the computerized CSRAM on MS Excel spreadsheet (Ökmen, 2008)

The next subsection introduces an example application to show how the managerial flexibilities expand under uncertainty in practice compared to traditional CPM when CPM is implemented through CSRAM.

4.1.2 An Example Application

The example application is carried out on an illustrative project containing the design and construction of a production plant on behalf of a client based on a turnkey contract system, i.e. the contractor undertakes the full responsibility of design, procurement and construction and delivers the fully functioning facility to the client in the end. Furthermore, it is assumed that the payment scheme in the contract is the ‘cost-plus-fixed fee with guaranteed maximum cost’ and the contract contains some terms that allow a bonus payment to the contractor if the project is delivered earlier than the contractually negotiated duration. However, the contract also declares the execution of a financial penalty to the contractor in case of a non-excusable delay caused in the timely delivery of the project.

The contractor starts with envisaging the activity network data to be used for preparing the CPM schedule of the project. The data in question has been given in Table 4.1. The activity durations mentioned in Table 4.1 also represent the estimated values for the most-likely (expected) durations. In other words, the data in Table 1 is not only used in the execution of traditional CPM but also during the CSRAM application for the reason CPM is implemented repetitively through the MCS iterations in CSRAM.

In this section, firstly, the CPM and CSRAM applications assumed to be conducted by the contractor before signing the contract are introduced. Then, the section continues with disclosing how the results obtained through these two applications affect the decisions taken by the contractor. Finally, the results in terms of the managerial flexibilities obtained by the CPM and CSRAM applications and how these flexibilities can be utilized by the contractor are compared and discussed, respectively.

The time schedule of the project assumed to be prepared by the contractor through CPM's forward/backward pass algorithm is illustrated on the activity-on-node network diagram shown in Figure 4.4. The reader is referred to Newitt (2009) and Oberlender (2014) for detailed explanations on the algorithm and computation procedures of CPM. The representation of the data in the quadrilaterals is indicated by the "activity notation". The CPM application has revealed that:

- The activities A, B, F, H, I, and J are the critical activities having no float times (shown by red quadrilaterals in Figure 4.4) ,
- The activities C, D, E, and G are the noncritical activities having float times,
- The path 1 (A–B–C–D–E–H–I–J) and path 3 (A–B–G–I–J) are the noncritical paths,
- The path 2 (A–B–F–H–I–J) is the critical path.

The total, free, shared, and independent float times of the activities, float sharing activities, float times of the paths, and the criticalities of the activities and the paths are given in Table 4.2. As shown in Figure 4.4, the shortest possible project completion time is 120 days (which is equal to the late finish time of the last activity) according to CPM.

The contractor estimates the activity durations used during the CPM application based on his/her previous experience and in compliance with the available resources. Therefore, the shortest possible project duration, which is 120 days and other content presented in Table 4.2 are all insulated from the risk-factors that may affect the project. Therefore, the contractor appeals to CSRAM before negotiating the details of the contract in terms of project completion (delivery) time, risk allocations and float usage entitlements, which would also affect the managerial flexibilities.

Table 4.1 Activity network data used in CPM application on the example project

Activity Label	Activity Description	Activity Duration (day)	Predecessor Activity	Network Relationship
A	Start / Site Takeover	1	-	-
B	Design & Owner's Approval	30	A	FS
C	Prefabrication / Formwork	7	B	FS
D	Prefabrication / Reinforcement	7	C	FS
E	Prefabrication / Concrete	20	D	FS
F	Excavation & Foundation	40	B	FS
G	Machinery / Production & Transfer	65	B	FS
H	Prefabricated Units / Transfer & Montage	30	E & F	FS
I	Machinery / Montage & Testing	14	H & G	FS
J	Finish / Project Delivery	5	I	FS

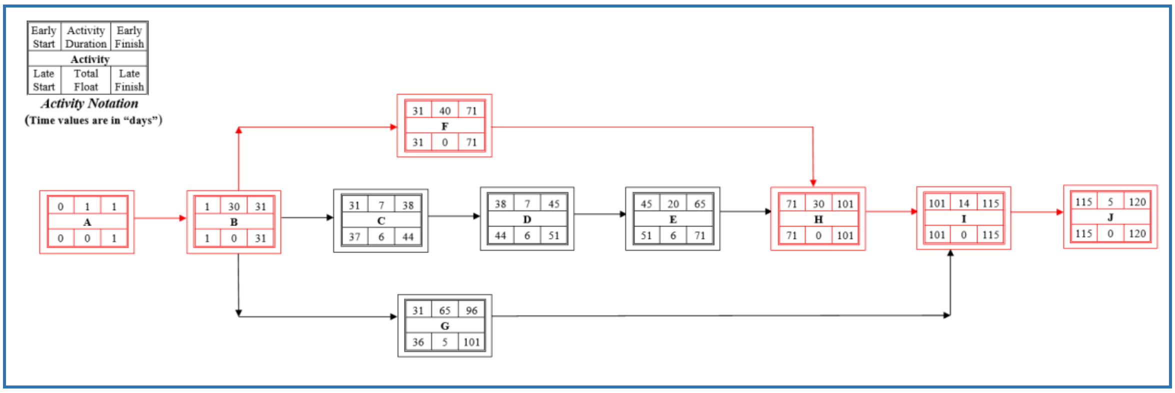

Figure 4.4 Activity-on-node network diagram of the example project

It is assumed that the contactor utilises the data given in Table 4.3 during the execution of CSRAM on the project. The activity durations used during the CPM application before are accepted as the most-likely durations in CSRAM application. Besides, the minimum (optimistic) and maximum (pessimistic) activity durations have been estimated and in turn the activity durations have been represented by using these three time estimations. The network and predecessor relationships between the activities used in CPM application given in Table 4.1 are used also in CSRAM application. Furthermore, major risk-factors that might be affective on the schedule have been determined along with their individual influence degrees in the form of effective (E), very effective (VE), and ineffective (IE) qualitative terms and risk-factor situation probability boundary values in the form of better-than-expected, expected and worse-than-expected quantitative terms (refer to Figure 4.1) (Ökmen & Öztaş, 2008). Table 4.3 contains the MCS preferences to be used during CSRAM application. The iteration number was selected as 10000, which is sufficiently a high value in order to provide the required precision on the results. Moreover, it is estimated that the risk-factors 2 and 10, and 4 and 5 have positive correlations in between. Therefore, the correlation between risk-factors have been defined to CSRAM accordingly based on this assumption.

Table 4.2 Results of CPM application on the example project

Activity/ Path No.	Free Float Time*	Shared Float Time	Independent Float Time	Total Float Time	Float Sharing Activity	Path Float Time	Criticality
A	0	0	0	0	-	N/A	Critical
B	0	0	0	0	-	N/A	Critical
C	0	6	0	6	D & E	N/A	Noncritical
D	0	6	0	6	C & E	N/A	Noncritical
E	6	6	0	6	C & D	N/A	Noncritical
F	0	0	0	0	-	N/A	Critical
G	5	0	5	5	-	N/A	Noncritical
H	0	0	0	0	-	N/A	Critical
I	0	0	0	0	-	N/A	Critical
J	0	0	0	0	-		Critical
Path 1	N/A	N/A	N/A	N/A	N/A	6	Noncritical
Path 2	N/A	N/A	N/A	N/A	N/A	0	Critical
Path 3	N/A	N/A	N/A	N/A	N/A	5	Noncritical

*All time values are given in “days”.

In order to execute the CSRAM, firstly, CPM and CSRAM have been formulated on MS Excel spreadsheet (refer to Figure 4.3). Then, by the help of @Risk Software, MCS was performed and statistical results were obtained. The results of CSRAM application are given in Figure 4.5, and in Tables 4.4, 4.5, and 4.6, respectively. Figure 4.5 shows the graph of the cumulative probability distribution with regard to the project completion time along with some statistical information in a tabular format next to the graph. Table 4.4 presents the results regarding the project duration uncertainty and project/risk-factor sensitivity. Next, Table 4.5 introduces the results regarding the uncertainty in floats and criticalities. Finally, Table 4.6 gives the results regarding the path float uncertainty and path/risk-factor sensitivity.

Table 4.3 Data used in CSRAM application on the example project

		Risk-factors, Risk-factor situation probability boundaries & Activity / Risk-factor influence degrees[*]									
MCS Iteration Number 10000 **Correlated Risk-factors:** 2 & 10; 4 & 5		1- Design changes	2- Delays caused by Owner	3- Underground soil conditions	4- Weather conditions	5- Labor productivity on construction site	6- Labor productivity during prefabrication	7- Delays caused by Supplier	8- Design & montage faults on construction site	9- Malfunctioning of machinery during testing	10- Disputes with Owner
Risk-factor Situations	Better-than-expected	0.20	0.10	0.20	0.10	0.10	0.20	0.20	0.30	0.40	0.10
	Expected	0.60	0.50	0.70	0.40	0.40	0.70	0.40	0.60	0.70	0.50
	Worse-than-expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Activities & Activity Durations in days (Minimum Expected / Most likely / Maximum Expected)	A 1 / 1 / 3	IE	VE	IE	IE	IE	IE	IE	IE	IE	IE
	B 25 / 30 / 50	VE	VE	IE	IE	IE	IE	IE	IE	IE	VE
	C 5 / 7 / 15	E	IE	IE	IE	IE	VE	IE	IE	IE	IE
	D 5 / 7 / 15	E	IE	IE	IE	IE	VE	IE	IE	IE	IE
	E 16 / 20 / 30	E	IE	IE	IE	IE	VE	IE	IE	IE	IE
	F 25 / 40 / 50	E	E	VE	VE	VE	IE	IE	IE	IE	IE
	G 50 / 65 / 100	E	E	IE	E	IE	IE	VE	VE	VE	IE
	H 25 / 30 / 50	IE	IE	IE	VE	VE	IE	IE	VE	IE	IE
	I 10 / 14 / 30	IE	E	IE	IE	E	IE	E	VE	VE	E
	J 3 / 5 / 10	IE	E	IE	IE	IE	IE	IE	IE	IE	VE

[*]E: effective, VE: very effective, IE: ineffective

Figure 4.5 Results of CPM and CSRAM applications on project duration uncertainty

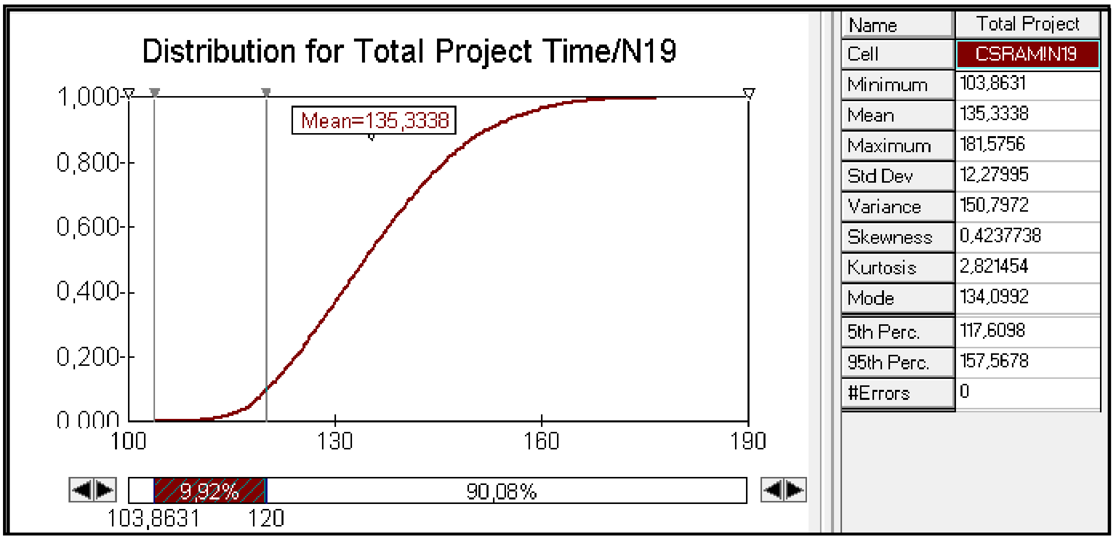

Table 4.4 Results of CSRAM for the uncertainty on project duration and sensitivity of the project to the risk-factors

Scenario	Minimum Project Duration (day)	Mean Project Duration (day)	Maximum Project Duration (day)	Standard Deviation of Project Duration	Coefficient of Variation	Sensitivity Rank
All Risk-Factors	103,86	135,33	181,58	12,28	0,09	-
Risk-Factor 1	116,09	121,22	128,46	2,87	0,02	3
Risk-Factors 2 ~ 10 (Correlated)	111,82	125,59	144,23	8,16	0,06	1
Risk-Factors 3	116,50	120,01	122,33	1,16	0,01	4
Risk-Factor 4 ~ 5 (Correlated)	113,20	125,18	139,20	6,90	0,06	1
Risk-Factor 6	120,00	121,20	132,19	2,90	0,02	3
Risk-Factor 7	119,70	120,70	124,37	1,18	0,01	4
Risk-Factor 8	116,93	121,98	132,27	4,09	0,03	2
Risk-Factor 9	118,60	120,75	128,76	2,27	0,02	3

Table 4.5 Results of CSRAM application on uncertainty in floats and criticalities

Activity/ Path No.	Free Float Time*	Shared Float Time	Independent Float Time	Total Float Time	Path Float Time	Float Sharing Activity	Criticality	Uncertainty in Criticality
	(Minimum / Mean / Maximum)							
A	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	-	-	Critical	-
B	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	-	-	Critical	-
C	0,00/0,00 /0,00	0,00/6,19 /23,14	0,00/0,00 /0,00	0,00/6,19 /23,14	-	D & E	Near Critical	High
D	0,00/0,00 /0,00	0,00/6,19 /23,14	0,00/0,00 /0,00	0,00/6,19 /23,14	-	C & E	Near Critical	High
E	0,00/0,00 /0,00	0,00/6,19 /23,14	0,00/0,00 /0,00	0,00/6,19 /23,14	-	C & D	Near Critical	High
F	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00 / 1,74/23,65	-	-	Near Critical	High
G	0,00/8,39 /34,76	0,00/0,00 /0,00	0,00/8,39 /34,76	0,00/8,39 /34,76	-	-	Near Critical	High
H	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,55 /17,33	-	-	Near Critical	High
I	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00 / 0,00 /0,00	-	-	Critical	-
J	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00/0,00 /0,00	0,00 / 0,00 /0,00	-	-	Critical	-
Path 1	-	-	-	-	0,00 / 6,19/23,16	-	Near Critical	High
Path 2	-	-	-	-	0,00 / 1,74/23,65	-	Near Critical	High
Path 3	-	-	-	-	0,00 / 8,39/34,76	-	Near Critical	High

Table 4.6 Results of CSRAM application on path float uncertainty and path/risk-factor sensitivity

Path 1 / A - B - C - D - E - H - I - J							
Scenario	**Minimum Path Float (day)**	**Mean Path Float (day)**	**Maximum Path Float (day)**	**Mean Path Duration (day)**	**Standard Deviation of Path Duration**	**Coefficient of Variation of Path Duration**	**Sensitivity Rank**
All Risk-Factors	0,00	6,19	23,16	129,15	12,48	0,10	-
Risk-Factor 1	0,00	4,78	6,15	116,44	4,73	0,04	3
Risk-Factors 2 ~ 10 (Correlated)	3,75	6,26	7,50	119,33	7,55	0,06	1
Risk-Factors 3	2,50	6,01	8,33	114	0,00	0,00	-
Risk-Factor 4 ~ 5 (Correlated)	2,04	7,10	10,67	118,08	5,00	0,04	3
Risk-Factor 6	0,00	5,07	11,60	116,14	5,50	0,05	2
Risk-Factor 7	6,00	6,37	9,17	114,33	0,43	0,00	-
Risk-Factor 8	6,00	6,00	6,00	115,98	4,10	0,04	3
Risk-Factor 9	6,00	6,19	9,16	114,56	1,77	0,02	4

Path 2 / A - B - F - H - I - J							
Scenario	**Minimum Path Float (day)**	**Mean Path Float (day)**	**Maximum Path Float (day)**	**Mean Path Duration (day)**	**Standard Deviation of Path Duration**	**Coefficient of Variation of Path Duration**	**Sensitivity Rank**
All Risk-Factors	0,00	1,74	23,65	133,59	12,12	0,09	-
Risk-Factor 1	0,00	0,00	0,00	121,21	2,87	0,02	3
Risk-Factors 2 ~ 10 (Correlated)	0,00	0,00	0,00	125,59	8,16	0,06	1
Risk-Factors 3	0,00	0,00	0,00	120,01	1,16	0,01	4
Risk-Factor 4 ~ 5 (Correlated)	0,00	0,08	3,82	125,10	7,05	0,06	1
Risk-Factor 6	0,00	1,20	12,19	120,00	0,00	0,00	-
Risk-Factor 7	0,00	0,37	3,17	120,33	0,43	0,00	-
Risk-Factor 8	0,00	0,00	0,00	121,98	4,09	0,03	2
Risk-Factor 9	0,00	0,19	3,16	120,56	1,77	0,01	4

Path 3 / A - B - G - I – J							
Scenario	**Minimum Path Float (day)**	**Mean Path Float (day)**	**Maximum Path Float (day)**	**Mean Path Duration (day)**	**Standard Deviation of Path Duration**	**Coefficient of Variation of Path Duration**	**Sensitivity Rank**
All Risk-Factors	0,00	8,39	34,76	126,95	12,51	0,10	-
Risk-Factor 1	3,10	4,54	5,00	116,68	3,56	0,03	3
Risk-Factors 2 ~ 10 (Correlated)	3,00	4,47	5,00	121,12	8,75	0,07	1
Risk-Factors 3	1,50	5,01	7,33	115,00	0,00	0,00	-
Risk-Factor 4 ~ 5 (Correlated)	0,00	8,89	19,50	116,29	1,66	0,01	4
Risk-Factor 6	5,00	6,20	17,19	115,00	0,00	0,00	-
Risk-Factor 7	0,00	3,29	8,50	117,41	3,57	0,03	3
Risk-Factor 8	3,50	4,98	6,83	117,00	4,82	0,04	2
Risk-Factor 9	0,00	4,69	8,50	116,09	4,62	0,04	2

The managerial flexibilities supplied in case of CSRAM application when compared to the CPM application is discussed and evaluated below based on the results obtained through the example project. The evaluation is made from the contractor’s perspective;

first by considering the phase before signing the contract, second for the construction phase after contract signing.

At the end of CPM application, the project completion time was computed 120 days as shown in Figure 4.4. Furthermore, it was explored that path 2 (A - B - F - H - I – J**)** is critical and the paths 1 (A - B - C - D - E - H - I – J) and 3 (A - B - G - I – J) are noncritical paths. Table 4.2 contains different types of float times belonging to the activities and the float times possessed by the activity paths together with the criticalities of the activities and the paths. The distinguishing feature of these values is that they are completely invariable and deterministic values. Before signing the contract, the contractor has to negotiate with the client about how long after the start the project must be completed. Knowing that the project completion time is 120 days is quite misleading for the contractor before signing the contract because of the fact that this value is calculated by not taking into account the uncertainty and risks that might affect the project. In case of declaring the project delivery time as 120 days within the contract, the contractor might face with delay penalties during construction in case of any delay. Besides, managing the project by benefitting from the flexibilities provided by CPM associated with the activity and path float times similarly would mislead the contractor; this time during the construction phase, due to the same reason that these values may deviate from the expected values and cause a misleading sense of flexibility in terms of float usage and resource levelling. Since the contract is a turnkey cost-plus-fixed fee with guaranteed maximum cost type of contract, any ceiling amount for the project cost determined based on the 120 days of project duration may not only cause delay penalties but also may lead to a loss in the fixed fee that the contractor will be paid in the end because of overrunning the maximum guaranteed cost determined in the contract.

When the results obtained by the CSRAM application are examined, it can be recognised that the whole picture is highly complicated and different when compared with the situation that is drawn up by the traditional CPM. However, this complicated view fortunately provides various new flexibilities ready to be benefitted. The results of CSRAM application given in Figure 4.5 and Tables 4.4, 4.5, and 4.6 are discussed below at the activity, path and project levels both for the pre-contacting and construction project phases:

- Figure 4.5 shows the cumulative probability distribution explored by the CSRAM application regarding the uncertainty in project duration. On the same graph, the probability of completing the project within 120 days, which was previously calculated by the CPM application, is also shown. If the contractor negotiates on 120 days with the client as for the project completion time, he/she will has only 9.92% chance of completing the project within this duration. Indeed, this is relatively a low probability value. Thanks to the results obtained by CSRAM, the contractor has a flexibility in terms of decision-making to envisage the project completion time before signing the contract. It can be observed on Figure 4.5 that the project duration may vary from minimum approximately 104 days up to maximum approximately 182 days with a mean value of 135 days. The contractor has now the opportunity of determining a project duration based on the risk balance between time and cost in order to avoid a possible overrunning of the maximum guaranteed cost. By this way, the contractor may also get the chance of taking the bonus by completing the project before the negotiated contractual date. Regarding with this issue, no need to say the duration proposed by the contractor during the negotiations before signing the contract should be definitely greater than 120 days or better between 135 days and 182 days for the sake of being on the safe side. However, the contractor, depending on his/her general risk attitude, could alternatively enforce the limits to complete the project within or even below 120 days even though he/she negotiates on a longer project delivery duration in the contract. Such a flexibility of this kind, which can be categorised as a project-level flexibility, empowers the decision-making capability of the contractor before signing the contract and also the managing capability during the construction depending on the increase in the probability of completing the project in the scheduled duration.
- Table 4.4 contains the results that the CSRAM application provided on project duration uncertainty and project/risk- factor sensitivity. The sensitivity of the project to the risk-factors have been evaluated based on the coefficient of

variation values (the ratio of standard deviation to the mean) obtained by executing the CSRAM with turning on the risk-factor queried and turning off the other risk-factors in each sensitivity analysis case. In each case, during which the sensitivity is measured in terms of a single risk-factor or a correlated risk-factor pair separately, the minimum, maximum, mean and standard deviation of project duration have changed and the variation on the coefficient of variation statistic has disclosed the relative influence of the risk-factors on the project duration. As shown in Table 4.4, the most effective risk-factors on the schedule are the correlated risk-factors 2 and 10, i.e. 'Delays caused by Owner' and 'Disputes with Owner', respectively, the correlated risk-factors 4 and 5, i.e. 'Weather conditions' and 'Labor productivity on construction site', respectively, and the risk-factor 8, i.e. 'Design & montage faults on construction site'. Now, the contractor holds in hand the flexibility of being aware of the most effective risk-factors on the project duration. This is a critical information from the decision-making perspective during the pre-contracting stage and also important during construction in terms of controlling the processes in relation with these risk-factors with caution.

- Table 4.5 contains the results of CSRAM application regarding the uncertainty in floats and criticalities of the activities and the paths, separately. When the results of Table 4.5 are compared with the results in Table 4.2, which were obtained through the CPM application, it can be observed that all of the activities and paths have the potential of becoming critical during construction. However, while some of the activities have a high level of uncertainty with regard to criticality, in turn which can be considered as near-critical, some of them are always critical without no doubt when the difference between the maximum and minimum total float times are taken into account. A similar situation exists for also the paths. The variation observed on the path float times show that each path has the chance of being critical, near-critical or uncritical. Furthermore, uncertainty has also been encountered in terms of the other float types, i.e. free, shared and independent as the results given in Table 4.5 shows. Now, the question is, in what sense this information does have importance from the flexibility perspective. The difference between the float times obtained with respect to the project duration that would be negotiated between the client and contractor along with the target project duration that the contractor aims to complete the project to get the bonus payment will constitute an additional flexibility that can be benefitted by the contractor. For instance, if the client and the contractor negotiates on the 150 days of project completion time and the contractor gets aware of that it is also possible to finish the project within 120 days (the duration calculated through CPM application) by adopting the appropriate risk response strategies in line with the risk information provided through CSRAM, which are given in Tables 4.4, 4.5, and 4.6, the contractor would have more managerial flexibilities than expected in that case. Obviously, the solution put forward by CPM represents only a single cross-section among a quite many CPM possibilities, and managing the activity and path floats in line with being aware of the all possible cross-sections thanks to the CSRAM would create an expansion in managerial flexibilities besides getting the opportunity of taking the required risk mitigation measures.

- CSRAM discloses the risk-factor sensitivity both at project-level and path-level as the results given in Table 4.6 shows. In a CPM schedule, floats should not be considered only belonging to activities, rather they also belong to paths. In other words, there is a strong relationship between activity floats and path floats. The results in Table 4.6 show the risk sensitivities for each path respectively for each risk-factor through the rankings in terms of coefficient of variations calculated for the path floats. Furthermore, the contractual project duration will determine the path floats that the contractor will be able to consume. However, being aware of the minimum and maximum possible float values that may occur for each path in addition to the risk sensitivities would increase the managerial flexibilities of the contractor during the construction phase with respect to resource levelling among the noncritical activities, schedule crashing through the critical activities and resource transferring from the noncritical activities to critical activities, which can be utilized in case of any requirement by benefitting from the path float times.

4.2 DISCUSSION OF PROJECT RISK MANAGEMENT PROCESSES PROPOSED BY PMBOK GUIDE FROM THE PERSPECTIVE OF SCHEDULING

In this section, the processes defined within the scope of project risk management knowledge area of project management in the PMBOK Guide (Project Management Institute, 2017) will be examined from the scheduling and flexibility perspectives in order to explore the means of connecting the traditional project schedule management to the complexity incorporated project risk management over which a more flexible (hybrid) project schedule management could be built. As previously mentioned, the incorporation of the 'complexity' into the risk management will be handled in the next chapter. Besides the PMBOK Guide, Construction Extension to the PMBOK Guide (Project Management Institute, 2016) and Practice Standard for Project Risk Management (Project Management Institute, 2009) are also taken into account during the discussion in this section.

According to the PMBOK Guide, the project risk management knowledge area includes the processes; risk management planning, risk identification, risk analysis, risk response planning, risk response implementation, and monitoring risk on a project as shown in Figure 4.6 (Project Management Institute, 2017, pp. 396). The processes related to the project risk management knowledge area can be observed in the form of "input-tools & techniques-output" on this figure (Project Management Institute, 2017). It should be mentioned that the inputs and outputs belonging to these processes have also connections with the other processes included into other knowledge areas. In some manner, the PMBOK Guide draws a network that is composed of various project management processes in order to establish an actual picture of the complicated structure of project management as much as possible.

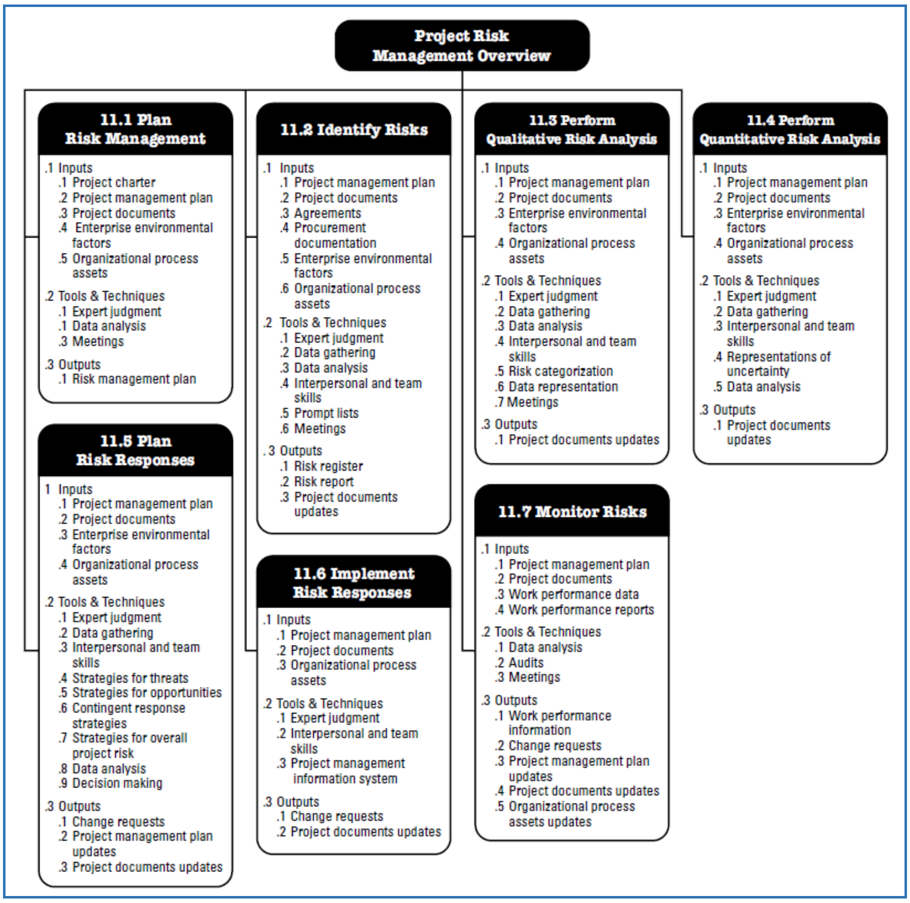

Figure 4.6 The overview of PMBOK Guide on Project Risk Management (Project Management Institute, 2017, pp.396)

PMBOK Guide has a two-sided perspective on the individual project risks, i.e. it assumes that the risks could have either positive (opportunity) or negative (threat) effect on the project (Project Management Institute, 2017). As previously discussed in the previous chapters (refer to Figure 1.2), this approach is indeed compatible with the approach adopted for the complexity problem in the literature by the researchers like Bosch-Rekveldt *et al*. (2014) who suggest a more positive approach, i.e. embracing complexity by considering it as an opportunity instead of seeing the complexity completely as a threat. The similarity in question between the two approaches in terms of risk and complexity, respectively, will be utilised in the next section during the incorporation of complexity assessment into project risk management processes.

The PMBOK Guide recommends the implementation of the risk management processes during the lifetime of the projects in an iterative way instead of applying them only at the beginning of the projects during planning, conception or feasibility phases. This recommendation also carries importance from the flexible project management perspective. In a project environment where the flexibility is required to cope with complexity, uncertainty and dynamism, not only the style of managing the schedule but also the style of managing the project risks need to be sufficiently adaptable and iterative. In this sense, in spite of the fact that the general overview existing throughout the PMBOK Guide, which is dominantly traditional, is also observed on its approach to the project risk management as shown in the stepwise procedure in Figure 4.7, current need for incorporating additional features to the traditional way of project risk management in order to convert it to a more flexible and adaptive process has also been acknowledged by the PMBOK Guide. The approach proposed by the PMBOK Guide, i.e. while being traditional, being open to development in terms of flexibility at the same time (Project Management Institute, 2017), is assumed to be useful in incorporating flexibility to traditional project risk management. Therefore, this approach will be further elaborated and utilised in the upcoming chapters for the development of the hybrid approach carrying both traditional and flexible features to be used in managing the CPM based project schedules, which is the final purpose of this research (refer to Chapter 1).

When the processes related with the project risk management proposed in the PMBOK Guide (Project Management Institute, 2017) and the Construction Extension to the PMBOK Guide (Project Management Institute, 2016) are evaluated from the scheduling perspective, it is observed that the necessary tools that could be required for the realisation of the main purpose of this research mentioned above already have been emphasized, especially within the processes related to risk analysis. For instance, the usage of the quantitative risk analysis is mostly recommended in large-scale complex construction projects (Project Management Institute, 2016). Furthermore, The PMBOK Guide recommends the usage of the Monte Carlo Simulation in case stochastic schedule analysis is required (Project Management Institute, 2016). This remark reminds the CSRAM, the MCS based schedule risk analysis model, which was explained and used for evaluating the expansion of flexibilities in CPM scheduling under uncertainty in the previous section within this chapter. In this respect, as a first step, building the complexity incorporated flexible project risk management process on CPM scheduling, and then in the second step, by moving from the point arrived at this first step, finally proposing the hybrid schedule management approach will be the procedure that will be followed in the upcoming chapters.

4.3 CONCLUDING REMARKS

In this chapter, CPM has continued to stand at the centre of the research. This time, different from the previous chapter, it is aimed at finding out the ways of flexibly managing the CPM based schedules in complex construction projects under uncertain and frequently changing dynamic conditions. As a step towards the achievement of this purpose, the preceding chapter, Chapter 3, firstly introduced the potential managerial flexibilities inherent with the traditional CPM scheduling. Next, the chapter continued with expanding the subject from method-level to process-level, i.e. from CPM to Project Schedule Management. This second part of the discussion was performed based on the processes proposed related with the project schedule management in the last version of the PMBOK Guide (the 6th edition) (Project Management Institute, 2017). The purpose of evaluating the flexibility concept first at method-level based on the CPM and then at process-level based on the project schedule management processes proposed in the PMBOK Guide (Project Management Institute, 2017) was to explore the managerial flexibilities already existing in the so-called ‘traditional’ agents of the project scheduling. By this way, the research problem stated in Chapter 1 has been handled from the viewpoint of the traditional project management, firstly by evaluating the managerial flexibilities provided by the traditional CPM scheduling, and then by discussing the processes put forward in the PMBOK Guide with regards to the project schedule management knowledge area of project management (Project Management Institute, 2017). Now, in Chapter 4, the problem has been carried to the project risk management knowledge area of project management (Project Management Institute, 2017) for the purpose of handling the ‘uncertainty’ component of the definition of ‘flexibility’. The findings obtained can be aggregated in line with the three main questions raised at the beginning of the chapter, which were;

- in what way the uncertainties and project risks influence the CPM based schedules,
- how the managerial flexibilities provided by CPM can be expanded to be utilised under uncertainty,
- and how the schedule risks will be managed within the scope of project risk management.

In order to bring up answers to these questions, firstly, in the first section, CPM was applied within the framework of a previously developed schedule risk analysis model called the Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen & Öztaş, 2008). By the implementation of CSRAM and comparing the results obtained against the results of CPM, the expansion of managerial flexibilities in CPM have been evaluated. Since the flexibilities in traditional CPM were evaluated at three levels in Chapter 3, i.e. activity, path and project levels, the same multi-level approach has been implemented also in this chapter to evaluate the expansion in flexibilities of CPM under uncertainty in case CPM is applied within the frame of CSRAM. The evaluation in question has been performed on an illustrative example project and the results have been discussed in detail. Finally, it was shown that even on such a relatively simplified project examined, the managerial flexibilities provided by CPM expands in various directions at different levels, i.e. activity, path and project levels, in case it is implemented by taking the uncertainty and risks into account through the utilisation of CSRAM.

Next, in the second section, the processes defined within the project risk management knowledge area of project management in the PMBOK Guide (Project Management Institute, 2017) have been examined from both the scheduling and flexibility perspectives. The findings obtained essentially reveal that the implementation of standard and traditional risk analysis procedures such as probability-impact matrices (Project Management Institute, 2017) become inappropriate and insufficient to analyse the impacts of risks on the schedules especially under highly uncertain and complex project conditions and in turn, especially complex construction projects scheduled by CPM require the utilisation of advanced quantitative risk analysis models such as the

CSRAM that simulate the complex and uncertain conditions of real life in a practical way as much as possible. The usage of simulation based schedule risk analysis models would help manage the schedules of complex projects more flexibly. The investigation and discussion conducted on the PMBOK Guide also has shown that the Guide recommends the application of the risk management processes throughout different phases of the projects in an iterative way instead of applying them only at the beginning of the projects during planning, conception or feasibility phases. This recommendation also carries importance from the flexible project management perspective. In this sense, in spite of the fact that the general overview existing throughout the PMBOK Guide, which is dominantly traditional, is also observed on its approach to the project risk management as shown in the stepwise procedure in Figure 4.6, the investigation performed in this section has shown that the current need for incorporating additional features to the traditional way of project risk management in order to convert it to a more flexible and adaptive process has also been acknowledged by the PMBOK Guide (Project Management Institute, 2017). In other words, the PMBOK Guide considers the risk management as a dynamic process that should be performed continuously along the project life cycle especially in case of large-scale construction projects (Project Management Institute, 2017). The aforementioned approach proposed by the PMBOK Guide, i.e. while being traditional, being open to development in terms of flexibility at the same time, is assumed to be useful in incorporating flexibility to traditional project risk management. Therefore, this approach will be further elaborated and utilised in the upcoming chapters for the development of the hybrid approach carrying both traditional and flexible features to be used in managing the CPM based project schedules, which is the final purpose of this research (refer to Chapter 1).

In the next chapter, another dimension of the flexibility problem, i.e. the complexity, is investigated within the scope of project risk management (Project Management Institute, 2017). The purpose is to incorporate the TOE Complexity Assessment Framework developed by Bosch-Rekveldt *et al*. (2011) into the project risk management to be implemented on CPM schedules through the utilisation of the CSRAM developed by Ökmen & Öztaş (2008), the Detail-Dynamic Project Management Model developed by Hertogh & Westerveld (2010), the relevant processes of the PMBOK Guide (Project Management Institute, 2017), and the Fit-for-Purpose Project Management Strategy (Van de Loo, 2015).

5 INCORPORATION OF THE COMPLEXITY ASSESSMENT INTO THE PROJECT RISK MANAGEMENT

The perceptions of the researchers and practitioners generally differ on the complexity of projects. People, even working within the same organisation, on the same projects, and with comparable roles, can identify entirely different elements of complexity within the same project. This phenomenon is called as “perceived complexities” or “subjective character of complexity” (Bosch-Rekveldt *et al.* 2014). Different perceptions on the complexity may affect the project performance negatively in case they are not managed, however they make positive contribution to the project performance if they are managed properly (Bosch-Rekveldt *et al.*, 2014). In this regard, the management of perceived complexities is called as the “perception-based management” (Bosch-Rekveldt *et al.*, 2014). While Baccarini (1996) considers the complexity as the situation of having many and various parts interrelated in between which can be explained based on their differentiation degree and interdependency, Vidal & Marle (2008) make another proposal such that the complexity is a characteristic of a project which converts it to a difficult form to comprehend, predict and control its complete behaviour, even if complete and reasonable information is given about the project (Vidal & Marle, 2008). Besides, the drivers of the project complexity are the factors related to the project’s size, variety, interdependence and context (Vidal & Marle, 2008).

In Chapter 3, the managerial flexibilities inherent with CPM were evaluated and the project schedule management processes proposed in the PMBOK Guide (Project Management Institute, 2017) were examined from the flexibility perspective. The purpose was to discuss the flexibility in terms of the traditional CPM scheduling and traditional project management, respectively. Then, in Chapter 4, the managerial flexibilities in CPM under uncertainty was evaluated by implementing the CSRAM (Ökmen & Öztaş, 2008). Furthermore, the project risk management processes in the PMBOK Guide were examined from both the scheduling and flexibility perspectives. The purpose of Chapter 4 was to discuss the expansion of the managerial flexibilities in CPM scheduling under uncertainty in case CPM is implemented in the form of a schedule risk analysis model, the CSRAM, which enables simulating the uncertain conditions that the construction project schedules face with in reality (Ökmen & Öztaş, 2008). In this chapter, firstly, the complexity assessment will be incorporated into the project risk management through the utilisation of the TOE Framework (Bosch-Rekveldt *et al.*, 2011) and the relevant processes of the PMBOK Guide (Project Management Institute, 2017). Then, the CPM will be built into this integrated structure by means of the CSRAM (Ökmen & Öztaş, 2008). Afterwards, as being a preparatory step for the next chapter, this new approach will be converted to an "integrated flexible complexity/risk management procedure" by further integrating the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010). It is aimed to expand the territory of the traditional project risk management through the incorporation of the complexity assessment within the framework of CPM scheduling. Accordingly, it is desired to open the way of achieving the main goal of this research, i.e. the proposal of a hybrid approach carrying both traditional and flexible features that can be used in the management of schedules prepared by the Critical Path Method under the complex, uncertain and dynamic conditions to which today's complex construction projects are exposed (refer to Chapter 1). Finally, the applicability of the proposed "integrated flexible complexity/risk management procedure" will be shown on an example project. The chapter will end up with the concluding remarks.

5.1 TOE COMPLEXITY ASSESSMENT FRAMEWORK

The TOE (Technical, Organizational, and External) Framework was developed through a literature survey and an empirical study implemented in the process engineering industry (Bosch-Rekveldt, 2011). The framework contains the complexity elements which make contribution to the project complexity in terms of the theoretical and practical perspectives (Bosch-Rekveldt *et al.*, 2011). It can be used to assess the especially the complexity of large-scale engineering projects during the front-end development project phase (Bosch-Rekveldt *et al.*, 2011). At the end of an application, the complexity footprint of a project is obtained, which creates the potential for the management of that project in a better way (Bosch-Rekveldt *et al.*, 2011). Although the Framework was specifically developed to be used during the front-end development project phase, its repeated usage is recommended in also different project phases due to the changing dynamics of the projects along the execution (Bosch-Rekveldt *et al.,* 2011).

The complexity footprint obtained through the TOE Framework also becomes supportive in the risk assessment process conducted in the early project phases. However, the staff that will be involved in the complexity assessment process should be determined with care due to the subjective nature of the complexity and the assessment process. (Bosch-Rekveldt *et al.,* 2011).

The TOE Framework proposes 47 complexity elements under three categories: technical, organizational and external complexity (Bosch-Rekveldt *et al.,* 2011). Furthermore, 14 subcategories again under these three categories were defined, which are the goals, scope, tasks, experience, and risk under the technical category; size, resources, project team, trust, and risk under the organisational category, and stakeholders, location, market conditions and risk under the external category (Bosch-Rekveldt *et al.,* 2011). The 47 complexity elements is shown in Table 5.1 under the categorisation in question (Bosch-Rekveldt *et al.,* 2011). In the TOE Framework, the risk is considered as an important complexity element. In order to show this importance, separate risk elements under each of the 3 categories, i.e. technical, organisational and external, have been included and called the technical risks, organisational risks and external risks as shown in table 5.1 (Bosch-Rekveldt *et al.,* 2011). Furthermore, various aspects regarding the risk have been covered through different complexity elements located under each of the categories, for instance within the elements concerning uncertainty like weather conditions and political influence (Bosch-Rekveldt *et al.,* 2011). Besides, the number of risks as well as their probability and impact may also increase the project complexity (Bosch-Rekveldt *et al.,* 2011).

The importance of the risk management in projects rise up because of the increasing project complexity and therefore risk management is required to be implemented throughout the whole lifecycles of the projects (Jaafari, 2001). Vidal & Marle (2008) consider the project complexity as one of the sources of project risks in either direct or indirect manner and recommends the complexity assessment modelling as an aid for project risk management (Vidal & Marle, 2008).

In line with the consideration of such a solid mutual relationship assumed to exist between risk and complexity, the upcoming sections discuss the incorporation of complexity assessment into project risk management for the implementation on CPM schedules.

Table 5.1 TOE framework (Bosch-Rekveldt *et al.*, 2011)

TOE	Sub-ordering	ID	Source L/E/B[1]	Elements defined	Explanation
T	Goals	TG1	L	Number of goals	What is the number of strategic project goals?
T	Goals	TG2	B	Goal alignment	Are the project goals aligned?
T	Goals	TG3	B	Clarity of goals	Are the project goals clear amongst the project team?
T	Scope	TS1	B	Scope largeness	What is the largeness of the scope, e.g. the number of official deliverables involved in the project?
T	Scope	TS2	B	Uncertainties in scope	Are there uncertainties in the scope?
T	Scope	TS3	E	Quality requirements	Are there strict quality requirements regarding the project deliverables?
T	Tasks	TT1	B	Number of tasks	What is the number of tasks involved?
T	Tasks	TT2	B	Variety of tasks	Does the project have a variety of tasks (e.g. different types of tasks)?
T	Tasks	TT3	B	Dependencies between tasks	What is the number and nature of dependencies between the tasks?
T	Tasks	TT4	B	Uncertainty in methods	Are there uncertainties in the technical methods to be applied?
T	Tasks	TT5	B	Interrelations between technical Processes	To what extent do technical processes in this project have interrelations with existing processes?
T	Tasks	TT6	B	Conflicting norms and standards	Are there conflicting design standards and country specific norms involved in the project?
T	Experience	TE1	B	Newness of technology (world-wide)	Did the project make use of new technology, e.g. non-proven technology (technology which is new in the world, not only new to the company!)?
T	Experience	TE2	B	Experience with technology	Do the involved parties have experience with the technology involved?
T	Risk	TR1	B	Technical risks	Do you consider the project being high risk (number, probability and/or impact of) in terms of technical risks?
O	Size	OS1	L	Project duration	What is the planned duration of the project?
O	Size	OS2	B	Compatibility of different project management methods and tools	Do you expect compatibility issues regarding project management methodology or project management tools?
O	Size	OS3	B	Size in CAPEX	What is the estimated CAPEX of the project?
O	Size	OS4	B	Size in Engineering hours	What is the (expected) amount of engineering hours in the project?
O	Size	OS5	B	Size of project team	How many persons are within the project team?
O	Size	OS6	E	Size of site area	What is the size of the site area in square meters?
O	Size	OS7	B	Number of locations	How many site locations are involved in the project, including contractor sites?
O	Resources	ORE1		B	Project drive Is there strong project drive (cost, quality, schedule)?
O	Resources	ORE2	B	Resource and skills availability	Are the resources (materials, personnel) and skills required in the project, available?
O	Resources	ORE3	B	Experience with parties involved	Do you have experience with the parties involved in the project (JV partner, contractor, supplier, etc.)?
O	Resources	ORE4	E	HSSE awareness	Are involved parties aware of health, safety, security and environment (HSSE) importance?
O	Resources	ORE5	B	Interfaces between different disciplines	Are there interfaces between different disciplines involved in the project (mechanical, electrical, chemical, civil, finance, legal, communication, accounting, etc.) that could lead to interface problems?
O	Resources	ORE6	B	Number of financial resources	How many financial resources does the project have (e.g. own investment, bank investment, JV-parties, subsidies, etc.)?
O	Resources	ORE7	B	Contract types	Are there different main contract types involved?
O	Project team	OP1	B	Number of different nationalities	What is the number of different nationalities involved in the project team?
O	Project team	OP2	B	Number of different languages	How many different languages were used in the project for work or work related communication?
O	Project team	OP3	B	Cooperation JV partner	Do you cooperate with a JV partner in the project?
O	Project team	OP4	B	Overlapping office hours	How many overlapping office hours does the project have because of different time zones involved?
O	Trust	OT1	B	Trust in project team	Do you trust the project team members (incl JV partner if applicable)
O	Trust	OT2	B	Trust in contractor	Do you trust the contractor(s)?
O	Risk	OR1	B	Organizational risks	Do you consider the project being high risk (number, probability a nd/or impact of) in terms of organizational risks?
E	Stakeholders	ES1	B	Number of stakeholders	What is the number of stakeholders (all parties (internal and external) around the table, pm=1, project team=1, NGOs, suppliers, contractors, governments)?
E	Stakeholders	ES2	B	Variety of stakeholders' perspectives	Do different stakeholders have different perspectives?
E	Stakeholders	ES3	B	Dependencies on other stakeholders	What is the number and nature of dependencies on other stakeholders?
E	Stakeholders	ES4	B	Political influence	Does the political situation influence the project?
E	Stakeholders	ES5	B	Company internal support	Is there internal support (management support) for the project?
E	Stakeholders	ES6	B	Required local content	What is the required local content?
E	Location	EL1	E	Interference with existing site	Do you expect interference with the current site or the current use of the (foreseen) project location?
E	Location	EL2	E	Weather conditions	Do you expect unstable and/or extreme weather conditions; could they potentially influence the project progress?
E	Location	EL3	E	Remoteness of location	How remote is the location?
E	Location	EL4	E	Experience in the country	Do the involved parties have experience in that country?
E	Market conditions	EM1	E	Internal strategic pressure	Is there internal strategic pressure from the business?
E	Market conditions	EM2	B	Stability project environment	Is the project environment stable (e.g. exchange rates, raw material pricing)?
E	Market conditions	EM3	B	Level of competition	What is the level of competition (e.g. related to market conditions)?
E	Risk	ER1	B	Risks from environment	Do you consider the project being high risk (number, probability and/or impact of) in terms of risk from the environment?

[1]L = based on literature data, E = based on empirical data, B = based on both literature and empirical data.

5.2 INCORPORATION OF THE TOE COMPLEXITY ASSESSMENT FRAMEWORK INTO THE PROJECT RISK MANAGEMENT

When the TOE Framework given in Table 5.1 is examined, it can be noticed that “risk” has been taken into consideration as a complexity creating factor. Accordingly, three different complexity elements directly associated with the ‘risk’ have been given place within the Framework separately under the titles; technical risks, organisational risks, and external risks. As mentioned in the previous section, in TOE Framework, the complexity was also considered as a direct or indirect source of risks, and the number of risks as well as their probability and impact may also increase the project complexity (Bosch-Rekveldt *et al.*, 2011). Depending on this, besides the abovementioned complexity elements directly associated with the ‘risk’, TOE Framework also includes complexity elements that might induce risks indirectly such as weather conditions, political influence and number of tasks. Therefore, from the perspective of the TOE Framework and in terms of the relevant literature introduced in Chapter 2, it can be claimed that there is a natural mutual relationship between the complexity and risk as well as between the complexity assessment and risk management in projects. So how could these two interrelated systems be integrated? The answer of this question is embedded in the fact that since the TOE Framework queries the complexity-induced risks directly through the triple complexity elements related to ‘risk’, and also contains the risk creating complexity elements and in turn tries to disclose the indirect paths extending from project complexities to project risks, some connections could be set up between the project complexity assessment and project risk management.

In Figure 2.1 and Figure 4.7, the tasks generally conducted in a risk management application and the processes proposed in the PMBOK Guide to be carried out during project risk management were illustrated, respectively (Project Management Institute, 2017). For the purpose of incorporating the TOE Complexity Assessment Framework (Bosch-Rekveldt *et al.*, 2011) into the risk management, the general overview of risk management given in these figures has been modified as shown in Figure 5.1. In that case, the traditional project risk management processes shown in Figure 2.1 (Project

Management Institute, 2017) (refer to Chapter 2) would be modified and expanded as follows (the former processes are given in italics):

- Process 1: *Plan risk management* ⟹ Plan complexity/risk management
- Process 2: Assess project complexities with TOE Framework
- Process 3: *Identify risks* ⟹ Identify risks and complexity-induced risks
- Process 4: Classify risks and complexity-induced risks
- Process 5: *Perform qualitative risk analysis* ⟹ Perform qualitative risk analysis based on identified complexities and risks
- Process 6: *Perform quantitative risk analysis* ⟹ Perform quantitative risk analysis based on identified complexities and risks
- Process 7: *Plan risk responses* ⟹ Plan risk responses and complexity embracement strategies
- Process 8: *Implement Risk Responses* ⟹ Implement risk responses and complexity embracement strategies
- Process 9: *Monitor Risks* ⟹ Monitoring and controlling of the risks and complexities
- Process 10: Feedback and update

The abovementioned 10 processes and the flowchart given in Figure 5.1 together represent a new complexity assessment incorporated project risk management approach based on the usage of TOE Framework (Bosch-Rekveldt *et al.*, 2011) and relevant processes of the PMBOK Guide (Project Management Institute, 2017). Obviously, the proposed approach contains traditional features and has limited flexibility as shown in Figure 5.1. However, it will be converted to a more flexible procedure for the implementation on CPM schedules in the upcoming subsections.

When the flowchart of the proposed complexity assessment incorporated project risk management approach illustrated in Figure 5.1 is examined, two important aspects of it seem to prioritize. One is that the ‘complexity assessment’ implemented through the utilisation of TOE Framework provides information to both the ‘complexity/risk identification’ and ‘risk response & complexity embracement strategy planning’ from two different channels. The other aspect is its cyclic structure generated through monitoring, controlling, feedback and updating. The latter aspect represents the limited flexibility inherent with the approach. However, the former aspect is related with the broader nature of the project complexities established by the TOE Framework when compared with the project risks that traditionally being handled. Since the complexity assessment performed by the means of TOE Framework will not only disclose the complexity-induced risks directly and risk creating complexity elements indirectly but also those complexity elements standing out of the territory of 'risk', different kind of complexities would be possible to be handled together in one single complexity/risk management system by this way (refer to Figure 5.1).

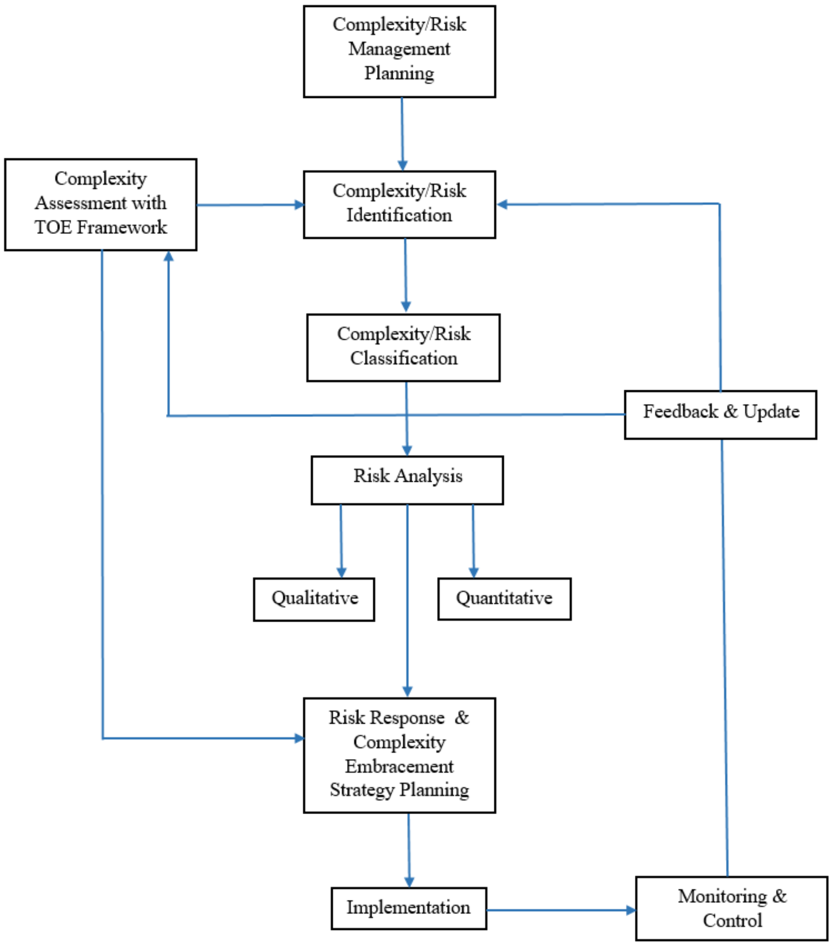

Figure 5.1 Flowchart of the proposed complexity assessment incorporated project risk management approach (traditional form for general application)

5.2.1 Customization of the Proposed Complexity/Risk Management Approach for the Implementation on CPM Scheduling through the Integration of CSRAM

In order to integrate the CSRAM into the complexity/risk management approach proposed in the previous section and illustrated in Figure 5.1, and in turn to customise it for implementation on CPM scheduling, the approach has been modified as shown in Figure 5.2. Since it is aimed to finally obtain a procedure that could be used specifically during the management of CPM schedules, the customised version of the approach has been provided to have interfaces with the related project schedule management processes of the PMBOK Guide, which were previously explained in Chapter 3 (refer to Figure 3.9).

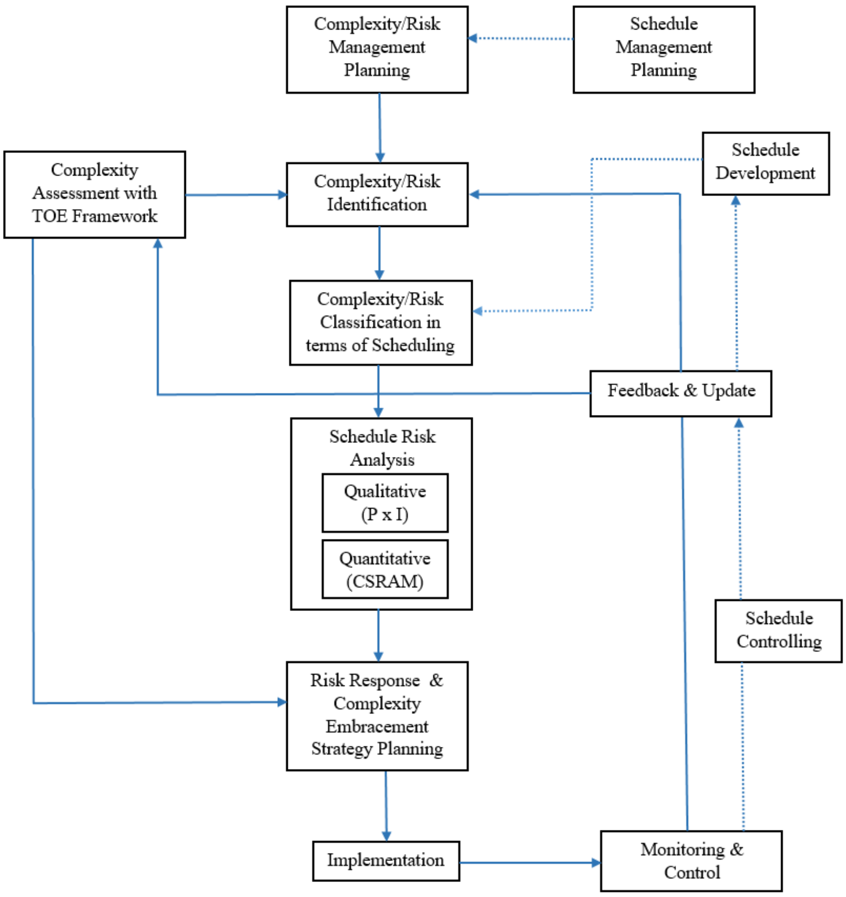

Figure 5.2 Flowchart of the complexity assessment incorporated project risk management approach based on TOE Framework and CSRAM (customised form for implementation on CPM scheduling)

The customized form of the proposed approach for the purpose of providing applicability on CPM schedules as illustrated in Figure 5.2 starts with the *complexity/risk management planning* process supported by the *schedule management planning* process of the project schedule management (refer to Figure 3.9). The reason of the establishment of such an interface is to keep the complexity/risk management planning process within the scope of schedule management. Then, the procedure continues with the *complexity/risk identification* process, which takes data from the *complexity assessment* carried out by the usage of TOE Framework, i.e. the *complexity assessment with TOE Framework* process. Since the TOE Framework is not only about scheduling but related with all kinds of project complexity (Bosch-Rekveldt *et al.*, 2011), first of all, it is required to convey the complexities that are assumed to be indirectly effective on the schedule to the *risk response & complexity embracement strategy planning* process. Next, the complexity-induced risks assumed to be directly effective on the schedule are transferred to the complexity/risk identification and *complexity/risk classification in terms of scheduling* processes together with the other data obtained regarding the complexity. The latter process is supported with data coming from the *schedule development* process of project schedule management (refer to Figure 3.9) in order to refine properly the complexity-induced risks that really would affect the schedule among the others. Afterwards, the accumulated data is exposed to *schedule risk analysis*; first, qualitative risk analysis through Probability x Impact (PxI) scoring, second, quantitative risk analysis through CSRAM. The input-output chain of CSRAM previously given in Figure 4.1 (Ökmen & Öztaş, 2008) will change as illustrated in Figure 5.3 (Ökmen & Öztaş, 2008) when the Model is utilized in joint with complexity assessment within the currently proposed approach. The output data obtained at the end of the risk analysis process is used during the risk response & complexity embracement strategy planning process together with the other data flowing from the *TOE Framework complexity assessment* process. Then, the determined complexity embracement strategies and risk responses are implemented during the management of the schedule. Next, during the implementation, the *monitoring & control* and *feedback & update* processes supported by the *schedule controlling* process of the project schedule management (refer to the Figures 3.9 and 5.2) are generated. The results obtained not only introduces updated data to the complexity assessment but also supports the *schedule development* process of the schedule management. Finally, the current form of the approach is applied repetitively in a cyclic form as illustrated in Figure 5.2 throughout the management of the CPM schedules.

In the next section, the current form of the complexity/risk management approach proposed to be used during the management of CPM schedules in Figure 5.2 will be converted to a more flexible form by further integrating the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010). In the end, it is aimed to propose an "integrated flexible complexity/risk management procedure" that could be used specifically on CPM schedules under uncertainty and complexity.

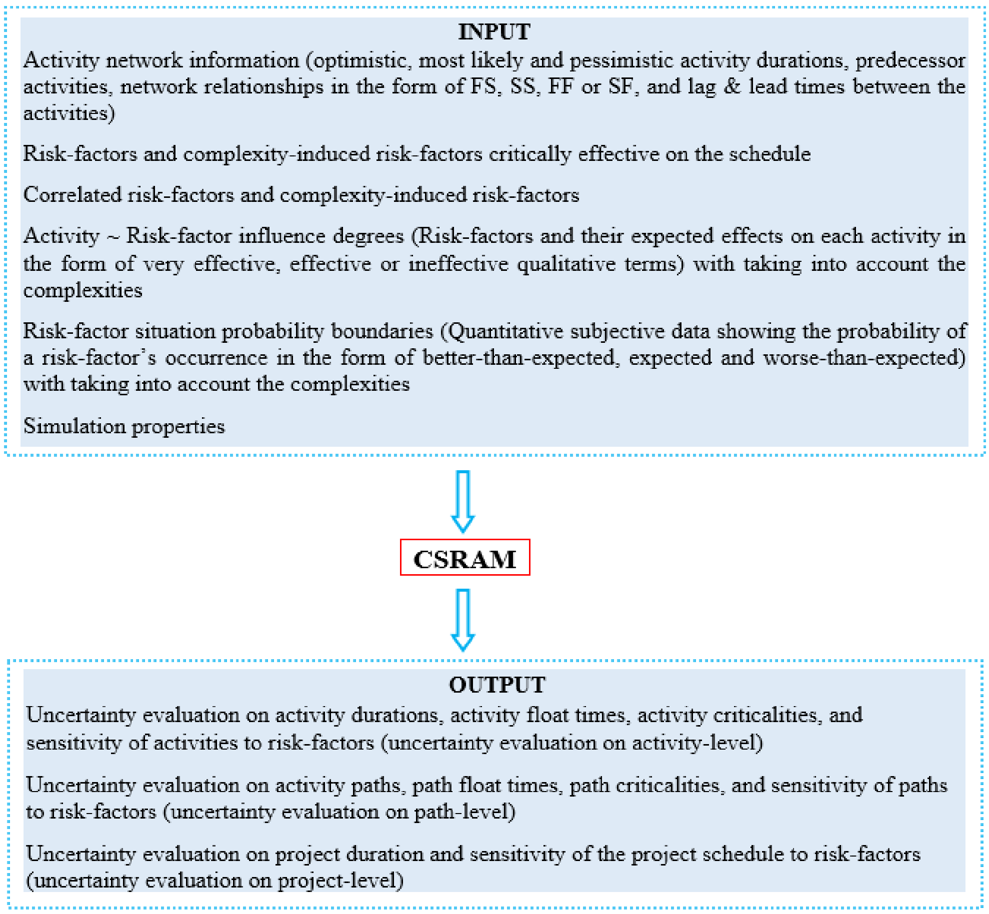

Figure 5.3 Modified input-output chain of CSRAM in case incorporated with the complexity assessment (Ökmen & Öztaş, 2008)

5.2.2 Conversion of the Proposed Complexity/Risk Management Approach to a Flexible Procedure

The complexity/risk management approach proposed to be used during the management of CPM schedules in the previous section and illustrated as a flowchart in Figure 5.2 has been designed to a great extent in accordance with the traditional logic existing in the PMBOK Guide. In other words, this form of the approach is more like a stepwise process that is neglecting the factors like the subjective character of complexity, project dynamics and the need for stakeholder involvement in projects and therefore possesses the features of traditional project management. Therefore, it is required to convert it to a more flexible form in order to get able to use it during the development of the hybrid project management approach to be used on CPM schedules in the next chapter.

The flexibility will be provided on the aforementioned form of the approach through the integration of the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010). These subject has been explained previously in Chapter 2. For the purpose of reminding, project complexity is modelled by two different dimensions in Detail-Dynamic Project Management Model: detail and dynamic (Hertogh & Westerveld, 2010). While the detail complexity is associated with a high number of components, a high degree of interrelatedness, the dynamic complexity is associated with the potential to change over time, the limited comprehensibility and predictability (Hertogh & Westerveld, 2010). When detail complexity is high, it is considered that the system is complicated, when dynamic complexity is high, it is considered that the system is complex (Hertogh & Westerveld, 2010). When both are high, it is both complicated and complex, i.e. dynamic (Hertogh & Westerveld, 2010). The model is shown in Figure 2.7 (Hertogh & Westerveld, 2010, pp.228). The building blocks in this figure is based on the systems (control) management and interactive (interaction) management and different management strategies are proposed to cope with detail and dynamic complexity (Hertogh & Westerveld, 2010). Detail-Dynamic Project Management Model distinguishes 4 types of management approaches as given below (Hertogh & Westerveld, 2010):

- Internal approach

- Control approach
- Interactive approach
- Dynamic approach (both control and interaction)

Chapter 2 also contains brief explanation on the Fit-for-Purpose Project Management, which is another approach related with flexible project management that will be taken into account in this section. Again, for the purpose of reminding, the basic consideration behind the fit-for-purpose is that every project has different features and therefore, they should be managed through different approaches or styles. The current projects carry high uncertainty and complexity. Therefore, an ordinary project planning becomes insufficient due to the increased project dynamics (Shenhar & Dvir, 2007). For this reason, instead of approaching the projects in the same direction as the traditional project management dominantly does, the modern project management approaches consider the projects as differing endeavours and claim the necessity to adapt the managerial practices to the specific purpose of each project (Bakker *et al.* 2016) as the fit-for-purpose project management proposes (Van de Loo, 2015).

The "perception-based management" (Bosch-Rekveldt *et al.* 2014) is the other approach that will be utilised during the conversion of the proposed procedure into a more flexible form. Brief information about these approaches were given in Chapter 2 and also at the beginning of this chapter. It should be mentioned that the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010), Fit-for-Purpose Project Management (Van de Loo, 2015), and Perception-Based Management (Bosch-Rekveldt *et al.* 2014) have a distinctive common point in terms of flexibility for the reason all of these approaches acknowledge the influence and importance of the project dynamics as well as the need for adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex and uncertain conditions. In this regard, the integration of these approaches within a complexity incorporated risk management system has the potential to provide a substantially flexible environment in terms of project management as well as for the management of CPM schedules.

Using this theoretical background, the flexible features desired to be provided through the proposed procedure have been identified as follows:

- Flexible Feature 1: The involvement of the relevant internal and external stakeholders at any level into the processes for which different perceptions and experiences are required to be harmonized for the sake of ensuring the implementation of Perception-Based Management, establishment of shared mental model and taking into consideration the issue of subjectivity of complexity.
- Flexible Feature 2: The repetitive implementation through successive iterations at each milestone predetermined on the baseline CPM schedule as well as through the revised target schedules throughout the execution of the project for the sake of ensuring the dynamic and adaptable attributes required.
- Flexible Feature 3: The incorporation of the complexity assessment process into the risk management process in terms of scheduling through the involvement of the relevant processes belonging to the "Project Schedule Management" for the sake of ensuring the identification of complexities directly or indirectly influencing the schedule, determination of the required complexity embracement and risk response strategies simultaneously, and flow of data from one process to another which are assumed to be interrelated in between the proposed procedure and the "Project Schedule Management".
- Flexible Feature 4: The utilization of the Fit-for-Purpose Management along with the Detail-Dynamic Project Management Model during the determination of the complexity embracement strategies and risk responses for the sake of ensuring the implementation of systems (control), interactive, or dynamic (hybrid or carrying both systems and interactive features) management approaches (refer to Figure 2.12) as well as the usage of the complexity footprint of the project put forward by the TOE Complexity Assessment Framework through its application based on the experiences and thoughts of the involved stakeholders.
- Flexible Feature 5: The openness of the established complexity/risk management system to development and adaptation to changes during the

project execution by allowing the number of successive iterations carried out to be increased whenever a major revision is required.

- Flexible Feature 6: The monitoring, control, feedback and update features enabling the incremental convergence to the optimum level of risk complexity/risk awareness and adoption of the best complexity embracement and risk response strategies.
- Flexible Feature 7: The availability to benefit from the managerial flexibilities inherent with the CPM in its traditional form (refer to Chapter 3) and the expansion of the managerial flexibilities in CPM under risk and uncertainty in case CPM is applied integrated with MCS through the usage of CSRAM (refer to Chapter 4).
- Flexible Feature 8: The availability of customization of the procedure in accordance with the unique features and changing requirements specific to different projects through the utilization of different approaches in terms of the complexity assessment methods, risk identification techniques, schedule risk analysis models, flexible project management models, and etc.
- Flexible Feature 9: The eligibility of the procedure for being utilizable in different phases of the projects' lifecycles through customised modifications made on the procedure by the usage of different flexible project management approaches in case of any requirement.
- Flexible Feature 10: The appropriateness of the procedure for being integrated as a whole to a flexible project schedule management model carrying similar flexible features.

The Flexible Feature 10 will be utilized in the next chapter during the development of a hybrid CPM-based schedule management approach carrying both traditional and flexible features.

In direction with the abovementioned flexible features, the flexible form of the complexity assessment incorporated project risk management approach has been built up, the flowchart of which is given in Figure 5.4. From this point ahead, this form of the approach will be called as the 'Integrated Flexible Complexity/Risk Management

(IFCRM) Procedure'. The details of the IFCRM Procedure and the logic laying behind it are clarified below in a stepwise manner based on its flowchart given in Figure 5.4 and by referring to its abovementioned flexible features:

Step 1:

The procedure starts with the 'Complexity/Risk management planning' process as shown in Figure 5.4. The information including, but are not limited to, staffing, organising, assignment of responsibilities, resources to be utilised, number of meetings, and tools and methods to be used are all decided and put into a plan at the very beginning. For the reason the 'Complexity/Risk management planning' process should be aligned with the 'Schedule management planning' process of the Project Schedule Management (Project Management Institute, 2017), data flow is allowed from the 'Schedule management planning' process to the 'Complexity/Risk management planning' process. The data transferred would be similar to the decisions taken during the 'Complexity/Risk management planning' process such as staffing, organising, assignment of responsibilities, resources to be utilised, number of meetings, tools and methods to be used; but this time related with the schedule management. The synchronisation of the two similar processes belonging to two different and interrelated project management processes, i.e. project risk management and project schedule management, would help build the required communication channels between the responsible teams as well as help flow the useful data regarding the scheduling efficiently. So, all the stakeholders related with these processes will have been involved by the means of meetings, brainstorming sessions and establishment of communication channels, and etc. In this regard, the Flexibility Feature 1 will be ensured. Furthermore, the interface established between the project schedule management and project risk management by this way provides the requirement for the Flexible Feature 10, which will be utilized in the development of the hybrid approach in the next chapter.

Step 2:

Next, the 'Risk identification and classification' process is started. During this process, the risk identification and classification techniques such as risk checklists, brainstorming meetings, and risk breakdown structuring, which were discussed in Chapter 2, can be applied. This attribute is in agreement with the Flexibility Feature 8.

However, the process is supported by the data coming from the 'Schedule development' process of Project Schedule Management and through the involvement of the relevant stakeholders in agreement with the Flexibility Feature 1. Furthermore, this interface is in agreement with the Flexible Feature 10 and will be utilized in the development of the hybrid approach in the next chapter.

<u>Step 3</u>:

The procedure continues with the 'Complexity assessment based on TOE Framework' process. In this process, the subjective character of complexity and the principles of Perception-Based Management are the main subjects taken into account. By means of this process along with the processes 'Refinement of the complexities' and 'Refinement of the complexity-induced risks', the complexities affecting the project in general, the complexities indirectly affecting the CPM schedule, and the complexities directly affecting the CPM schedule and in turn leading to 'complexity-induced risks' are all determined separately. Naturally, the stakeholders from different units within a company, consortium or corporation related with the project and the schedule such as the managers, experts, schedulers, engineers, foremen and even the workers should be involved into this multi-stage complexity assessment process. By this way, both the Flexibility Features 1 and 3 are ensured. However, the necessary preconditions should be provided in advance for ensuring the assessment of the project complexities in full and the settlement of a shared mental model (refer to Chapter 2) by the application of Perception-Based Management. Besides, the 'Refinement of the complexity-induced risks (directly affecting the CPM schedule)' process is supported by the data transferred from the 'Schedule development' process of Project Schedule Management and the 'Risk identification and classification' process as illustrated in Figure 5.4. Different methods and techniques such as the cause-effect analysis, influence diagramming method, risk breakdown structures, and risk registers can be used to refine the complexity-induced risks as well as the complexities indirectly influencing the CPM schedule (refer to the Andringa, 2021). Thereby, the Flexibility Feature 8 is provided.

<u>Step 4</u>:

Up to this point, the complexities effective on the project and the schedule, directly or indirectly, have been explored, the project risks have been identified and classified, and the CPM schedule have been developed. Next, the identified risks and complexity-induced risks effective on the CPM schedule must be analysed. This process has been designated as the ‘Schedule risk analysis’ process in Figure 5.4. It is supported by the data coming from the ‘Schedule development’ process of Project Schedule Management (Project Management Institute, 2017) and through the involvement of the relevant stakeholders. This interface is in agreement with the Flexible Feature 10 and will be utilized in the development of the hybrid approach in the next chapter. The ‘Schedule risk analysis’ process is carried out in two steps: qualitative risk analysis through the Probability (P) x Impact (I) scoring and the quantitative risk analysis based on the CSRAM. By the means of P x I scoring, the most effective critical risks are determined and the complexity-induced risks are distinguished. Afterwards, these risks are analysed through the CSRAM. By the means of the ‘Schedule Risk Analysis’ process implemented during this step, the Flexibility Feature 7 is provided.

Step 5:

The next process is the ‘Risk response & complexity embracement planning’. Within the scope of this process, besides the implementation of the standard risk response strategies discussed previously in Chapter 2, the complexity embracement strategies proposed by the Detail-Dynamic Project Management Model are utilized as shown in Figure 5.4 in line with the Fit-for-Purpose Management (Van de Loo, 2015). During this process, the results of the ‘Schedule risk analysis’ and the ‘Refinement of the complexities’ processes along with the other data accumulated up to this point are utilized. Thus, the Flexible Feature 3 is ensured through the ‘Risk response & complexity embracement planning’ process implemented during the current step.

Step 6:

Afterwards, the decisions taken during the previous process are started to be implemented through the process ‘Implementation’ as shown in Figure 5.4. When all the milestones are completed or with another saying when the project is completed, the implementation of the procedure ends up. Otherwise, the iterations continue after performing the ‘Feedback & Update’ process for the milestone in question in line with the Flexible Features 2 and 5.

Step 7:

Afterwards, the implementations are monitored and controlled through the process 'Monitoring & Control' in line with Flexible Feature 6. Since the strategies in question are applied on the CPM schedule, the 'Monitoring & Control' process is naturally conducted in parallel with the 'Schedule controlling' process of the Project Schedule Management as illustrated in Figure 5.4. This interface is in agreement with the Flexible Feature 10 and will be utilized in the development of the hybrid approach in the next chapter. These two parallel interfaced processes end up at the decision point designated as the 'Milestones completed?'. The main argument here is ensuring the implementation of the IFCRM Procedure repetitively starting with the reimplementation of the 'Complexity assessment based on TOE Framework' and the 'Risk identification and classification' processes until all the milestones within the CPM schedule are completed. In this regard, the procedure carries a repetitive character and aims to help reach at the project goals in an incremental way, which is an attribute in line with the Flexible Features 2 and 5.

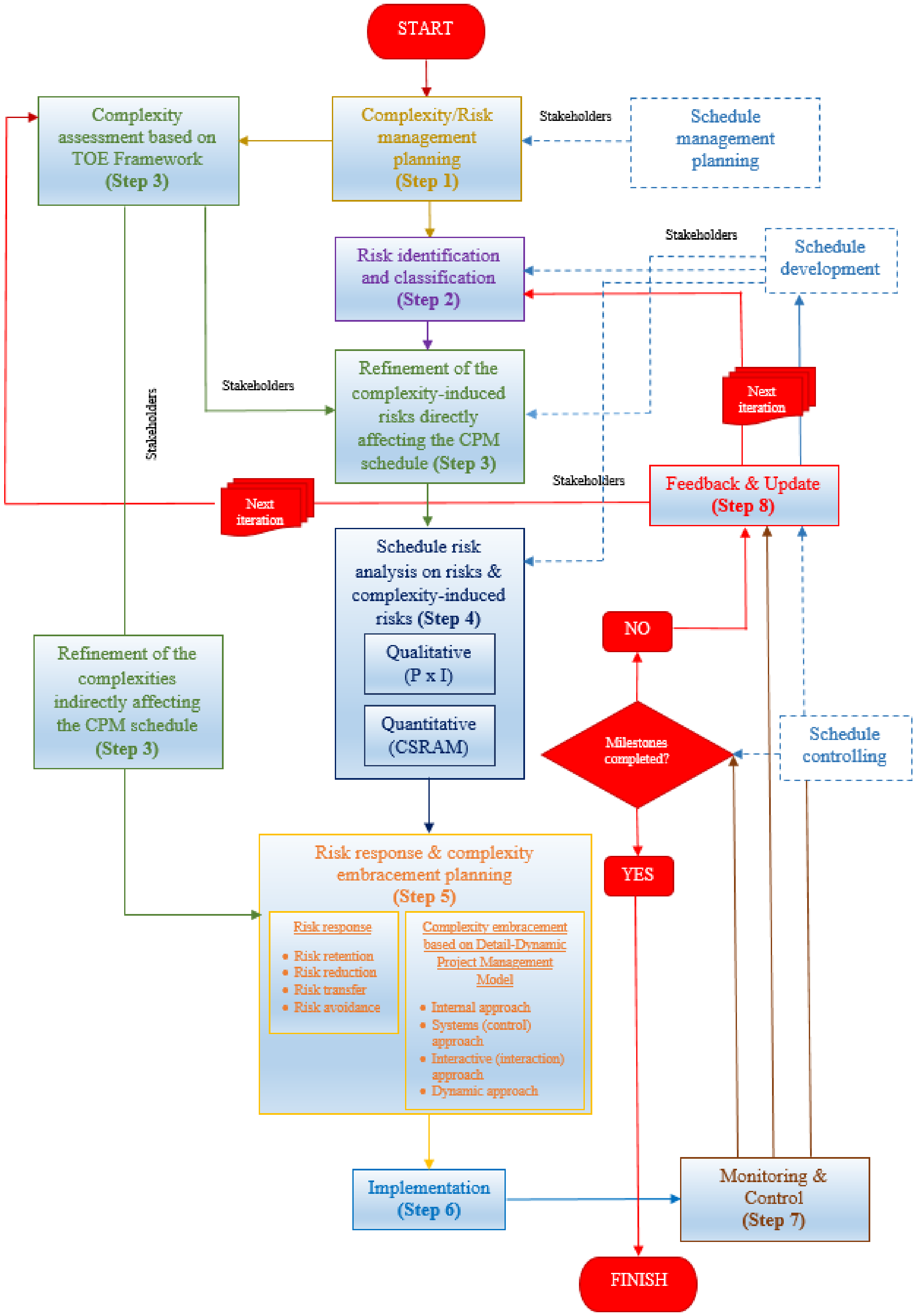

Figure 5.4 Flowchart of the IFCRM Procedure

Step 8:

When all the milestones are completed or with another saying when the project is completed, the implementation of the procedure ends up as illustrated in Figure 5.4. Otherwise, the iterations continue after performing the ‘Feedback & Update’ process for the milestone in question to which relevant data is transferred from the “Monitoring & Control” process and the ‘Schedule controlling’ process of the Project Schedule Management. The next iteration starts with the data flow from the ‘Feedback & Update’ process to the the ‘Complexity assessment based on TOE Framework’ and the ‘Risk identification and classification’ processes in line with the Flexible Features 5 and 6. Furthermore, the ‘Schedule development’ process of the Project Schedule Management is supported with the data coming from the ‘Feedback & Update’ process as illustrated in Figure 5.4. This interface is in agreement with the Flexible Feature 10 and will be utilized in the development of the hybrid approach in the next chapter. It should be mentioned that the Flexible Feature 9 can be processed through the incorporation of different approaches into the modular structure of the procedure that is established on different processes, models and frameworks.

In the next section, the applicability of the IFCRM Procedure will be shown on an example project based on the abovementioned steps and the process flowchart shown in Figure 5.4.

5.3 AN EXAMPLE APPLICATION OF THE IFCRM PROCEDURE

The data that will be used in this section for showing the applicability of the IFCRM Procedure belongs to the design job of an irrigation project previously realized in Turkey by a company specialized on designing hydraulic and water resources projects. This company is designated as the ‘Designer’ throughout the current application. The owner of the project was a public corporation responsible for realizing infrastructure projects for the development and management of the water resources in Turkey since 1950’s after its first establishment. The central office (general directorate) of the Owner is located in Ankara under which the regional offices (regional directorates) have been constituted in various cities all over Turkey. This public corporation is designated as the

‘Owner’ throughout the current application. The contracting authority is one of the regional offices of the Owner’s organization. This regional office is designated as the ‘Contracting Authority’ throughout the current application.

5.3.1 Brief Description of the Project

The official name of the project is the “Design of the Gönen Plain Irrigation Project” on the contract (State Hydraulic Works, 2011). The aim of the project is to supply irrigation water with pressurized pipes to an area of 3750 ha of farm land in Balıkesir City/Gönen Town of Turkey. The major source of water for irrigation is the reservoir of the Gönen Dam. The water is to be delivered by four different pumping stations to the irrigation area from the ‘primary open channels’ of another project called the “Gönen Plain Open Channel Irrigation Project” which takes the water from the reservoir of the Gönen Dam. The Designer is responsible for preparing the design drawings of the irrigation pipe network system including the primary, secondary and tertiary pipelines with using pressurized High Density Polyethylene (HDPE) and Glass Fiber Reinforced Polyester (GRP) pipes. Furthermore, the Designer carries the responsibility of preparing the technical reports in compliance with the contract clauses, specifications and technical criteria. In other words, the “Design of the Gönen Plain Irrigation Project”, as its name implies, includes only the pre-construction design phase. After the completion of this design project, the construction phase of the project was awarded through a public tender conducted based on the design drawings, technical reports and cost estimations prepared through the “Design of the Gönen Plain Irrigation Project”. The construction of the irrigation pipeline network in question was completed and have been under operation since 2013 (İlci Construction Co., 2020).

The schedule submitted to the Contracting Authority by the Designer at the beginning of the project was a simple bar chart. There were 19 different activities in the bar chart schedule and the Contracting Authority approved this schedule. The project should have been completed within 300 calendar days according to the bar chart schedule. This bar chart schedule is given in Figure 5.5. However, the actual situation occurred different than it was envisaged in the approved bar chart schedule (baseline schedule). The

Designer requested time extensions several times from the Contracting Authority in different dates after the project had started and the Owner had to accept some of these requests in compliance with the contract conditions. Depending on these time extensions, the 300 calendar days of contractual (planned) project completion time increased to 683 days. In other words, the project could be completed with 383 days of delay.

The primary reasons of this high schedule overrun were the insufficiency of the bar chart schedule in properly managing such a complex project, the inaccuracy of the predictions made regarding the schedule, having not implemented any risk analysis and risk management, not being aware of the complexities inherent with the project and not taking the demands and suggestions of the internal and external stakeholders sufficiently. Obviously, the dependencies between the activities and the existence of the critical activities that directly affect the project duration could not be disclosed by a bar chart schedule. Furthermore, the effect of various risks, uncertainties and complexities on the schedule could not be identified and managed because of not having implemented the necessary processes especially belonging to the project risk management and project schedule management (Project Management Institute, 2017). Besides, the interactive and flexible conditions required for achieving success in the management of such projects could not be created for the reason of neglecting the stakeholders, for instance the farmers, who will use the project as the end-users.

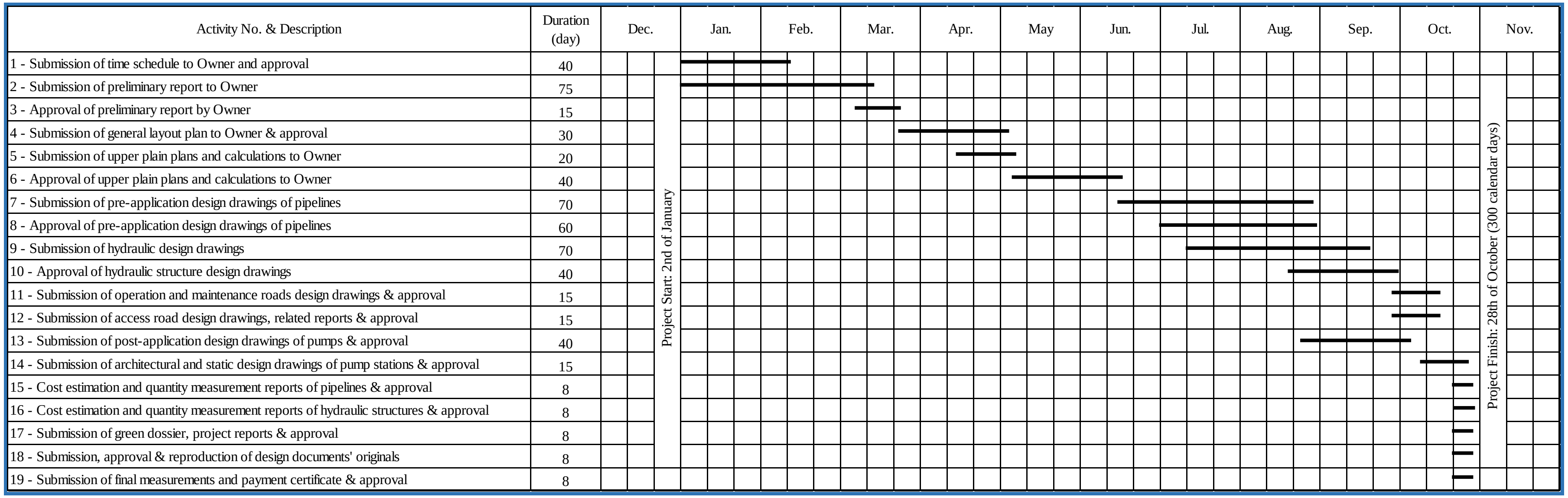

Figure 5.5 Bar chart schedule of the “Design of the Gönen Plain Irrigation Project” approved by the Owner

In this regard, an example application of the IFCRM Procedure proposed in the previous section and shown in Figure 5.4 as a flowchart will be presented on the “Design of the Gönen Plain Irrigation Project” based on a scenario established in line with the processes constituting the procedure in order to show its applicability and also to disclose the achievements that would have been obtained in terms of schedule management to avoid the occurrence of such a long delay in case this procedure had been implemented. For the sake of introducing the example application clearly as much as possible, the details of the implementation scenario set up are conveyed below in accordance with the processes involved in the IFCRM Procedure shown in Figure 5.4 step by step under different headings by starting with the schedule management planning, complexity/risk management planning and schedule development processes along with the identification of the internal and external stakeholders.

5.3.2 Complexity Risk Management Planning and Identification of the Stakeholders (Step 1)

The stakeholders of the project can be categorised under two groups from the Designer’s perspective: internal and external. The internal stakeholders are the responsible units established within the organisation of the Designer in relation with the risk management, complexity assessment, designing, schedule development and schedule management processes. On the other hand, the external stakeholders are the units directly responsible with the execution of the project and also indirectly related with the project within the organisation of the Owner, and also the farmers as the end-users who will use the irrigation pipeline network after it is constructed. Before listing the stakeholders, the organisational structure of the Owner and the workflow of the designing tasks applied for the irrigation projects in general within this structure are explained below.

The Owner’s organisation is established in three hierarchical management levels. At the top level, the General Directorate in Ankara (the capital city) stands as the central office. At the second level, the central units specialised in different technical areas are constituted also in Ankara under the central office. The third management level is composed of the regional offices (Regional Directorates) dispersed to the different regions of the country. The typical workflow implemented during the designing phase of the irrigation projects within this organisational structure is as follows:

1. The Designer submits the design documents to the regional office responsible of the irrigation project in question. In this example application, the responsible regional office is also the contracting authority.
2. The regional office controls and approves the submitted design documents and then transfers to the responsible central unit. In this example application, the responsible central unit is the Design & Construction Unit, which is the department responsible of design and construction phases of irrigation projects.
3. The central unit (Design & Construction Unit) once more controls the design documents submitted by the regional office to the central office after the first approval. Finally, the design documents are approved by the central unit (Design & Construction Unit) after applying the necessary revisions.

The same workflow is also applied during the design development, which is an important stage of the designing phase. The main task of the design development stage is the control and approval of the 'Initial Report' submitted by the Designer to the regional office first and then transferred to the central unit after the initial approval. The Owner takes important decisions about the design during the design development stage, which influence the cost, schedule, and scope during the construction phase. Therefore, the Design & Construction Unit, which is the central unit responsible of the approval of the Initial Report after the approval of the regional office, takes the views of the other central units specialised on different fields related with the project before finally approving the Initial Report. In this regard, the central units associated with the "Design of the Gönen Plain Irrigation Project" are the 'Planning Unit', the 'Expropriation Unit', the 'Geotechnical Unit', and the 'Maintenance & Operation Unit'. Furthermore, the 'Project Risk Management Unit' assumed to be constituted under the Design & Construction Unit is the other important stakeholder for it is being the unit responsible for conducting the risk management processes on projects and for building the necessary collaboration with the Designer or Contractor Companies on the identification and management of project risks.

Besides the ‘Initial Report’, the ‘Planning Report’ is the other important document for an irrigation project, the approval responsibility of which belongs to the Planning Unit. This document is transferred to the Design & Construction Unit before the realisation of the design tender. The Planning Report contains detailed information about the feasibility and the other design aspects needed for an irrigation project along with the preliminary design drawings. The content of the Planning Report is reviewed and re-evaluated during the Initial Report preparation stage conducted under the responsibility of the Designer within the Design & Construction Unit.

Under the enlightenment of the above information, the internal and external stakeholders presumably taken into consideration during the implementation of the IFCRM Procedure (refer to Figure 5.4.) on the “Design of the Gönen Plain Irrigation Project” are as follows:

- Internal Stakeholders (under the organization of the Designer)
  - Design Units
  - Reporting Units
  - Cost Estimation Unit
  - Project Risk Assessment Unit
  - Project Scheduling Unit
- External Stakeholders
  - Design & Construction Unit of the Owner
  - Planning Unit of the Owner
  - Expropriation Unit of the Owner
  - Geotechnical Unit of the Owner
  - Maintenance & Operation Unit of the Owner
  - Project Risk Management Unit of the Owner
  - Regional Office (Contracting Authority) under the Owner’s organisation
  - Farmers (End-users) and Farmer Associations
  - Politicians responsible of the region

- Environmental Associations (regional or nationwide)
- Regional Authorities (Municipality, village representatives)

As proposed in Figure 5.4, the planning processes carried out during the implementation of the IFCRM Procedure on the "Design of the Gönen Plain Irrigation Project" are the processes entitled Schedule Management Planning, Schedule Development and Complexity/Risk Management Planning. The units mainly responsible of these processes are the Project Scheduling Unit and Project Risk Assessment Unit constituted under the Designer's organization. However, the Design Units, Reporting Units and Cost Estimation Unit are the other internal stakeholders, and the Design & Construction Unit, Contracting Authority and the Project Risk Management Unit of the Owner are the external stakeholders involved in these processes. The Schedule Management Planning and Complexity/Risk Management Planning processes address the procedures and plans that should be followed with regard to how the project schedule management and project risk management along with the complexity assessment will be carried out. The information including, but are not limited to, staffing, organising, assignment of responsibilities, resources to be utilised, number of meetings, and tools and methods to be used are all decided and recorded on a plan during these processes. On the other hand, the Schedule Development process is realised under the responsibility of the Project Scheduling Unit and therefore the CPM schedule of the "Design of the Gönen Plain Irrigation Project" has been prepared by that unit through consultation with the stakeholders involved in this process.

In this context, firstly, the officially approved bar chart given in Figure 5.5 was converted into an activity network on which CPM could be applied by using the same activity durations used in the bar chart schedule in order to keep the compatibility between the two schedules. However, the new activity network contained 32 activities for providing the required network logic. Table 5.2 shows the activities and network data used in CPM application, Figure 5.6 illustrates the activity-on-node diagram of the CPM schedule, and Table 5.3 contains the results of the CPM application on the data presented in Table 5.2, respectively.

The results of the CPM application given in Table 5.3 show that the “Design of the Gönen Plain Irrigation Project” can be completed in 316 days, i.e. within a duration close to the contractual duration approved by the Owner through the bar chart schedule illustrated in Figure 5.5. The reason of such a closeness between these two duration estimates is the utilization of the activity durations used in the bar chart schedule also during the CPM calculations. As it can be observed in Table 5.3, the total float times of the activities 1, 4, 5, 6, 8, 9, 10, 11, 12, 13, 20, 21, 22, 23, 26, 27, 31, and 32 are zero. In other words, they are the critical activities as shown in bold in Figure 5.6. The activity 20 is the single milestone assigned on the CPM schedule.

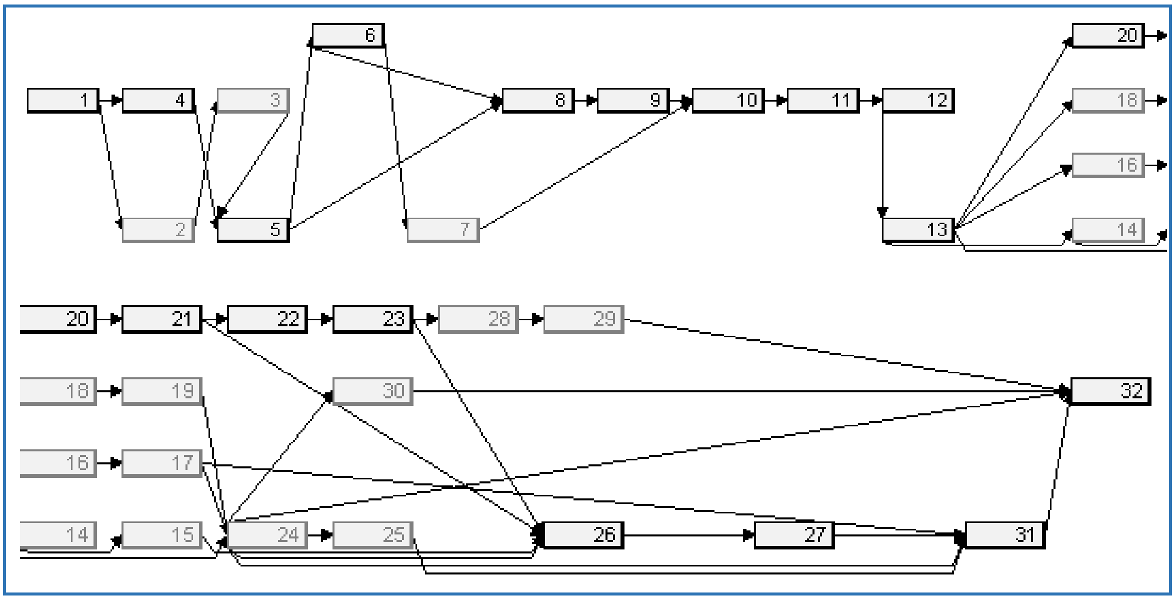

Figure 5.6 CPM Activity-On-Node Diagram of the “Design of the Gönen Plain Irrigation Project”

Table 5.2 Activities and network information of the "Design of the Gönen Plain Irrigation Project"

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship
1	Work Takeover	1	-
2	Submission of work schedule to Owner	30	1 (FS)
3	Approval of work schedule by Owner	10	2 (FS)
4	Submission of initial report to Owner	75	1 (FS)
5	Approval of initial report by Owner	20	3 (FS) 4 (FS)
6	Submission of general layout plan to Owner	20	5 (FS)
7	Approval of general layout plan by Owner	10	6 (FS)
8	Submission of upper plain plans and calculations to Owner	15	5 (FS) +8 6 (SS) +13
9	Approval of upper plain plans and calculations by Owner	5	8 (FS)
10	Submission of pre-application design drawings to Owner	30	7 (FS) 9 (FS)
11	Approval of pre-application design drawings by Owner	10	10 (FS)
12	Submission of post-application design drawings to Owner	70	11 (FS)
13	Approval of post-application design drawings by Owner	60	12 (SS) +16
14	Submission of hydraulic structure design drawings to Owner	70	13 (SS) +10
15	Approval of hydraulic structure design drawings by Owner	40	14 (SS) +40
16	Submission of operation and maintenance roads design drawings to Owner	10	13 (FS)
17	Approval of operation and maintenance roads design drawings by Owner	5	16 (FS)
18	Submission of access road design drawings and reports to Owner	10	13 (FS)
19	Approval of access road design drawings and reports by Owner	5	18 (FS)
20	Submission of post-application design drawings of pumping elevation lines to Owner	30	13 (FS)
21	Approval of post-application design drawings of pumping elevation lines by Owner	10	20 (FS)
22	Submission of architectural and static design drawings of pumping stations to Owner	10	21 (FS)
23	Approval of architectural and static design drawings of pumping stations by Owner	5	22 (FS)
24	Submission of cost estimation and quantity measurement reports of pipelines to Owner	4	13 (FS) 17 (FS) 19 (FS)
25	Approval of cost estimation and quantity measurement reports of pipelines by Owner	4	24 (FS)
26	Submission of cost estimation and quantity measurement reports of hydraulic structures and pumping station to Owner	4	15 (FS) 21 (FS) 23 (FS) 24 (SS)
27	Approval of cost estimation and quantity measurement reports of hydraulic structures and pumping station by Owner	4	26 (FS)
28	Submission of green dossier and project reports to Owner	4	23 (FS) 24 (SS)
29	Approval of green dossier and project reports by Owner	4	28 (FS)
30	Submission, approval and reproduction of design document originals	8	24 (SS)
31	Submission of final measurements and payment certificate to Owner	4	17 (FS) 25 (FS) 27 (FS) 24 (SS)
32	Approval of final measurements and payment certificate by Owner	4	29 (FS) 30 (FS) 31 (FS), 24 (SS)

Table 5.3 Results of CPM application on the "Design of the Gönen Plain Irrigation Project"

Activity No.	Early Start Time	Late Start Time	Early Finish Time	Late Finish Time	Free Float Time*	Shared Float Time	Independent Float Time	Total Float Time	Float Sharing Activity	Criticality
1	0	1	0	1	0	0	0	0	-	Critical
2	1	31	36	66	0	35	0	35	3	Noncritical
3	31	41	66	76	35	35	0	35	2	Noncritical
4	1	76	1	76	0	0	0	0	-	Critical
5	76	96	76	96	0	0	0	0	-	Critical
6	96	116	96	116	0	0	0	0	-	Critical
7	116	126	119	129	3	0	3	3	-	Noncritical
8	109	124	109	124	0	0	0	0	-	Critical
9	124	129	124	129	0	0	0	0	-	Critical
10	129	159	129	159	0	0	0	0	-	Critical
11	159	169	159	169	0	0	0	0	-	Critical
12	169	239	169	239	0	0	0	0	-	Critical
13	185	245	185	245	0	0	0	0	-	Critical
14	195	265	220	290	0	25	0	25	15	Noncritical
15	235	275	260	300	25	25	0	25	14	Noncritical
16	245	255	285	295	0	40	0	40	17,18,19	Noncritical
17	255	260	295	300	0	40	0	40	16,18,19	Noncritical
18	245	255	285	295	0	40	0	40	16,17,19	Noncritical
19	255	260	295	300	0	40	0	40	16,17,18	Noncritical
20	245	275	245	275	0	0	0	0	-	Critical
21	275	285	275	285	0	0	0	0	-	Critical
22	285	295	285	295	0	0	0	0	-	Critical
23	295	300	295	300	0	0	0	0	-	Critical
24	260	264	300	304	0	40	0	40	30	Noncritical
25	264,	268	304	308	40	0	0	40		Noncritical
26	300	304	300	304	0	0	0	0		Critical
27	304	308	304	308	0	0	0	0		Critical
28	300	304	304	308	0	4	0	4	29	Noncritical
29	304	308	308	312	4	4	0	4	28	Noncritical
30	260	268	304	312	44	40	4	44	24	Noncritical
31	308	312	308	312	0	0	0	0		Critical
32	312	316	312	**316***	0	0	0	0	-	Critical

*Project Completion Time in "days".

5.3.3 Risk Identification & Classification and Complexity Assessment Based on TOE Framework (Steps 2 and 3)

The next stage in the implementation of the IFCRM Procedure contains the 'Risk Identification & Classification' and the 'Complexity assessment based on TOE Framework' processes (refer to Figure 5.4). Although the CPM schedule established in tabular format in Tables 5.2 and 5.3, and illustrated as a network diagram in Figure 5.6 contains managerial flexibilities in line with the findings of Chapter 3, the schedule in this form is not sufficient to cover the need for flexibility from the complexity and uncertainty perspectives.

In accordance with this argument, the Project Risk Assessment unit of the Designer conducts complexity assessment on the "Design of the Gönen Plain Irrigation Project" by using the TOE Framework and through accumulating the opinions and insights of the Design and Reporting Units constituted within the organization of the Designer as well as the relevant units under the Owner’s organization in compliance with the subjective character of complexity and for the purpose of generating the Perception-Based Management to establish a shared mental model regarding the complexities influencing the project. During the implementation of the complexity assessment, several brainstorming meetings are held at which the complexity elements in the TOE Framework given in Table 5.1 are scored by the participants. After the scores given by different participants are gathered, the means of the scores assigned to each complexity element are found and in turn, the complexity footprint of the project is obtained based on the identification of the complexity elements possessing higher priority with respect to others. Since the complexity assessment carried out during this process aims at exploring all the complexities affecting the “Design of the Gönen Plain Irrigation Project” without any distinction, the complexities indirectly affecting the CPM schedule is refined through another process subsequently carried out, which is designated as the ‘Refinement of the complexities indirectly affecting the CPM schedule’ in Figure 5.4. The Project Scheduling Unit of the Designer also engages to this process in compliance with the Perception-Based Management. The complexities refined during the process of ‘Refinement of the complexities indirectly affecting the CPM schedule’ are transferred directly to the ‘Risk response/complexity embracement’ process as can be observed in Figure 5.4. On the other hand, the refinement of the complexity-induced risks directly affecting the CPM schedule is carried out through another process, named as the ‘Refinement of the complexity-induced risks directly affecting the CPM schedule’ in Figure 5.4, which comes after the ‘Risk identification & classification’ process (refer to Figure 5.4) again by the jointly involvement of the Project Risk Assessment and Project Scheduling Units of the Designer as well as the Project Risk Management Unit of the Owner. In the context of the explanations made up to now, the results obtained after the implementation of the process ‘Complexity assessment based on TOE Framework’ are introduced in Figure 5.7. The results of the implementation of the process ‘Refinement of the complexity-induced risks directly affecting the CPM schedule’ will be introduced in the next step.

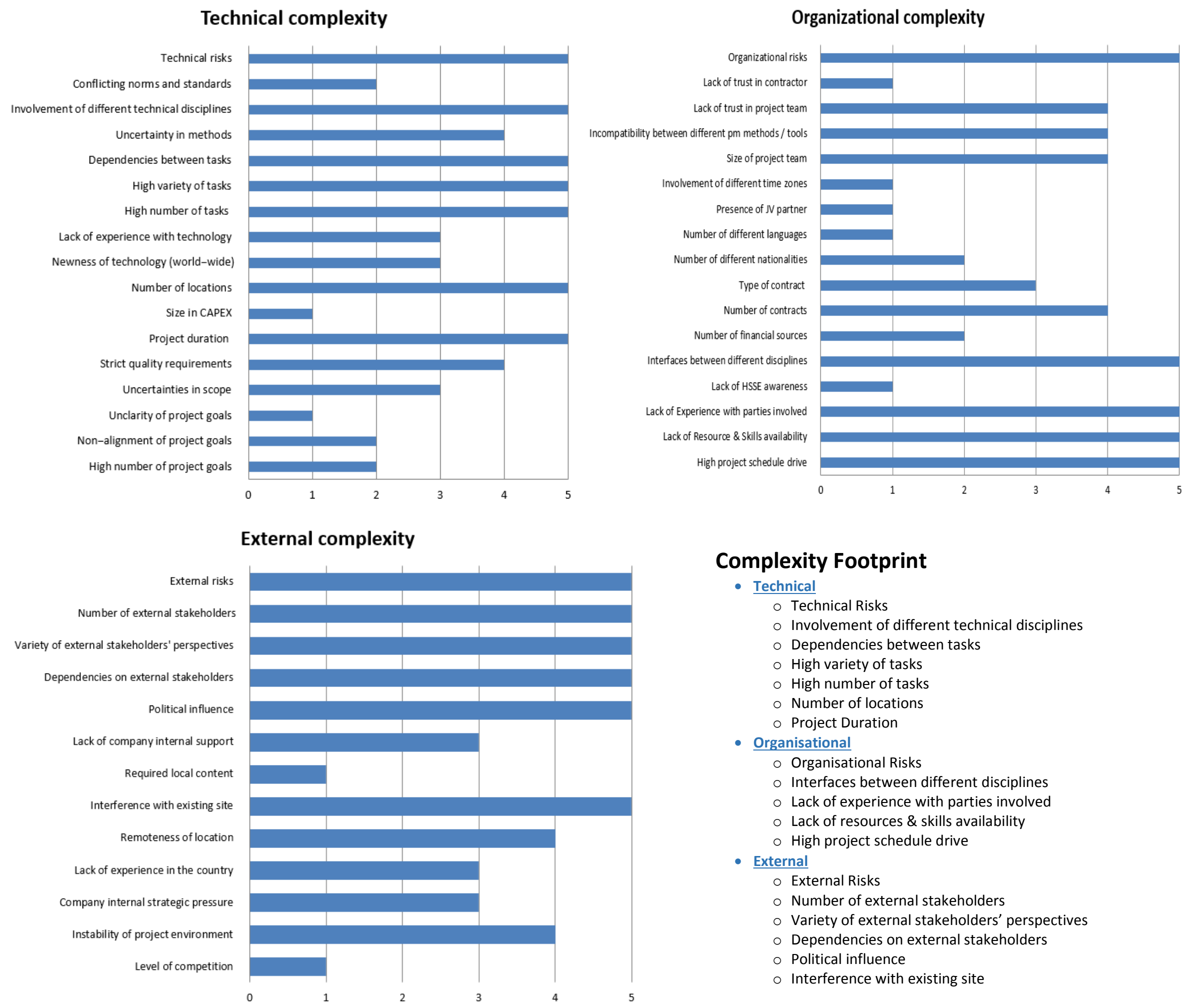

Figure 5.7 Results of the 'Complexity Assessment based on TOE Framework' process implemented on the "Design of the Gönen Plain Irrigation Project"

Using the complexity footprint obtained by the implementation of the TOE Complexity Assessment Framework, which is presented in Figure 5.7, the complexities indirectly affecting the CPM schedule is refined in an interactive way through the involvement of the relevant stakeholders as described above. The complexities decided to be included in this group and transferred directly to the "Risk Response/Complexity Embracement Planning" process (refer to Figure 5.4) are given below:

- Technical
    - Involvement of different technical disciplines
    - Dependencies between tasks
    - High variety of tasks

    - High number of tasks
    - Number of locations
- Organisational
    - Interfaces between different disciplines
    - Lack of experience with parties involved
    - Lack of resources & skills availability
    - High project schedule drive
- External
    - Number of external stakeholders
    - Variety of external stakeholders' perspectives
    - Dependencies on external stakeholders
    - Political influence

Through the assessment of the complexities effective on the "Design of the Gönen Plain Irrigation Project" through the TOE Framework, the complexities indirectly effective on the CPM schedule have been identified through meetings to which the relevant internal and external stakeholders are assumed to participate. With the adoption of a similar scenario, but this time with the participation of a broader involvement of the stakeholders including the Project Scheduling Units, Design Units, Reporting Units, Cost Estimation Unit, Project Risk Management Unit of the Owner, Design & Construction Unit, Contracting Authority, Farmers and Farmer Associations, Regional Authorities, Environmental Associations under the governance of the Project Risk Assessment Unit and based on the directions put forward in the Complexity/Risk Management Plan, the "Risk identification & classification" and "Refinement of the complexity-induced risks directly affecting the CPM schedule" processes are performed. Different risk identification techniques and tools such as risk checklists, brainstorming meetings, risk breakdown structuring, cause-effect evaluation and influence diagramming can be utilized during these processes (refer to Chapter 2). Eventually, the complexity elements directly affecting the CPM schedule have been identified and classified from the findings of the TOE Framework application given in Figure 5.7. These complexities are introduced below:

- Technical

  - Technical Risks
  - Project Duration
- Organisational
  - Organisational Risks
- External
  - External Risks
  - Interference with existing site

As can be observed in Figure 5.7, the above complexity elements together with the complexities indirectly affecting the schedule, which were determined previously, compose the complexity footprint constituted by the complexity elements that have been given the highest average scores at the end of the TOE Framework application. While the "Project Duration" complexity, which is considered at the same time as one of the complexity-induced risks affecting the CPM schedule, will be analyzed during the quantitative risk analysis based on CSRAM that will be carried out in the upcoming process, the complexity with regard to the "Interference with existing site" will be directly utilized as a source of risk-factors directly affecting the CPM schedule (the so-called complexity-induced risks) during the risk identification. Furthermore, the risks that could be categorized under the complexity elements, i.e. the technical risks, organizational risks and external risks, are also identified during the "Risk identification & classification" process. Later, these risks will be used during the CSRAM application after distinguishing the schedule risks from the other project risks associated with the complexities in question, i.e. the technical risks, organizational risks and external risks. The risks determined to affect the CPM schedule of the "Design of the Gönen Plain Irrigation Project" at the end of 'Risk identification & classification' and 'Refinement of the complexity-induced risks directly affecting the CPM schedule' processes are given below:

- Technical
  - Design changes requested by the Design & Construction Unit
  - Design changes requested by the Regional Office
  - Disputes with the Design & Construction Unit on technical and contractual issues

  - Disputes with the Regional Office on technical and contractual issues
  - Change in crop pattern over time with respect to the Planning Report
  - Design changes inside the organization of the Designer
- Organisational
  - Late approval of design documents by the Design & Construction Unit
  - Late approval of design documents by the Regional Office
  - Owner’s delay in payments
  - Inconsistent data & design parameters existing in the Planning Report
  - Prolongation of the decision-making on design prior to the approval of the Initial Report
  - Delay in written communication within the Owner's organization
  - Low productivity among the staff of Designer
  - Staff shortage within the organization of Designer
  - Lack of experience and skill among the staff of Designer
- External
  - Bad weather conditions during the site investigation (This risk has been identified as a complexity-induced risk directly affecting the CPM schedule based on the complexity element “interference with existing site”.)
  - Rejections to land expropriation by farmers
  - Rejections to project by local authorities
  - Political influence on project

5.3.4 Schedule Risk Analysis on the Risks & Complexity-Induced Risks (Step 4)

In the previous steps, three groups of factors have been determined that are assumed to affect the CPM schedule. The first group includes the complexities that indirectly influence the CPM schedule, which were identified based on the complexity footprint established through the TOE Framework (refer to Figure 5.7). The complexities in this group were directly transferred to the ‘Risk response/complexity embracement planning’ process (refer to Figure 5.4) which will be handled in the next step. The second group is composed of the complexity-induced risks directly affecting the CPM schedule, which were also identified based on the complexity footprint established through the TOE Framework (refer to Figure 5.7). This group will be directly taken into account during the quantitative risk analysis process implemented through CSRAM in the current step. The third group contains the risks predicted to affect the CPM schedule, which have been identified and classified traditionally through the risk identification methods in terms of the technical, organizational and external categories. These risks, which are under the third group, also represent the complexity elements "technical risks", "organizational risks" and "external risks" identified based on the complexity footprint established through the TOE Framework (refer to Figure 5.7). The risk-factors under this group will be taken into consideration during the quantitative risk analysis that will be conducted through the CSRAM after exposing these risk-factors to qualitative risk analysis to refine the most effective ones to be used in the CSRAM application. The complexity elements and the risk-factors which are predicted to be not effective on the CPM schedule are not taken into account in the IFCRM Procedure.

As can be observed in Figure 5.4 and pointed out above, the next process in the IFCRM Procedure is the implementation of the 'Schedule risk analysis' on the identified risks and complexity-induced risks. This process consists of two subsequent tasks: qualitative risk analysis and quantitative risk analysis. As explained above and in line with the flowchart of the procedure illustrated in Figure 5.4, firstly the qualitative risk analysis has been carried out through the 'Probability (P) x Impact (I)' scoring method under the responsibility of the Project Risk Assessment Unit of the Designer and with the involvement of the relevant stakeholders. The results of the qualitative risk analysis are given in Table 5.4. The risks with the 'occurrence probability x impact level' degree higher than 7, between 3 and 7, and less than 3 are accepted as possessing high, medium and low priority, respectively. The risk-factors getting 'high' priority level during the qualitative risk analysis (refer to Table 5.4) and the complexity-induced risks determined are directly transferred to the quantitative risk analysis stage.

In Figure 5.3, the modified form of the input-output chain of CSRAM was illustrated in case the model is utilised within the IFCRM Procedure. In accordance with the requirements put forward in Figure 5.3 and under the responsibility of the Project Risk

Assessment Unit of the Designer and with the involvement of the relevant stakeholders, the input data used in the CSRAM application have been determined. This data is given in Table 5.5. The minimum (optimistic), most-likely and maximum (pessimistic) activity durations have been estimated and in turn the activity durations have been represented by using these three time estimations in CSRAM application. The network and predecessor relationships between the activities used during the CPM application and given in Table 5.2 are used also in the CSRAM application. Furthermore, the activity/risk-factor influence degrees in the form of effective (E), very effective (VE), and ineffective (IE) qualitative terms and risk-factor situation probability boundary values in the form of better-than-expected, expected and worse-than-expected quantitative terms are given in Table 5.5. Furthermore, this table contains the MCS iteration number used during the CSRAM application. The iteration number was selected as 1000, which is sufficiently a high value in order to provide the required precision on the results. Besides, it is estimated that the risk-factors 3 and 4 have positive correlation in between.

Table 5.6 contains the results of CPM and CSRAM applications in a comparative form regarding the uncertainty on activity criticality for the "Design of the Gönen Plain Irrigation Project". While CPM reveals the criticalities in a deterministic way based on the single activity total float times and in turn one of "critical" or "noncritical" is assigned to each activity, CSRAM discloses the uncertainty on the activity criticalities in a stochastic way and in turn one of 'critical', 'noncritical' or 'near-critical' is assigned to each activity along with the uncertainty level on criticality based on the difference between minimum and maximum possible total float times. This information is utilizable by the Designer during the management of the CPM schedule as previously discussed in Chapter 4.

Figure 5.8 illustrates the results obtained through the Bar Chart Method, CPM and CSRAM applications on project duration uncertainty for the "Design of the Gönen Plain Irrigation Project". While the project completion time is deterministically 300 (refer to Figure 5.5) and 316 days (refer to Table 5.3) with respect to the Bar Chart and CPM Schedules respectively, CSRAM envisages the uncertainty on the project completion time in a stochastic way and shows the project completion time as a cumulative probability curve. The Designer can use these probabilistic project durations during the upcoming "risk response and complexity embracement strategy planning" process.

Table 5.4 Qualitative Risk Analysis on the "Design of the Gönen Plain Irrigation Project"

Risk No.	Category	Description	Occurrence Probability (P)	Impact Level (I)	P x I	Priority
1	Technical	Design changes requested by the Design & Construction Unit	0.9	9	8.1	High
2	Technical	Design changes requested by the Regional Office	0.8	9	7.2	High
3	Technical	Disputes with the Design & Construction Unit on technical and contractual issues	0.8	9	7.2	High
4	Technical	Disputes with the Regional Office on technical and contractual issues	0.8	7	5.6	Medium
5	Technical	Change in crop pattern over time with respect to the Planning Report	0.6	7	4.2	Medium
6	Technical	Design changes inside the organization of the Designer	0.9	9	8.1	High
7	Organisational	Late approval of design documents by the Design & Construction Unit	0.9	10	9.0	High
8	Organisational	Late approval of design documents by the Regional Office	0.7	9	6.3	Medium
9	Organisational	Owner's delay in payments	0.8	9	7.2	High
10	Organisational	Inconsistent data & design parameters existing in the Planning Report	0.6	8	4.8	Medium
11	Organisational	Prolongation of the decision-making on design prior to the approval of the Initial Report	0.7	8	5.6	Medium
12	Organisational	Delay in written communication within the Owner's organization	0.8	9	7.2	High
13	Organisational	Low productivity among the staff of Designer	0.9	9	8.1	High
14	Organisational	Staff shortage within the organization of Designer	0.8	9	7.2	High
15	Organisational	Lack of experience and skill among the staff of Designer	0.7	9	6.3	Medium
16	External	Rejections to land expropriation by farmers	0.6	6	3.6	Medium
17	External	Rejections to project by local authorities	0.3	4	1.2	Low
18	External	Political influence on project	0.4	7	2.8	Low

Table 5.5 Data used as input to CSRAM applied on the "Design of the Gönen Plain Irrigation Project"

		Risk-factors, Risk-factor situation probability boundaries & Activity / Risk-factor influence degrees*									
MCS Iteration Number 1000 **Correlated Risk-factors:** 3 & 4		**1-** Design changes inside the organization of the Designer	**2-** Design changes requested by the Regional Office	**3-** Design changes requested by the Design & Construction Unit	**4-** Late approval of design documents by the Design & Construction Unit	**5-** Low productivity among the staff of Designer	**6-** Staff shortage within the organization of Designer	**7-** Bad weather conditions during the site investigation	**8-** Owner's delay in payment	**9-** Disputes with the Design & Construction Unit on technical and contractual issues	**10-** Delay in written communication within the Owner's organization
Risk-factor Situations	Better-than-expected	0.40	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.40	0.10
	Expected	0.80	0.90	0.20	0.20	0.50	0.80	0.60	0.70	0.80	0.50
	Worse-than-expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Activities & Activity Durations in days (Minimum Expected / Most likely / Maximum Expected)	**Act. 1** 1/1/1	IE	IE	IE	IE	IE	IE	IE	IE	E	VE
	Act. 2 20/30/35	IE	IE	IE	IE	E	IE	IE	IE	IE	IE
	Act. 3 7/10/40	IE	IE	IE	E	IE	IE	IE	IE	IE	IE
	Act. 4 60/75/90	VE	IE	IE	IE	VE	VE	VE	IE	IE	IE
	Act. 5 15/20/50	IE	IE	VE	VE	IE	IE	IE	IE	E	VE
	Act. 6 15/20/40	VE	IE	IE	IE	VE	VE	E	E	IE	IE
	Act. 7 7/10/80	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 8 10/15/40	E	IE	IE	IE	VE	E	E	E	IE	IE
	Act. 9 5/5/50	IE	IE	IE	VE	IE	IE	IE	IE	E	IE
	Act. 10 20/30/50	E	IE	IE	IE	VE	VE	IE	E	IE	IE

Table 5.5 (cont'd)

MCS Iteration Number 1000 **Correlated Risk-factors:** 3 & 4		Risk-factors, Risk-factor situation probability boundaries & Activity / Risk-factor influence degrees* **1-** Design changes inside the organization of the Designer	**2-** Design changes requested by the Regional Office	**3-** Design changes requested by the Design & Construction Unit	**4-** Late approval of design documents by the Design & Construction Unit	**5-** Low productivity among the staff of Designer	**6-** Staff shortage within the organization of Designer	**7-** Bad weather conditions during the site investigation	**8-** Owner's delay in payment	**9-** Disputes with the Design & Construction Unit on technical and contractual issues	**10-** Delay in written communication within the Owner's organization
Risk-factor Situations	Better-than-expected	0.40	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.40	0.10
	Expected	0.80	0.90	0.20	0.20	0.50	0.80	0.60	0.70	0.80	0.50
	Worse-than-expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Activities & Activity Durations in days (Minimum Expected / Most likely / Maximum Expected)	**Act. 11** 7/10/90	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 12 50/70/100	E	IE	IE	IE	VE	VE	VE	VE	IE	IE
	Act. 13 40/60/150	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 14 60/70/90	E	IE	IE	IE	VE	VE	E	E	IE	IE
	Act. 15 30/40/120	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 16 7/10/20	E	IE	IE	IE	VE	E	IE	E	IE	IE
	Act. 17 5/5/40	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 18 7/10/30	E	IE	IE	IE	VE	E	IE	E	IE	IE
	Act. 19 5/5/40	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 20 20/30/40	E	IE	IE	IE	VE	VE	IE	E	IE	IE

Table 5.5 (cont'd)

	MCS Iteration Number 1000 **Correlated Risk-factors:** 3 & 4	**1-** Design changes inside the organization of the Designer	**2-** Design changes requested by the Regional Office	**3-** Design changes requested by the Design & Construction Unit	**4-** Late approval of design documents by the Design & Construction Unit	**5-** Low productivity among the staff of Designer	**6-** Staff shortage within the organization of Designer	**7-** Bad weather conditions during the site investigation	**8-** Owner's delay in payment	**9-** Disputes with the Design & Construction Unit on technical and contractual issues	**10-** Delay in written communication within the Owner's organization
		Risk-factors, Risk-factor situation probability boundaries & Activity / Risk-factor influence degrees*									
Risk-factor Situations	Better-than-expected	0.40	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.40	0.10
	Expected	0.80	0.90	0.20	0.20	0.50	0.80	0.60	0.70	0.80	0.50
	Worse-than-expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Activities & Activity Durations in days (Minimum Expected / Most likely / Maximum Expected)	**Act. 21** 10/10/60	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 22 7/10/30	E	IE	IE	IE	VE	VE	IE	E	IE	IE
	Act. 23 5/5/60	IE	E	VE	VE	IE	IE	IE	IE	E	IE
	Act. 24 3/4/20	IE	IE	IE	IE	VE	E	IE	E	IE	IE
	Act. 25 3/4/40	IE	IE	IE	VE	IE	IE	IE	IE	IE	IE
	Act. 26 3/4/10	IE	IE	IE	IE	VE	E	IE	E	IE	IE
	Act. 27 3/4/40	IE	IE	IE	VE	IE	IE	IE	IE	IE	IE
	Act. 28 3/4/10	IE	IE	IE	IE	E	E	IE	E	IE	IE
	Act. 29 3/4/40	IE	IE	IE	VE	IE	IE	IE	IE	IE	IE
	Act. 30 7/8/60	IE	IE	IE	E	IE	IE	IE	E	IE	IE

Table 5.5 (cont'd)

MCS Iteration Number 1000 Correlated Risk-factors: 3 & 4		Risk-factors, Risk-factor situation probability boundaries & Activity / Risk-factor influence degrees*									
		1- Design changes inside the organization of the Designer	**2-** Design changes requested by the Regional Office	**3-** Design changes requested by the Design & Construction Unit	**4-** Late approval of design documents by the Design & Construction Unit	**5-** Low productivity among the staff of Designer	**6-** Staff shortage within the organization of Designer	**7-** Bad weather conditions during the site investigation	**8-** Owner's delay in payment	**9-** Disputes with the Design & Construction Unit on technical and contractual issues	**10-** Delay in written communication within the Owner's organization
Risk-factor Situations	Better-than-expected	0.40	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.40	0.10
	Expected	0.80	0.90	0.20	0.20	0.50	0.80	0.60	0.70	0.80	0.50
	Worse-than-expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Act. 31 3/4/10	IE	IE	IE	IE	VE	E	IE	E	IE	IE
	Act. 32 3/4/60	IE	IE	IE	VE	IE	IE	IE	IE	IE	IE

*E: effective, VE: very effective, IE: ineffective

Table 5.6 Results of CPM and CSRAM applications regarding the uncertainty on activity criticality for the "Design of the Gönen Plain Irrigation Project"

Activity No.	Total Float (CPM)	Criticality (CPM)	Minimum Total Float (CSRAM)	Maximum Total Float (CSRAM)	Criticality (CSRAM)	Uncertainty in Criticality (CSRAM)
1	0	Critical	0	0	Critical	-
2	35	Noncritical	0	45	Near-Critical	High
3	35	Noncritical	0	45	Near-Critical	High
4	0	Critical	0	0	Critical	-
5	0	Critical	0	0	Critical	-
6	0	Critical	0	0	Critical	-
7	3	Noncritical	0	21	Near-Critical	High
8	0	Critical	0	21	Near-Critical	High
9	0	Critical	0	21	Near-Critical	High
10	0	Critical	0	0	Critical	-
11	0	Critical	0	0	Critical	-
12	0	Critical	0	0	Critical	-
13	0	Critical	0	0	Critical	-
14	25	Noncritical	12	128	Noncritical	-
15	25	Noncritical	12	128	Noncritical	-
16	40	Noncritical	19	100	Noncritical	-
17	40	Noncritical	19	100	Noncritical	-
18	40	Noncritical	19	100	Noncritical	-
19	40	Noncritical	19	100	Noncritical	-
20	0	Critical	0	0	Critical	-
21	0	Critical	0	0	Critical	-
22	0	Critical	0	0	Critical	-
23	0	Critical	0	0	Critical	-
24	40	Noncritical	19	100	Noncritical	-
25	40	Noncritical	23	100	Noncritical	-
26	0	Critical	0	0	Critical	-
27	0	Critical	0	0	Critical	-
28	4	Noncritical	1	11	Near-Critical	High
29	4	Noncritical	1	11	Near-Critical	High
30	44	Noncritical	19	131	Noncritical	-
31	0	Critical	0	0	Critical	-
32	0	Critical	0	0	Critical	-

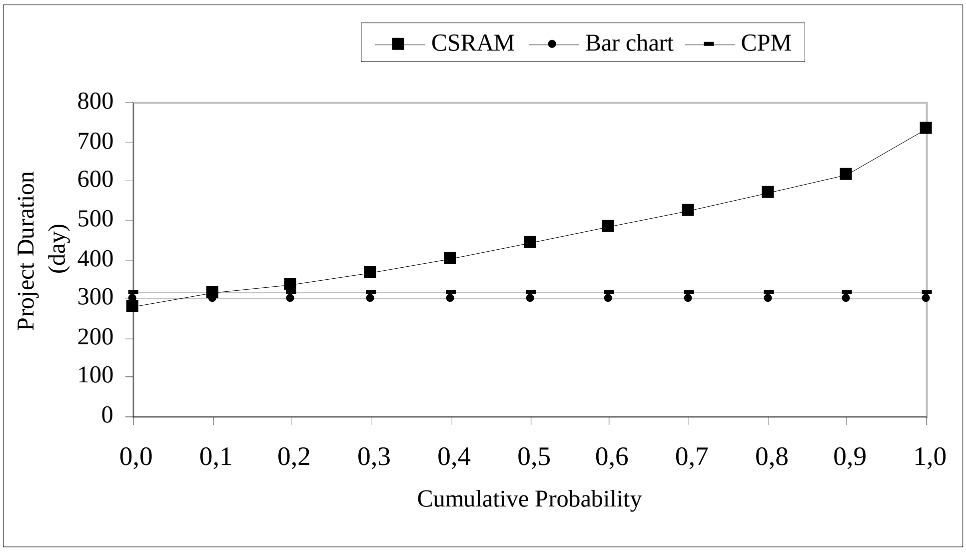

Figure 5.8 Results of Bar Chart Method, CPM and CSRAM applications on project duration uncertainty for the "Design of the Gönen Plain Irrigation Project"

Table 5.7 Results of CSRAM application on project duration uncertainty and project/risk-factor sensitivity for the "Design of the Gönen Plain Irrigation Project"

Scenario	Minimum Project Duration (day)	Mean Project Duration (day)	Maximum Project Duration (day)	Standard Deviation of Project Duration	Coefficient of Variation	Sensitivity Rank
All Risk-Factors	281.41	457.09	735.45	113.52	-	-
Risk-Factor 1	308.47	315.42	328.03	4.91	0.02	3
Risk-Factor 2	312.83	316.99	364.44	6.04	0.02	3
Risk-Factors 3 ~ 4 (Correlated)	295.93	450.39	659.20	114.71	0.25	1
Risk-Factor 5	299.37	326.06	362.79	17.64	0.05	2
Risk-Factor 6	303.61	316.11	335.41	5.46	0.02	3
Risk-Factor 7	311.91	316.45	321.47	2.13	0.01	4
Risk-Factor 8	312.04	316.66	326.79	3.52	0.01	4
Risk-Factor 9	311.22	321.54	378.68	16.73	0.05	2
Risk-Factor 10	314.88	317.71	322.92	2.57	0.01	4

As previously mentioned, the “Design of the Gönen Plain Irrigation Project” was completed in 683 days, i.e. in excess of 383 days with respect to the contractual project duration on the bar chart schedule shown in Figure 5.5. In this regard, it is important from the perspective of the Designer to be aware of the probabilities belonging to different project durations during the upcoming “risk response/complexity embracement strategy planning” process.

Table 5.7 shows the results obtained through the CSRAM application regarding the project duration uncertainty and project/risk-factor sensitivity for the “Design of the Gönen Plain Irrigation Project”. When all of the risk-factors are generated during the CSRAM application, the minimum, mean and maximum expected project durations evolve as 281, 457 and 735 days, respectively. The contractual project duration, which is the 300 days, and the actual project duration achieved at the completion of the project, which is 683 days, are both on this range disclosed by CSRAM. Furthermore, it is important for the Designer to be aware of the sensitivity of the project duration to the risk-factors taken into account during the CSRAM application. Table 5.7 shows that the risk-factors 3, 4, 5, and 9 (Design changes requested by the Design & Construction Unit, Late approval of design documents by the Design & Construction Unit, Low productivity among the staff of Designer, and Disputes with the Design & Construction Unit on technical and contractual issues) are the risk-factors to which the project duration is sensitive to a great extent. As previously mentioned, the Designer requested time extensions several times from the Owner in different dates after the project had started and the Owner had to accept some of these requests in compliance with the contract conditions. Depending on these time extensions, the 300 calendar days of contractual (planned) project completion time (project duration) was increased to 683 days after a delay of 383 days in total, which is more than the contractual project duration put forward on the baseline schedule. In other words, the “Design of the Gönen Plain Irrigation Project” actually could be completed in a period higher than two times of the initially planned duration, i.e. 300 days. The sensitivities of the project duration to the risk-factors presented in Table 5.7 are compatible with the root causes of the schedule delay ocurred during the execution of the project.

5.3.5 Risk Response & Complexity Embracement Strategy Planning (Step 5)

In the preceding processes carried out up to now; firstly the complexity elements indirectly influencing the CPM schedule have been revealed and transferred to the 'Risk response & complexity embracement strategy planning' process, which will be tackled in the current step. Secondly, the complexity elements directly impacting the CPM schedule (the so-called complexity-induced risks) and the schedule risks effective on the "Design of the Gönen Plain Irrigation Project" have been disclosed. Then, the complexity-induced risks and the schedule risks have been analysed through qualitative risk analysis and quantitative schedule risk analysis techniques. Now, it is time to perform the next process of the IFCRM Procedure (refer to Figure 5.4), the 'Risk response & complexity embracement strategy planning' based on the traditional risk response procedures and the complexity embracement methodologies proposed by the Detail-Dynamic Project Management Model.

If the Designer had benefitted from the results of the schedule risk analysis process during the contracting stage as well as during the preparation of the baseline CPM schedule instead of using simply a bar chart schedule which was unfortunately the case in reality, he/she would have had the opportunity of utilising the identified complexities and schedule risks in conjunction with the results of the schedule risk analysis during the establishment of the risk response and complexity embracement strategies and as well as during the implementation of these strategies throughout the execution of the project. Thereby, a more rational project completion time would have been proposed to the Owner, a superior schedule based on CPM would have been submitted at the beginning of the project, and the schedule delays occurred in reality would have been prevented up to an extent by managing the CPM schedule in accordance with the risk response/complexity embracement strategies that will be proposed below and through benefitting from the managerial flexibilities provided both by the traditional CPM and its extension, the CSRAM.

In order to handle the complexity footprint of the "Design of the Gönen Plain Irrigation Project" put forward based on TOE Complexity Assessment Framework and to propose a specific fit-for-purpose management strategy over this complexity footprint in compliance with the Perception-Based Management without ignoring the subjective character of complexity, it is assumed that the Designer ensured the involvement of the relevant internal stakeholders to the process in question through holding the meetings envisaged in the Complexity/Risk Management Plan (refer to Figure 5.4). Furthermore, the Designer uses the Detail-Dynamic Project Management Model to determine strategies to embrace the complexities indirectly affecting the CPM schedule and utilise the traditional risk response techniques to tackle with the risks influencing the schedule.

In this context, the following strategies are proposed to response the risks and embrace the complexities effective on the CPM schedule on behalf of the Designer:

- *Project Duration*: This is a complexity element previously identified as a technical complexity based on the TOE Framework and considered to affect the CPM schedule directly. Indeed, all the effort established during the management of the CPM schedule is to keep this complexity under control, embrace it and complete the project on time. In this regard, it can be a considered as a general and important complexity from the scheduling perspective. When the 300 days of project duration contractually determined based on the bar chart schedule (refer to Figure 5.5), the 316 days of project duration calculated by CPM (refer to Table 5.3), the cumulative probability curve of project duration envisaged by CSRAM (refer to Figure 5.8) and the actual project duration at completion, which is 683 days, are all compared in between, it can be concluded that the Designer should have submitted to the Owner a CPM schedule instead of a bar chart schedule having a more realizable project duration different from 300 or even 316 days. The cumulative probability curve of the project duration in Figure 5.8 shows that the minimum, mean and maximum expected project durations are 281, 457 and 735 days, respectively, according to CSRAM. This would be a matter of decision-making from the perspective of the Designer based on his/her risk attitude and previous experiences. Besides, the risk-factor/project duration sensitivity of the CPM schedule explored by CSRAM (refer to Table 5.7) should have been taken into account during managing the project because the awareness on the most effective risk-factors that cause variation in activity durations is crucial to properly allocate the efforts and existing resources to the right points. Furthermore, the managerial flexibilities provided by CPM (refer to Table 5.3 and for more explanation refer to Chapter 3) and the variation on those flexibilities disclosed by CSRAM (refer to Table 5.6 and for more explanation refer to Chapter 4) should be benefitted by the Designer during the execution of the project through the usage of an appropriate project scheduling software to generate these managerial flexibilities in full.

- *Interference with existing site*: This is a complexity element previously identified under the external category of TOE Framework and considered to be effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project". It was taken into account as a complexity-induced risk and used as a risk-factor during the CSRAM application under the name of 'Bad weather conditions during the site investigation (Risk-Factor-10)'. When the risk-factor/project duration sensitivity of the CPM schedule revealed through CSRAM (refer to Table 5.7) is examined, it is observed that this complexity-induced risk has no profound impact on the schedule when compared with the other risk-factors. Nevertheless, the activities requiring frequent site visits should be inserted on the CPM schedule compatible with the weather conditions expected in the Gönen region during the aforementioned period of the year. Thereby, the Designer would have kept this risk-factor under control.
- *Design changes inside the organization of the Designer*: This is the risk-factor-1 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule is not so sensitive to this risk-factor. Design changes inside the organisation of the Designer may primarily occur due to the shortage of coordination and communication between the design units and among the skilled design staff. Therefore, the Designer should establish a risk control (reduction) strategy by enforcing the communication and coordination between the design units inside the organisation.
- *Design changes requested by the Regional Office*: This is the risk-factor-2 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule is not so sensitive also to this risk-factor.

Design changes may be requested by the Regional Office mainly because of the incompliance of the design documents with the contractual specifications or the technical requirements requested by the Regional Office in line with the demands coming from the farmers and other regional stakeholders. Depending on this, the Designer should establish a risk control strategy by enforcing the interaction with the relevant units within the Regional Office and the communication with the other regional external stakeholders. The design changes occurring due to the requests of the Regional Office may cause delays on the relevant activities in the CPM schedule and these delays may cause delay on the timely submission of the design documents to the General Directorate and in turn lead to schedule overrun depending on the criticality conditions and float times of those activities. From this perspective, the Designer should approach with caution to the activities surrounded by the dynamics of this risk-factor.

- *Design changes requested by the Design & Construction Unit and Late approval of design documents by the Design & Construction Unit*: These are the risk-factor-3 and risk-factor-4, respectively, used as correlated risk-factors in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule is most sensitive to these two correlated risk-factors among the others. Therefore, the project duration envisaged through the CPM schedule may be impacted extensively due to the uncertainty created by these correlated risk-factors. The time extension requests delivered to the Owner by the Designer during the execution of the "Design of the Gönen Plain Irrigation Project" were mainly due to the combined effect of these risk-factors. Accordingly, the Designer firstly should apply risk control measures to ensure the timely approval of the design documents by the Regional Office and then submission of the documents by the Regional Office to the Central Office without delay. Secondly, he/she should establish strong communication channels with the relevant units of the Project & Construction Department through the highly-skilled design staff. Thirdly, the Designer should follow the approval process closely inside the Owner's organisation in order to prevent the ignorance of the design documents in somewhere. Another cause of the schedule overrun occurred in the “Design of the Gönen Plain Irrigation Project” was the technical meetings held within the Design & Construction Unit with the participation of various internal and external stakeholders before the preparation of the “Initial Report”. In those meetings, the implementation of major design changes were decided by the Owner due to the inaccuracy of design formulation put forward within the Planning Report of the project. These design changes led to schedule overrun and time extension requests by the Designer. Therefore, the Designer should take the necessary measures regarding the technical problems that might occur depending on the deficiencies in the Planning Report. As a measure, he/she may alert the Owner on these deficiencies earlier by directing the experienced and highly-skilled staff to review the Planning Report in detail before the meetings in question are held.

- *Low productivity among the staff of Designer*: This is the risk-factor-5 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule is sensitive to this risk-factor. Any decrease in the motivation and productivity among the staff of the Designer would lead to late submission of the design documents and the submission of faulty design as well. In order to respond to this risk-factor, the Designer should take some control measures in order to keep the motivation of the staff high and keep the experienced staff within the company. Furthermore, the Designer may implement a risk transfer strategy by subcontracting some parts of the design task to other design companies or designers in case of urgent situations. Since this risk-factor is completely under the control of the Designer, any delay in the activities caused due to low productivity among the staff would lead to delay penalties applied based on the conditions of the contract.
- *Staff shortage within the organization of Designer*: This is the risk-factor-6 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule shows sensitivity to this risk-factor. Staff shortage may cause delays on the timely completion of the activities and in turn lead to schedule overrun. The Designer should apply risk reduction and transfer

techniques similar to the ones proposed for the previous risk-factor. Especially, measures should be applied to prevent the transfer of the experienced staff to other companies, which is frequently encountered among the design companies.

- *Owner's delay in payment*: This is the risk-factor-8 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule shows sensitivity to this risk-factor. The Designer should establish interactive control measures among the units within the Owner's organisation effective on the payment process to lower the occurrence probability of this risk-factor.
- *Disputes with the Design & Construction Unit on technical and contractual issues*: This is the risk-factor-9 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule shows high sensitivity to this risk-factor. Disputes may arise especially in case of huge faults detected by the Design & Construction Unit on one of the design documents and in turn, the document is sent back to the Regional Office to restart the review and approval process. In such cases, the Designer loses time and depending on this, the rejection of the design documents by the Design & Construction Unit may lead to disputes between the Designer and the Owner. In order to keep this risk-factor under control, the Designer should apply strategies to ensure the preparation of the design documents within the quality limits and in compliance with the technical criteria envisaged in the specifications. For instance, the usage of wrong type of pipe, i.e. HDPE or GRP, the mistakes made during the pipe optimisation, faults made in maximum pipe pressure calculations, and inappropriate layout of the pipe network on the field all might cause the rejection of the design documents and in turn lead to disputes between the Designer and the Owner.
- *Delay in written communication within the Owner's organization*: This is the risk-factor-10 used in CSRAM application during the quantitative risk analysis (refer to Table 5.5). According to the results of CSRAM regarding the project/risk-factor sensitivity given in Table 5.7, the CPM schedule shows

sensitivity to this risk-factor. The Designer should take risk control measures by monitoring the written communication channels within the Owner's organisation closely and interactively in order to prevent the occurrence of this type of delays.

- *Involvement of different technical disciplines*: This is one of the technical complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The existence of different units within the organisation of the Designer responsible of different technical aspects of the project such as design, reporting, cost estimation and scheduling as well as the existence of different units within the organisation of the Owner related with the irrigation and drainage projects previously pointed out among the external stakeholders cause the complexity element in question being effective on the management of the CPM schedule. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Involvement of different technical disciplines" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. Depending on only the baseline schedule and following a control (system) approach would not be sufficient for the management of this complexity that is impossible to think as absolutely having a detail character.
- *Dependencies between tasks*: This is one of the technical complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. It is obvious that this complexity has been determined as being effective on the CPM schedule because of the fact that the tasks are dependent on each other with different precedencies such as FS and SS as can be observed in Table 5.2. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity

element “Dependencies between tasks” can be considered as having dominantly a detail character for this project, the application of a control approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. However, due to the existence of various internal and external stakeholders impacting the realisation of the tasks would enforce the Designer to implement an alternative strategy that is more dynamic (both interactive and control) depending on the conditions. Furthermore, the managerial flexibilities associated with the CPM discussed and evaluated previously in Chapters 3 and 4 should be benefitted by the Designer during the management of the CPM schedule in order to provide control with respect to this complexity.

- *High variety of tasks*: This is one of the technical complexities determined as indirectly effective on the CPM schedule of the “Design of the Gönen Plain Irrigation Project” during the implementation of IFCRM Procedure. When the descriptions of the activities constituting the CPM schedule given in Table 5.2 are taken into account, it can be discussed about the effectiveness of the complexity in question. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element “High variety of tasks” can be considered as having dominantly a detail character for this project, the application of a control approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. It should be mentioned that the detail for the activities given in Table 5.2 was hold at a certain level for decreasing the number of activities to be handled for this example application. During the execution of the project, sub-activities would evolve and the complexity regarding the “high task variety” would increase.
- *High number of tasks*: This is one of the technical complexities determined as indirectly effective on the CPM schedule of the “Design of the Gönen Plain Irrigation Project” during the implementation of IFCRM Procedure. When the number of activities constituting the CPM schedule given in Table 5.2, which is 32, are taken into account, the effectiveness of the complexity in question might

be disputable. However, it should be mentioned that the detail for the activities given in Table 5.2 was hold at a certain level for decreasing the number of activities to be handled for this example application. During the execution of the project, sub-activities would evolve and the complexity regarding the number of tasks would increase. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "High number of tasks" can be considered as having dominantly a detail character for this project, the application of a control approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The managerial flexibilities associated with the CPM discussed and evaluated previously in Chapters 3 and 4 should be benefitted by the Designer during the management of the CPM schedule of the project in order to provide control with respect to this complexity.

- *Number of locations*: This is one of the technical complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. When the activities constituting the CPM schedule given in Table 5.2, the stakeholders involved and the remote location of the project site on the Gönen Region are taken into account, it can be discussed about the effectiveness of the complexity in question. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Number of locations" can be considered as having both detail and dynamic characters for this project, the application of a dynamic (both control and interactive) approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should apply a control approach based on the CPM schedule as well as an interactive approach to build the necessary interaction with the stakeholders existing in different locations.

- *Interfaces between different disciplines*: This is one of the organisational complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The existence of various internal and external stakeholders stands as the root cause for the effectiveness of this complexity on the project. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Interfaces between different disciplines" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should establish an interactive approach to build the necessary interaction channels throughout the interfaces between different disciplines responsible of the execution of various activities on the CPM schedule.
- *Lack of experience with parties involved*: This is one of the organisational complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The existence of various stakeholders and the lack of sufficient experience of the Designer with these parties is the cause of that complexity's influence on the project. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Lack of experience with parties involved" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should establish an interactive approach to build the necessary interaction channels between the parties involved in order to convert the effect of this complexity into an opportunity and create value for the project.

- *Lack of resources & skills availability*: This is one of the organisational complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The lack of resources and skills available within the organisation of the Designer might evolve as a complexity and affect the timely completion of the activities on the CPM schedule. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Lack of resources & skills availability" can be considered as having both detail and dynamic character for this project, the application of a dynamic (both control and interactive) approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer, while interactively embracing the aforementioned complexity through well-established resource management procedures, he/she should also benefit from the best practices of resource scheduling built upon the CPM. This would create a value for the project by increasing the possibility of completing the activities within their envisaged early start and finish times.
- *High project schedule drive*: This is one of the organisational complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The Owner generally desires the delivery of the irrigation projects without delay in order to carry out the tender of the construction phase as soon as possible. This happened also for the case of the "Design of the Gönen Plain Irrigation Project" and the Designer faced with the complexity of "High project schedule drive". Unfortunately, as previously mentioned, a very long delay has occurred at completion in this project. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "High project schedule drive" can be considered as having dominantly a detail character for this project, the application of a control approach would create value during the schedule

management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should utilise all the features and managerial flexibilities of CPM and CSRAM in order to manage the CPM schedule in the best way. Such an effort would create value for the project by increasing the possibility of the achievement of schedule targets.

- *Number of external stakeholders*: This is one of the external complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The existence of the external stakeholders such as the farmers, regional authorities and politicians can be considered as the source of the complexity in terms of the number of external stakeholders. Since the irrigation projects serve to the agriculture sector after completion, various external stakeholders generally interfere with these projects during the design and construction phases. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Number of external stakeholders" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should establish an interactive approach to build the necessary interaction channels with the external stakeholders involved in order to convert the effect of this complexity into an opportunity and create value for the project.
- *Variety of external stakeholders' perspectives*: This is one of the external complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. The existence of the external stakeholders such as the farmers, regional authorities and politicians can be considered as the source of the complexity also in terms of the variety of external stakeholders' perspectives. Besides, the perspectives of the Regional Office and the Design & Construction Unit may also differ. As abovementioned, since the irrigation projects serve to the agriculture sector after completion, various external

stakeholders having conflictive interests and perspectives may interfere with these projects during the design and construction phases. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Variety of external stakeholders' perspectives" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should apply an interactive approach to build the necessary interaction channels with the external stakeholders involved in order to convert the effect of this complexity into an opportunity and create value for the project through the establishment of the goal alignment among the external stakeholders.

- *Dependencies on external stakeholders*: This is one of the external complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain Irrigation Project" during the implementation of IFCRM Procedure. As abovementioned, irrigation projects are highly dependent on various external stakeholders throughout their lifecycles from conception till the end of project life. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Dependencies on external stakeholders" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should apply an interactive approach to build the necessary interaction channels with the external stakeholders involved in order to convert the effect of this complexity into an opportunity and create value for the project through regulating the dependencies on the external stakeholders from a schedule management perspective.
- *Political Influence*: This is one of the external complexities determined as indirectly effective on the CPM schedule of the "Design of the Gönen Plain

Irrigation Project" during the implementation of IFCRM Procedure. Since the irrigation projects serve to the agriculture sector, they generally possess high social effects and unavoidably attract the political attention. The interference of the political authority on the project might also influence the implementation of the target schedule during the project execution. Therefore, the Designer should apply an appropriate fit-for-purpose strategy specific to the management of this complexity to embrace the opportunities that will evolve and in turn to create value for the project. Since the complexity element "Political Influence" can be considered as having dominantly a dynamic character for this project, the application of an interactive approach would create value during the schedule management with respect to the Detail-Dynamic Management Model illustrated in Figure 2.12. The Designer should apply an interactive approach to build the necessary interaction channels with the politicians in order to convert the effect of this complexity into an opportunity and create value for the project.

5.3.6 Implementation, Monitoring & Control, Feedback & Update and the Next Iteration after the First Milestone (Steps 6 - 8)

After having performed the risk response/complexity embracement planning process and determining what kind of risk response techniques as well as complexity embracement strategies will be implemented during the management of the CPM schedule of the "Design of the Gönen Plain Irrigation Project", the next processes to be carried out by the Project Risk Assessment and Scheduling Units of the Designer according to the flowchart of the IFCRM Procedure given in Figure 5.4 are the 'Implementation', 'Monitoring & Control', and the 'Feedback & Update' processes that should be conducted respectively on the 'Risk response/complexity embracement plan'. As it is illustrated in Figure 5.4, while the 'Monitoring & Control' process is conducted in relation with the 'Schedule Control' process of the project schedule management, 'Feedback & Update' process is carried out in relation with the 'Schedule Development' process of the project schedule management through the involvement of the relevant stakeholders.

Since the IFCRM Procedure requires the reimplementation of all of the processes included through successive iterations after the completion of each milestone activity of the CPM schedule, the Designer should check the progress achieved up to the single milestone determined on the CPM schedule as shown in Figure 5.5 by the means of the relevant processes of the Project Schedule Management and then should continue with the next iteration (refer to Figure 5.4). It should be mentioned that according to the procedure's Flexibility Feature 5, the number of iterations can be increased in line with the project conditions. In case the progress is behind the target schedule, then the processes of the IFCRM Procedure should be repeated with due diligence in the next iteration and the Risk response/complexity embracement plan established in the first iteration should be revised and improved. Through this iterative approach, the Designer would assure the provision of flexibility required during the implementation of the IFCRM Procedure on the CPM schedule of the "Design of the Gönen Plain Irrigation Project". Furthermore, he/she would experience the advantage of using various managerial flexibilities provided by the traditional CPM when compared against the bar chart schedule as well as the expansion of the managerial flexibilities in the CPM schedule based on the usage of the CSRAM. Moreover, the incorporation of the TOE Complexity Assessment Framework into the project risk management and the utilisation of the Detail-Dynamic Project Management Model based on Perception-Based Management and Fit-for-Purpose Management would increase the dynamism on the schedule management and in turn enrich the managerial flexibility needed by the Designer to tackle with the complexities and uncertainties to complete the project on schedule.

5.4 CONCLUDING REMARKS

In this chapter, another aspect of the project management recently under discussion among the researchers, i.e. the 'complexity', for which the flexible project management approaches are assumed to be effective to manage it, has been investigated in conjunction with the 'uncertainty' within the scope of project risk management and from the scheduling perspective in line with the topic of this research. The objective was to incorporate the TOE Complexity Assessment Framework developed by Bosch-

Rekveldt *et al*. (2011) into the project risk management through the utilisation of the CSRAM developed by Ökmen & Öztaş (2008), the Detail-Dynamic Project Management Model developed by Hertogh & Westerveld (2010) and the relevant processes of the PMBOK Guide (Project Management Institute, 2017). The final aim was to propose an integrated flexible complexity incorporated risk management procedure that could be implemented on CPM schedules.

A step-by-step methodology has been followed to achieve this aim. Firstly, a complexity assessment incorporated project risk management approach was put forward based on the usage of TOE Framework and the processes of the PMBOK Guide related with the project risk management knowledge area (Project Management Institute, 2017). Besides being a first step, this attempt was representing the effort of combining the relatively new concept of project management, i.e. the complexity assessment, with the traditional process of project management, i.e. project risk management. However, the procedure obtained at the end of this step, the flowchart of which is illustrated in Figure 5.1, had limited flexibility and was utilisable only for the general application. Therefore, this initial approach should have been modified and developed one step forward. For this, the procedure has been customised for making it implementable during the management of CPM schedules. This was achieved by integrating the CSRAM and by establishing interfaces with the relevant project schedule management processes of the PMBOK Guide as shown in Figure 5.2.

However, this new version of the integrated complexity/risk management procedure still was of a traditional one designed as a stepwise process that is neglecting the factors like subjective character of complexity, project dynamics and the need for stakeholder involvement in projects. Therefore, it needed to be converted to a more flexible form in order to get able to use it during the development of the hybrid project management approach to be used on CPM schedules in the next chapter. For this purpose, based on 10 different flexible features determined through literature survey, the procedure was improved through the integration of the Detail-Dynamic Project Management Model along with the Fit-for-Purpose Project Management and Perception-Based Management. It should be mentioned that the Detail-Dynamic Project Management Model, Fit-for-

Purpose Management Strategy and Perception-Based Management have a distinctive common point in terms of flexibility for the reason all of these approaches acknowledge the influence and importance of the project dynamics as well as the need for adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex and uncertain conditions. In this regard, the integration of these approaches within a complexity incorporated risk management system has the potential to provide a substantially flexible environment in terms of project management as well as for the management of CPM schedules.

The flexibility established on this new and final version of the procedure, which is named as the ‘Integrated Flexible Complexity/Risk Management (IFCRM) Procedure’ and the flowchart of which is illustrated in Figure 5.4, has been further enriched by adding iteration capability, which could be generated at least after the achievement of each predetermined milestone of the CPM schedule, and by ensuring the involvement of the relevant stakeholders in order to create an interactive project management environment. Furthermore, the exploration of the complexity-induced risks directly effective on the schedule and the complexities indirectly effective on the schedule has been enabled for the insertion of all kinds of complexities that thought to be effective on the schedule into the risk analysis and risk response/complexity embracement strategy development processes.

The applicability of the IFCRM Procedure also has been illustrated on an example design project previously realised in Turkey in the public construction sector called the “Design of the Gönen Plain Irrigation Project” (State Hydraulic Works, 2011). This example application carries importance firstly for showing that the IFCRM Procedure is not only applicable on the construction phase but also on the pre-construction phases. Secondly, the managerial advantages provided by the implementation of the proposed procedure when compared with the actual story of the project, which unfortunately includes a long schedule delay at completion, have shown that the schedule management is not a simple task that could be undertaken by preparing an insufficient schedule at the beginning and use this schedule throughout the project without doing any analysis on it. Rather, the schedule management, if success is really desired, requires the fulfilment of much more things as revealed through the example application of the IFCRM Procedure on the "Design of the Gönen Plain Irrigation Project". The interaction with the stakeholders, their involvement into the processes, adoption of Perception-Based Management and by this way, establishment of a shared-mental model through the perceived complexities (i.e. subjective character of complexity) evolve as the key issues as discussed in this chapter. While responding to risks, embracing the complexities instead of fully keeping them under control to benefit from the opportunities that would be created by them is believed to be the strategy to be followed to constitute an appropriate fit-for-purpose management model as proposed by the IFCRM Procedure.

As previously mentioned in Chapter 1, the researcher has been assigned as a supervisor within the thesis committees of two different master of science studies realised under the Construction Management and Engineering (CME) Master Program of TU Delft. Under one of these studies entitled "Investigation of relationship and interactions between complexities and risks in complex construction projects for usage during the risk management process" and conducted by Lise Andringa, an approach has been developed to incorporate the complexity assessment into the risk identification process of project risk management in complex construction projects by the means of cause-effect searching and risk influence diagramming techniques. This approach can also be used within the IFCRM Procedure during the identification of the complexity-induced risks and complexities directly and indirectly affecting the CPM schedule respectively. Furthermore, the correlated risk-factors could be identified through the developed approach to be used during the quantitative risk analysis process based on the CSRAM. The cover and abstract pages of this thesis, together with the other thesis supervised, are given in Appendix A. The reader is referred to Andringa (2021) for detailed information about the developed approach.

In the next chapter, through the usage of the managerial flexibilities inherent with CPM as well as the expanded flexibilities obtained in case of CPM's usage under uncertainty in the form of CSRAM, which have been revealed in the previous chapters, and also through the utilisation of the IFCRM Procedure developed in this chapter, a CPM-based hybrid project schedule management approach carrying both traditional and flexible features will be proposed.

6 PROPOSAL OF A HYBRID APPROACH FOR THE FLEXIBLE MANAGEMENT OF CPM SCHEDULES IN COMPLEX CONSTRUCTION PROJECTS

This chapter introduces the final attempt undertaken to achieve the main goal of this research, i.e. 'to propose a hybrid approach carrying both traditional and flexible features that can be used in the management of CPM schedules under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to'. The literature review conducted in Chapter 2 and the findings of the succeeding chapters constitute the required alignment towards the achievement of this goal. The main argument put forward since the beginning of the report is that the flexible management of schedules would not mean completely leaving the usage of methods and techniques of traditional project management but rather exploring their potential aspects that might contribute to the establishment of flexibility. The literature review in Chapter 2, and the evaluation of the inherent managerial flexibilities in traditional CPM and the examination of project schedule management processes of the PMBOK Guide (Project Management Institute, 2017) in terms of flexibility in Chapter 3 were conducted based on this argument. In Chapter 4, the discussion was expanded to the exploration of the managerial flexibilities in case CPM is implemented in the form of a simulation-based risk analysis model through the CSRAM (Ökmen & Öztaş, 2008), to observe its capabilities under uncertainty. Furthermore, the project risk management processes of the PMBOK Guide (Project Management Institute, 2017) were examined from the flexibility viewpoint and in terms of CPM scheduling within the same chapter. The results of both the theoretical evaluations and practical applications carried out until Chapter 5 have shown that the traditional side of the problem, as expected, has the potential for establishing flexibility in the management of CPM schedules up to a certain extent, however which needs to be improved. In this regard, in Chapter 5, another key point of the research problem, the 'complexity' was handled within the context of project risk management (Project Management Institute, 2017). In the end of Chapter 5, the IFCRM Procedure has been proposed for the incorporation of complexity assessment into the schedule risk management through the TOE Framework (Bosch-Rekveldt *et al.*, 2011) and for enabling the flexibility on CPM schedules in terms of complexity assessment and risk management in an integrated manner. The IFCRM Procedure will be used as a component to the hybrid approach that will be developed in this chapter. In accordance with the general argument of this research as emphasized above, the proposed hybrid approach will include several aspects compatible with the principles of flexible project management approaches such as "Agile" (Agile Methodology, 2014; Crowder & Friess, 2015; Agile Manifesto, 2020) and "Lean" (Lean Construction Institute, 2020; Ballard, 2000; Blom, 2014; Jalali-Sohi, 2018, Jalali-Sohi *et al.*, 2019a) while promoting the usage of already existing flexibilities in the traditional implementations of CPM as having been discussed so far in the previous chapters. This is the reason of calling this new approach as 'hybrid' due to the traditional and flexible features that it carries.

In the next section, the features of agile and lean approaches along with the dynamic scheduling method, among which it will be filtered to get able to use during the development of the hybrid approach, will be introduced based on the literature review performed in the previous chapters, the studies of Jalali-Sohi *et al.* (2016, 2019a, 2019b, 2019c) with regard to the flexible project management and the "Dynamic Scheduling" method proposed by Vanhoucke (2012). Afterwards, the hybrid approach will be introduced in the succeeding sections. Similar with the previous chapters, this chapter also contains an example application on which the applicability of the developed approach is illustrated. Finally, the chapter will end up with the presentation of the concluding remarks specific to this chapter.

6.1 LITERATURE REVIEW ON THE AGENTS OF FLEXIBILITY IN PROJECT MANAGEMENT

Jalali-Sohi *et al.* (2019a; 2019b; 2019c), through their extensive literature survey and the studies conducted to explore the perspectives of the practitioners, claim that the increasing complexity and uncertainty in specifically large-scale construction projects require the implementation of more flexible project management methodologies to cope with the dynamics of the projects. However, Jalali-Sohi *et al.* (2019a) also point out that a shortage exists in terms of the procedures and methods that would provide flexibility to the project management in practice (Jalali-Sohi *et al*., 2019a). Some researchers have stated the deficiencies of traditional project management in dealing with the increasing complexity and uncertainty of today's projects (Maylor, 2010; Turner & Cochrane, 1993; Whitty & Maylor, 2009; Williams, 2005; Baccarini, 1996; Geraldi, 2008; Hobday, 1998; Williams, 1999). Based on this fact, the literature emphasize the requirement of the new flexible approaches in project management (Aritua *et al*., 2009). The traditional project management puts the emphasis mostly on planning and control (Bosch-Rekveldt, 2011, Koppenjan *et al.,* 2011). The reason for the traditional project management being inadequate any more might be due to this excess focus (Atkinson *et al*., 2006) or much emphasis on the achievement of the determined goals (Aritua *et al.*, 2009), or unnecessarily concentrating on the time, budget and performance constraints (Koppenjan *et al.,* 2011) based on the assumption that the goals in a project can be determined at the beginning of the project and do not change throughout the project (Atkinson *et al*., 2006). However, the rigid planning beforehand is becoming more inappropriate nowadays due to the increasing complexity, uncertainty and the satisfaction needs of the stakeholders in projects (Hertogh & Westerveld, 2010; Williams, 2005). For this reason, rather than following a rigid plan prepared in detail at the beginning of a project that takes the traditional constraints into account, the emphasis should be put on the actual performance in terms of the value to be created as well as the stakeholder satisfaction (Perminova *et al*., 2008). Accordingly, there is a need for the new flexible approaches that take the project complexity and uncertainty into consideration and also the flexible tools that would reduce the rigidness in traditional project management to cope with the challenges related to the project complexity and uncertainty (Atkinson *et al*., 2006; Koppenjan *et al.,* 2011). The hybrid approach that will be proposed at the end of this chapter for the flexible management of CPM schedules of construction projects under complexity and uncertainty can be considered as a step that would be taken in this context.

As presented in Chapter 3, PMBOK Guide points out the importance of the style of life cycle implemented in a project for the reason that the management style applied in a project, which may be traditional, (pure) flexible or hybrid, becomes clear essentially through the implemented life cycle style (Project Management Institute, 2017). Figure

3.10 shows the different styles in question (Project Management Institute, 2017). As it can be observed on Figure 3.10, according to the PMBOK Guide (Project Management Institute, 2017), project life cycles might be predictive (plan-driven), adaptive (agile), iterative, incremental, or hybrid (Project Management Institute, 2017). The main features of the predictive life cycles are the high-level stakeholder alignment, less changeable scope, detailed up-front planning, and detailed specification of requirements at the beginning (Project Management Institute, 2017). As the execution phase progresses based on the detailed plan prepared at the beginning, the constraints in terms of the cost, time and scope are tried to be kept under control through monitoring and controlling processes (Project Management Institute, 2017).

On the other hand, in case of the adaptive (agile) life cycles, the plans prepared in high-level detail are utilised at the beginning and then these plans are elaborated to the required detail level based on the stakeholder requirements along the lifecycle (Project Management Institute, 2017). For this reason, the predictive and adaptive life cycles are different from each other depending on the amount and time of the planning performed. Therefore, iterative planning and executing cycles become important in adaptive or agile life cycles (Project Management Institute, 2017). The improvement of the initial plans progressively leads to reduction in risks and cost. The relevant stakeholders continuously take action and give feedback so that the changes are responded more quickly and also better quality is provided. (Project Management Institute, 2017).

As the Figure 3.10 suggests, the style of the life cycle to be implemented may stand somewhere in between the predictive and agile management styles based on the requirements, the handling of risk and cost, and the level of stakeholder involvement (Project Management Institute, 2017). In other words, hybrid management style may also be implemented. Furthermore, different life cycles may be applied in different phases of a project (Project Management Institute, 2017). Another subject specially emphasized in the PMBOK Guide is the self-organisation needed for the successfully application of the adaptive management approach (Project Management Institute, 2017). Instead of assigning a project manager who determine and rank the tasks, high-level requirements and objectives are disclosed at the beginning and the authorised members of the self-organising teams determine the tasks as a group to achieve the objectives. (Project Management Institute, 2017).

After having explored some of the flexibility agents above as a preliminary step through the evaluation of the view of the PMBOK Guide (Project Management Institute, 2017). on flexible project management, next the studies of Jalali-Sohi *et al.* (2016, 2019a, 2019b, 2019c) with regard to the flexible project management have been examined in order to put forward a comprehensive inventory of the flexibility agents among which it will be possible to filter the flexibility elements that will be utilised in this study. The summary of this literature review is given in Appendix C.

The focus point of this research report is the CPM schedules and it is tried to propose a more flexible approach to be used in the management of CPM schedules in this chapter. When the issue is the project schedule management in terms of CPM scheduling, it is inevitable to consider also the 'monitoring & controlling' aspect besides the scheduling. This was also the case for the IFCRM Procedure, which will be used as a component to the hybrid approach that will be proposed in this chapter. These processes will be taken into account also in the hybrid approach that will be proposed but, in a way compatible with the many aspects of flexible project management discussed in this section and the dynamic project scheduling method proposed by Vanhoucke (2012), which was discussed in Chapter 2.

The hybrid approach that will be proposed in this chapter will contain the monitoring & controlling process based on the EVM and S-Curve Analysis in compliance with the dynamic project scheduling approach of Vanhoucke (2013) (refer to Chapter 2). The risk analysis process of the IFCRM Procedure will fulfil the need for the schedule risk analysis aspect of the Dynamic Scheduling (Vanhoucke, 2013). Furthermore, the findings of the Chapters 3 and 4 in terms of the managerial flexibilities will also be utilised within the proposed approach. Prior to introducing the hybrid approach, the flexibility enablers or aspects that will be processed in its development are to be determined. The following subsection contains a discussion in this regard.

6.2 DETERMINATION OF THE FLEXIBILITY AGENTS TO BE UTILISED IN THE DEVELOPMENT OF THE HYBRID APPROACH

The schedules prepared by CPM in construction projects illustrate the execution dates of the tasks (activities) and/or the work packages (groups) in different detail levels along with the milestone events in the form of activity networks (refer to Chapter 2). While the information of 'what' and 'how' is introduced through the project plans prepared in compliance with presumably well-defined scope at the beginning of a project, the information including, but is not limited to, 'when' and 'who' is substituted by the activity network schedules (e.g. activity-on-node diagrams) in case CPM is used. By this way, the project plan is converted to a practical tool, i.e. the schedule, ready to be implemented. As the project progresses and the front-end development stage is completed, with a detailed plan and a CPM schedule at hand, the remaining stages (design or construction, or both at the same time) start up. Then, managing, monitoring and controlling of the CPM schedule become the issue for the completion of the project successfully. The whole scheme in question from the early beginning through the front-end development stage until the end of the construction phase is conducted based on the processes of the project schedule management (Project Management Institute, 2017).

The story summarised above belongs to a typical application in a traditionally managed construction project. In other words, it represents a plan-driven predict & control approach (refer to Chapters 1 and 2). As strongly emphasized in this report up to now, complexities and uncertainties continuously impact the construction projects and therefore it is inevitable to adopt more flexible project management methodologies for achieving success. It is almost impossible in complex construction projects to determine the scope and the owner requirements (along with the requirements of various stakeholders) completely in advance and reflect this in a detailed plan and a schedule before the project execution. Therefore, more flexible approaches are required in this regard. For the sake of reminding, throughout this research, the flexibility in project management has been considered as 'the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions'. The question of "how the more flexible management will be established" based on the management of CPM schedules in construction projects is going to be answered within the context of the aforementioned definition of flexibility in the remaining parts of this chapter by benefitting from the accumulated knowledge in this report up to now.

A consistent method of converting the traditional plan-driven management of CPM schedules into a more flexible change-driven form is to incorporate the appropriate flexibility agents associated directly and indirectly with scheduling into the traditional project schedule management processes. By this way, the development of a hybrid approach carrying both traditional and flexible features will have been possible. The flexibility agents to be utilised in the development of the hybrid approach can be determined by a discussion on the inventory of the flexibility agents revealed from the relevant literature in the previous section. Given below contains the discussion made in this context in terms of the flexibility agents filtered out of this inventory. It is worth mentioning that among the flexibility agents determined, there also exist ones inferred from the findings of the previous chapters with regard to the managerial flexibilities of CPM and the flexibilities provided by the IFCRM Procedure. The flexibility agents discussed below have been designated by ordered codes to make them referable during the development of the hybrid approach in the next section.

- *Flexibility Agent 1 (FA-1) – CPM's managerial flexibilities:* CPM, as a scheduling technique, contains various flexibilities from the managerial point of view at three levels, i.e. activity, path and project levels (refer to Chapter 3). Naturally, the flexible management of construction projects scheduled with CPM necessitate benefitting from these managerial flexibilities. Increasing the awareness on these flexibility features of CPM among the staff is essential. However, contractual arrangements might be required to prevent disputes between the parties like the owner, contractor and subcontractor on issues such as the usage of activity float times, which is one of the primary components of flexibility in CPM.
- *Flexibility Agent 2 (FA-2) – Managerial flexibilities provided by CPM based schedule risk analysis*: Expansion on the managerial flexibilities of CPM is possible provided that risk analysis capability is added to CPM through MCS

and risk modelling, and in turn it is converted from a deterministic technique to a stochastic method that enables analysing the impact of uncertainties on the schedule (refer to Chapter 4). Awareness on this issue among the staff involved as well as among the different stakeholders of the contract is critical. When the assumption that flexibility is required to mitigate also with the uncertainty besides the complexity and project dynamics in project schedule management is taken into account, it becomes essential to be aware of how the flexibilities provided by CPM expand in case of the risk-based usage of CPM under uncertainty and to be able to benefit from these flexibilities.

- *Flexibility Agent 3 (FA-3) – Continuous response to schedule risks and complexities based on the IFCRM Procedure:* Traditional project risk management is assumed to be not sufficient to control the uncertain, complex and dynamic conditions of construction projects in this study based on the relevant literature. Accordingly, the IFCRM Procedure has been proposed in Chapter 5. The processes embedded in the IFCRM procedure contain interfaces with the project schedule management and therefore it is possible to ensure continuous response to schedule risks and complexities based on the IFCRM Procedure through these interfaces.
- *Flexibility Agent 4 (FA-4) – Continuous monitoring and control of the progress based on the EVM and S-Curve Analyses*: Schedule control is an important component of project schedule management as discussed in Chapters 2 and 3. In order to give the proper direction to the implementation of the CPM schedule, continuous monitoring and control of the progress based on the EVM and S-Curve Analyses (refer to Chapter 2) is required. By this way, optimum manoeuvres (adaptations) compatible with the needs of flexible schedule management can be applied for not to fall behind the target schedule. However, the results of the progress analysis should be transparent to the staff and other stakeholders.
- *Flexibility Agent 5 (FA-5) – Continuous support for the schedule control and schedule development processes by the IFCRM Procedure*: The schedule control and schedule development processes in a project schedule management system

aimed to be constituted sufficiently flexible would require continuous support from project risk management in order not to neglect the impact of risks and uncertainties. The IFCRM Procedure already has been designed in accordance with this requirement (refer to Chapter 5). While the risks and complexities are continuously responded, the continuous support of the control and development processes of the project schedule management is ensured through the interfaces existing in the IFCRM Procedure.

- *Flexibility Agent 6 (FA-6) – Continuous involvement of key stakeholders into schedule development and transparent real-time progress monitoring visible to stakeholders:* Transparency and involvement of the relevant stakeholders are the two essential elements of flexible project management. Depending on this fact, the two important components of the project schedule management, i.e. schedule development and schedule control (progress monitoring) are required to be implemented in compliance with these principles.

- *Flexibility Agent 7 (FA-7) – High-level front-end planning and scheduling & Short iterative scheduling*: Instead of preparing a detailed schedule at the beginning of the project (i.e. front-end development phase), it is required to establish a high-level schedule in terms of detail (e.g. a schedule based on milestones) and to adopt its usage during the project execution in increments (execution cycles) in an iterative manner to enable flexibility against possible changes in scope, design, resource requirement, etc. In each iteration, a specific portion of the high-level schedule prepared in the beginning of the project is handled and a detailed schedule is prepared for that part before starting the execution. The selection of the part that is to be handled depends on the owner's requirements, priority in introducing value to the stakeholders in the soonest time, the perceptions and capabilities of the crews, etc. It is assumed that learning curve would improve at the end of each iteration by the means of common meetings held in which the staff gets the chance of sharing experiences in a transparent environment and the value is created and delivered to the Owner in increments in advance without waiting for the completion of the project.

- *Flexibility Agent 8 (FA-8) – Allowing self-organising among the highly-skilled teams:* Instead of vertical hierarchical organisational structures and the teams directed from top to bottom, flexible management of projects necessitate horizontal structures composed of mostly self-organised highly-skilled teams. The motivation of the staff is assumed to be higher in case the teams behave in a self-organised manner. Accordingly, value creation would be faster through the delivery of the project in increments instead of commissioning of the whole project at the end as in the case of traditional applications. The project manager serves as a coordinator in such an organisational structure. The teams and crews responsible for establishing the detailed schedules between iterations determine what they can achieve in the next iteration out of the backlog of work packages previously determined in high detail level.
- *Flexibility Agent 9 (FA-9) – Meeting together as one team at one location*: Instead of holding the meetings regarding the schedule management processes in different locations, promoting the spirit of being one single team working at one location is essential. The physical conditions of the location where the meetings are held should be arranged accordingly for the sake of better availability of the resources to each other, better communication, higher level of communication, higher efficiency, etc. The preparation of the detailed schedules before each iteration succeeding each incremental progress together with the progress controlling are the main tasks that can only be carried out properly by behaving as one team both physically and emotionally.
- *Flexibility Agent 10 (FA-10) – Higher level of experience of the project manager*: The project manager should undertake the role of coordinating the self-organised highly-skilled teams instead of directing the staff and tell "who will do what until when" as in the case of traditional project management. However, the experience and skills of the project manager should be high and compatible with the requirements of flexible management. Providing the required communication among the stakeholders along with their continuous involvement into the processes are of the responsibilities of the project manager in this new role.

- *Flexibility Agent 11 (FA-11) – Evaluation of all the alternatives and extending the decision making process related to the alternatives until the last moment as much as possible*: Value is created and delivered to the Owner (client or customer) and relevant stakeholders in increments through iterative scheduling in the new system. Therefore, wasting the resources in the first attempt and reversing from mistake would carry the project into burdensome and deteriorate the trust. Therefore, consideration of all the alternatives and delaying the decision making process related to the alternatives till the last point as much as possible is essential in flexible schedule management. Working on all the alternatives and discussing them during the meetings would cause spending a great deal of time but putting forward the effort in advance is always better than delivering the unsatisfying increment or reversing back in expense of wasting time and other resources.
- *Flexibility Agent 12 (FA-12) – Promoting the usage of standardisation more based on the previously performed projects*: Using the standard procedures as much as possible related to the schedule management processes based on the previously performed projects would create advantage in optimum usage of time during the meetings and increase the chance for stakeholder satisfaction. Protecting the corporation memory by working with the same teams as much as possible would help develop the standardisation.
- *Flexibility Agent 13 (FA-13) – Transparent information circulation through the frequently performed meetings:* The information regarding the schedule whenever required need to be circulated in a transparent way among the team members and other relevant staff as well as among the relevant stakeholders through frequently held meetings, if possible with daily meetings. This is required also for setting the properly operating channels needed for a high level of efficient communication.
- *Flexibility Agent 14 (FA-14) – Selection of the tasks to be performed in each iteration freely by the highly skilled teams:* In order to sustain the motivation of the highly-skilled self-organised teams and incorporate the cumulative experience and knowledge of the staff into schedule management processes, the

tasks to be performed in each iteration should be freely selected by the teams themselves from the backlog containing work packages or milestones. Naturally, the selection process would not randomly generate but rather will be based on several circumstances such as the priorities of the owner and technical constraints.

- *Flexibility Agent 15 (FA-15) – Mutual trust, top management support and suitability of the contract conditions:* The applicability and success of managing the projects in a flexible manner is highly sensitive to the existence of mutual trust between the parties, the top management support and the suitability of the contract conditions so that the legislative base does not contradict with the practice.

When the flexibility agents pointed out above are examined, it is observed that they are associated with how the flexibility in terms of the organisational structure will be established, with whom the flexibility will be generated, where and when the issues with regard to sustaining the flexibility during the execution of the schedule will be discussed, and how the implementation of the schedule in a flexible way will be provided. Therefore, in some manner, the problem can be considered as a puzzle composed of different components in terms of 'how', 'who', 'where' and 'when' dimensions of flexibility as illustrated in Figure 6.1. These dimensions constitute the flexibility related component of the problem. On the other hand, another component of the problem is associated with the project complexity and uncertainty as shown in Figure 6.1. The flexibility agents are clustered with respect to the component to which they are related in Figure 6.1. In the next section, while proposing the hybrid approach on CPM based project schedule management, such a categorisation will help build the flexibility from the aforementioned dimensions based on the relevant flexibility agents.

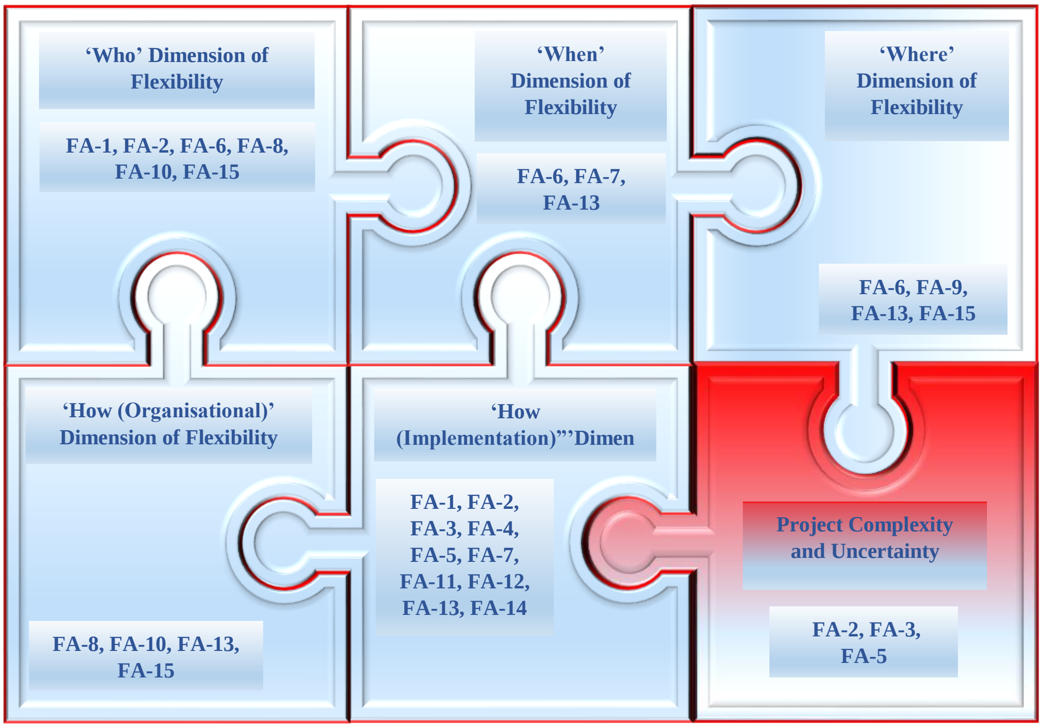

Figure 6.1 Illustration of the problem on a puzzle: The pieces represent the components and the related flexibility agents

6.3 DEVELOPMENT OF THE HYBRID APPROACH

Managing a CPM schedule is mainly managing the time devoted to a project’s activities, tasks or work packages that are required to be completed within a logical framework for the project in question to be completed. The times allocated to the activities enable the calculation of the project completion time based on the precedency relationships assigned between the activities and through the network calculation algorithm of CPM called the forward and backward pass calculations. Furthermore, managing a CPM schedule also means managing various resources such as cost, labour, machines, equipment and materials consumed during the execution of the activities. On top of this, managing a CPM schedule also means managing various stakeholders either directly involved to the production or indirectly influencing the project. While the subcontractors responsible of building specific parts of the project are the typical example to the former, the suppliers providing materials to the project and the owner’s representative responsible of approving the completed parts can be shown as the typical examples to the latter. The managerial complicatedness caused due to the various functions abovementioned that the CPM schedules fulfil naturally leads to project complexity. Furthermore, the level of project complexity rises up as the size and the context of the project enlarges. Besides the complexity, by the impact of various uncertainties as well as the impact of the factors creating a highly changeable, unforeseeable and dynamic environment, the management of a CPM schedule turns to a very challenging process. Currently, a common opinion comes forward that the traditional project management approaches are no more sufficient as the high percentage of delays recorded in the construction projects are taken into account. In case of traditional CPM application, the plan and schedule of the project is prepared in detail based on assumptions and predictions at the beginning of the project under the title of baseline schedule, approved by the owner and then regularly controlled and revised whenever needed to prevent major deviations from the scope written in the contract, frequently in expense of cost overrun and time delay. In this regard, incorporation of the managerial flexibilities determined in the previous section under the name of flexibility agents into the project schedule management in terms of the CPM scheduling and convert the current traditional approach to a more flexible but a hybrid one, and by this way bringing a solution to the aforementioned problem is the primary objective in this section.

In order to achieve this objective, four subsections have been constituted. In the first subsection, the organisational structure of the teams that would be responsible of developing, implementing and controlling the schedule will be presented. Afterwards, the physical conditions, content and the frequency of the meetings that will be held by the teams will be pointed out. Next, the iterative and incremental scheduling procedure of the proposed hybrid approach will be introduced. Finally, in the fourth subsection, the integration of the whole system with the IFCRM Procedure will be presented.

6.3.1 Teams and Organisational Structure: The ‘Who’ and ‘How (Organisational)’ Dimensions of Flexibility

The teams or with another saying, the components of an organisation in a flexible system needs to be sufficiently get rid of rigid hierarchical settings and to have enough flexibility to be able to self-organize, cross-function, and in turn pick out the optimum steps expected to be taken in order to obtain the desired schedule progress and to deliver value to the stakeholders in time. Keeping this fact in mind and by taking into consideration the explanations made under the ‘Flexibility Agent 8 (FA-8)’ in the previous section, i.e. ‘allowing self-organising among the highly-skilled teams’ and the ‘Flexibility Agent 10’, i.e. ‘higher level of experience of the project manager (FA-10)’, the typical configuration of the scheduling teams and different organisational levels for which the involved parties are assumed to be in relation with these teams is illustrated in Figure 6.2.

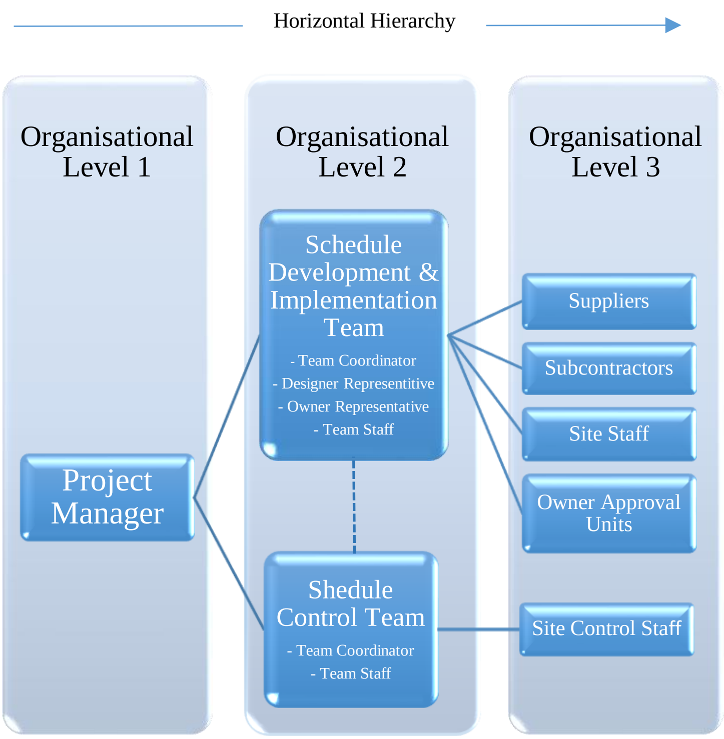

Figure 6.2 Typical configuration of the scheduling teams and the parties constituted in a horizontal hierarchy at different organisational levels

The organisational levels shown in Figure 6.2 represents the responsibility burden the parties are exposed to. For instance, the project manager is expected to undertake a new role in line with the ‘Flexibility Agent 10 (FA-10)’ and carry the major responsibility in managing the schedule. However, as the ‘Flexibility Agent 10 (FA-10)’ suggests, this upper-level responsibility evolves as a coordinator position rather than a traditional management position in which the project manager directs the staff in a vertical traditional hierarchy. This is the new normal from the perspective of the proposed approach as the organisational structure needs to be in the form of horizontal hierarchy rather than vertical for the sake of establishing the desired managerial flexibility, uncovering the self-organising capabilities of the highly-skilled teams and involving the relevant stakeholders, as illustrated in Figure 6.2.

Two self-organising teams are needed to be built; the ‘schedule development & implementation team’ and the ‘schedule control team’. The details of the team structures are to be determined in the schedule management plan. These teams are authorised in compliance with the general spirit of the horizontal hierarchy for the sake of uncovering the team members’ high-skills within a self-organising atmosphere and in turn provide efficiency, innovativeness and success during the management of the schedule. The schedule development & implementation team is composed of the representatives from different parties; a team coordinator selected by the team members who will report to the project manager, team staff experienced and trained in flexible management of CPM schedules as well as capable of triggering the managerial flexibilities of CPM in line with the Flexibility Agents 1 (FA-1) and 2 (FA-2) (refer to Chapters 3 and 4), the representative of the ‘owner’ who will deliver the varying requirements of the owner that will give direction to the schedule, and the representative of the ‘designer’ who will contribute to the scheduling process from the perspective of design requirements. Similarly, the schedule control team is composed of a team coordinator and the team staff. The representatives of the owner and the designer from the schedule development & implementation team are assumed to be active also within the design control team through the cross-functional attributes of the proposed organisational structure (represented by dashed line in Figure 6.2). The idea of setting up two different teams under the missions “schedule development and implementation” and “schedule control” is compatible with the two main functions of project schedule management, i.e. scheduling and control. The reason of separating the responsibilities is for the sake of opening the development areas by assigning the duty of monitoring and controlling the schedule to a different team and by this way to separate these two main functions. In that case, the project manager would be responsible of exploring these development areas based on the reports submitted to him/her by these two separate teams working in parallel for the same goal, i.e. successfully implementation of the schedule.

The third organisational level, as illustrated in Figure 6.2, consists of the parties which are not directly responsible for the development, implementation and control of the schedule like the teams and the project manager but should be indispensably involved into the scheduling process. The reason is that they either service in the implementation of the activities (tasks) constituting the schedule on the site or in the office, such as the site staff and subcontractors, or do impact the implementation of the schedule as the external stakeholders such as the suppliers and owner's approval units. The actual data from the construction site regarding the completed activities along with the new forecasts needed to rebuild and develop the schedule are provided from these parties by the teams through a relationship in compliance with the requirements of horizontal hierarchy. Such a configuration, which is illustrated in Figure 6.2 by the means of solid lines used in between the different organisational levels, has been established as required by the Flexibility Agent 6 (FA-6), i.e. 'Continuous involvement of key stakeholders into schedule development and transparent real-time progress monitoring visible to stakeholders' and the Flexibility Agent 13 (FA-13), i.e. 'Transparent information circulation through the frequently held meetings', which was explained in the previous section. Another remarkable point that can be noticed in Figure 6.2 is the difference between the site staff providing information to the schedule development & implementation team and the site control staff providing information to the schedule control team. The purpose of assigning these similar duties to two different staff operating on the site (or the office according to the nature of the task) is once more to separate these two sensitive responsibilities for the sake of transmission of accurate, reliable and unbiased data to the teams regarding the achieved progress.

The organisational structure proposed in Figure 6.2 as a component of the hybrid approach can be considered as a typical configuration. On the condition of not diverging from the main features required for the provision of the managerial flexibilities in terms of the Flexibility Agents 1, 2, 6, 8, 10, and 13, in terms of the spirit of the horizontal hierarchy along with authorizing the teams with self-organising freedom, new parties or stakeholders may be included to the organisation depending on the conditions of the projects on which the hybrid approach is implemented. The details such as the number of the staff in the teams, their professions and the tools needed by the teams may change from project to project. However, as suggested by the Flexibility Agent 15 (FA-15), i.e. ‘Mutual trust, support of top management and suitability of the contract conditions’, the conditions needed for the properly implementation of the approach should be established in advance and sustained throughout the project by trust, support of top-management and appropriate contract conditions. In the next subsection, the second major component of the hybrid approach, i.e. the physical conditions, content and the frequency of the meetings that would be held by the teams will be introduced.

6.3.2 Meetings and Location: The ‘When’ and ‘Where’ Dimensions of Flexibility

The team organisation and the configuration of the organisational structure introduced in the previous subsection lead to the establishment of the ‘who’ and ‘how’ dimensions of flexibility for the hybrid approach aimed to be developed. In other words, the answer to the question ‘with whom and how (in terms of organisational structure) will the flexibility be generated?’ could be given by this way. The remaining questions still waiting to be answered are associated with the ‘when’, ‘where’ and ‘how (in terms of schedule implementation)’ dimensions of the flexibility. In this regard, this subsection aims to bring a solution to the ‘when’ and ‘where’ dimensions of the flexibility desired to be constituted. As done in the previous subsection, the flexibility agents previously identified will once more be used as the primary reference points.

The organisational structure substituted in horizontal hierarchy with the involvement of different parties such as general contractor (project manager, the team staff), owner, subcontractor(s), designer(s), site staff, and etc. firstly require a physically appropriate meeting location with the necessary tools and equipment readily available in it such as a sufficiently big size of work board, computers, printers, scheduling software, projection device, big size LCD monitor, big size working table, etc. needed while working on the schedule as one team at one location in accordance with the Flexibility Agent 9 (FA-9), i.e. ‘meeting together as one team at one location’. Furthermore, meeting together, discussing the schedule and taking decisions in collaboration and transparency is the main purpose as required by the Flexibility Agents 6 (FA-6) and 13 (FA-13), i.e. ‘continuous involvement of key stakeholders into schedule development and transparent real-time progress monitoring visible to stakeholders’ and ‘transparent information circulation through the frequently performed meetings’, respectively.

An important point worth mentioning regarding the constitution of the ‘where’ flexibility, the details of the physical conditions of the meeting location, the responsibilities assigned to the parties for the properly setting of these conditions, and detailed explanations regarding the frequency, type and content of the meetings should be given place in the contract. This issue can be considered as a requirement of the Flexibility Agent 15 (FA-15) entitled ‘Mutual trust, top management support and suitability of the contract conditions’. As the flexible project management represents a paradigm change in construction project management, the support of the top management, the constitution of mutual trust, and the legalisation of this new and modified system through the contract conditions are the crucial matters in order to ensure the provision of the flexibility and to prevent possible disputes between the parties during the execution phase. These issues are especially important during the period until the corporate cultures achieve to transform permanently in agreement with the desired paradigm change in question.

After proposing a solution towards the provision of the ‘where’ flexibility within the framework of the hybrid approach, the other side of the problem, i.e. ‘when’ to provide the flexibility in terms of the frequency, content, type and function of the meetings still needs to be answered. For bringing a solution to when to arrange the meetings for the creation of a more flexible project schedule management in terms of CPM schedules, besides the flexibility agents benefitted so far, with no doubt the procedures that will be proposed related to the ‘how (in terms of schedule implementation)’ component of flexibility that will be examined in the next subsection needs to be taken into account. Since flexibility is needed to deal with the complexity, uncertainty and dynamics in a project, and because the flexibility in some manner means the capability of adapting to varying project conditions, first of all, ‘daily meetings’ that will be held separately by the schedule development & implementation team and the schedule control team at the organisation level 2 (refer to Figure 6.2) are being suggested. Daily meetings that will last not more than half an hour with the participation of all the team members would fulfil the following functions within the scope of the proposed hybrid approach:

- Evaluation of the implementation of the schedule by the members of the schedule development & implementation team would bring quick and timely solutions to the problems encountered.
- Daily monitoring and controlling of the schedule progress by the members of the schedule control team separately from the schedule development & implementation team based on the actual data provided from the site would ensure the flow of accurate and unbiased information from the site to the organisational level 1, i.e. the project manager.
- In daily meetings, the schedule development & implementation team will be flexible enough in deciding for the actions that will be performed to achieve the objectives of the project portion handled.
- As the Flexibility Agent 13 (FA-13) entitled the 'transparent information circulation through the frequently performed meetings' offers, the daily meetings would fulfil an important portion of the requirement in terms of the transparent information circulation among the relevant stakeholders such as the owner's representative, designer's representative and staff of the scheduling teams.
- As the Flexibility Agent 6 (FA-6) entitled the 'continuous involvement of key stakeholders into schedule development and transparent real-time progress monitoring visible to stakeholders' offers, the daily meetings together with the schedule iteration preparation and review meetings, which will be explained below, would ensure the involvement of the relevant stakeholders and monitoring of the progress based on real-time data transparently visible to the stakeholders.

The content of the daily meetings would be dependent to a great extent on the actual data that will flow from site to the teams. Therefore, the requirements in terms of communication, scheduling software and hardware infrastructure must be covered in advance before the meetings. This is also needed for the activation of the managerial flexibilities of CPM as the Flexibility Agents 1 (FA-1) and 2 (FA-2) offer in accordance with the findings of the Chapters 3 and 4.

Another meeting type offered within the scope of the proposed hybrid approach is the 'Schedule Iteration Preparation Meetings' to which the schedule development & implementation team from the organisational level 2 and the parties from the organisational level 3 will attend (refer to Figure 6.2) and which will be realised at the beginning of each schedule iteration. The logic behind the iterative scheduling will be clarified in the next subsection. During the schedule iteration preparation meetings, the parties responsible of managing and executing the schedule at the organisational levels 2 and 3 come together at one location in line with the Flexibility Agent 9 (FA-9) entitled 'Meeting together as one team at one location' to discuss and determine the content of the schedule that will be handled in the next schedule iteration. The schedule development & implementation team later builds the detailed schedule to be used during that iteration based on the decisions taken in the schedule iteration preparation meeting.

Another meeting needed to be held for the implementation of the proposed hybrid approach is the 'Schedule Iteration Review Meetings' (weekly or in every two weeks according to the iteration duration determined in compliance with the size and complexity of the project) that will be realised by the participation of the parties from the organisational levels 2 and 3 (refer to Figure 6.2). During the schedule iteration review meetings in which both the schedule development & implementation team and the schedule control team together participate, the progress on the recently completed schedule iteration is reviewed and related problems are discussed together with the parties from the organisational level 3 such as the suppliers, subcontractors and site staff.

Another meeting type proposed within the scope of the hybrid approach is the monthly 'High-level Schedule Update Meetings' which will be realised by the participation of the parties from the organisational levels 1 and 2 (refer to Figure 6.2). The purpose of the high-level schedule update meetings is to update the high-level schedule built upon the milestones or work packages at the beginning of the project depending on the requirements of the owner that are given place also in the contract and its attachments such as the design drawings, reports and technical specifications. The proposed hybrid approach requires the avoidance of the preparation of a detailed schedule at the beginning of the project in which all the activities of the CPM schedule as well as all the precedency relationships between the activities are given place as done in case of the traditional project schedule management. Instead, in line with the Flexibility Agent 7 (FA-7) entitled ‘High-level front-end planning and scheduling & Short iterative scheduling’, a high-level schedule is to be prepared at the start of the project depending on the announced requirements. Later, this schedule will be used as a reference schedule for the preparation of the detailed schedules, which will be used during the short schedule iterations or execution cycles. This subject will be clarified in the next subsection. For now, it should be mentioned that high-level schedule update meetings provide the opportunity of updating the high-level schedule, which is utilised during the preparation of the iteration schedules, within the knowledge of the project manager and owner’s representative based on the up-to-date and updated requirements of the owner, the project itself, the results of the schedule iteration review meetings and the reports of the schedule control team submitted to the project manager.

The last meeting type needed during the implementation of the proposed hybrid approach is the ‘Schedule Progress Review Meetings’ that will be realised in every 3 months with the participation of the parties together from the organisational levels 1, 2 and 3 (refer to Figures 6.2 and 6.3). The purpose of these meetings is to discuss and evaluate the general progress recorded in the project from the perspective of the implementation of the schedule by the participation of all the relevant parties. The function of these meetings will be explained in detail in the next subsection along with the other type of meetings suggested up to now. Figure 6.3 presents the partial illustration of the hybrid approach in terms of when, where, who and how (in terms of organisational structure) dimensions of flexibility to the extent described so far.

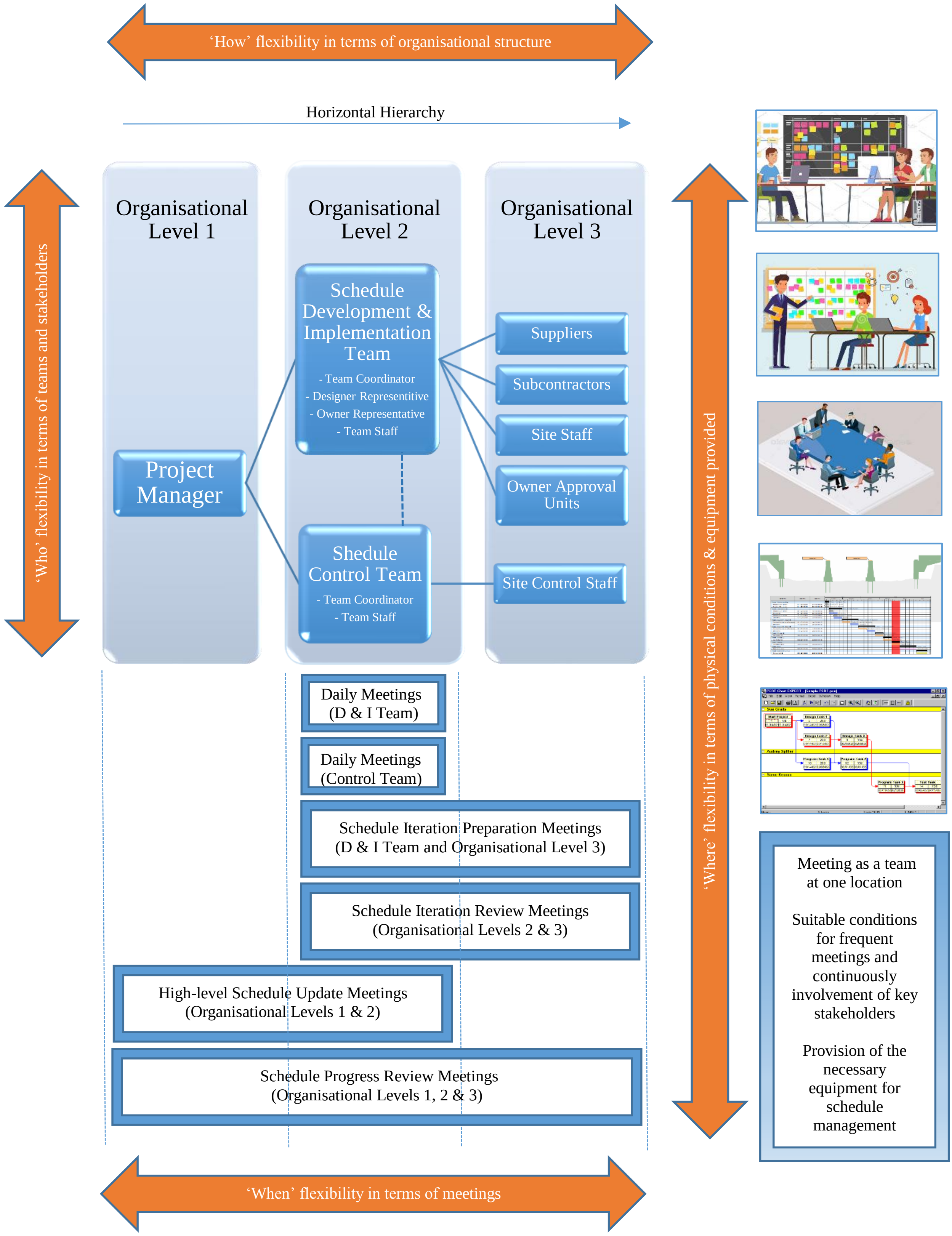

Figure 6.3 Partial illustration of the proposed hybrid approach in terms of different dimensions of flexibility to the extent described so far

6.3.3 Iterative Scheduling: The ‘How (Implementation)’ Dimension of Flexibility

This subsection introduces the third stage, i.e. “iterative scheduling”, coming after the first and second stages, i.e. ‘teams and organisational structure’ and ‘meetings and location’, respectively, in the development of the proposed hybrid approach. As it is illustrated in Figure 6.3, the following flexibility dimensions have been handled up to now:

- ‘who’ flexibility in terms of the teams and stakeholders either undertaking direct responsibility or having role in the associated processes
- ‘how’ flexibility in terms of the organisational structure through the constitution of an organisation in horizontal hierarchy composed of three different organisational levels containing the project manager, self-organised highly-skilled teams and various stakeholders involved in the management of the schedule
- ‘where’ flexibility in terms of the physical conditions and the equipment provided for the activation of the responsible parties in harmony as required for the establishment of flexibility
- ‘when’ flexibility in terms of the meetings to be realised with the participation of the parties directly responsible in the implementation or involved indirectly in the associated processes

In order to constitute the abovementioned dimensions of flexibility, the ‘flexibility agents’ identified in the previous section have been utilised. In summary, the Flexibility Agents 1, 2, 6, 7, 8, 9, 10, 13, and 15, i.e. 9 out of the 15 flexibility agents in total, have been revisited so far.

In this context, another dimension of the flexibility, i.e. ‘how’ flexibility in terms of the implementation of the schedule, will be handled in this subsection. Once more, similar to the methodology followed up to now, the previously identified flexibility agents will be taken into consideration. Furthermore, since it is aimed to propose a hybrid approach having both traditional and flexible features that will be utilisable on CPM schedules under uncertainty and complexity in construction projects, the features specific to CPM scheduling and attributable to the construction projects will be taken into account. It is believed that pure flexible approaches like agile (refer to Figure 3.10), which has been specifically developed suitable to the conditions of the software development projects, would not be applicable fully and properly in case of the construction projects. Accordingly, in this research, rather than obtaining a pure flexible approach, it is aimed to develop a hybrid approach which is based on iterative scheduling (refer to Figure 3.10). However, the extent to which flexibility will be activated would actually be dependent not only on the project and contract conditions, but also on the project phase to which the proposed approach is being implemented. Actually, the early project phases prior to the building (construction) phase such as the concept development, feasibility study, and design phases, which are also called front-end engineering & development phases, constitute a more suitable project environment for activating the proposed approach's flexible features when compared with the construction phase. The trade-off in question is illustrated in Figure 6.4. The curves on this figure represents the general trend expected to occur along the phases of a typical construction project lifecycle. While the curve in green designates the decreasing applicability of the flexible iterative scheduling as approached closer to the project completion phase, the other curve in red represents the increasing appropriateness of a more traditional control-based approach instead, which is not adaptable to scope changes as much as the iterative scheduling. The situation illustrated in Figure 6.4 can be explained by different arguments including, but is not limited to, the conditions of the construction sites, the decreasing absorption capacity in terms of scope changes as getting closer to the project completion phase and the appropriateness of the pre-construction phases for utilising the flexible iterative scheduling when the similarity of these phases with the software development projects are taken into account.

As it can be inferred from the Figure 6.4, the proposed hybrid approach stands somewhere between pure flexible and pure traditional in terms of the implementation of schedule management. Accordingly, a balance between flexible iterative scheduling and traditional control-based scheduling is required to be established in practice throughout the different phases of the project lifecycle depending on the varying project conditions.

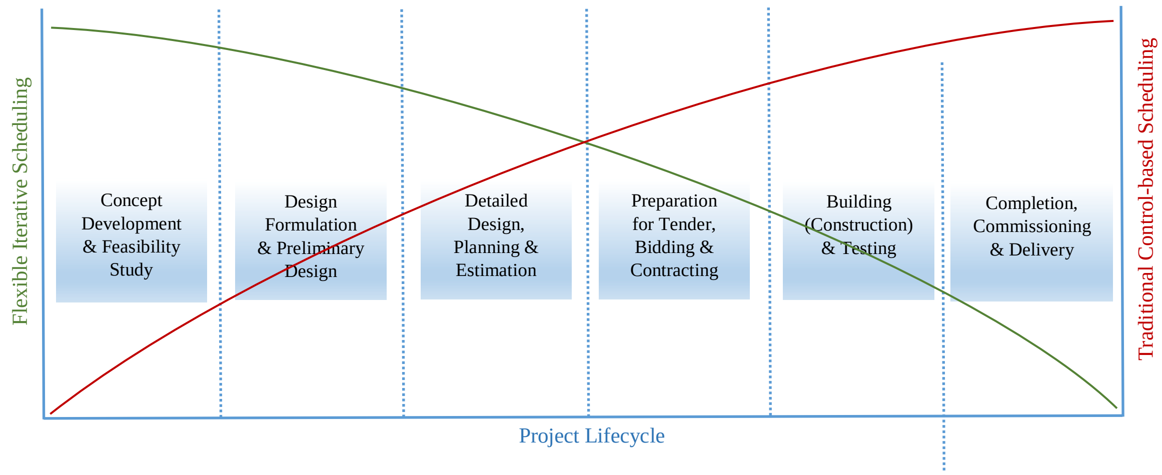

Figure 6.4 Varying balance between flexible iterative scheduling vs. traditional control-based scheduling along the phases of a typical construction project lifecycle

Based on this argument, two alternative procedures for the implementation of the iterative scheduling will be presented in the following subsections, the first one for the case of preconstruction phases, the second one for the case of construction phase. In both cases, the CPM scheduling will be at the centre of the discussion.

6.3.3.1 Iterative Scheduling for the Preconstruction Phases

The preconstruction phases or the early project phases in a construction project are typically composed of the concept development, feasibility study (preliminary vs. detailed), evaluation of the design alternatives & design formulation, preliminary design, detailed design, estimation and planning. In case, the contract system is a traditional design-bid-build, the next phase would be the preparation of the tender documents, bidding and contracting after which the building (construction) and testing phases are carried out. Finally, after the completion of the project, the commissioning task is performed and the work is delivered to the owner. Afterwards, the operation phase, which is usually out of the scope of project management, starts up. The sequence of the aforementioned phases has been shown on Figure 6.4. In case of the other type of contract systems rather than the traditional design-bid-build such as the design-build or design-build-operate, the sequence and content of these phases would not change to a great extent. Accordingly, as previously mentioned, the fact that the tasks undertaken during the preconstruction phases possess more suitable features for the utilization of a more flexible schedule management would not change with the contract system utilized.

While the structure of the teams and stakeholders previously put forward and illustrated in Figure 6.2 could be customized in accordance with the conditions of the preconstruction phases, the organizational structure, which is also shown on the same figure, will not be changed during the implementation of iterative scheduling for the sake of activating the flexibility as much as possible. This policy is also valid for the meetings and location, which has been formulized in the preceding sections to provide the 'where' and 'when' dimensions of flexibility and which was illustrated in Figure 6.3. Based on this approach, the flowchart diagram of the iterative scheduling process that is proposed for the preconstruction phases is given in Figure 6.5. The iterative scheduling process in question represents a solution for another dimension of the flexibility, i.e. 'how' flexibility in terms of the implementation of the schedule specifically for the case of preconstruction phases. Its alternative for the construction phase will be illustrated and explained later in the subsequent section.

The iterative scheduling process is started with the 'schedule management planning' task (refer to Figure 6.5). Within the schedule management plan, various subjects are handled included, but are not limited to, the rules and principles of the game, the responsible parties, team structures, the meetings to be held, the physical conditions and the equipment to be provided, the scheduling methods and tools to be utilised, and the interfaces required with the other project management processes. The schedule management planning task also provides information to the IFCRM Procedure Implementation process as shown in Figure 6.5 and as can be observed also in Figure 5.4. The relationship between the project risk management process (Project Management Institute, 2017) based on the IFCRM Procedure and the project schedule management process (Project Management Institute, 2017) in terms of the currently proposed hybrid approach will be introduced in the upcoming section. This relationship has been constituted within the proposed hybrid approach as required by the Flexibility Agents 3 (FA-3) and 5 (FA-5), i.e. 'continuous response to schedule risks and complexities based on the IFCRM Procedure' and 'continuous support for the schedule control and schedule development processes by the IFCRM Procedure', respectively.

Next, monthly 'high-level schedule update meeting' is held with the participation of parties from the organisational levels 1 and 2 (refer to Figures 6.3 and 6.5). The first meeting is followed with the task of 'preparing the high-level list of work packages based on the project scope'. Later, during the same task, the list prepared at the beginning of the project is updated. The high-level schedule update meetings are carried out monthly until the project is completed. Instead of preparing a detailed CPM schedule for the whole project in advance at the very beginning of the project including the information like the activity descriptions, activity durations, precedency constraints between the activities, milestones, etc., alternatively a high-level schedule in the form of a list of work packages to be completed is prepared as required by the Flexibility Agents 7 (FA-7) and 14 (FA-14), i.e. the 'High-level front-end planning and scheduling & Short iterative scheduling' and 'Selection of the tasks to be performed in each iteration freely by the highly skilled teams', respectively. This approach will also provide later the flexible conditions for possible scope changes depending on the new requirements of the owner and the project itself. Furthermore, it would be possible for the self-organising schedule development & implementation team to pull from this list the most appropriate work packages that will be handled during the next schedule iteration.

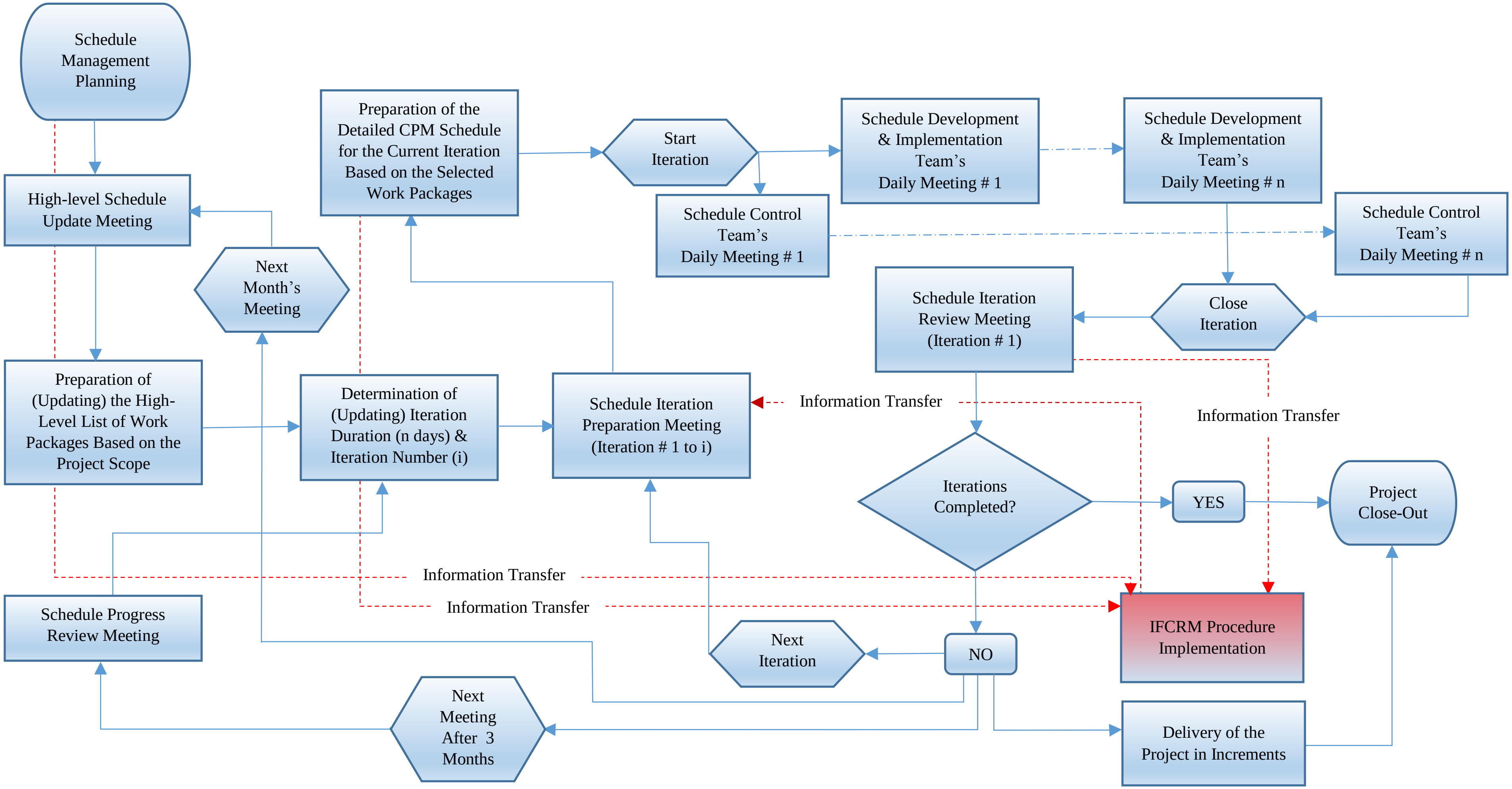

Figure 6.5 Flowchart diagram of the iterative scheduling process for the preconstruction phases (the 'how' flexibility dimension of the proposed hybrid approach in terms of the implementation of schedule)

The iteration duration and the iteration number are determined during the ‘determination of (updating) iteration duration (n days) & iteration number (i)’ task based on various factors such as the experience of the technical staff, the volume of works to be accomplished, the number of staff, etc. The ‘determination of (updating) iteration duration (n days) & iteration number (i)’ task comes after the ‘preparing the list of work packages based on the project scope’ task. Later, the iteration duration and iteration number can be updated within the scope of this task in line with the performance and progress achieved during the iterations. This can be considered as another flexible side of the proposed approach. Afterwards, the ‘schedule iteration preparation meeting’ is carried out with the participation of parties from the organisational level 3 and the schedule development & implementation team (refer to Figures 6.3 and 6.5). Relevant information is transferred from the ‘IFCRM Procedure implementation’ process to this meeting as shown in Figure 6.5. This information together with the other information gathered up to that moment is processed during the following task, i.e. ‘preparation of the detailed CPM schedule for the current iteration based on the selected work packages’ from the list of work packages, which was previously prepared. However, relevant information obtained at the end of the task ‘preparation of the detailed CPM schedule for the current iteration based on the selected work packages’ is also transferred in the opposite direction, i.e. towards the IFCRM Procedure implementation process. The task ‘preparation of the detailed CPM schedule for the current iteration based on the selected work packages’ obviously would be in agreement with the Flexibility Agent 14 (FA-14), i.e. the ‘Selection of the tasks to be performed in each iteration freely by the highly skilled teams’. By this way, a more consistent CPM schedule having greater chance to be completed on time would have been prepared in terms of the work packages selected. Furthermore, the teams would get the opportunity of adopting the Flexibility Agents 11 (FA-11) and 12 (FA-12), i.e. ‘Evaluation of all the alternatives and extending the decision making process related to the alternatives until the last moment as much as possible’ and ‘Promoting the usage of standardisation more based on the previously performed projects’, respectively. However, the logical constraints from the perspective of CPM scheduling that would exist between the work packages selected for the iteration and the work packages remained in the predetermined list should not be disregarded for the sake of integrating the pieces of the project that will be separately handled through the schedule iterations. Keeping this in mind, the iteration is started. With the start of the iteration, daily meetings of the schedule development & implementation and schedule control teams to be realised separately are also given a start (refer to Figures 6.3 and 6.5). By the end day of the iteration, the iteration is closed. During these daily meetings, every effort should be put forward in order to assure the completion of the tasks in the CPM schedule prepared for the iteration processed at that moment. For this, the flexibilities inherent with the CPM, which were evaluated in Chapters 3 and 4, should be utilised as required by the Flexibility Agents 1 (FA-1) and 2 (FA-2), i.e. 'CPM's managerial flexibilities' and 'managerial flexibilities provided by CPM based schedule risk analysis', respectively.

After the closure of the iteration, 'schedule iteration review meeting' is held with the participation of parties from the organisational levels 2 and 3 (refer to Figures 6.3 and 6.5). The achievements recorded during the previous iteration, the completed and uncompleted activities, the problems encountered and other related issues are discussed during this meeting. Furthermore, necessary information on these issues is transferred to the IFCRM Procedure implementation process as shown in Figure 6.5. On top of this, the critical information gathered at the end of this meeting is utilised during the next month's high level schedule update meeting and during the tasks subsequently performed just after this meeting till the next schedule iteration preparation meeting (refer to Figure 6.5). Based on this information, if required, the list of work packages is updated, the iteration number and duration is changed and necessary measures are put into force. This process continues in a cyclic manner through the schedule iterations performed till the completion of all the iterations and in turn, the completion of the project. This approach would be in agreement with the Flexibility Agent 13 (FA-13), i.e. 'transparent information circulation through the frequently performed meetings'.

Another meeting, i.e. the 'schedule progress review meeting', which is organised with the participation of the parties from the organisational levels 1, 2 and 3, is held every three months until the completion of the project (refer to Figures 6.3 and 6.5). In these meetings, the general picture obtained up to that date is discussed among the stakeholders and accordingly decisions are taken in consensus. The project is delivered to the owner in increments after each iteration and feedback is received in turn instead of delivering the project as a whole after the completion of all iterations. By this way, early value creation is provided along with the provision of the required flexible conditions for the scope changes that will be possibly ordered by the owner.

The application of the iterative scheduling process for the preconstruction phases proposed in this subsection will be shown on an example project within this chapter after the integration of the proposed hybrid approach with the IFCRM Procedure developed in the previous chapter. However, firstly, the iterative scheduling process proposed for the construction phase is introduced in the next subsection.

6.3.3.2 Iterative Scheduling for the Construction Phase

The construction phase, which starts after the tendering, bidding and contract signing phase in a traditional design-bid-build project delivery system, is composed of activities required to be realized in order to build the structure and/or infrastructure defined within the design and contract documents. The main features associated with the construction phase different from the preconstruction phases are the increased number of stakeholders, increased complexity and uncertainty, increased exposure to the severe conditions of weather and earth on the construction site, and increased concerns on safety, environment and stakeholder satisfaction. All these challenging issues make the construction phase less suitable with respect to preconstruction phases for implementing the most important flexible feature of the proposed hybrid approach, i.e. iterative scheduling. However, apart from these conditions, the most important difficulty in implementing iterative scheduling during the construction phase is the limited freedom in selecting the activities to be carried out during an iteration due to the strict logic constraints not easily unchangeable between the activities in the CPM network of a project’s construction phase.

The decreasing suitability of iterative scheduling towards the construction phase was previously discussed and illustrated in Figure 6.4. It has been mentioned that a varying degree of balance between the flexible and traditional control-based scheduling is required depending on the project phase. Since, the preconstruction phases, which consist of activities mostly performed in the office environment, are assumed to be more suitable to activate the flexible sides of the iterative scheduling, the flowchart diagram of the iterative scheduling process for the preconstruction phases was constituted accordingly in Figure 6.5 and related explanations were brought in this direction. In this regard, this subsection introduces a solution to the problem of "how the desired flexibility will be established at least to an extent during the implementation of CPM scheduling in the construction phase".

The process flowchart introduced in Figure 6.6 introduces the iterative scheduling process proposed for covering the 'how' flexibility dimension in terms of the implementation of the schedule specifically for the case of construction phase. When the proposed process is compared with the previous one given in Figure 6.5, it can be observed that both common and different parts exist between the two processes. Instead of focussing on the similarities and differences between the two cases, the process given in Figure 6.6 will be explained in detail below firstly as was done for the process given in Figure 6.5.

While the structure of the teams and stakeholders previously put forward and illustrated in Figure 6.2 could be customized in accordance with the conditions of the construction phases, the organizational structure, which is also shown on the same figure, will not be changed during the implementation of iterative scheduling for the sake of activating the flexibility as much as possible. This policy is also valid for the meetings and location, which has been formulized in the preceding sections to provide the 'where' and 'when' dimensions of flexibility and which was illustrated in Figure 6.3.

The iterative scheduling process proposed for the construction phase starts with the 'schedule management planning' task (refer to Figure 6.6). Within the schedule management plan, various subjects are handled included, but are not limited to, the rules and principles of the schedule management methodology to be applied, the responsible parties involved, team structures, the meetings to be held, the physical conditions and the equipment to be provided, the scheduling methods and tools to be utilised, and the interfaces required with the other project management processes. The schedule management planning task also provides information to the IFCRM Procedure Implementation process as shown in Figure 6.6 and as can be observed also in Figure 5.4. The relationship between the project risk management process based on the IRCRM Procedure and the project schedule management process in terms of the currently proposed hybrid approach will be introduced in the upcoming section. The aforementioned relationship has been constituted within the scope of the proposed hybrid approach in line with what the Flexibility Agent 3 (FA-3), i.e. 'continuous response to schedule risks and complexities based on the IFCRM Procedure' and Flexibility Agent 5 (FA-5), i.e. 'continuous support for the schedule control and schedule development processes by the IFCRM Procedure', offer and require.

Next, monthly 'high-level schedule update meeting' is held with the participation of parties from the organisational levels 1 and 2 (refer to Figures 6.3 and 6.6). The first meeting is followed by the task of 'preparing (updating) the high-level work breakdown structure (WBS) & high-level baseline (target) CPM schedule'. Later, during the same task, the WBS and the baseline CPM schedule prepared at the beginning of the project is updated. The high-level schedule update meetings are carried out monthly until the project is completed. Instead of preparing a detailed CPM schedule for the whole project in advance at the very beginning of the project, a high-level baseline schedule is prepared as required by the Flexibility Agent 7 (FA-7), i.e. 'High-level front-end planning and scheduling & Short iterative scheduling'. This approach will also provide later the flexible conditions for possible scope changes depending on the new requirements of the owner and the project itself.

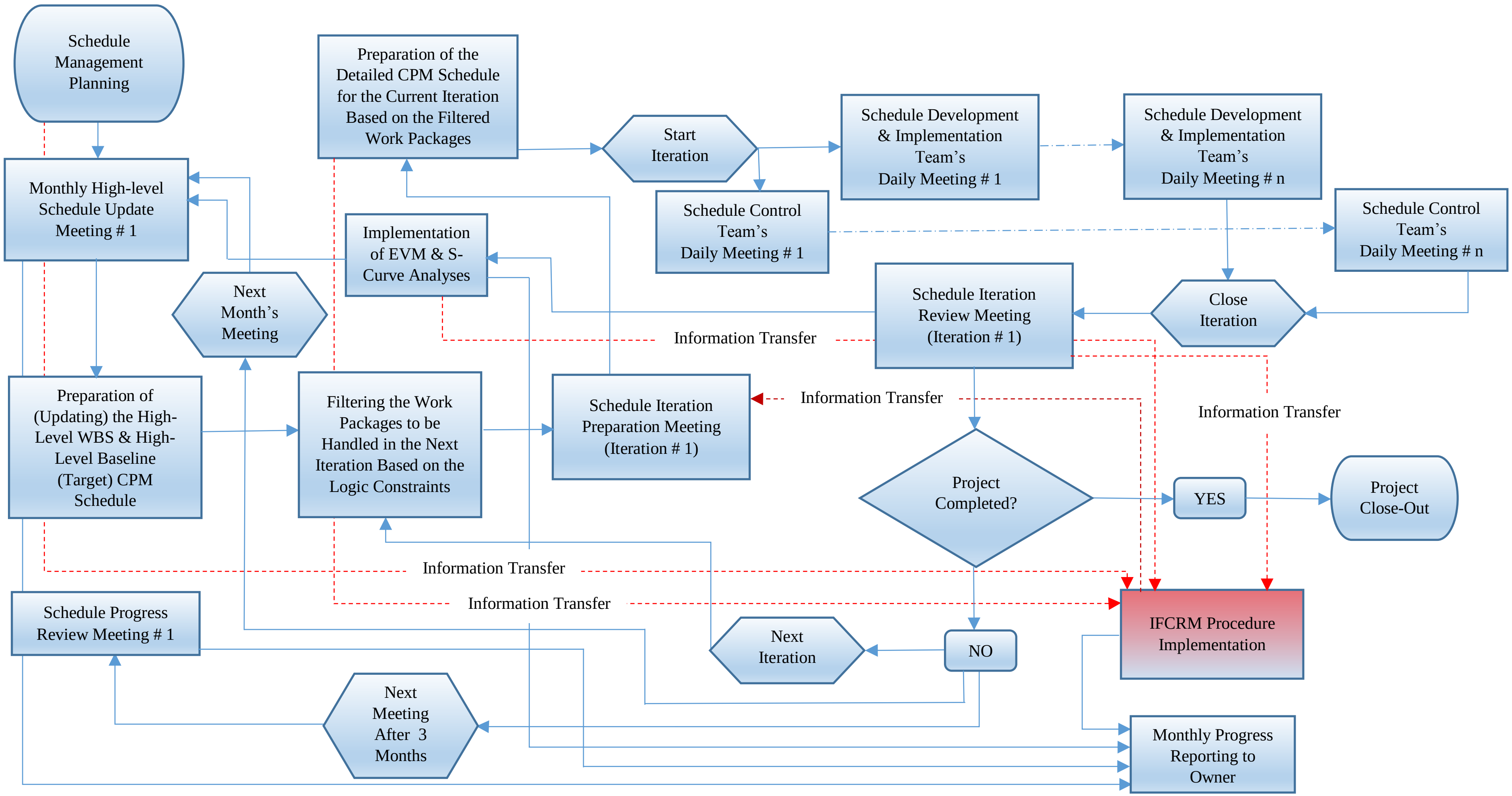

Figure 6.6 Flowchart diagram of the iterative scheduling process for the construction phase (the 'how' flexibility dimension of the proposed hybrid approach in terms of the implementation of schedule)

Afterwards, the task of ‘filtering the work packages to be handled in the next iteration based on the logic constraints’ is carried out. This is achieved in compliance with the baseline or target CPM schedule established. Then, the ‘schedule iteration preparation meeting’ is held with the participation of parties from the organisational level 3 and also the schedule development & implementation team (refer to Figures 6.3 and 6.6). Relevant information is transferred from the ‘IFCRM Procedure implementation’ process to this meeting as shown in Figure 6.6. This information together with the other information gathered up to that moment is processed during the following task, i.e. ‘preparation of the detailed CPM schedule for the current iteration based on the filtered work packages’. By this way, a more consistent CPM schedule having greater chance to be completed on time would have been prepared in terms of the work packages at hand. Furthermore, the teams would get the opportunity of generating the Flexibility Agents 11 (FA-11) and 12 (FA-12), i.e. ‘Evaluation of all the alternatives and extending the decision making process related to the alternatives until the last moment as much as possible’ and ‘Promoting the usage of standardisation more based on the previously performed projects’, respectively. Then, the iteration is started. With the start of the iteration, daily meetings of the schedule development & implementation and schedule control teams to be realised separately are also given a start (refer to Figures 6.3 and 6.6). By the end day of the iteration, the iteration is closed. During these daily meetings, every effort should be put forward in order to assure the completion of the tasks in the CPM schedule prepared for the iteration processed at that moment. For this, the flexibilities inherent with the CPM, which were evaluated in Chapters 3 and 4, should be utilised as required by the Flexibility Agents 1 (FA-1) and 2 (FA-2), i.e. ‘CPM’s managerial flexibilities’ and ‘managerial flexibilities provided by CPM based schedule risk analysis’, respectively.

After the closure of the iteration, ‘schedule iteration review meeting’ is held with the participation of parties from the organisational levels 2 and 3 (refer to Figures 6.3 and 6.6). The achievements recorded during the previous iteration, the completed and uncompleted activities, the problems encountered and other related issues are discussed during this meeting. Furthermore, necessary information on these issues is transferred to the IFCRM Procedure implementation process as shown in Figure 6.6. Then, the task ‘implementation of EVM & S-Curve analysis’ is performed based on the data gathered in the previous iteration. By this task, the requirement of the Flexibility Agent 4 (FA-4), i.e. ‘continuous monitoring and control of the progress based on the EVM and S-Curve analyses’, would be covered. On top of this, the critical information gathered at the end of the schedule iteration review meeting and the implementation of the EVM and S-Curve analyses is utilised during the next month’s high-level schedule update meeting and during the tasks subsequently performed just after this meeting till the next schedule iteration preparation meeting (refer to Figure 6.6). Based on this information, if required, the WBS and baseline CPM schedule is revised. This process continues in a cyclic manner through the schedule iterations performed till the completion of the project. Such an approach would be in agreement with the Flexibility Agent 13 (FA-13), i.e. ‘transparent information circulation through the frequently performed meetings’. Furthermore, the relevant information obtained during the task ‘implementation of EVM & S-Curve analysis’ is also transferred to the IFCRM Procedure implementation process.

Another meeting, i.e. the ‘schedule progress review meeting’, which is organised with the participation of the parties from the organisational levels 1, 2 and 3, is held every three months until the completion of the project (refer to Figures 6.3 and 6.6). In the schedule progress review meetings, the general picture obtained up to that date is discussed among the stakeholders and accordingly decisions are taken in consensus. Besides, the results obtained at the high-level schedule update and schedule progress review meetings together with the data gathered through the tasks ‘IFCRM Procedure implementation’ and ‘implementation of EVM & S-Curve Analyses’ are utilised in the preparation of the monthly progress reports that will be submitted to the Owner as shown in Figure 6.6.

The differences between the two iterative scheduling processes proposed separately for the preconstruction and construction phases of which the flowcharts are given in Figures 6.5 and 6.6, respectively, are discussed in the next section.

6.3.3.3 Differences Between Iterative Scheduling Processes Proposed for the Preconstruction Phases and the Construction Phase

Below, the differences between the iterative scheduling processes proposed for the preconstruction phases, which was illustrated in Figure 6.5, and the construction phase, which was illustrated in Figure 6.6, have been explored.

- After the high-level schedule update meeting, while the iterative scheduling for the preconstruction phase continues with the tasks ‘preparation of (updating) the list of work packages based on the project scope’ and ‘determination of (updating) iteration duration (n days) & iteration number (i)’ just before the conduction of the ‘schedule iteration preparation meeting’, the iterative scheduling for the construction phase continues with the tasks ‘preparation of (updating) the high-level WBS & high-level baseline (target) CPM schedule’ and ‘filtering the work packages to be handled in the next iteration based on the logic constraints’ before the ‘schedule iteration preparation meeting’. For the case of preconstruction phases, depending on the nature of the activities to be performed (e.g. designing, technical calculations & report preparation, and data gathering from the construction site) and working conditions (most of the time at the office and other times on the construction site to make observation and gather data), it would be possible to start the project with a high-level list of work packages instead of a detailed CPM schedule for the sake of ensuring the desired level of flexibility through the schedule iterations for which the number and duration of iterations are fixed in advance to extract the capabilities of the highly-skilled self-organised teams. Eventually, the aforementioned teams are given the opportunity of freely determining and selecting the work packages that they will perform before each iteration. Whereas, for the case of construction phase, where the working conditions are harder than the preconstruction phases due to the factors like the increasing number of stakeholders, the complexities on the construction site and the risk-factors affecting the project, a high-level WBS and a baseline CPM schedule is required at the beginning in expense of the degree of freedom allocated to the teams. Rather than selecting the work packages freely as in the case of preconstruction phases, the teams will have to filter the work packages to be handled during an iteration based on the logic constraints set up through the baseline CPM schedule. The aforementioned difference between the two processes is one of the root causes of the difference in between in terms of the level of flexibility each process provides.

- Preceding the determination of the work packages to be handled in the coming iterations, a detailed CPM schedule is prepared based on the work packages determined before starting an iteration. However, while the detailed CPM schedule prepared for the preconstruction phases is constituted based on the freely selected work packages by the teams, the schedule prepared for the construction phase is built upon the work packages that are required by the baseline or target CPM schedule in order not to break the logical constraints put forward in advance.
- For the case of preconstruction phases, after each iteration is completed, it is checked whether all the iterations, which the total number was determined in advance, have been completed just after the 'schedule iteration review meeting'. If the iterations are not completed yet, the iterative scheduling process continues in a cyclic manner and the next iteration starts, if required, with the updated iteration number and duration. After all the iterations are completed, the project is closed out and delivered to the owner. However, for the case of construction phase, after every iteration and the conduction of the 'schedule iteration review meeting', the progress achieved in that iteration is controlled through comprehensive EVM and S-Curve analyses based on the actual data gathered from the construction site together with the utilisation of relevant information transferred from the 'IFCRM Procedure implementation'. By using the results of these analyses and the information gathered, the high-level WBS and baseline CPM schedule is updated at the next 'high-level schedule update meeting' and accordingly the whole process starts again from that point rather than searching whether the fixed number of iterations are completed or not as done in case of preconstruction phases.
- While it is possible to deliver the project to the owner in increments in case of preconstruction phases thanks to the specific characteristics of the work done

during these phases, delivery of the project in increments generally would be impossible during the construction phase. Therefore, instead of incremental delivery, monthly progress reporting to the owner is performed based on the data obtained at the monthly 'high-level schedule update meeting' and 'schedule progress review meeting', and through the 'IFCRM Procedure implementation' and the 'implementation of EVM & S-Curve analyses'.

6.3.4 Implementation of the IFCRM Procedure and Transition of Information through Interfaces

The Integrated Flexible Complexity/Risk Management (IFCRM) Procedure proposed in Chapter 5 specifically for the implementation on CPM schedules carry the function of being a component of the proposed hybrid approach. This has been realised through the interfaces in between as illustrated in Figure 5.4, which illustrates the flowchart of the IFCRM Procedure and the Figures 6.5 and 6.6, which present the flowcharts of the iterative scheduling component of the hybrid approach. There are 3 interfaces in total between the IFCRM Procedure and the hybrid approach. While these interfaces have been shown through the tasks entitled 'risk management planning', 'schedule development' and 'schedule control' in case of IFCRM Procedure as shown in Figure 5.4, they have been illustrated in the form of information transfer channels in case of iterative scheduling as shown in Figures 6.5 and 6.6. These information channels enable the transmission of information between the two processes in a number of ways as explained below:

- From the 'schedule management planning' task of the iterative scheduling component of the hybrid approach to the 'complexity/risk management planning' task of the IFCRM Procedure,
- From the 'feedback & update' task of the IFCRM Procedure to the 'schedule iteration preparation meeting' of the iterative scheduling component of the hybrid approach, which was represented by the 'schedule development' in the flowchart of the IFCRM Procedure.
- From the 'schedule iteration review meeting' of the iterative scheduling component of the hybrid approach, which was represented by the 'schedule

controlling’ in the flowchart of the IFCRM Procedure to the ‘feedback & update’ task of the IFCRM Procedure.

- From the ‘preparation of the detailed CPM schedule for the current iteration based on the filtered work packages’ task of the iterative scheduling proposed for the construction phase and ‘preparation of the detailed CPM schedule for the current iteration based on the selected work packages’ task of the iterative scheduling proposed for the preconstruction phases, which was represented by the ‘schedule development’ in the flowchart of the IFCRM Procedure, to the ‘risk identification & classification’, ‘refinement of the complexity-induced risks’ and ‘schedule risk analysis’ tasks of the IFCRM Procedure.
- From the ‘implementation of EVM & S-Curve analyses’ task of the iterative scheduling proposed for the construction phase, which was represented by the ‘schedule controlling’ in the flowchart of the IFCRM Procedure, to the ‘feedback & updat’ task of the IFCRM Procedure.

The interfaces in question and the transmission of the information through these interfaces by the information transfer channels as explained above are realised thanks to a common property of the IFCRM Procedure and the proposed hybrid approach, i.e. the flexibility. Since the IFCRM Procedure is considered as a major component of the proposed hybrid approach, they are like the two different sides of a single coin and information sharing is enabled among them in two directions. By this way, also the remaining flexibility agents, the Flexibility Agent 3 (Continuous response to schedule risks and complexities based on the IFCRM Procedure) and Flexibility Agent 5 (Continuous support for the schedule control and schedule development processes by the IFCRM Procedure), which waits to be handled, have been utilised.

In this research, since flexible project management is being considered as a response and a solution to the complexity, uncertainty and dynamics of complex construction projects and this argument is being investigated specifically from the scheduling perspective, the IFCRM Procedure has been designed to deal with the complexity assessment, risk analysis and risk management in terms of the CPM scheduling, and the hybrid approach has been proposed to deal with the dynamics of the complex construction projects again based on the same reference point, i.e. the CPM scheduling. By this way, all the dimensions of the research problem, i.e. project complexity, project uncertainty and project dynamics are having been handled through two interrelated flexible project management processes proposed in this research, i.e. IFCRM Procedure and the hybrid approach, based on the project risk management and project schedule management knowledge areas of the project management (Project Management Institute, 2017), which intersects each other by nature as illustrated in Figure 1.2. One of these proposed processes, i.e. the IFCRM Procedure, has been installed to the other proposed process, i.e. the hybrid approach, as a component. In this way, the hybrid approach has been brought to a position by which it can be given a new identity as done in the next section and be proposed as the final product of this research under this new identity henceforth.

6.3.5 Proposal of the Flexible CPM-Based Schedule Management Approach (FSMA-CPM)

The hybrid approach proposed based on the study performed in this chapter as well as through the findings, evaluations and productions of the preceding chapters is ready to be called with its new name from this moment on: the Flexible CPM-Based Schedule Management Approach (FSMA-CPM). As mentioned in the previous section, the IFCRM Procedure proposed in Chapter 5 is a major component of the FSMA-CPM. Keeping this in mind, it is worth discussing firstly what the name 'FSMA-CPM' implies. The word that attracts attention in the first instance is the 'flexible'. This is compatible with the aim of this research, which has been stated in Chapter 1. However, rather than obtaining a pure flexible approach similar to as proposed by the agile methodologies, a hybrid type of flexibility that contains the arguments of the flexible project management methodologies as well as the traditional project management has been created. Another feature of the proposed hybrid approach which can be distinguished exclusively from its name is its being a schedule management approach specifically developed to be implemented on the CPM schedules. After this short discussion over FSMA-CPM based on what its name implies, its components are briefly revisited below through the illustration given in Figure 6.7.

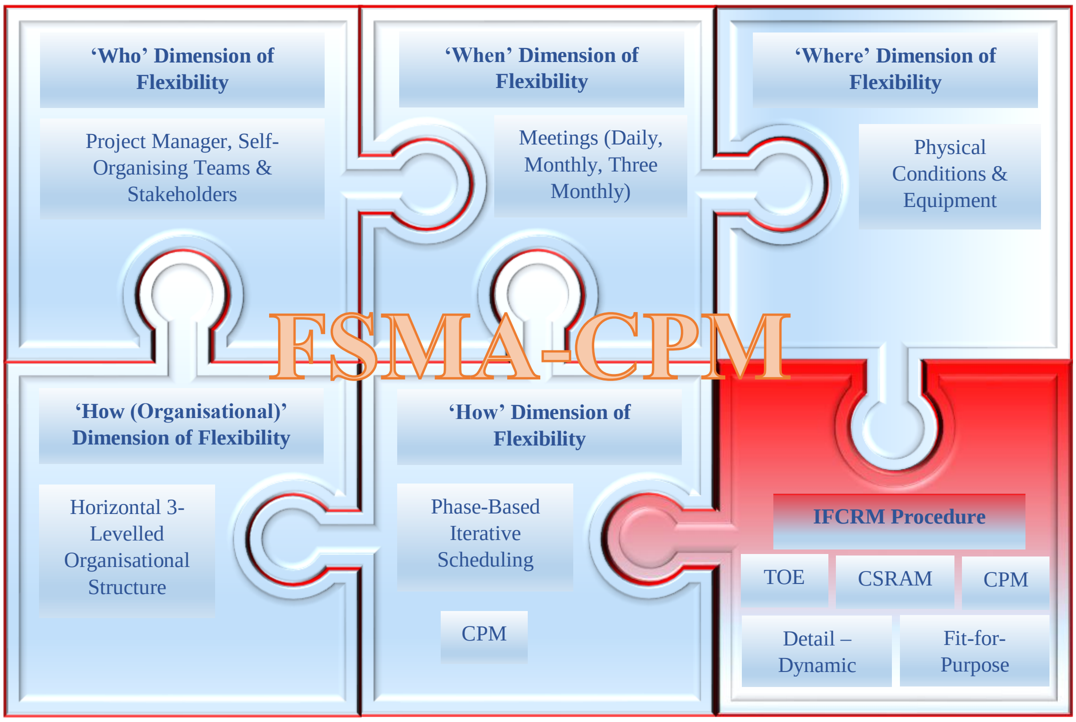

Figure 6.7 Formation of the FSMA-CPM: Completed pieces of the puzzle

The managerial flexibility in FSMA-CPM has been constituted by the utilisation of the 15 different flexibility agents determined in this chapter as the main principles that are considered to exist in a schedule management approach as such based on the relevant literature and the evaluations and findings obtained in the previous chapters. These flexibility agents are mainly based on;

- the principles of various project management methodologies of flexible character such as agile (scrum) and lean (LPS),
- the flexibility provided by the IFCRM Procedure in terms of complexity assessment and risk management in an integrated manner through the utilisation of a number of methods such as TOE Framework, CSRAM, Detail-Dynamic Project Management Model and Fit-for-Purpose Management Strategy,
- the managerial flexibilities associated with the CPM,
- and the expanded flexibilities obtained when CPM is used in association with a risk analysis model such as the CSRAM.

Based on these flexibility agents, the FSMA-CPM has been constituted through the combination of 6 different components just like a puzzle as shown in Figure 6.7 (refer to Figure 6.1), which are:

- ‘who’ dimension of flexibility in terms of the teams and stakeholders either undertaking direct responsibility or having role in the associated processes (refer to Figures 6.2 and 6.3),
- ‘where’ dimension of flexibility in terms of the physical conditions and the equipment provided for the activation of the responsible parties in harmony as required for the establishment of flexibility (refer to Figure 6.3),
- ‘when’ dimension of flexibility in terms of the meetings to be realised with the participation of the parties responsible directly in the implementation or involved indirectly in the associated processes (refer to Figure 6.3),
- ‘how’ dimension of flexibility in terms of the organisational structure through the constitution of an organisation in horizontal hierarchy composed of three different organisational levels containing the project manager, self-organised highly-skilled teams and various stakeholders involved in the management of the schedule (refer to Figures 6.2 and 6.3),
- ‘How’ dimension of flexibility in terms of the schedule implementation through iterative scheduling in a balanced manner between pure flexible and traditional (refer to Figure 6.4) and in two different ways, i.e. one proposed for the preconstruction phases (refer to Figure 6.5) and the other proposed for the construction phase (refer to Figure 6.6),
- The IFCRM Procedure to deal with the project complexity and uncertainty in a flexible and integrated way within the framework of CPM scheduling (refer to Figure 5.4).

If we remember the main aim of this research once more, i.e. ‘to propose a hybrid approach carrying both traditional and flexible features that can be used in the management of schedules prepared by the Critical Path Method under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to’, which component meets which side of this aim becomes more clear. While the first five components sorted above can be considered as a response to the dynamic project conditions, the last component, the IFCRM Procedure represents the response to the project complexity and uncertainty (refer to Figure 6.7). The reason for not adapting pure flexibility based on agile (scrum) instead of a hybrid approach that is partially based on the project schedule management and project risk management processes proposed by the PMBOK Guide is essentially the unique conditions specific to the complex construction projects in different phases throughout their lifecycles when compared to the conditions of software development projects in which pure flexible methodologies, especially the agile approach, has been proved to be efficient in practice to a great extent. Depending on this fact, two different balanced approaches standing between pure flexible and pure traditional have been proposed for the preconstruction and construction phases as illustrated in Figures 6.4, 6.5 and 6.6.

In the next section, the FSMA-CPM will be implemented on an example project for the purpose of presenting its applicability. Afterwards, the chapter will end with the concluding remarks.

6.4 AN EXAMPLE APPLICATION OF THE FSMA-CPM

In this section, the applicability of the FSMA-CPM is illustrated on the “Design of the Gönen Plain Irrigation Project”, which is the example project also used to in Chapter 5. The FSMA-CPM will be implemented step by step in line with the stages followed during its development in the previous section as shown in Figure 6.7. For the sake of not going beyond the scope, the implementation of the IFCRM Procedure will not be illustrated in the current example. Since the “Design of the Gönen Plain Irrigation Project” covers the design phase of the Gönen Plain Irrigation Project, the applicability of the FSMA-CPM will be shown based on the process flowchart given in Figure 6.5, which has been proposed for the iterative scheduling of the preconstruction phases. Brief information regarding the “Design of the Gönen Plain Irrigation Project” as well as the responsible parties and stakeholders involved in this project can be found in Chapter 5.

6.4.1 Step 1 – Teams and Organisational Structure: The ‘Who’ and ‘How’ (Organisational) Dimensions of Flexibility

In Step 1, an organisational structure in the form of horizontal hierarchy has been established jointly by the Designer and the Owner compatible with the format put forward in Figure 6.2. Since the contractually responsible party for the execution of the project is the Designer, the organisational structure in question was constituted within the organisation of the Designer but in a fashion independent from any existing top-down structure. As the Figure 6.2 suggests, three organisational levels have been constituted under this structure. At the lateral top, which is named as the organisational level 1, the Project Manager is located. The Project Manager, as an employee of the Designer, would not only be responsible of managing the project schedule but also be responsible of managing the whole project. But for the current application, which is completely related to schedule management, the Project Manager occupies the leading position within the organisational structure that is horizontally established. However, the main responsibility of the Project Manager within this structure is to monitor the schedule management process like a general coordinator.

Organisational level 2 has been constituted also in accordance with Figure 6.2. While the Schedule Development & Implementation Team is composed of the team coordinator, the representative of the Owner and the team staff, the Schedule Control Team is composed of only the team coordinator and the team staff. These two teams have been established by the highly-skilled engineering staff experienced either on CPM scheduling and/or designing of irrigation projects. Therefore, they are presumably capable of working in a self-organised manner. Rather than commanding the teams, the team coordinators are in a position responsible of coordinating the meetings held through the participation of the parties from different organisational levels and also responsible of regularly reporting the progress to the Project Manager. The representative of the Owner is a design engineer or a team composed of design engineers from the Owner’s organisation or from an externally hired source competent and authorised of timely conveying the requirements of the Owner about the project to the Schedule Development & Implementation Team. Such a configuration would create flexibility in terms of schedule management as it would become possible to timely transfer the requirements of the Owner to the Schedule Development & Implementation Team and in turn guide the implementation of the project in line with the Owner's satisfaction. In order to achieve this purpose, the representative of the Owner functions as a member of the Schedule Development & Implementation Team. Another important point is that the functions, authorities and responsibilities of the Schedule Development & Implementation Team and the Schedule Control Team have been separated from each other as the FSMA-CPM offers for the sake of ensuring the principle of "separation of duties", which is important for unbiased reporting to the Project Manager and the parties in the organisational level 3.

Organisational level 3 is composed of internal stakeholders, i.e. the stakeholders within the Designer's organisation, and external stakeholders, i.e. the stakeholders within the Owner's organization and also the third parties. The stakeholders in question are listed below:

- Internal Stakeholders (within the Designer's organization)
    - Design Units
    - Reporting Units
    - Cost Estimation Unit
    - Project Risk Assessment Unit
    - Site Staff
- External Stakeholders (within the Owner's organization and the third parties)
    - Design & Construction Unit of the Owner
    - Planning Unit of the Owner
    - Expropriation Unit of the Owner
    - Geotechnical Unit of the Owner
    - Maintenance & Operation Unit of the Owner
    - Project Risk Management Unit of the Owner
    - Regional Office (Contracting Authority) under the Owner's organisation
    - Farmers (End-users) and Farmer Associations
    - Subcontractor designers

The parties of organisational level 3 are not directly responsible of schedule management like the teams at the organisational level 2. However, they are involved either directly through the tasks within the schedule which are under their responsibility like the design units or indirectly through their external impacts on the schedule such as the farmers (end-users). However, all the parties involved within this horizontally built three-levelled organisational structure are considered as the constituents of the same organisational structure in line with the working spirit aimed by the FSMA-CPM. Thereby, the 'who' and the 'how (organisational)' dimensions of flexibility are provided. The advantages of bringing different parties together from both the Owner's and Designer's organisations along with the third parties such as the farmers (end-users) within the same organisational structure will be experienced while managing the schedule, i.e. during the implementation of the iterative scheduling in Step 3.

6.4.2 Step 2 – Meetings and Location: The 'When' and 'Where' Dimensions of Flexibility

The 'when' dimension of flexibility is associated with the type and timing of the meetings that will be held with the participation of the parties from the three different organisational levels horizontally constituted during Step 1. Therefore, the configuration put forward in Figure 6.3 has been taken into account during Step 2. The information about the teams, organisational structure, meetings, location and the implementation of the iterative scheduling, which represent the first five components of the FSMA-CPM (refer to Figure 6.7), are given place within the schedule management plan. Information about the implementation of the IFCRM Procedure, which is the remaining sixth component of the FSMA-CPM (refer to Figure 6.7), was included in the complexity/risk management plan (refer to Figure 5.4). The Designer undertakes the responsibility of meeting the requirements regarding the "where" dimension of flexibility by supplying a suitable working place and appropriate working conditions for the meetings to be held and the necessary equipment and software to properly manage the CPM schedule through the highly-skilled self-organised teams, i.e. Schedule Development & Implementation Team and Schedule Control Team. While the schedule management plan contains detailed information about these issues, they might also be included briefly in the contract in order to establish the legal background of the proper implementation of the FSMA-CPM.

In this context, the information about the type of the meetings, the parties that will attend to these meetings, the properties of the meeting location and the necessary equipment, which has been given place also in the schedule management plan, is introduced below:

- Daily Meetings (Schedule Development & Implementation Team): Daily meetings will be held during the implementation of the iterative scheduling with the participation of the members of the Schedule Development & Implementation Team, i.e. the team coordinator, the representative of the Owner and the team staff. Daily meetings will be short meetings during which the daily progress is reviewed and in turn the ongoing schedule iteration is directed. The team members will always gather at the same meeting location under the coordination of the team coordinator. Necessary hardware and scheduling software along with the communication devices required to establish the communication among the parties from the organisational levels 1, 2 and 3 will be provided by the Designer.
- Daily Meetings (Schedule Control Team): These are the daily meetings to be held separately from the previous one during the schedule iterations with the participation of the members of the Schedule Control Team, i.e. the team coordinator and the team staff. The common point is that these will be also short meetings during which the daily progress is reviewed and reported to the Project Manager. The team members will always gather at the same meeting location under the coordination of the team coordinator. Necessary hardware and scheduling software along with the communication devices required to establish the communication among the parties from the organisational levels 1, 2 and 3 will be provided by the Designer.
- Schedule Iteration Preparation Meetings: These meetings will be realised before starting each schedule iteration through the participation of the Schedule Development & Implementation Team and the relevant parties from the

organisational level 3 such as the design units, site staff and subcontractor designers. The decisions taken during this meetings will help the Schedule Development & Implementation Team prepare the detailed CPM schedule to be used during the iteration to be started based on the work packages selected out of the high-level list of work packages in agreement with the parties from the organisational level 3. Meanwhile, information transfer will be realised from the IFCRM Procedure implementation to this meeting as shown in Figure 6.5 by the Designer's Project Risk Assessment Unit. The detailed CPM schedule prepared based on the selected work packages will be used during the starting iteration through benefitting from its various flexibilities as discussed in Chapters 3 and 4. The team members always will be gathered at the same meeting location under the coordination of the team coordinator. Necessary hardware and scheduling software along with the communication devices required to establish the communication with the parties from the organisational level 3 will be provided by the Designer.

- Schedule Iteration Review Meetings: These meetings will be performed through the participation of the Schedule Development & Implementation Team, Schedule Control Team and the relevant parties from the organisational level 3 such as the design units, site staff and subcontractor designers after the closure of each schedule iteration. The aim is to review the project progress achieved at the end of each completed schedule iteration. The achievements recorded during the previous iteration, the completed and uncompleted activities, the problems encountered and other related issues will be discussed during this meeting. Furthermore, necessary information on these issues will be transferred to the IFCRM Procedure implementation process by the Designer's Project Risk Assessment Unit as shown in Figure 6.5. On top of this, the critical information gathered at the end of this meeting will be utilised during the next month's "high level schedule update meeting" and during the tasks subsequently performed just after this meeting till the next schedule iteration preparation meeting (refer to Figure 6.5). Based on this information, if required, the list of work packages can be updated, the iteration number and duration can be changed and necessary measures can be put into force in agreement with the Owner's Representative.

- High-level Schedule Update Meetings: These are the monthly meetings that will be organised among the parties from the organisational level 1, i.e. the Project Manager and organisational level 2, i.e. the Schedule Development & Implementation and Schedule Control Teams (refer to Figure 6.3). The purpose of the high-level schedule update meetings is to update the high-level schedule built upon the high-level list of work packages determined at the beginning of the project based on the requirements of the Owner. The high-level schedule update meetings will provide the opportunity of updating the high-level schedule within the knowledge of the Project Manager and the Owner's Representative based on the up-to-date requirements of the Owner, the project itself, the results of the schedule iteration review meetings and the reports submitted by the Schedule Control Team to the Project Manager (refer to Figure 6.5).
- Schedule Progress Review Meetings: These are the 3-monthly meetings that will be held among the parties from all the three organisational levels (refer to Figures 6.2 and 6.3). The purpose of these meetings is to discuss and evaluate the general progress achieved in the implementation of the schedule by the participation of all the relevant parties.

FSMA-CPM is comparable with Last Planner System (LPS) in terms of the meetings to be performed. For instance, "daily learning meetings" held by last planners at the end of the day in case of LPS is similar to the daily meetings held by the teams in case of FSMA-CPM in terms of the frequency (Ballard, 2000; Lean Construction Institute, 2020). However, the two systems differ in the sense that while the daily learning meetings of LPS are held at the end of the day by only last planners for the purpose of evaluating the daily progress and fixing the problems, the daily meetings of FSMA-CPM are held separately by two different teams at the beginning of the day for the purpose of discussing the tasks to be done during the day and evaluating the progress of the previous day.

Another meeting proposed in LPS is the "weekly work planning meetings" or "weekly check-ins" held among the last planners and workers for the purpose of ensuring that workers and last planners are familiar with which of the upcoming tasks are under their responsibility for each week (Ballard, 2000; Lean Construction Institute, 2020). In FSMA-CPM, no weekly meeting has been proposed as such but it is assumed that the daily meetings held by the schedule development and implementation team along with the participation of responsible parties from organisational level 3 fulfil a similar function with the LPS's weekly work planning meetings in a more frequent manner, i.e. daily instead of being weekly.

The meetings held for the creation of master schedules and phase schedules in LPS is partially similar to the high-level schedule update meetings and schedule iteration preparation meetings of FSMA-CPM, respectively (Ballard, 2000; Lean Construction Institute, 2020). However, they differ from each other in terms of handling the details of the schedule, the parties attending the meetings, and the iterative character of the FSMA-CPM. In the same manner, the "make work ready planning meetings" of the LPS are partially similar to the schedule iteration preparation meetings of the FSMA-CPM (Ballard, 2000; Lean Construction Institute, 2020). Their main difference is that while the "make work ready planning meetings" are held for discussing the tasks that are to be completed within four to six weeks' time as of the date of the meeting, the schedule iteration preparation meetings are held to prepare for the next schedule iteration and take decisions that would be effective in establishing the detailed CPM schedule of the next iteration. Another important difference between FSMA-CPM and LPS is that schedule iteration review meetings and schedule progress review meetings proposed by the FSMA-CPM do not have their equivalents in LPS.

6.4.3 Step 3 – Iterative Scheduling: The How (Implementation) Dimension of Flexibility

The Designer starts preparing the schedule management plan after the project is started. As previously pointed out, the information about the teams, organisational structure, meetings, location and the implementation of the iterative scheduling, i.e. information associated with the issues of Steps 1 and 2 are given place within the schedule management plan. This plan is reviewed and approved at the beginning of Step 3 by the Owner's Design and Construction Unit in order to gain validity. The approval of the schedule management plan starts the implementation of the iterative scheduling. Afterwards, the monthly ‘high-level schedule update meeting’ is performed in line with the schedule management plan as shown in Figure 6.5. Rather than being an update meeting, the first high-level schedule update meeting is naturally more like a high-level schedule ‘preparation’ meeting. During this meeting, the Owner’s Representative, who is also a member of the Design & Implementation Team, transfers the requirements of the Owner regarding the project in detail based on the project scope and preliminary explanations put forward within the contract. After the meeting, the high-level list of work packages is prepared by the Design & Implementation Team in agreement with the decisions taken during the high-level schedule update meeting. Figure 6.8 presents the list of work packages in question and the high-level schedule prepared based on these work packages. According to this high-level schedule, the project is aimed to be completed within 300 calendar days as of the project start, which is compatible with the project duration officially mentioned in the contract of the “Design of the Gönen Plain Irrigation Project” as shown in Figure 5.5. Next, the Schedule Development & Implementation Team determines the iteration duration and iteration number as 60 days and 4, respectively, through taking the views of the relevant stakeholders from the organizational level 3 into account based on the high-level list of work packages, the high-level schedule and the envisaged project duration as well.

The information gathered up to this point regarding the schedule management plan, high-level list of work packages, and the high-level schedule is transferred to the IFCRM Procedure implementation process (refer to Figure 6.5). Next, the schedule iteration preparation meeting of the 1st schedule iteration is performed by the participation of the Design & Implementation Team, Design Units, Risk Assessment Unit, site staff, Design & Construction Unit, the farmers and other relevant parties. The Risk Assessment Unit transfers information from the IFCRM Procedure implementation process to this meeting. In terms of the decisions taken during the first schedule iteration preparation meeting, the work packages to be handled during this iteration are determined and subsequently the detailed CPM schedule is prepared by the Schedule Development & Implementation Team. The detailed CPM schedule prepared for the 1st schedule iteration is shown in Table 6.1.

High-Level List of Work Packages	Duration (day)	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Work-Package-1 Submission of the schedule management plan and approval	10												
Work-Package-2 Preparation of the initial report	60												
Work-Package-3 Preparation of the pre-application genaral layout plans	30												
Work-Package-4 Preparation of the upper plain plans and related calculations	20												
Work-Package-5 Preparation of the pre-application plan-profile design drawings of the irrigation network	60												
Work-Package-6 Preparation of the application general layout plans and plan-profile design drawings of the irrigation network	60												
Work-Package-7 Preparation of the hydraulic structures' design drawings	30												
Work-Package-8 Preparation of the operation and maintenance roads' design drawings	15												
Work-Package-9 Preparation of the access roads' design drawings	15												
Work-Package-10 Preparation of the design drawings of the pumps and related calculations	20												
Work-Package-11 Preparation of the architectural and static design drawings of the pumping stations	30												
Work-Package-12 Preparation of the cost estimation and quantity measurement reports of the irrigation network	15												
Work-Package-13 Preparation of the cost estimation and quantity measurement reports of the hydraulic structures and roads	15												
Work-Package-14 Preparation of the green dossier and project reports	20												
Work-Package-15 Preparation and reproduction of the design drawings' original copies	15												

Project Start: 2nd of January

Project Finish: 28th of October (300 calendar days)

Figure 6.8 List of high-level work packages and high-level schedule of the “Design of the Gönen Plain Irrigation Project”

The work package handled in the 1st iteration is the 'preparation of the initial report', i.e. the work-package-2 of the high-level schedule shown in Figure 6.8. It can be observed in Table 6.1 that the number of activities used to build the detailed CPM schedule of the 1st iteration is 10 though only one work package, the work-package-2, has been dealt. Furthermore, the duration of the 1st iteration is 60 days (i.e. late finish time of the activity 10 in Table 6.1), which is compatible with the iteration duration determined previously.

Table 6.1 Detailed CPM schedule of the 1st iteration prepared based on the work-package-2

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship	Early Start Time	Early Finish Time	Late Start Time	Late Finish Time	Total Float Time	Criticality
1	Preliminary site investigation	3	-	0	3	0	3	0	Critical
2	Review of the Planning Report	4	1 (FS)	3	7	3	7	0	Critical
3	Interviews with the Farmers	3	2 (FS)	7	10	7	10	0	Critical
4	Meetings with the Owner's relevant central units	7	3 (FS)	10	17	10	17	0	Critical
5	Meetings with the Owner's regional office	3	4 (SS)	10	13	10	13	0	Critical
6	Preparation of the design alternatives	15	5 (FS)	13	28	13	28	0	Critical
7	Meetings with the Owner's Design & Construction Unit	3	6 (FS)	28	31	28	31	0	Critical
8	Preparation of the Initial Report based on the selected design alternative	15	7 (FS)	31	46	31	46	0	Critical
9	Submission of the Initial Report to the regional office and approval	7	8 (FS)	46	53	46	53	0	Critical
10	Submission of the Initial Report to the Design & Construction Unit and approval	7	9 (FS)	53	60	53	**60**	0	Critical

Afterwards, the iteration is started. The Schedule Development & Implementation Team starts to manage the schedule on behalf of the Project Manager through daily meetings and by establishing the required communication with the relevant parties from the organisational level 3. The managerial flexibilities provided by the CPM (refer to Chapters 3 and 4) are utilised throughout the iteration under the coordination of the Schedule Development & Implementation Team. The schedule is updated daily by means of a scheduling software based on the actual data provided from the stakeholders and the updated version is shared transparently with the stakeholders. Besides the Schedule Development & Implementation Team, the Schedule Control Team performs daily meetings and monitors the schedule progress throughout the 1st iteration for the purpose of reporting the progress to the Project Manager. At the end of the 1st iteration, the schedule iteration review meeting is carried out by the parties from the organisational levels 2 and 3. Since the iteration duration is assumed as 60 days in this example application, the second high-level schedule update meeting is to be realised 30 days after the start of the first iteration.

At the end of the third high-level schedule update meeting, information is transferred to the IFCRM Procedure implementation and also from the IFCRM Procedure implementation to the next schedule iteration review meeting. For the current example application, it is assumed that the IFCRM Procedure is implemented repetitively at the end of each iteration and the iteration schedules are managed in accordance with the risk response/complexity embracement strategies determined during the latest implementation of the IFCRM Procedure. This would create an advantage for the completion of the iterations in time without any delay. The information transferred in two directions between the FSMA-CPM and the IFCRM Procedure through the interfaces provided (refer to the Figures 5.4 and 6.5) as previously explained ensures the management and control of the complexity and uncertainty affecting the schedule.

After the completion of the 1st iteration, the whole process starts from the beginning through the schedule iteration review meetings of the 2nd, 3rd, and 4th iterations. The detailed CPM schedules utilised throughout these iterations are given in Tables 6.2, 6.3 and 6.4, respectively. During the 2nd, 3rd, and 4th iterations, the work-packages 3 to 5, 6 to 8, and 9 to 15 shown in Figure 6.8 have been handled, respectively. Meanwhile, the schedule progress review meetings are performed every three months with the parties from all three organisational levels. The project is delivered to the Owner in increments by the closure of each iteration. The Owner's feedback about the delivered project increments along with the design changes or further requirements (if exist) are conveyed to the Designer by the Owner's Representative before starting the next iteration. However, since the Owner's Representative acts as a member of the Schedule Development and Implementation Team, a similar information transfer is also provided continuously from the Owner towards the Schedule Development and Implementation

Team throughout the iterations. These two feedback and information transfer channels create continuous flexibility in terms of the scope throughout the project. Furthermore, flexibility is also provided by the continuous information transfer from the parties involved within the third organisational level through the daily, schedule iteration preparation, schedule iteration review, and schedule progress review meetings.

The iterations in FSMA-CPM carry the purpose of revisiting the high-level list of work packages a number of times rather than processing the same tasks on a specific model iteratively for the purpose of converging towards a result. In this sense, through the iterations, FSMA-CPM aims at delivering the project in increments instead of delivering it as a whole at the end (refer to Figure 6.5). While the incremental project delivery can be implemented easily for the preconstruction phases, it might be inappropriate during the construction phase. Therefore, FSMA-CPM proposes incremental reporting instead of incremental project delivery for the construction phase through schedule iterations (refer to Figure 6.6). Accordingly, the implementation of the schedule through iterations along with the delivery of the project in increments have been the case in Step 3 for the reason the project handled contains the designing tasks.

Table 6.2 Detailed CPM schedule of the 2nd iteration prepared based on the work-packages-3 to 5

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship	Early Start Time	Early Finish Time	Late Start Time	Late Finish Time	Total Float Time	Criticality
1	Preparation of the pre-application general layout plans of the irrigation network	15	-	0	15	0	15	0	Critical
2	Preparation of the upper plain plans and related calculations	10	1 (SS)+10	10	20	25	35	15	Noncritical
3	Approval of the pre-application general layout plans of the irrigation network	15	1 (FS)	15	30	15	30	0	Critical
4	Approval of the upper plain plans and related calculations	10	2 (FS)	20	30	35	45	15	Noncritical
5	Preparation of the pre-application plan-profile design drawings of the irrigation network	15	3 (FS)	30	45	30	45	0	Critical
6	Approval of the pre-application plan-profile design drawings of the irrigation network	15	4 (FS) 5 (FS)	45	60	45	**60**	0	Critical

Table 6.3 Detailed CPM schedule of the 3rd iteration prepared based on the work-packages-6 to 8

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship	Early Start Time	Early Finish Time	Late Start Time	Late Finish Time	Total Float Time	Criticality
1	Preparation of the application general layout plans and plan-profile design drawings of the irrigation network	30	-	0	30	0	30	0	Critical
2	Approval of the application general layout plans and plan-profile design drawings of the irrigation network	15	1 (FS)	30	45	30	45	0	Critical
3	Preparation of the hydraulic structures' design drawings	15	1 (SS)	0	15	30	45	30	Noncritical
4	Approval of the hydraulic structures' design drawings	10	3 (FS)	15	25	45	55	30	Noncritical
5	Preparation of the operation and maintenance roads' design drawings	10	2 (FS)	45	55	45	55	0	Critical
6	Approval of the operation and maintenance roads' design drawings	5	4 (FS) 5 (FS)	55	60	55	**60**	0	Critical

Keeping the scope sufficiently flexible against the Owner's and other stakeholders' changing requirements, increasing the adaptability of the project by this way and in contrast, keeping the time (targeted project duration) and in turn the cost (targeted project budget) sufficiently rigid, and finally managing the schedule through iterations with taking into account the risks, uncertainties and complexities all would help the completion of the "Design of the Gönen Plain Irrigation Project" presumably without any schedule delay. Since each schedule iteration does take 60 days to be completed as shown in Tables 6.1, 6.2, 6.3, and 6.4, the project has been aimed at completing within 240 days after the start, which is earlier than the 300 days which the high-level schedule in Figure 6.8 offers and also the contract officially requires. This 60 days of period has been reserved as a time contingency or time buffer to compensate the delays that might occur during the schedule iterations. The reserved duration in question has been determined according to the results of CSRAM application performed within the IFCRM Procedure (refer to Table 5.7). The minimum expected project duration is 281 days according to the CSRAM, which is close to 240 days (with the reserved time not included) and 300 days (with the reserved time included), which have been used in this example application.

Table 6.4 Detailed CPM schedule of the 4th iteration prepared based on the work-packages-9 to 15

Activity No.	Activity Name	Activity Duration (day)	Predecessor activity & network relationship	Early Start Time	Early Finish Time	Late Start Time	Late Finish Time	Total Float Time	Criticality
1	Preparation of the access roads' design drawings	10	-	0	10	0	10	0	Critical
2	Approval of the access roads' design drawings	5	1 (FS)	10	15	25	30	15	Noncritical
3	Preparation of the design drawings of the pumps and related calculations	10	1 (SS)	0	10	20	30	20	Noncritical
4	Approval of the design drawings of the pumps and related calculations	10	3 (FS)	10	20	30	40	20	Noncritical
5	Preparation of the architectural and static design drawings of the pumping stations	20	1 (SS)	0	20	0	20	0	Critical
6	Approval of the architectural and static design drawings of the pumping stations	10	5 (FS)	20	30	20	30	0	Critical
7	Preparation of the cost estimation and quantity measurement reports of the irrigation network	10	6 (FS)	30	40	30	40	0	Critical
8	Preparation of the cost estimation and quantity measurement reports of the hydraulic structures and roads	10	2 (FS)	15	25	30	40	15	Noncritical
9	Preparation of the green dossier and project reports	10	4 (FS) 7 (FS) 8 (FS)	40	50	40	50	0	Critical
10	Preparation and reproduction of the design drawings' original copies	10	9 (FS)	50	60	50	**60**	0	Critical

6.4.4 Step 4 – The Project Complexity and Uncertainty: Implementation of the IFCRM Procedure

In Step 4, the IFCRM Procedure is implemented under the responsibility of the Project Risk Assessment Unit of the Designer separately for each of the schedule iteration by taking into consideration the detailed CPM schedules prepared after the schedule iteration preparation meetings. The purpose of processing the iterative character of the IFCRM Procedure as much as possible by this way is to ensure the synchronisation between the FSMA-CPM and IFCRM Procedures from the flexibility perspective through the interfaces in between as discussed in Section 6.3.4. Brief explanations regarding the information transfer from or to the IFCRM Procedure have been introduced in Step 3. Since the Schedule Development and Implementation Team aims to complete the project in 4 iterations within 240 days, i.e. 60 days earlier than the contractual duration for the purpose of keeping this time frame as a reserve or time buffer, the risk retention/complexity embracement plan established at the end of the IFCRM Procedure becomes important for success. Besides, the managerial flexibilities provided by the CPM, which was discussed in Chapters 3 and 4, are the other supportive features used by the Schedule Development & Implementation Team during the management of schedule iterations.

6.5 CONCLUDING REMARKS

This was the last chapter of a number of subsequent chapters starting with Chapter 2, which constitute the main body of this research report. After the development of the IFCRM Procedure in the previous chapter, the FSMA-CPM, which is the final product proposed at the end of this research in accordance with the major goal of the research, has been introduced. IFCRM Procedure has been used as a component within the FSMA-CPM. This can be observed in Figures 6.5 and 6.6 and is further illustrated in Figure 6.7 together with the other 5 components that constitute the proposed approach.

The FSMA-CPM has been proposed for the flexible management of CPM schedules of construction projects under complexity and uncertainty. One of the major arguments put forward in this research was the inappropriateness of managing the schedules of complex construction projects in a traditional way based on detailed schedules established in advance. Complexities and uncertainties continuously impact the construction projects and therefore it is inevitable to put into implementation more flexible project management methodologies for achieving success. It is almost impossible in complex construction projects to determine the scope and the owner requirements (along with the requirements of various stakeholders) completely in advance and reflect this in a detailed plan and a schedule before project execution starts. Therefore, more flexible approaches are required.

In this context, a flexible structure has been constituted in which the relevant stakeholders are involved and the schedules are developed iteratively in an incremental way under suitable working conditions and within a horizontally established organisation as shown in Figures 6.2 - 6.6. The flexibility in question has been built upon 15 different flexibility agents determined based on the studies of the researchers Jalali-Sohi *et al.* (2016, 2019a, 2019b, 2019c) and Vanhoucke (2012) as well as the PMBOK Guide (Project Management Institute, 2017) and the findings of this research introduced between the Chapters 2 and 5. Based on these predetermined flexibility agents, flexibility has been constituted through 5 different components, each representing different dimensions of flexibility, and with the incorporation of the IFCRM Procedure as the 6th component as shown in Figure 6.7. Based on the combination of these 6 different components, the FSMA-CPM has been developed.

The flexibility agents utilised during the development of the FSMA-CPM are mainly based on;

- the principles of various project management methodologies of flexible character such as agile (scrum) and lean (LPS),
- the flexibility provided by the IFCRM Procedure in terms of complexity assessment and risk management in an integrated manner through the utilisation of a number of methods such as TOE Framework, CSRAM, Detail-Dynamic Project Management Model and Fit-for-Purpose Management Strategy,
- the managerial flexibilities associated with the CPM,
- and the expanded flexibilities obtained when CPM is used in association with a risk analysis model such as the CSRAM.

The 6 different components on which the FSMA-CPM has been constituted, which is also illustrated in the form of a puzzle in Figure 6.7, are as follows:

- ‘who’ dimension of flexibility in terms of the teams and stakeholders either undertaking direct responsibility or having role in the associated processes (refer to Figures 6.2 and 6.3),
- ‘where’ dimension of flexibility in terms of the physical conditions and the equipment provided for the activation of the responsible parties in harmony as required for the establishment of flexibility (refer to Figure 6.3),

- ‘when’ dimension of flexibility in terms of the meetings to be realised with the participation of the parties responsible directly in the implementation or involved indirectly in the associated processes (refer to Figure 6.3),
- ‘how’ dimension of flexibility in terms of the organisational structure through the constitution of an organisation in horizontal hierarchy composed of three different organisational levels containing the project manager, self-organised highly-skilled teams and various stakeholders involved in the management of the schedule (refer to Figures 6.2 and 6.3),
- ‘How’ dimension of flexibility in terms of the schedule implementation through iterative scheduling in a balanced manner between pure flexible and traditional (refer to Figure 6.4) and in two different ways, i.e. one proposed for the preconstruction phases (refer to Figure 6.5) and the other proposed for the construction phase (refer to Figure 6.6),
- The IFCRM Procedure to deal with the project complexity and uncertainty in a flexible and integrated way within the framework of CPM scheduling (refer to Figure 5.4).

While the first five components can be considered as a response to the dynamic project conditions, the last component, i.e. the IFCRM Procedure, represents the response to the project complexity and uncertainty (refer to Figure 6.7). The reason for not adapting pure flexibility is essentially the unique conditions specific to the complex construction projects when compared to the conditions of software development projects in which pure flexible methodologies, especially the agile approach, have been proved to be efficient to a great extent. Depending on this fact, two different hybrid approaches balanced between pure flexible and pure traditional have been proposed for the preconstruction and construction phases, respectively, in Figures 6.5 and 6.6. Proposing different processes for different project phases as such is due to the changing conditions along the project lifecycles as illustrated in Figure 6.4.

The chapter gave an example application of the FSMA-CPM on a project which was also handled in Chapter 5 for the purpose of showing the applicability of the IFCRM Procedure. Using the same example project has eliminated the need for repeating the implementation of the IFCRM Procedure during the application of FSMA-CPM. The research report will continue with the discussion of the results and limitations of the research, and the conclusions and recommendations for future research in the following chapters.

7 DISCUSSION OF THE RESULTS AND LIMITATIONS OF THE RESEARCH

This chapter introduces the discussion of the results obtained in this research. The limitations of the research are disclosed as well. The chapter is divided into two sections. The first section in which the research results are discussed can also be considered as a summary of the chapters completed so far. In the second section, the limitations of the research are presented.

7.1 DISCUSSION OF THE RESULTS

In Chapter 1, an introduction was made under 6 different headings: research topic, problem statement, aim and objectives, scope, research methodology, and outline of the research report. Relevant literature was briefly visited and the methods, which have been utilized throughout the research, were pointed out. Furthermore, the master theses supervised and the academic activities attended during the research period were introduced (refer to the Appendixes A and B).

While traditional project management puts the emphasis on rigid planning and control to achieve success in projects, modern project management considers flexibility as a requirement for success. While traditional project management represents a predictive plan-driven approach, flexible project management, which can be considered the representative of the modern project management, has an adaptable change-driven character (Koppenjan *et al.*, 2011). However, most of the time, a hybrid approach in between these two extreme approaches is required. The aim of this research is to propose a hybrid approach carrying both traditional and flexible features that can be used in the management of schedules prepared using the Critical Path Method (CPM) under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to.

In Chapter 2, the theoretical background associated with the scope of the research has been introduced through a literature survey. The literature review has been conducted under the following headings:

- Complexity Assessment in Project Management
- Project Risk Management
- Project Schedule Management
- Flexible Project Management

Complexity assessment is a relatively new subject in project management. Therefore, the reviewed models and frameworks regarding the project complexity are mainly associated with studies claiming the need for a paradigm change in project management, i.e. from traditional and plan-driven towards flexible, adaptable and change-driven. The TOE Complexity Assessment Framework developed by Bosch-Rekveldt *et al*. (2011) has been used in this research.

After conducting literature review on complexity assessment, the literature regarding project schedule management and project risk management has been introduced respectively with taking the PMBOK Guide into consideration (Project Management Institute, 2017).

Finally, at the end of Chapter 2, modern approaches recently developed in project management literature to tackle the new conditions of projects, i.e. complex, highly uncertain and dynamic, have been reviewed. In this research, ‘flexibility’ in project management is considered as *the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions*. While the section regarding the complexity assessment was about the ‘complexity’ component, the sections regarding the project risk management and flexible project management were related to the ‘uncertainty’ and ‘dynamic’ components, respectively. The section regarding the project schedule management was related to the core focus of the current research, i.e. scheduling.

In Chapter 3, firstly, managerial flexibilities inherent with the traditional method of the activity network scheduling, the CPM, have been evaluated. Next, the flexibilities in the PMBOK Guide's (Project Management Institute, 2017) view on project management have been examined from the scheduling perspective. The reason of handling the PMBOK Guide as the main reference is that it has been widely recognized as a primary source of project management both in the literature and practice, including the construction sector. The "Construction Extension to the PMBOK Guide" (Project Management Institute, 2016) and the "Practice Standard for Scheduling" (Project Management Institute, 2017) also have been taken into consideration during this evaluation. The PMBOK Guide conceives Project Schedule Management as one of the main knowledge areas of project management (Project Management Institute, 2017). CPM is a traditional scheduling method and the general view on project management in the PMBOK Guide is dominantly of a traditional character. The purpose was to understand the existing flexibilities in traditional approaches, both at method-level, i.e. based on CPM, and at process-level, i.e. based on the processes proposed in the PMBOK Guide (Project Management Institute, 2017) to become aware of the areas open to development for obtaining more flexible project management from the perspective of scheduling.

The managerial flexibilities provided by CPM were evaluated at three levels, i.e. activity, path, and project, first conceptually, then through two different example CPM applications. In spite of its criticized deterministic features, it was noticed that CPM contains various flexible aspects from a managerial viewpoint. Potential flexibilities in CPM are mainly associated with its features including, but are not limited to, resource levelling, uncritical activities, uncritical paths, activity float times, activity float types, and float times of uncritical paths. CPM contains complete flexibility through independent activity floats and resource levelling capability. However, the managerial flexibilities of CPM are not limited to these features. Some of the other capabilities of CPM creating flexibility from the managerial perspective are project compression (schedule crashing and fast-tracking), time-cost trade-off analysis (optimization), delay analysis, float allocation, dispute resolution, schedule risk analysis, what-if analysis, updateability via CPM based scheduling software, monitoring and control (Earned

Value Method and S-Curve analysis), integration with linear scheduling method, multi-calendar analysis, preparation of reports at various detail levels by means of scheduling software, and etc. The discussion on CPM also has revealed that CPM is not as rigid as it is assumed as far as the manager using it is aware of the means of benefitting from its flexible features. For instance, it is important to make the required distinction between the activity float types in a CPM network schedule, i.e. total, free, shared, and independent floats. While the total float times belonging to noncritical activities are well-known to practitioners, the free, shared and independent floats that are contained within the total floats should be taken into account during the schedule management.

The second part of Chapter 3, in which the PMBOK Guide was examined from the scheduling perspective, also provided starting points for the succeeding chapters. The general view of the PMBOK Guide on project schedule management, which has been taken as a reference for being dominantly traditional, predictive and plan-driven character, can be taken as a pivot point on which the final product of the research can be built upon, i.e. a more flexible CPM-based schedule management approach to be used under complex, uncertain and dynamic conditions. In spite of the criticism it attracts from the literature for being traditional, the PMBOK Guide indeed acknowledges the need for a flexible paradigm change in project management in its last version, i.e. the 6th Edition (Project Management Institute, 2017) and recommends the implementation of project phases of a project constituting its life cycle through an agile (adaptable), iterative, incremental, overlapping or hybrid approach depending on the project conditions. The PMBOK Guide recognises the current need for an adaptable (agile) and change-driven approach in project management based on the "prepare and commit" principles even though the means of how to achieve it were not sufficiently clarified. It was concluded that the project schedule management processes and the recent recommendations regarding the adaptable approaches in the PMBOK Guide do have flexible features worth being benefitted in the subsequent parts of the research.

In this research, 'flexibility' in project management conceptually has been perceived as *the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions*. ***In***

Chapter 4, the research problem has been handled from the framework of "uncertainty", addressing the following questions:

- in what way the uncertainties and project risks influence the CPM-based schedules,
- how the managerial flexibilities provided by CPM can be expanded to be utilised under uncertainty,
- and how the schedule risks will be managed within the scope of project risk management.

In order to answer these questions, firstly, CPM was applied in the form of the Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen & Öztaş, 2008). By the implementation of CSRAM and comparing the results against the results of CPM, the expansion of managerial flexibilities in CPM has been evaluated. The flexibilities in traditional CPM were evaluated at three levels in Chapter 3, i.e. activity, path and project levels, and this same multi-level approach was followed. The evaluation has been performed on an illustrative example project. It was shown that even on such a relatively simplified project, the managerial flexibilities provided by CPM expand in various directions at different levels, i.e. activity, path and project levels, in case CSRAM is implemented.

Next the processes defined within the project risk management knowledge area of project management in the PMBOK Guide (Project Management Institute, 2017) were examined from both the scheduling and flexibility perspectives. This was done in order to explore the means of connecting the traditional project schedule management to the complexity incorporated project risk management to build more flexible project schedule management. The implementation of standard and traditional risk analysis procedures such as probability-impact matrices becomes inappropriate and insufficient to analyse the impacts of risks on the schedules especially under highly uncertain and complex project conditions. Especially complex construction projects scheduled by CPM require the utilisation of advanced quantitative risk analysis models such as the CSRAM that simulate the complex and uncertain conditions of real life in a practical way as much as possible. The usage of simulation based schedule risk analysis models would help to manage the schedules of complex projects more flexibly. The investigation and discussion conducted on the PMBOK Guide also has shown that the Guide recommends the application of the risk management processes throughout the different phases of the projects in an iterative way instead of applying them only at the beginning of the projects during planning, conception or feasibility phases. This recommendation also carries importance from the flexible project management perspective. In a project environment where flexibility is required to cope with complexity, uncertainty and dynamic project conditions, not only the style of managing the schedule but also the style of managing the project risks need to be sufficiently adaptable and iterative. Indeed the PMBOK Guide, which is dominantly traditional, also acknowledges the current need for incorporating additional features to the traditional project risk management in order to convert it to a more flexible and adaptive process. Besides, the Guide considers the risk management as a dynamic process that should be performed continuously along the project life cycle especially in case of large-scale construction projects (Project Management Institute, 2017). The aforementioned approach proposed by the PMBOK Guide, i.e. while being traditional, simultaneously being open to development in terms of flexibility, is assumed to be useful in incorporating flexibility to traditional project risk management. Accordingly, this hybrid approach has been further elaborated and utilised in the succeeding chapters.

In Chapter 5, ‘complexity’, for which flexible project management approaches are assumed to be effective on its management, has been investigated in conjunction with ‘uncertainty’. Complexity assessment was incorporated into project risk management (Project Management Institute, 2017) through the utilisation of the TOE Framework (Bosch-Rekveldt *et al.*, 2011) and the relevant processes of the PMBOK Guide. CPM was built into this integrated structure through CSRAM (Ökmen & Öztaş, 2008). This new approach was finally converted to an ‘integrated flexible complexity/risk management procedure’ by integrating the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010). It was aimed to expand the territory of the traditional project risk management through the incorporation of complexity assessment within the framework of CPM scheduling.

At the beginning of Chapter 4, firstly, a complexity assessment incorporated project risk management approach was put forward based on the usage of the TOE Framework (Bosch-Rekveldt *et al.,* 2011) and the processes of the PMBOK Guide (Project Management Institute, 2017) related with the project risk management knowledge area. Besides being a first step, this attempt was representing the effort of combining a relatively new concept of project management, i.e. the complexity assessment, with one of the main processes of traditional project management, i.e. project risk management. The procedure obtained at the end of this step (Figure 5.1), had limited flexibility and only helped general application. Therefore, this initial approach was modified and developed by integrating CSRAM (Ökmen & Öztaş, 2008) and by establishing interfaces with the relevant project schedule management processes of the PMBOK Guide (Project Management Institute, 2017) as shown in Figure 5.2.

This new version of the integrated complexity/risk management procedure still was 'traditional' in terms of a stepwise process that is neglecting the factors such as the subjective character of complexity, project dynamics and the need for stakeholder involvement in projects. Accordingly, it was needed to be converted to a more flexible form to make it usable in the development of the hybrid approach. To achieve this, the procedure was improved through the integration of the Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010) along with the utilisation of Fit-for-Purpose Project Management (Van de Loo, 2015) and Perception-Based Management (Bosch-Rekveldt *et al.,* 2014). The Detail-Dynamic Project Management Model, Fit-for-Purpose Management Strategy and Perception-Based Management all acknowledge the influence and importance of project dynamics as well as the need for adaptability of the managerial actions to changes in project requirements. The integration of these approaches within a complexity incorporated risk management system was considered to have the potential to provide a substantially flexible environment in terms of project management as well as for the management of CPM schedules. The flexibility established on this new and final version of the procedure, which is named the *Integrated Flexible Complexity/Risk Management (IFCRM) Procedure* (Figure 5.4), has been empowered by adding iteration capability, which could be generated at least after the achievement of each predetermined milestone of the CPM schedule, and by providing the inclusion of the relevant stakeholders in order to create an interactive project management environment.

The applicability of the IFCRM Procedure has been illustrated on an example design project previously realised in Turkey in the public construction sector called the “Design of the Gönen Plain Irrigation Project”. This example application shows that the IFCRM Procedure is not only applicable on the construction phase but also on the pre-construction phases. The hypothesized managerial advantages provided by the implementation of IFCRM were compared to the actual story of the project. The project suffered from a long schedule delay at completion, illustrating that the schedule management is not a simple task as such. Thorough schedule management requires the fulfilment of much more things as revealed through the example application of the IFCRM Procedure on the “Design of the Gönen Plain Irrigation Project”. The interaction with the stakeholders, their involvement into the processes, adoption of Perception-Based Management and by this way, establishment of a shared-mental model through the perceived complexities (i.e. subjective character of complexity) evolve as key focus areas. While responding to risks, embracing the complexities in order to benefit from the opportunities that would be created instead of reducing complexities, is believed to be the strategy to be followed to constitute an appropriate fit-for-purpose management model as proposed in the IFCRM Procedure.

The researcher has been assigned as a supervisor within the thesis committees of two different master of science thesis projects realised under the Construction Management and Engineering (CME) Master Program of TU Delft. Under one of these studies entitled “Investigation of relationship and interactions between complexities and risks in complex construction projects for usage during the risk management process” conducted by Lise Andringa (Andringa, 2021), an approach has been developed to incorporate the complexity assessment into the risk identification and assessment process of project risk management in complex construction projects by means of cause-effect searching and risk influence diagramming techniques. This approach can also be used within the IFCRM Procedure during the assessment of the complexity-induced risks and complexities directly and indirectly affecting the CPM schedule. The correlated risk-factors can be identified as well through the developed approach so that this information could be utilised in the implementation of CSRAM. The cover and executive summary of this thesis, together with the other thesis supervised during the research period, are given in Appendix A. The reader is referred to Andringa (2021) for detailed information about the developed approach.

Chapter 6 has contained the final attempt undertaken to achieve the main goal of this research, i.e. *to propose a hybrid approach carrying both traditional and flexible features that can be used in the management of CPM schedules under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to*. The literature review conducted in Chapter 2 and the findings of the succeeding chapters constituted the required alignment towards the achievement of this goal. The main argument put forward since the beginning of the report was that the flexible management of schedules would not mean completely leaving the usage of methods and techniques of traditional project management but rather exploring their potential aspects that might contribute to the establishment of flexibility.

The IFCRM Procedure has been used as a component within the hybrid approach proposed in Chapter 6. In accordance with the general argument of this research, the proposed hybrid approach include several aspects compatible with the principles of flexible project management approaches such as agile and lean while promoting the usage of already existing flexibilities in the traditional implementations of CPM. This research has shown that literature suggests the development of new methods and tools within the context of flexible project management to cope with the increasing complexity and uncertainty in projects. The hybrid approach proposed at the end of Chapter 6 for flexible management of CPM schedules of construction projects under complexity and uncertainty can be considered as a step in that direction.

The hybrid approach developed in Chapter 6 for the flexible management of CPM schedules of construction projects under complexity and uncertainty has been called as the ‘Flexible CPM-Based Schedule Management Approach’ (FSMA-CPM). One of the major arguments put forward in this research was the inappropriateness of managing the schedules of complex construction projects in a traditional way based on detailed schedules established in advance. Complexities and uncertainties continuously impact the construction projects and therefore it is inevitable to put into implementation more flexible project management methodologies for achieving success. It is almost impossible in complex construction projects to determine the scope and the owner requirements (along with the requirements of various stakeholders) completely in advance and reflect this in a detailed plan and a schedule before the project execution. Therefore, more flexible approaches are required in this regard.

In this context, a flexible structure has been built in which the relevant stakeholders are involved and the schedules are developed iteratively in an incremental way under suitable working conditions and within an appropriate organisational structure having horizontal hierarchy as shown in Figures 6.2 - 6.6. The flexibility has been built upon 15 different flexibility agents based on the studies of Jalali-Sohi *et al.* (2016, 2019a, 2019b, 2019c) on flexible project management, the study of Vanhoucke (2012) on Dynamic Scheduling, the PMBOK Guide (Project Management Institute, 2017) and the managerial flexibilities of CPM explored in this research. Based on these flexibility agents, flexibility has been constituted through 5 different dimensions and with the incorporation of the IFCRM Procedure as a component as shown in Figure 6.7. Based on the combination of these 6 different components, the FSMA-CPM has been developed.

The 6 different components on which the FSMA-CPM has been constituted are illustrated in the form of a puzzle in Figure 6.7:

1. 'who' dimension of flexibility in terms of the teams and stakeholders either having direct responsibility or having a role in associated processes (refer to the Figures 6.2 and 6.3),
2. 'where' dimension of flexibility in terms of the physical conditions and the equipment provided for the activation of the responsible parties in harmony as required for the establishment of flexibility (refer to the Figure 6.3),

3. ‘when’ dimension of flexibility in terms of the meetings to be realised with the participation of the parties responsible directly in the implementation or involved indirectly in the associated processes (refer to the Figure 6.3),
4. ‘how’ dimension of flexibility in terms of the organisational structure through the constitution of an organisation in horizontal hierarchy composed of three different organisational levels containing the project manager, self-organised highly-skilled teams and various stakeholders involved in the management of the schedule (refer to the Figures 6.2 and 6.3),
5. ‘how’ dimension of flexibility in terms of the schedule implementation through iterative scheduling in a balanced manner between pure flexible and traditional (refer to the Figure 6.4), one proposed for the preconstruction phases (refer to Figure 6.5) and the other proposed for the construction phase (refer to the Figure 6.6),
6. the IFCRM Procedure, as a component that deals with the project complexity and uncertainty in a flexible and integrated way within the framework of CPM scheduling (refer to the Figure 5.4).

If we remember the main aim of this research once more, i.e. ‘to propose a hybrid approach carrying both traditional and flexible features that can be used in the management of schedules prepared by the CPM under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to’, which component meets which side of this aim becomes more clear. The first five components sorted above can be considered as a response to the dynamic project conditions. The last component, i.e. the IFCRM Procedure, represents the response to the project complexity and uncertainty (refer to the Figure 6.7). The reason of not adapting pure flexibility based on agile (scrum) and applying a hybrid approach instead is mainly due to the conditions of complex construction projects when compared to the conditions of software development projects for which agile project management is widely accepted as an efficient methodology. Two different balanced approaches carrying both flexible and traditional features have been proposed for the preconstruction and construction phases (Figures 6.5 and 6.6), respectively. In Chapter 6, also an example application of the FSMA-CPM has been presented to show its applicability using the same project as described in Chapter 5.

7.2 LIMITATIONS OF THE RESEARCH

One of the limitations of the research is its focus on CPM. Since the CPM is one of the major activity network planning techniques of construction projects and probably the most widely used, it has been the focus of this research. However, other scheduling methods used in construction projects such as the Linear Scheduling Method (Harmelink & Rowings, 1998), Repetitive Scheduling Method (Harris & Ioannou, 1998), Line of Balance Method (Lumsden, 1968), and the Critical Chain Method (Goldratt, 1997) are required to be evaluated in a similar way based on the methodology followed in this study. Depending on the project characteristics such as requirements, type and complexity level, more than one of these methods frequently are needed to be used simultaneously together with the CPM especially in different parts of the projects as in the case of highway and railway projects which are categorised as linear (repetitive) type of infrastructure projects. For this reason, the investigation of flexibility in case of combined or integrated usage of these methods arises as another research problem. It should be mentioned that the IFCRM Procedure and the FSMA-CPM proposed in this research are open to development in terms of the aforementioned scheduling methods. The modular structure of the IFCRM Procedure and the FSMA-CPM would enable the incorporation of these methods. Meanwhile, this can be considered as another flexible feature of these approaches.

Another limitation of the research is associated with the inherent flexibilities of the CPM at the project-level which was evaluated in Chapter 3. The flexibility at project-level has been evaluated only partially, in terms of the CPM's resource levelling capability. The completely utilisation of the managerial flexibilities of the CPM at all the levels, i.e. activity, path and the project-level, is promoted within the FSMA-CPM through the flexibility agents used during its development (refer to Chapter 6).

In Chapter 4, the managerial flexibilities of CPM are evaluated under uncertainty through the usage of the CSRAM (Ökmen & Öztaş, 2008), which is a CPM-based schedule risk analysis model capable of simulating the risk exposure on the network schedules through Monte Carlo Simulation (MCS) iteratively by taking into account the correlations between the activities and between the schedule risks. Furthermore, the CSRAM, which was previously developed by the Researcher in his doctoral thesis (Ökmen, 2008) and published in Ökmen & Öztaş (2008), has been given place at the quantitative risk analysis stage of the IFCRM Procedure (refer to Figure 5.4). As stated in Ökmen & Öztaş (2008), CSRAM has some limitations as well such as the need for its full computerisation in a more user-friendly form and the high subjectivity in determining the input data such as the envisaged correlations between the risk-factors. These limitations also evolve as the limitations of the IFCRM Procedure as well as the FSMA-CPM to some extent. The limitations of the CSRAM are open to new investigations for their elimination. The research of Zhong *et al.* (2015) and the research of Ökmen (2013b) can be given as the examples to the studies conducted for the purpose of improving the CSRAM and eliminating its limitations. It should be mentioned that other schedule risk analysis models also exist in the literature such as Ökmen & Öztaş (2014) and Wang & Demsetz (2000) which could be alternatively used instead of the CSRAM or in conjunction with it during the implementation of the IFCRM Procedure. As abovementioned, both the IFCRM Procedure and the FSMA-CPM are sufficiently flexible also from the point that it would be possible to utilise different methods in practice instead of the TOE Framework and CSRAM.

Another limitation of the research is related with the need for the full validation of the IFCRM Procedure and the FSMA-CPM. Example applications have been conducted on real or hypothetical data in each chapter for the purpose of evaluating the managerial flexibilities of the CPM (refer to the Chapters 3 and 4) or showing the applicability of the IFCRM Procedure and the FSMA-CPM (refer to the Chapters 5 and 6). However, these approaches still require real-time validation in full scale through their implementation on ongoing complex construction projects. The insufficiency of the length of the research period, which is 12 months in total, as well as the difficulties occurred due to the large-scale measures taken against the COVID-19 Pandemic

(Coronavirus Disease Pandemic) all over the world as well as in the Netherlands almost during the whole research period, i.e. between 17.02.2020 and 15.02.2021, made it impossible to carry out such application of the proposed approaches on a case or pilot project under execution.

8 CONCLUSIONS & RECOMMENDATIONS FOR FUTURE RESEARCH

This postdoctoral research has been carried out in the Engineering Project Management Research Group of the Integral Design & Management Section of the Faculty of Civil Engineering and Geosciences of Delft University of Technology (TU Delft), The Netherlands, between 17.02.2020 and 15.02.2021 through the support of Jean Monnet Scholarship. Jean Monnet Scholarship is the part of the Jean Monnet Program, funded by the European Union within the framework of the instrument for pre-accession assistance. The research also has been officially supported by the Ministry of Transport and Infrastructure of the Republic of Turkey. This research report has been prepared in order to present the subject, content and findings of the research as well as the academic activities carried out during the research period.

In the previous chapter, the results of the research were discussed and subsequently, the limitations of the research were pointed out. In this final chapter, firstly the conclusions are presented and then the recommendations for the future research are introduced.

8.1 CONCLUSIONS

The main objective in construction projects is to complete the projects at the scheduled time, in the prescribed budget and within the pre-determined scope along with meeting the expectations regarding the quality and safety and ensuring stakeholder satisfaction. This objective can only be achieved by completing numerous interrelated activities through using different resources such as labour, equipment and materials under various weather and land conditions in accordance with the work schedules prepared in advance. Project management, more specifically the Critical Path Method (CPM), needs to be applied in order to manage such a complex network of activities consisting of many interrelated activities. In line with this fact, the CPM was handled as the focus of this research. The research problem was established based on the argument that the traditional project management and related approaches are no more sufficient to achieve the abovementioned goals due to the increasing complexity, uncertainty and dynamic conditions in today's complex and large-scale construction projects. The relevant literature frequently points out the disappointing statistics with regard to the low success rates achieved in construction projects especially in terms of the time and budget goals (refer to Chapter 1). So, what is the solution of this problem from the perspective of the CPM-based schedule management? In this research, the answer of this problem has been investigated.

The usage of modern project management and the related approaches such as Agile Project Management, Lean Project Management, Detail-Dynamic Project Management along with the complexity assessment models such as the TOE Framework has been considered as being a possible solution to the abovementioned research problem. While the traditional project management is mainly characterised by its rigid plan-driven viewpoint on project management, the major distinctive feature of the modern project management is its dominantly flexible and change-driven side. In this regard, in this study, the flexibility has been accepted as the key term that represents the current paradigm change in project management, i.e. from 'traditional' towards 'modern'. In order to enlighten the route of the research, firstly, the definition of flexibility from the perspective of project management was introduced: *the adaptability of the managerial actions performed in a project to the changes in project requirements stemming from the complex, uncertain and dynamic conditions*. Secondly, based on the relevant literature, the modern project management has been categorised as 'flexible project management' and the principles of the modern project management approaches such as 'Agile' and 'Lean' were considered as the flexibility agents that are needed in order to be able to propose a solution to the research problem. However, instead of aiming to establish a pure flexible approach, for instance, based on Agile, the development of a hybrid approach carrying both traditional and flexible features has been targeted. The reason for trying to develop a hybrid approach instead of a full flexible or a pure agile approach is due to the distinctive features specific to the construction projects with respect to the projects realised in the other sectors such as the software development projects for which the success story of the pure agile approaches has been widely pointed out by the researchers and practitioners. But how would such a hybrid approach in terms of schedule management be established if the focus of the problem is the traditional method of scheduling, i.e. the CPM?

Succeeding the conduction of an extensive literature review and the introduction of the theoretical background, firstly, the inherent managerial flexibilities in CPM were investigated in order to find out an answer to this research question. Then, the project schedule management processes of the PMBOK Guide were examined from the flexibility perspective. Afterwards, the discussion was expanded to the exploration of the managerial flexibilities in case CPM is implemented in the form of a simulation-based risk analysis model called CSRAM (Ökmen & Öztaş, 2008) to observe its capabilities under uncertainty. Furthermore, the project risk management processes of the PMBOK Guide were examined from the flexibility point and in terms of CPM scheduling. The results of both the theoretical evaluations and practical applications carried out have shown that the traditional side of the problem, as expected, has the potential for establishing flexibility in the management of CPM schedules up to a certain extent, however which needs to be improved. In this regard, another key point of the research problem, the 'complexity' was handled within the framework of project risk management. Eventually, based on the TOE Framework (Bosch-Rekveldt *et al.*, 2011), the processes of the PMBOK Guide (Project Management Institute, 2017), Detail-Dynamic Project Management Model (Hertogh & Westerveld, 2010), CSRAM (Ökmen & Öztaş, 2008), Fit-for-Purpose Project Management (Van de Loo, 2015) and Perception-Based Management (Bosch-Rekveldt *et al.*, 2014), the IFCRM Procedure has been proposed by incorporating the complexity assessment into the project risk management within the framework of CPM scheduling.

After the development of the IFCRM Procedure, the Flexible CPM-Based Schedule Management Approach (FSMA-CPM), which is the name given to the hybrid approach proposed at the end of this research, has been introduced. The IFCRM Procedure has been used as a component within the FSMA-CPM. This can be observed in Figures 6.5 and 6.6 as well as within the illustration introduced in Figure 6.7 together with the other 5 components that constitute the FSMA-CPM. Since the FSMA-CPM has been proposed for the flexible management of CPM schedules of construction projects under complexity and uncertainty, the IFCRM Procedure, as being a component of the FSMA-CPM, deals with the project complexity and uncertainty in a flexible and integrated way within the framework of CPM scheduling (refer to the Figure 5.4).

FSMA-CPM includes several aspects compatible with the principles of flexible project management approaches such as Agile and Lean while promoting the usage of the existing flexibilities of CPM, which were explored up to an extent in this research. This has been the reason of calling this new approach as ‘hybrid’ due to the traditional and flexible features that it carries. This research has shown that the literature points out the requirement for the development of new methods and tools within the context of flexible project management to cope with the increasing complexity and uncertainty in projects. FSMA-CPM, which is proposed for the flexible management of CPM schedules of construction projects under complexity and uncertainty, can be considered as a step that was taken in this context.

The main aim of this research was to propose a hybrid approach having both traditional and flexible features that can be used in managing the CPM schedules under the complex, uncertain and dynamic conditions that today's complex construction projects are exposed to. In this context, FSMA-CPM has been developed based on an extensive literature study. Given the findings, the proposed approach is considered an important step towards the development of a more flexible project management methodology that can be used in managing the schedules of complex construction projects.

8.2 RECOMMENDATIONS FOR FUTURE RESEARCH

In this section, recommendations for future research are introduced along with briefly addressing the limitations of the research, which were pointed out in the previous chapter.

This research has focused on CPM, which can be considered as a limitation. Some other scheduling methods are also used in construction projects such as the Linear Scheduling Method (Harmelink & Rowings, 1998), Repetitive Scheduling Method (Harris &

Ioannou, 1998), Line of Balance Method (Lumsden, 1968), and the Critical Chain Method (Goldratt, 1997). Therefore, these methods are also required to be evaluated in a similar way based on the methodology followed in this study. Depending on the project characteristics such as requirements, type and complexity level, generally more than one of these methods are required to be used simultaneously in conjunction with CPM especially in different parts of the projects as in the case of highway and railway projects, which are categorised as linear (repetitive) type of infrastructure projects. For this reason, the investigation of flexibility in case of combined or integrated usage of these methods arises as another research problem. Fortunately, the IFCRM Procedure and the FSMA-CPM proposed in this research are open to development also in terms of the aforementioned scheduling methods. The modular structure of the IFCRM Procedure and the FSMA-CPM would enable the incorporation of these methods through appropriate amendments. Meanwhile, this can be considered as another flexible feature of these approaches and accordingly, it creates an advantage for another future research that is recommended to be performed to improve the IFCRM Procedure and the FSMA-CPM based on the abovementioned scheduling methods that are widely used in construction projects.

Another limitation of the research is associated with the inherent flexibilities of the CPM at the project-level which was evaluated in Chapter 3. The flexibility at project-level has been evaluated only partially in terms of the CPM's resource levelling capability. However, the completely utilisation of the managerial flexibilities of the CPM at all the levels, i.e. activity, path and the project-level, is promoted within the FSMA-CPM through the flexibility agents used during its development (refer to Chapter 6). Accordingly, a research can be recommended to be performed to handle all of the project-level flexibilities inherent with the CPM. Such a study would also support the proper implementation of the FSMA-CPM in practice.

The managerial flexibilities of CPM were evaluated under uncertainty through the usage of the Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen & Öztaş, 2008), which was previously developed by the Researcher in his doctoral thesis (Ökmen, 2008) and published in Ökmen & Öztaş (2008). Furthermore, CSRAM is to be utilised at the quantitative risk analysis stage of the IFCRM Procedure (refer to Figure 5.4). As mentioned in the previous chapter, CSRAM has a number of limitations and this situation creates limitation for also the current research. In order to eliminate these limitations, future research is recommended. Both the IFCRM Procedure and the FSMA-CPM are sufficiently flexible also from the point that it is possible to utilize alternative methods during their implementation instead of the TOE Framework and CSRAM for instance, after necessary modifications depending on the requirements of the project on which they are implemented. In this regard, a future research is recommended to investigate the appropriateness of using alternative methods within the IFCRM Procedure and the FSMA-CPM.

Another limitation of the research is related to the need for the full validation of the IFCRM Procedure and the FSMA-CPM. Example applications have been conducted on real or hypothetical data in each chapter for the purpose of evaluating the managerial flexibilities of the CPM (refer to the Chapters 3 and 4) or showing the applicability of the IFCRM Procedure and the FSMA-CPM (refer to the Chapters 5 and 6). However, these approaches still require real-time validation in full scale through their implementation on ongoing complex construction projects. The insufficiency of the length of the research period, which is 12 months in total, as well as the difficulties occurred due to the large-scale measures taken against the COVID-19 Pandemic (Coronavirus Disease Pandemic) all over the world as well as in the Netherlands almost during the whole research period, i.e. between 17.02.2020 and 15.02.2021, made it impossible to carry out such application of the proposed approaches on a case or pilot project under execution. However, the example applications carried out throughout the study not only have provided a partial validation but also have opened the opportunity of the proposed approaches’ full validation on a case or pilot project under execution. In this regard, the real-time implementation of the FSMA-CPM on different projects under execution is recommended as a future research for its full validation.

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APPENDIX A – COVER PAGES AND EXECUTIVE SUMMARIES OF THE M. SC. THESES SUPERVISED BY THE RESEARCHER WITHIN THE CME MASTER PROGRAMME OF TU DELFT

Processing complexities in conjunction with risks to support the project risk management

L. Andringa

Investigation of relationships between complexities and risks in complex construction projects for usage during the project risk management process

by

L. Andringa

In partial fulfilment of the requirements for the degree

of Master of Science in Construction, Management and Engineering

at the Delft University of Technology

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Company supervisor:	Ir. N. Waterman (Drees & Sommer Netherlands)

an electronic version of this thesis is available at http://repository.tudelft.nl/

Executive summary

Currently, there are many examples of failures as a result of the growing size and complexity of construction projects. The complexity of projects is related to the increasing number of interfaces and dynamic character over time. The causes are the uncertainties and unpredictabilities that play a role and evolve in projects. Grey (2014) states the rise of complex projects represents an opportunity as well as a need for fresh thinking within risk management. Although there were many benefits to the use of the traditional risk management procedure, it appeared to be based on the impractical assumption of complexities being independent from risks. As a result, managers are unable to accumulate the knowledge necessary for understanding of the probability and impact of the risk-factors and their sources. However, this is inadequate for complex construction projects, since in order to investigate the total effect of uncertainty, the perceived complexity need to be assessed. Therefore, the research question of this study is as follows:

In what way can practitioners process the complexities in construction projects more consistently during the implementation of risk management?

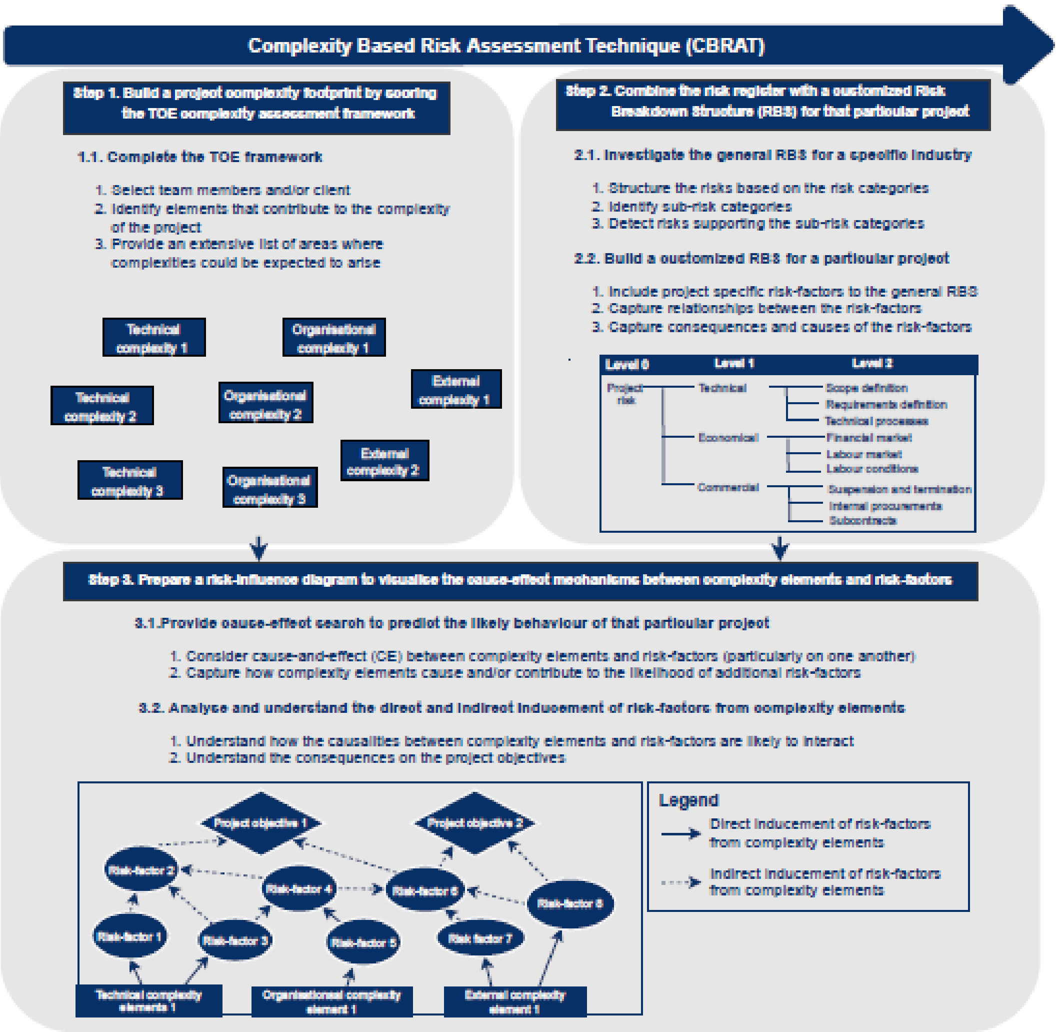
The goal of this research is to provide insights into the different types of relationships between complexity elements and risk-factors to be used in risk analysis and management of complex construction projects. On the basis of the reviewed literature, two essential insights into the interdependency between complexity elements and risk-factors were observed. Firstly, complexity elements are considered to create an unexpected event or risk-factor (direct inducement of risk-factors from complexity elements). Secondly, unexpected events are believed to influence the project objectives (indirect inducement of risk-factors from complexity elements). Based on this, it is concluded that complexities may trigger a causal effect for risks, while the risks affect the project objectives. Overall, the interdependency between project complexity and risks is observed as: *Complexity-induced events seem to be a major source of risks whose effect for the project are uncertain.* However, it is noticed that only establishing the relationship between complexities and risks is not enough to guarantee a successful project. The traditional risk management process need to succeed a complexity assessment process in case of a complex construction project, differently from ordinary projects.

In this research, a theoretical framework and empirical research are conducted to answer the research question. In preparation of the exploratory survey, a literature study is performed to review the available knowledge on project complexity, the influence of project complexity on project risk management and the interdependency between project complexity and risks. Subsequently, an exploratory survey is organised with twenty project managers and twenty risk managers from the company Drees & Sommer. The survey aims to investigate how the causal relationship between complexity elements and risk-factors is perceived and managed in complex construction projects. The survey consists of two parts, both focusing on whether the different viewpoints and attitudes of the experts have overlap with the theoretical findings. First, the previously developed Technical-Organisational-External (TOE) framework by Bosch-Rekveldt et al. (2011) is used to explore the causal effect between complexity elements and risk-factors. In doing so, the participants are asked to score the complexity elements that caused or contributed to additional risks based on their last completed complex project. After that, a questionnaire is used to evaluate the limitations of the current risk management process of Drees & Sommer.

Despite the divergences in literature, most practitioners see the causal relationship between complexity elements and risk-factors as an important contribution to the risk management process. However, they also recognize challenges such that practitioners prefer to manage risks in a rather personalised and inefficient way. Therefore, the risk management procedure is to be improved by an increased orientation towards the results, by requiring less time, better alignment and encouragement of original thinking and interactions within the team. Besides this, other practitioners link the expansion of the risk management process to including logical steps, suppress unnecessary details and to pay more attention to the elements that contribute to the complexity of a specific project and the integration of experiences from previous projects.

On the basis of the literature study and exploratory survey, it can be concluded that there is need for a better understanding of the causal relationship between complexity elements and risks. Project managers need to accept the complexities of a project and try to appreciate the dynamic behaviour, rather then reducing the complexities and risks. As a consequence, the idea of processing complexity more consistently during the implementation of project risk management is conceived. In addition, the *Complexity Based Risk Assessment Technique (CBRAT)* is designed to provide the first steps in capturing the cause-effect mechanisms between complexity elements and risk-factors.

The CBRAT strengthens the risk assessment capability by introducing the following three tools; the *TOE framework*, the *Risk Breakdown Structure (RBS)* and the *risk-influence diagram*. As described in the practical implications of the CBRAT in Figure 1, the TOE framework provides an extensive list of categories where complexities could be expected to arise. The aim is to enable scaling and putting more or less emphasis on certain complexity elements. In doing so, a project managers is able to come up with a risk management approach that is the most suitable for a project, given the unique circumstances of that project (incl. the industry requirements). After the complexity assessment, the traditional risk register is combined with a RBS. This enables to structure and decompose the risk-factors into sub-categories. Besides this, the RBS aims to record generic risk-factors which occur frequently as lessons learned for future reference. Finally, the CBRAT prefers to benefit from the risk-influence diagram in order to trace the direct and indirect inducement of risk-factors from complexity elements. The visualisation of the causal effect enables to understand how the causalities are likely to interact and their consequences on the project objectives.



Next, the applicability of the CBRAT was tested on the FA Terminal 3 project. Based on the results of the pilot study, the conclusion is drawn that the CBRAT would have supported the risk management procedure of Drees & Sommer. The reason for this is that the risk-factors, could have been linked to the complexity elements that are known at the early phase of the project. The reason for this is that there seem to be a cause-effect mechanisms between complexities and risk-factors in complex construction projects so during risk management these two concepts should be handled together. As a consequence, the CBRAT strengthens the risk assessment capability by identiying the causal relationships between complexities and risks. It is expected that once the causal relationship is understood, the impact and probability of the risks can be better analysed. Therefore, the CBRAT can be called a risk assessment technique.

In general, it can be concluded that it is of importance to define the complexity of a project early and clearly for successful risk management. The aim is to enable scaling and putting more or less emphasis on certain complexity elements. In doing so, a project manager is able to come up with a risk management approach that is the most suitable for a project, given the specific and unique circumstances of that project. Otherwise, risk analysis and management would not include especially complexity-induced risks, which in turn lead us to incomplete and misleading conclusions regarding the risk mitigation actions. Additionally, it is expected that once the relationships between complexities and risks are better understood, the impact and probability of the risk-factors and their sources can be better analysed.

With those insights, the practitioners can develop a strategy to process the complexities in construction projects more consistendly during the implementation of risk management. For this, the CBRAT can be used as a tool within the traditional risk management process, as shown in Figure 2. Depending on the characteristics unique to a particular project, the project manager can come up with a risk management approach by focusing attention on those risk-factors and causalities that have the highest potential to create negative consequences on the project objectives. Nonetheless, in the end, being aware of the relationships between complexities and risks in a particular project would be one of the most important success factors of managing risks.

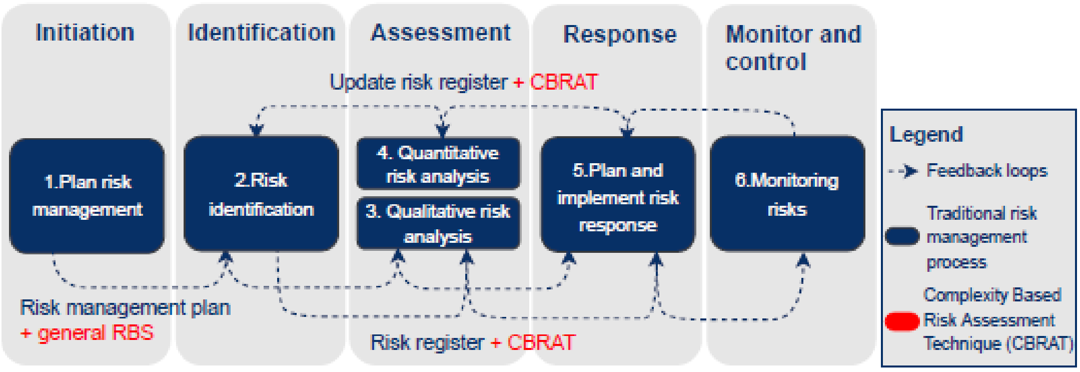


Figure 2: The CBRAT (visualised
in red) is positioned within the traditional risk management process (visualised in blue) and the dashed lines indicate the feedback loops.

However, one has to question whether it is realistic that practitioners are willing to change their risk management approach, since it is already difficult enough. Because of this, the CBRAT is designed in such a way that it does not provide time-consuming input information or unnecessary details. Therefore, the CBRAT is easily to incorporate during the implementations of risk management and fits well in the busy work schedules of average users of the concept.

Altogether, the contribution of this study consists of four main parts: it explored an important research theme that has potential to support the implementation of risk management, it conduced an empirical study to provide insight on how the causal relationship between complexity elements and risk-factors is perceived and managed within the construction industry; it proposed the CBRAT to capture the cause-effect mechanisms between complexity elements and risk-factors and finally, through a pilot study the CBRAT is shown to work well on a real life construction project.

Keywords: Project complexity, project risk management, complexity-induced risks, causal relationship, cause-effect mechanisms, Complexity Based Risk Assessment Technique (CBRAT), Technical-Organisational-External (TOE) framework, Risk Breakdown Structure (RBS), risk-influence diagram

USING CRITICAL SUCCESS FACTORS AND Q METHODOLOGY TO DISCOVER PERSPECTIVES ON PROJECT RISK MANAGEMENT WITHIN A CONSTRUCTION ORGANISATION

by

THEODORA STRATTON

in partial fulfillment of the requirements for the degree of

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in Construction Management and Engineering

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EXECUTIVE SUMMARY

Risk management is a vital process in the construction of large projects. It is necessary to protect the success of the project, the budget, the project timeline and the reputation of an organisation. Many tools exist to identify, measure and track risks. Risk management processes take place at all phases of a project and require input from employees at all levels of an organisation. Alongside the tools and techniques which exist to support risk management, it is also a process which depends on people's attitudes and decisions, their use of the available tools and how they follow procedures. Risk management is a "philosophy", beyond the quantitative tools and guidelines which exist. Attitude to risk is linked to personal traits such as personality, professional experience, age and gender.

This study sought to identify the perspectives which exist amongst a group of managers from a main contractor organisation with respect to what is important to risk management. Understanding the perspectives on what is important to risk management may help the organisation improve their risk management process as a whole. This research project was conducted at a main contractor organisation based in the Netherlands. Data was collected from managers who had all worked or were currently working on the same project, referred to as 'Project A'.

This project used Q methodology to discover perspectives on what is important to risk management. Q methodology allows the subjective opinions of individuals to be studied and groups of common perspectives to be described. Respondents are asked to do an activity in which they sort and rank a set of statements to illustrate their opinion on a particular topic. One of the first steps of a Q study is to create the Q set, the statements which respondents will rank. It was decided that the Q set would be a list of critical success factors of risk management. Critical success factors are activities which support the overall task of risk management, a literature study was conducted to identify these factors. A variety of factors were found, covering areas such as the organisational strategy, top management, culture, the role of employees, technical tools and resources available and involvement of external parties. A total of 78 items found in literature were narrowed down to a shortlist of 27 using three requirements set by the researcher. Next, these 27 were presented to the risk manager, who advised that five items be removed and three new items added given the characteristics of Project A, resulting in the 25 statements in the Q set.

A total of 15 managers performed the Q sorting question, five from each of three functional teams within the project, the design team, the execution team and the supporting team. The respondents were asked to rank the Q set along a scale, from least important to most important, when considering the sorting instruction, which was: *"In order to perform project risk management it is important to have/do..."*. After the Q sort had been completed, the respondents were interviewed and were asked to motivate the decisions they made when ranking the statements and explain why they considered items to be most or least important.

PQMethod (version 2.35) was used to analyse the quantitative data from the Q sorting activities. Factor analysis and factor rotation are used to develop clusters of respondents who have similar Q sort response charts. A total of three factors, or perspectives, were taken to the next stage of the study, these contained six, five and three of the respondents respectively and one respondent did not belong to any of the perspectives. The cumulative explained variance was 54%.

The interview transcripts were used with the software output to describe and compare the three perspectives. Plots of the Z scores are presented, showing the five most and least important statements for each perspective. Quotes from the interviews were used to enrich the discussion of the results. The three perspectives were named and are summarised below:

> Experience and Belief (Perspective 1) - This perspective values the personal expertise of the individual and that each person believes in the benefits of the risk management process. Other soft skills, such as risk culture and clear and honest communication, are also important to this perspective, along with a clear long-term strategy for the risk management.
>
> Procedures and Leaders (Perspective 2) - This perspective judges the consistent application of procedures, it's integration with other project management activities and the leadership actions of both the risk manager and top management to be the most important features of risk management.
>
> Culture and Communication (Perspective 3) - This perspective sees the risk culture as the cornerstone of risk management. They consider that a healthy risk culture, supported by clear and honest communication, can enable other processes of risk management to be enacted smoothly.

On average, the statements *Project organisation risk culture* and *Integration of risk management with other project management activities* achieved the two highest Z scores. The statements *Shared understanding and acceptance of the key concepts of risk management* and *Regular training to enhance risk management skills* received the lowest average Z scores. The relationship between the perspectives and the functional team to which a respondent belonged was explored, along with the perspectives and the number of years of experience a respondent had. Discussion was provided on two topics which came up frequently in the interviews but did not strictly fall under the scope of the Q sort, namely the complexity of risk management and the documentation of risks.

The results of the research were used to make recommendations to the organisation to improve their risk management. Future research could include repeating the study with a larger and more diverse group of respondents and investigating the links between perspectives and other personal characteristics such as personality type.

APPENDIX B – LIST OF THE ACADEMIC ACTIVITIES PARTICIPATED THROUGHOUT THE RESEARCH PERIOD

- Attendance to the Colloquium Meeting held on 06.03.2020.
- Attendance to the introductory meeting held with the Researcher's advisor Prof. Dr. Ir. Marcel Hertogh on 19.03.2020.
- Attendance to the Colloquium Meeting held on 03.04.2020 and presentation of the research topic.
- Engagement as an assistant to the course "DelftX: MEP201x Project Management: Mastering Complexity" between the dates 12.03.2020 and 16.04.2020.
- Attendance to the Kick-Off Meeting of the master student Theodora Stratton held on 21.04.2020.
- Attendance to the Colloquium Meeting held on 08.05.2020.
- Attendance to the Informing Meeting of the Human Resources Department of TU Delft held on 08.05.2020.
- Attendance to the Literature Review Meeting held on 19.05.2020 and presentation of a journal article.
- Attendance to the Colloquium Meeting held on 05.06.2020.
- Attendance to first the Mid-Term Meeting of the master student Theodora Stratton held on 09.06.2020.
- Attendance to the Kick-Off Meeting of the master student Lise Andringa held on 16.06.2020.
- Scoring the final assignments of the course "Project Management: Mastering Complexity TU Delft Course Number: MEP201Course Run:2020_Q4" between the dates 04.06.2020 and 25.06.2020.
- Attendance to the Literature Review Meeting held on 18.06.2020.

- Attendance to several meetings with Leon Hombergen, who is working as an instructor at TU Delft and as a senior advisor at Rijkswaterstaat, and with his colleagues from Rijkswaterstaat between 01.05.2020 and 30.06.2020 for the preparation of the paper submitted to the the 6th International Project and Construction Management Conference (IPCMC2020).
- Attendance to the Colloquium Meeting held on 03.07.2020.
- Attendance to the Section Meeting held on 10.07.2020.
- Attendance to the Bilateral Consultation Meeting with Prof. Dr. Hans Bakker on 10.07.2020.
- Attendance to the Doctoral Thesis Defence of the student Martine van den Boomen on 15.07.2020.
- Attendance to a meeting with the post-doctoral researcher Dr. Omar Kammouh on 27.07.2020 for the exploration of collaborative points in researches of each other.
- Attendance to the meeting held on 01.09.2020 regarding the preparation for the "DelftX: MEP101x Project Management of Engineering Projects: Preparing for Success" course.
- Attendance to the Mid-Term Meeting of the master student Lise Andringa held on 03.09.2020.
- Attendance to the 8th International Project Management Association (IPMA) Research Conference between 09 - 11.09.2020 held online due to the measures taken against the COVID-19 Pandemic and on 11.09.2020, online presentation of the conference paper entitled "Evaluation of Managerial Flexibilities in Critical Path Method Based Construction Schedules" and authored by Önder Ökmen, Marian Bosch-Rekveldt, and Hans Bakker. Link of the Conference: http://www.ipma-research-conference.world/programme/
- Attendance to the Section Meeting held on 11.09.2020.

- Attendance to the 6th International Project and Construction Management Conference (e-IPCMC2020) between 12 - 14.11.2020 held online due to the measures taken against the COVID-19 Pandemic and presentation of the conference paper entitled “Evaluation and Comparison of the Public Construction Legislations of Turkey and the Netherlands in the Context of Project Planning and Control” and authored by Önder Ökmen, Marian Bosch-Rekveldt, and Leon Hombergen. Links of the Conference: http://ipcmc2020.itu.edu.tr/
  https://www.youtube.com/channel/UCQINTgoHF4GA8ioik4VleYQ/videos

- Engagement as an assistant to the course “DelftX: MEP101x Project Management of Engineering Projects: Preparing for Success” between the dates 10.09.2020 and 12.11.2020.

- Attendance to sufficiently high number of meetings with Dr. Ir. Marian Bosch-Rekveldt throughout the research period held for monitoring the progress in my research, preparing the conference papers and exchanging information about the online courses.

- Attendance to the meeting held on 21.09.2021 for the evaluation of colloquium and literature review meetings realised up to that date.

- Attendance to the Bilateral Consultation Meeting with Prof. Dr. Hans Bakker on 09.10.2020.

- Attendance to the Colloquium Meeting held on 16.10.2020.

- Attendance to the second Mid-Term Meeting of the master student Theodora Stratton held on 27.10.2020.

- Attendance to the Doctoral Thesis Defence of the student Erfan Hoseini on 06.11.2020.

- Attendance to the Section Meeting held on 19.11.2020.

- Attendance to the Colloquium Meeting held on 20.11.2020.

- Attendance to the Greenlight Meeting of the master student Theodora Stratton held on 26.11.2020.
- Attendance to the Greenlight Meeting of the master student Lise Andringa held on 03.12.2020.
- Attendance to the Thesis Defence Meeting of the master student Theodora Stratton held on 17.12.2020.
- Attendance to the Colloquium Meeting held on 18.12.2020 and presentation of the research results.
- Attendance to the Thesis Defence Meeting of the master student Lise Andringa held on 11.01.2021.
- Attendance to the Colloquium Meeting held on 15.01.2021.
- Attendance to the Section Meeting held on 15.01.2020.
- Attendance to the Bilateral Consultation Meeting with Prof. Dr. Hans Bakker on 26.01.2021.

APPENDIX C – LITERATURE REVIEW ON THE AGENTS OF FLEXIBILITY IN PROJECT MANAGEMENT BASED ON THE STUDIES OF Jalali-Sohi *et al.* (2016, 2019a, 2019b, 2019c)

In Jalali-Sohi *et al.* (2016), the combined and implicit implementation of agile and lean approaches in project management is considered to be complementary to each other and hypothesized to be effective in mitigating with the project complexity. "*The validity of this hypothesis was investigated based on a correlation analysis on data gathered from a structured questionnaire. The research has shown that several lean and agile elements were shown to significantly correlate to either reducing complexity or managing complexity thanks to the flexibilities provided by these elements (agents)*" (Jalali-Sohi *et al.*, 2016). The lean and agile elements taken into consideration in the study of Jalali-Sohi *et al.* (2016) are categorised under five different headings as listed below (Jalali-Sohi *et al.*, 2016):

- "*Structure & Integration Elements*
    - *Working together as one team instead of dividing the project in several parts and merging them at the end for the sake of better availability of the resources to each other, better communication, higher level of communication, higher efficiency, etc.*
    - *Higher level of experience of the project manager.*
    - *Taking the constructability or the structure of the project into consideration to make the project goals clearer.*
    - *A more experienced project management.*
    - *All relevant alternatives are considered and worked out, the decision making process related to the alternatives is delayed as much as possible.*
    - *Using more standardisation based on the previously performed projects.*
    - *Cutting the project into smaller batches, or mini projects, with intermediate deliveries and feedback moment for the sake of a better understanding of the goals of the project.*
- *Coordination Elements*
    - *Daily meetings and information circulation.*

- *Tracking of performance on a daily basis.*
- *Monthly/weekly detail planning.*
- *Much information, like problems and corresponding action plan and the project's performance, is visualised and insightful to the team members at any given moment.*

- *Planning Elements*
    - *Proper planning through the involvement of the team members into the planning process depending on the increase of experience level in project management.*
    - *Selection of the tasks that will be performed by the team members by themselves.*
    - *One week/month planning on a weekly/monthly basis in which only the tasks with high priority (according to the customer) and for which all prerequisites met are included.*
- *Communication Elements*
    - *High level of efficient communication.*
    - *An increased level of awareness amongst the team members of "who is doing what".*
    - *Problems, even the smaller ones, are reported when they occur and made insightful to all team members"* (Jalali-Sohi *et al.*, 2016).

In Jalali-Sohi *et al.* (2019c), "*the answer to the question whether flexibility in project management in early project phases contribute positively to end-project performance*" (Jalali-Sohi *et al.*, 2019c) has been investigated. *"The research aimed at evaluating the relationships between project management flexibility in early project phases and end-project performance, the effect of project complexity on project performance and the mediating role of flexible project management. A statistical analysis was performed on the data gathered from 111 surveys. Seven hypotheses were tested; six hypotheses regarding the relationship of the flexibility areas (what, how-attitude, how-organization, who, when and where) on project performance and one hypothesis regarding the effect of project complexity on project performance. From all formulated hypotheses, two were supported. The flexibility of 'how-attitude' and 'how-*

organization' were shown to have a significant positive effect on project performance: the higher the flexibility of 'how-attitude' and 'how-organization', the better the project performance. Project complexity as a control variable also was shown to have a significant effect on project performance but in opposite direction: the less complex the project, the better the project performance" (Jalali-Sohi *et al.*, 2019c). The flexibility enablers (agents) identified and utilised in Jalali-Sohi *et al.* (2019c) are based on an extensive literature survey conducted on flexible project management (agile and lean) in Jalali-Sohi (2018). The flexibility enablers have been grouped under five different categories in Jalali-Sohi *et al.* (2019c); *"what, how, who, when, where as suggested by Osipova & Eriksson (2013)"* (Jalali-Sohi *et al.*, 2019b, Jalali-Sohi *et al.*, 2019c):

- *"What (the ability to be flexible in terms of project goals and scope)*
    - *Broad task definition: Scope of the project should be defined into broad tasks rather than by highly-detailed work packages.*
    - *Embrace change as much as needed: Instead of being resistance toward change, it is needed to develop a relaxed approach toward change.*
    - *Functional-realization-based contract: Conditions of the contract system should be sufficiently functional and realization-based compatible with the requirements of flexibility in management.*
- *How (the ability to be flexible in terms of the implementation process)*
    - *Self-steering of the complete project team: Steering has a horizontal character in a network of client, team, contractors, stakeholders, etc.*
    - *Open information exchange among different groups: The exchange of information among the involved parties should be open in order to avoid any probable exchange among different groups issue because of lack of information.*
    - *Shared interface management: Managing the interfaces is a shared task for the actors involved, rather than a task mainly driven by the formal project manager.*
    - *Contingency planning: In addition to a set of defined base plans, a set of alternative plans is required. Contingency plans reflect anticipated potential departures from the defined plans for a project. Alternatives can be used if the defined plans cannot be executed.*

- *Seizing opportunities and coping with threats: The ability of the decision-making process to deal with unexpected influences without risking indefinite delays or stalemates in the process by identifying opportunities and threats.*
- *Trust among involved parties: Involve all stakeholders in decision making, share incomplete information, information visible to all stakeholders.*
- *Standardize the process and design: Using standardisation to an extent that fits with the project's context in order to achieve reflective learning. Having simple standard process/design/layout!.., in order to be used for similar cases.*
- *Visualized project planning and progress: For easy and better understanding of project planning and progress, it is important to have big-enough figures, charts, diagrams hanging on a wall or by using boards. This provides a common place for discussions over the project.*
- *Possible alternatives: Considering an alternative plan/solution for cases that something happened unexpectedly and the ongoing plan cannot be continued, helps to reduce the delays caused by unknown unknowns.*
- *Network structure rather than hierarchical structure: To avoid traditional (and destructive) hierarchy in project organisation for decision-making process, it is better to establish a network as a project organisation structure.*
- *Continuous learning: Capturing lessons learned and using them in future projects in respect to their context.*
- *Management support: Support of senior management is crucial for the proper application of flexible management.*
- *Interactive decision-making: Decision-making processes should be conducted interactively.*
- *Close involvement of stakeholders: The project management processes should be carried out with the close involvement of the relevant stakeholders.*

- *Who (the ability to be flexible in the project team)*

- *Consensus among team members: Consensus among team members facilitates the decision-making processes.*
    - *Stable teams: The teams are stable and tasks will be assigned to existing teams and their team members rather than every time building new teams and members to be assigned to tasks.*
    - *Self-assigned individuals to tasks: Individuals decide what tasks they will do. In traditional management, tasks are assigned by management.*
    - *Team priority over individual priority: Team priority rather than individual priority.*
    - *Team members as stakeholders: Valuing team members in the team.*
    - *Delegation of responsibilities to team level: The responsibilities should be delegated to the self-organised teams composed of highly-skilled members.*
- *When (the ability to be flexible in terms of scheduling)*
    - *Late locking: An exploring iterative front-end process in which decisions are made at the latest possible moment.*
    - *Short feedback loops: Having short-term (e.g. daily) meetings, it can be possible to react to tasks that were done by others on short intervals rather than when the task going to be delivered.*
    - *Continuous locking (iterative): Decisions are made and locked iteratively during the process in the front-end phase. It can be done for example by using a stage gate model.*
    - *Iterative planning: Instead of planning all the tasks at the beginning, only those tasks that should be performed in the iteration will be defined at the beginning of the iteration.*
    - *Iterative delivery: Project split up into smaller subprojects or products. Each subproject will be delivered to the client when it is done, while considering the whole.*
- *Where (the ability to be flexible in terms of location of the project team)*
    - *Joint project office: The possibility for the project team to work together in one place (project team including client, consultant, contractor, or multi-contractors, multi-consultants, etc.)*

- *Have flexible desks: The possibility for individuals of the project team to select a place to work in order to sit together with others who work on the same assignment (task) from one project" (Jalali-Sohi et al., 2019c)*

In Jalali-Sohi *et al.* (2019a), the answers of the questions *"how project management could become flexible", "whether such flexibility would improve project performance", and "how to embed flexibility in the practice of project management in early project phases"* (Jalali-Sohi *et al.*, 2019a) have been investigated. Finally, a "*flexibility framework"* (Jalali-Sohi *et al.*, 2019a) was proposed. *"This framework comprises four subsequent and recycling stages: understanding the current situation, capturing the practitioners' perspectives on flexible project management, choosing enablers to become flexible, and applying selected enablers to improve project performance"* (Jalali-Sohi *et al.*, 2019a). One of the primary findings of this research was that "trust" appears not only to be an enabler of flexibility in project management but an existing perspective among the practitioners regarding the concept of flexibility. This perspective strongly emphasizes the "trust" as the most important enabler of flexibility. Moreover, the positive contribution of "trust" to project performance has been acknowledged in Jalali-Sohi *et al.* (2019a) and some suggestions to practitioners have been brought in terms of managerial implications as follows (Jalali-Sohi, 2019a):

- "*A balance is suggested to be established between the flexible (agile, lean, etc.) and traditional management approaches based on the specific project context. The practitioners can choose the right management approach only by understanding how complex the project is. This management approach can be a hybrid version of traditional and flexible project management approaches, for instance, by installing the agile (scrum) over the traditional approach through planning the project into iterations (short or long), organising co-located teams, focusing on value delivery rather than task delivery and establishing stable teams.*
- *The practice of agile (scrum) can be implemented based on the observed benefits such as structure of work, team spirit, interchange of knowledge, rework reduction and challenges like multitasking and intensity of scrum meetings.*

- *Different practitioners' perspectives ("trust", "scope flexibility by contractual flexibility" and "proactive management") over making project management flexible should be recognised.*
- *The priority should be given to the high-ranked flexibility enablers which fits to the project context based on the requirements and inherent complexity.*
- *Flexibility enablers can be applied to make the project management flexible. A consistent way of making the project management flexible is to enable the flexibility in terms of the scope of the project (what), in terms of project processes (how), the project team (who), project scheduling (when) and the location the project team is organised (where).*
- *The enablers within the "how" flexibility can be focused to improve the project performance"* (Jalali-Sohi *et al.*, 2019a).