ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

OPTIMUM FINANCE-BASED SCHEDULING

Ph.D. THESIS

Fırat Doğu AKIN

Department of Civil Engineering

Structure Engineering Programme

DECEMBER 2024

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

OPTIMUM FINANCE-BASED SCHEDULING

Ph.D. THESIS

Fırat Doğu AKIN
(501192007)

Department of Civil Engineering

Structure Engineering Programme

Thesis Advisor: Assoc. Prof. Dr. Atilla DAMCI

DECEMBER 2024

ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

FİNANS TABANLI İŞ PROGRAMLAMA ÜZERİNE BİR MODEL ÖNERİSİ

DOKTORA TEZİ

Fırat Doğu AKIN
(501192007)

İnşaat Mühendisliği Anabilim Dalı

Yapı Mühendisliği Programı

Tez Danışmanı: Doç. Dr. Atilla DAMCI

ARALIK 2024

Firat Doğu AKIN, a Ph.D. student of ITU Graduate School student ID 501192007, successfully defended the thesis/dissertation entitled “OPTIMUM FINANCE-BASED SCHEDULING”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assoc. Prof. Dr. Atilla DAMCI** ....
Istanbul Technical University

Jury Members : **Prof. Dr. Gül POLAT TATAR** ....
Istanbul Technical University

Assoc. Prof. Dr. Sevilay DEMİRKESEN ÇAKIR ....
Gebze Technical University

Prof. Dr. Aslı Pelin GÜRGÜN ....
Yıldız Technical University

Assoc. Prof. Dr. Onur Behzat TOKDEMİR ....
Istanbul Technical University

Date of Submission : 19 November 2024
Date of Defense : 24 December 2024

To my mother and father,

FOREWORD

There are no words to fully express how much I owe to my parents for their unwavering support and unconditional love. Their constant encouragement and sacrifices have been the foundation of all my achievements. I am deeply grateful for their presence in my life and the countless things they have done for me. It is with immense pride and gratitude that I dedicate this thesis to them.

I would like to express my deepest gratitude to my advisor, Assoc. Prof. Atilla DAMCI, for his invaluable guidance, unwavering support, and encouragement throughout the course of my PhD journey. His profound expertise, insightful advice, and constructive feedback have been pivotal in shaping both my research study and academic growth. I owe immense gratitude to my advisor not only for his academic mentorship but also for his extraordinary support in my personal life. He has consistently been a source of comfort and guidance during my most challenging moments. Whenever I faced personal difficulties, he was always there to offer reassurance and practical solutions, helping to ease my burdens. His selflessness and genuine care have left a profound impact on me.

I would also like to extend my heartfelt gratitude to Dr. David ARDITI for his invaluable insights, guidance, and support throughout my time in the USA. his extensive knowledge and attention to detail have greatly enriched my research, and HİS constructive feedback has helped me refine my work to its fullest potential. He has played a vital role in helping me adapt to life in the United States and went above and beyond during difficult times. After my accident, he accompanied me to the hospital and ensured I received proper care. When I was unwell, he brought medicine and food, demonstrating kindness and care that extended far beyond the responsibilities of an advisor. His compassion and generosity will always hold a special place in my heart.

I would like to express my heartfelt appreciation to Prof. Dr. Gül POLAT TATAR for her invaluable contributions to my academic journey. Her insightful comments and constructive feedback have significantly enhanced the quality of my work. I am also deeply grateful for the opportunity to collaborate with her on various projects prior to this thesis, which provided me with a solid foundation and invaluable learning experiences. I would like to extend my sincere gratitude to Assoc. Prof. Sevilay DEMIRKESEN CAKIR for her invaluable guidance. Her insightful suggestions and thoughtful feedback during the evaluation process have significantly contributed to improving the quality of this thesis. Her expertise and attention to detail were instrumental in shaping the final outcome.

December 2024 Firat Dogu AKIN
(Civil Engineer, M.Sc.)

TABLE OF CONTENTS

Page

ABBREVIATIONS

APR **:** Annual Percentage Rate
CPM **:** Critical Path Method

SYMBOLS

j : Activity j
A_j : Name of activity j
N : Total Number of Activities
d_j ; Duration of Activity j
T_{esj} : Early Start Time of Activity j
T_{efj} : Early Finish Time of Activity j
T_{lsj} : Late Start Time of Activity j
T_{lfj} : Late Finish Time of Activity j
TF_j : Number of Total Float of Activity j
k : Number of week
T : Time of the Final Payment at Final Completion
t : Payment Period
BM : Borrowed Money
RM : Repaid Money
SLT : Short-Term Loans
LTL : Long-Term Loans
LC : Line of Credit.
i : Monthly Effective İnterest Rate
$\hat{i}$: Monthly Effective Interest Rate per Period t
FC : Financing Cost
NTF_j : Normalized Total Float
RF : Resource Fluctuation
l : Resource-Leveling Method
u : Day Under Consideration
PD : Project Duration
R_{dev_u} : Deviation between Resources Required on Day u and u+1
R_{inc_u} : Increase in Resources Required on Day u and u+1
R_u : Resources Required on Day u
A_{rr} : Average Resource Usage over the Project.

BL_t **:** Balloon Loan at Period t

PMT **:** Payment of the Monthly Installment,

M **:** Number of Monthly Installments to Repay the Loan

A/P **:** Capital Recovery Factor

RM_{BL} **:** Balloon Payment Amount at T

LI **:** Line Item

n’ **:** Total Number of Line Items

P/F **:** Single Payment Present Worth Factor

LIST OF TABLES

LIST OF FIGURES

Page

OPTIMUM FINANCE-BASED SCHEDULING

SUMMARY

Financial issues are among the most common causes of business failure in the construction industry. Hence, construction contractors must acknowledge the financial parameters in the project's planning phase. However, the schedulers mostly neglected integrating work scheduling and finance management until finance-based scheduling methods were introduced. Although several researchers developed models to provide solutions for finance-based scheduling problems, they neglected essential issues that must be visited. Some of these researchers used the activities' total floats to shift the activities' start times to minimize the contractor's financing cost. However, they never considered that there could be more than one work schedule to provide the minimum financing cost. Also, except for a few of them, they never indicated that using the total floats of the activities may cause more critical work schedules. Moreover, the studies in finance-based scheduling literature involved parameters and used techniques for resource-leveling. Still, none considered the fact that there are nine different resource-leveling objective functions widely used to obtain smoother resource histograms. Lastly, most of the researchers in the finance-based scheduling literature use only the line of credit as the sole financing alternative. A few researchers considered other financing alternatives, such as short-term loans and long-term loans, but they neglected the use of more financing alternatives to minimize the financing cost of the contractor.

In this study, three different models are proposed to fill the gaps mentioned above. Using the first model ensures the selection of one schedule among multiple schedules with the minimum financing cost by calculating the float consumption cost and selecting the schedule with the minimum float consumption cost. In the first proposed model, a line of credit and short-term and long-term loans are used as the financing alternatives. Line of credit, short-term loans, and long-term loans are the financing alternatives to minimize the contractor's financing cost in the second proposed model of this study, which is similar to the first model. Besides, using the second model enables contractors to select the optimal work schedule by considering their priorities. If the contractor gives more importance to minimizing the financing cost of the project than the minimization of resource fluctuations, the contractor can obtain the work schedule with the minimum resource fluctuations among the schedules with the minimum financing cost by using the second proposed model of this study. On the contrary, if the contractor prioritizes the minimization of the resource fluctuations rather than the minimization of the financing cost, then the reverse of the first process becomes available to the contractor. Nine different resource-leveling objective functions are considered in the scope of the second proposed model to ensure that the selected work schedule provides the smoothest resource histogram possible. In the last proposed model of this study, balloon loans are considered in addition to other financing alternatives used in the first and second proposed models. Also, the contractors can frontload their offers along with the usage of the different financing alternatives, as mentioned earlier, to minimize the financing cost further. The users of all three models can obtain financing schedules that involve the borrowing and repaying time of the funds and the repaying time of the interest payments. The amounts

of these financial parameters can also be determined as the outputs of the three proposed models in this study.

However, the proposed models in this study have several limitations that can be addressed in future studies. First, none of the three models considered the likelihood of the contractor having many projects in their portfolio. Contractors in the construction sector typically manage multiple projects in their portfolios simultaneously, so improvements to the proposed models are needed to accommodate this aspect. Second, none of the models provided in this study use a stochastic method to forecast the uncertain environment of the construction industry. There is a need for additional research to close this gap. As a third limitation, the presented models do not incorporate any time-cost tradeoff analysis, which may assist contractors in reducing financing costs even more. Future research must take these assessments into account in order to increase the proposed models' performance. Fourth, all three models can incorporate a broader range of financing alternatives employed by contractors in the construction industry that have never been addressed in the present finance-based scheduling literature.

FİNANS TABANLI İŞ PROGRAMLAMA ÜZERİNE BİR MODEL ÖNERİSİ

ÖZET

Bir inşaat projesinin planlanan zamanda ve bütçede tamamlanması karşısında yüklenici inşaat firmalarının karşılaştığı en kritik sorunlardan biri finansal sorunlardır. Bu finansal sorunlar yüklenici firmaların başarısızlığında yaygın bir rol oynamaktadır. Özellikle işveren tarafından hakediş ödemelerinde sıklıkla uygulanan nakit teminat kesintisi ve ödemelerin yapılması gereken tarihten daha geç yapılması gibi uygulamalar yüklenici inşaat firmalarının nakit akışlarında dengesizliklere sebep olmaktadır. Yüklenici inşaat firmalarının gelirlerinin önemli bir kısmının bu hakedişlere bağlı olduğu dikkate alınırsa, işveren tarafından dayatılan bu uygulamaların yüklenicilerin nakit temini açısından sorun oluşturduğu kesindir. Bu sebeple, yüklenici inşaat firmaları nakit akışlarındaki dengesizlikleri önlemek için işveren harici üçüncü kaynaklardan finansman elde etmek zorundadır. Dış kaynaklardan (bankalar, fonlar ve çeşitli finansman kuruluşları) elde edilen bu finansman ise beraberinde faiz ödemesini getirmektedir. Dış kaynaklar kullanılarak elde edilen finansman karşılığında elde edilen finansman için ödenen faiz miktarı ise yüklenicinin finansman maliyetini oluşturmaktadır. Finansman maliyeti yüksek olan yüklenicilerin karlılığı azalmaktadır. Aynı zamanda, yüklenici firma nakit akışlarını oluşturma aşamasında ödünç alınan finansmanı, bu finansmanın geri ödenmesini ve faiz ödemesini dikkate almak zorundadır. Özellikle inşaat projelerinin erken zamanlarında, şantiye kurulumu ve malzeme temini gibi aktivitelerin yoğun olması dolayısıyla oluşabilecek negatif nakit akışının engellenebilmesi için efektif bir iş program hazırlanması şarttır. Bir yüklenici inşaat firmasının nakit akış diyagramlarını oluştururken sadece projenin doğası gereği oluşacak maliyetleri ve hakediş gelirlerini değil, aynı zamanda ek finansman elde edilecek gelir ve katlanılacak giderleri de hesaplamalarında dikkate alması gerekmektedir.

Nakit akışları ve iş programları hazırlanırken finansal parametrelerin dikkate alınması finans-tabanlı iş program hazırlama teknikleri geliştirilene kadar literatürde yer alan çoğu yayında ihmal edilmiştir. İlk denemelerden itibaren günümüze kadar birçok araştırmacı finans-tabanlı iş programı hazırlama problemi üzerine çeşitli modeller geliştirmiştir. Mevcut modeller konu hakkında birçok probleme çözüm sunmuş olmakla beraber bazı önemli hususları dikkate almamıştır. Bu çalışma kapsamında yapılan literatür taraması sonucunda finans-tabanlı iş program hazırlama modellerini geliştiren araştırmacıların sıklıkla aktivitelerin başlangıç zamanlarını öteleyerek finansman maliyetini azaltmaya çalıştığı anlaşılmıştır. Kaynak dengeleme tekniklerine benzer bir şekilde, aktivitelerin erken başlama zamanları toplam bolluk sınırları içerisinde kaydırılarak ek nakit ihtiyacının miktarı ve zamanlaması değişmektedir. Bu değişimin ise finansman maliyetini minimize edecek yönde olması hedeflenmiştir. Ancak, mevcut literatürde bulunan yayınlar aktivite bolluklarının kullanılmasının nasıl sonuçlara yol açabileceğine dair ek bir araştırma sunmamışlardır. İlk olarak, aktivitelerinin başlangıç zamanları farklı fakat aynı minimum finansman maliyetini sunan birden fazla iş programının oluşabilme ihtimali göz ardı edilmiştir. Yüklenici firma farklı iş programlarından hangisinin uygulanacağına karar vermek zorundadır.

Buna ek olarak, yükleniciler aktivitelerin başlangıç zamanlarını değiştirilirken bolluk kullanmanın nihai oluşacak iş programını “kritik” hale getirebileceğinin farkında olmalıdırlar. Çünkü kritik hale gelen iş programlarının uygulanması projenin zamanında tamamlanmasını engelleyebilmektedir. Çoğu mevcut finans-tabanlı iş programı hazırlama modellerinin ihmal ettiği bir başka husus ise kaynak yönetimi tekniklerinin kullanımıdır. Bazı modeller efektif kaynak yönetimi için kullanılması önerilen bazı parametreleri ve teknikleri dahil etseler bile, özellikle kaynak dengelemesi konusunda eksiklikler bulunmaktadır. Mevcut çalışmaların hiçbiri kaynak dengeleme amacıyla oluşturulmuş dokuz farklı amaç fonksiyonunu dikkate almamıştır. Her amaç fonksiyonu farklı kaynak kullanım diyagramlarını en uygun sonuç olarak tavsiye edeceği için bu dokuz farklı amaç fonksiyonunun her biri dikkate alınmalıdır. Bu çalışma kapsamında tespit edilen son problem ise literatürde yer alan mevcut çalışmaların çoğunda sadece bir adet finansman alternatifinin kullanılmasıdır. İnşaat sektöründe yer alan firmaların portföylerini yönetmek için çeşitli sayıda finansman alternatifi kullandığı göz önünde bulundurulduğunda, birden fazla finansman alternatifinin kullanımının şart olduğu tespit edilmiştir. Buna ek olarak, yükleniciler tarafından kullanılmayan fakat kullanımının finansman maliyetinin azaltılmasında fayda sağlayacağı düşünülen çeşitli alternatifler değerlendirilmelidir.

Yukarıda bahsedilen eksikliklerin giderilmesi ve mevcut modellerin geliştirilmesi için bu çalışma kapsamında yüklenici inşaat firmalarının kullanımı için üç adet model önerilmiştir. Birinci model kapsamında, iki aşamalı bir optimizasyon modeli kurulmaktadır. İlk modelin ilk aşamasında, aktivitelerin başlangıç zamanları bolluk değerleri sınırında değiştirilerek ve üç adet finansman alternatifi kullanılarak finansman maliyeti minimize edilmektedir. İkinci aşamada ise minimum finansman maliyetini sağlayan iş programlarından birinin en uygun iş programı olarak seçmek amacıyla bolluk kullanım maliyetleri hesaplanmakta ve yüklenici tarafından kullanılacak iş takviminin seçimi yapılmaktadır. Bu iş programı ise en düşük miktarda finansman maliyetinin sağlayan iş takvimlerinin içindeki en düşük bolluk kullanım maliyetine sahip olan iş programı olarak belirlenmektedir. İkinci model kapsamında, ikinci bir optimizasyon modeli en uygun iş programının belirlenmesi için geliştirilmiştir. Geliştirilen model yüklenicinin önceliğine göre ya en düşük kaynak dalgalanmasını temin eden iş programlarının arasından en düşük finansman maliyetini sunan iş programını seçmekte, ya da en düşük finansman maliyetini temin eden iş programlarının arasından en düşük kaynak dalgalanmasını sunan iş programını seçmektedir. Eğer yüklenicinin önceliği finansman maliyetinin minimize edilmesi ise ilk aşama seçilmeli, tersi durumda ise ikinci aşama takip edilmelidir. Geliştirilen model iki durum için de uygun iş programını seçebilmektedir. Sunulan modelin mevcut modellerden bir diğer farkı ise kaynak dengeleme için dokuz farklı amaç fonksiyonunu hesaplamalara dahil etmesidir. Böylece, sadece bir amacı değil birden fazla amacı dikkate alarak kaynak dalgalanmalarının azaltıldığı iş programı belirlenebilmektedir. Bu tez kapsamında geliştirilen son modelde ise dört farklı finansman alternatifinin (kredi marjı, kısa vadeli krediler, uzun vadeli krediler ve balon kredisi) yanı sıra ön-yükleme yöntemi ile yüklenicinin sunduğu teklif dengesiz hale getirilerek yüklenicinin finansman maliyetinin azaltılması amaçlanmıştır.

Bu tez kapsamında geliştirilen bu üç modelin nasıl uygulandığını ve etkinliğini göstermek için her bir model örnekler üzerinde uygulanmıştır. Örneklerin sonuçları incelendiğinde, bir inşaat yüklenicisi karşılaştığı probleme ve öncelik verdiği parametreleri dikkate alarak üç modelden herhangi birini kullanabileceği ve birçok iş programı alternatifi arasından uygun olanı seçilebileceği görülmüştür. Uygun iş programının seçiminin yanı sıra, önerilen modellerin kullanıcılarının finansal girdi ve çıktılarını da temin edilebileceği örnekler üzerinden kanıtlanmıştır. Yükleniciler bu programları kullanarak hangi finansman alternatifini ne zaman kullanabileceğini ve bu alternatifi kullanarak ne miktarda finansman elde edebileceğini görebilmektedir. Bunun yanı sıra, her bir modelin kullanımı sonucunda edinilen finansmanın anaparasının ve faiz ödemesinin ne zaman ve ne miktarda olacağı da belirlenebilmiştir. Elde edilen bu finansman programları yüklenicilerin nakit akışlarını hesaplarken tutarlı kararlar verebilmelerine olanak sağlamaktadır.

Ancak, bu tez kapsamında geliştirilen modellerin faydalarının yanı sıra bazı kısıtları da bulunmaktadır. İlk olarak, bu modeller sadece yüklenicinin portföyünde bir adet proje olduğu kabulünü yapmaktadır. İkinci olarak, geliştirilen üç model deterministik yöntemler ile maliyet tahminleri yapmaktadır. Üçüncü olarak, bu üç modelden hiçbiri zaman maliyet ödünleşimi tekniklerini dahil etmemiştir. Son olarak ise mevcut literatürde yer alan modellerin hepsinden daha fazla finansman alternatifi dikkate alınmış olsa dahi inşaat sektöründe faaliyet gösteren firmaların kullanabileceği diğer finansman alternatifleri modellere dahil edilmemiştir. Bu kısıtlar göz önünde bulundurulduğunda, gelecek çalışmalarda yukarıda bahsedilen model kısıtları dikkate alınabilir.

1. INTRODUCTION

One of the critical issues contractors face in the construction industry is obtaining the required funds to ensure project completion on time. Financial and budgetary issues are among the most common causes of business failure in this industry (Arditi et al., 2000). These challenges are frequently caused by progress payment delays and the typical practice of retaining a portion of payments until the project is completed, which disrupts contractors' cash flows and needs additional financing (Alavipour and Arditi, 2018a). Contractors usually rely on external financing to handle cash flow fluctuations, which causes financing costs and reduces profitability (Ali andElazouni, 2009).

Effective cash flow management using strategic financing is critical. Contractors should explore using their own money and owner progress payments as their primary source of financing, as this promotes self-sufficiency and decreases the need for external funding. However, when outside investment is required, understanding and including financing costs at the early stages is critical to avoiding negative cash flow. This is especially important because financial considerations are frequently disregarded in scheduling, causing significant financial hazards if not handled immediately (Ali and Elazouni, 2009; Arditi et al., 2000).

1.1 Problem Statement

The connection between financing and project scheduling was overlooked until Elazouni and Gab-Allah (2004) introduced the concept of finance-based scheduling, which offers promising solutions to financial issues. Since the groundbreaking introduction of finance-based scheduling by Elazouni and Gab-Allah in 2004, the construction industry has seen a surge of research aimed at solving the finance-based scheduling problem. However, these studies have often overlooked crucial issues, leaving a significant gap in the understanding of effective cash flow management in construction projects. Some of the issues are briefly explained in the following paragraphs.

The models developed in the literature enable professionals to schedule activities while considering both precedence relationships and financial constraints. A review of the literature on finance-based scheduling suggests that financing costs can be reduced by adjusting the start times of activities within the available total float. However, researchers often fail to acknowledge that the lowest financing cost can be achieved through multiple schedules, each with varying activity start times. None of the researchers in the finance-based scheduling literature acknowledge that there can be multiple schedules with minimum financing costs. Also, the cost of float consumption (cost of lost schedule flexibility) and the importance of float consumption in determining the best optimum schedule among the schedules with the minimum financing cost are neglected. This highlights the need for a comprehensive approach to finance-based scheduling.

Furthermore, some studies on finance-based scheduling have incorporated resource leveling and allocation techniques, using parameters like "release and rehire" (Elazouni and Abido, 2014; El-Abbasy et al., 2016; El-Abbasy et al., 2017), "resource idle days" (Elazouni and Abido, 2014; El-Abbasy et al., 2016; El-Abbasy et al., 2017; Abido and Elazouni, 2021), "moment" (Elazouni and Metwally, 2007), and "resource un-leveling penalty" (Elazouni and Metwally, 2007). Some of these studies even aimed to minimize resource fluctuations in finance-based scheduling (Elazouni and Abido, 2014; El-Abbasy et al., 2016; El-Abbasy et al., 2017). However, none of these studies differentiated between the various resource-leveling methods used in construction projects. While the core idea behind all resource-leveling methods is to achieve a uniform distribution of resources while maintaining the original project duration, each method targets the optimization of different parameters, leading to diverse resource utilization histograms (Damci and Polat, 2014). In other words, these methods may yield optimal results under certain conditions but suboptimal outcomes under others. It is crucial to determine which method is most suitable for specific conditions, as it remains uncertain whether such a determination can be made, highlighting the importance of optimization in resource utilization.

The last problem detected in the finance-based scheduling literature in the context of this thesis is that a contractor can secure project financing by borrowing from various lenders, each offering different agreements, interest rates, and repayment schedules. This variety allows the contractor flexibility in choosing the loan option that minimizes financing costs. Alavipour and Arditi (2018a) demonstrated that incorporating multiple financing options can result in lower financing costs. Therefore, it is crucial to consider various financing alternatives in construction projects to achieve better outcomes in finance-based scheduling. However, most studies have primarily used lines of credit as the only financing option for additional funding, with only a few exceptions (e.g., Jiang et al., 2011; Alavipour and Arditi, 2018a; Alavipour and Arditi, 2018ab; Alavipour and Arditi, 2019a; Alavipour and Arditi, 2019b; Tavakolan and Nikoukar, 2019) that also considered alternatives like short-term and long-term loans. Although Alavipour and Arditi (2018a) combined lines of credit, short-term loans, and long-term loans in a single model, they did not consider other financing options, such as balloon loans (Halpin and Senior, 2009), even though contractors occasionally use the balloon loans to achieve smoother cash flow and lower financing costs. Additionally, front-loading the bid is another technique contractors can use to reduce financing costs further. The use of the front-loading technique as a financing method is neglected in all of the studies in the finance-based scheduling literature.

1.2 Objectives of the Research

The main aim of this thesis is to provide three different models to help contractors in the construction industry when they face problems that have never been covered in the finance-based scheduling literature. The objectives of these models are:

1) The first finance-based scheduling model aims to create a two-phase approach to minimize the project's financing cost. The first phase involves reducing the contractor’s financing costs by adjusting the start times of activities using the activities' total floats and considering different financing alternatives, resulting in several optimal work schedules. In the second phase, one of these optimal schedules is selected as the final solution by identifying the schedule with the lowest cost of float consumption.

2) In the second model, an optimization model is introduced to examine how various resource-leveling methods impact the issues in finance-based scheduling problems. The model can recommend a work schedule among several options with the lowest financing cost, considering different resource-leveling objective functions, or another work schedule by selecting the one with the minimum resource fluctuation value among the schedules with the minimum financing cost.

3) The last model of this study aims to minimize the contractors' financing costs by considering different financing methods that have never been involved in any studies in the finance-based scheduling literature so far. Those financing methods: (1) using balloon loans along with lines of credit, short-term and long-term loans, and (2) front-loading the contractor’s bid.

1.3 Research Methodology

The following phases were performed in this study:

1) Reviewing the literature on models developed by researchers in finance-based scheduling literature.

2) Determining the parameters, constraints, variables, and objective functions that are used in studies in finance-based scheduling literature by reviewing the literature

3) Developing the first model after deciding the parameters, constraints, variables, and objective function of the first model.

4) Testing the first model on an illustrative example and discussing the results.

5) Developing the second model after deciding the parameters, constraints, variables, and objective function of the second model.

6) Testing the second model on an illustrative example and discussing the results.

7) Developing the third model after deciding the parameters, constraints, variables, and objective function of the third model.

8) Testing the third model on an illustrative example and discussing the results.

9) Discussing and concluding the results and performances of the three proposed models are introduced in this study.

1.4 Research Scope

This thesis proposes three different models to provide solutions for finance-based scheduling problems in the construction industry. The thesis outline is presented below.

The problem statement, the research objectives, the research methodology, and the research scope are presented in this chapter (Chapter 1).

In Chapter 2, a review of previous studies on finance-based scheduling literature is provided.

In Chapter 3, the standard parameters, variables, constraints, and objective functions used in the proposed models are determined.

In Chapter 4, the parameters, constraints, variables, and objective functions of the first model are determined, and the first model is implemented in an illustrative case to demonstrate its effectiveness.

In Chapter 5, the parameters, constraints, variables, and objective functions of the second model are determined, and the second model is implemented in an illustrative case to demonstrate its effectiveness.

In Chapter 6, the parameters, constraints, variables, and objective functions of the second model are determined, and the second model is implemented in an illustrative case to demonstrate its effectiveness.

In Chapter 7, a general overview of the results and effectiveness of the proposed models are discussed. Also, the limitations of the models are mentioned, along with the possible improvements.

6

2. LITERATURE REVIEW

2.1 The Summary of the Studies and the Research Gaps in Finance-Based Scheduling Literature

Many finance-based scheduling studies have been conducted to help contractors solve their problems. The majority of these studies sought to improve existing models by creating new ones to address several gaps in the finance-based scheduling literature. The publications analyzed in the literature review are listed below:

Elazouni and Gab-Allah's (2004) model is the first in the literature to use the finance-based scheduling approach. This model allows for extending the project duration to keep the required cash for project execution from exceeding a predetermined limit. Elazouni and Gab-Allah's (2004) model was improved by Elazouni and Metwally (2005), who included profit elements. Thus, a multi-objective optimization model was created. While the proposed model aimed to increase project profit, it also sought to shorten project duration. A genetic algorithm is used to find solutions to these conflicting objectives. However, neither model considered schedule flexibility, resource constraints beyond cash for activities, or various financing alternatives.

Elazouni and Metwally (2007) created a model to maximize project profit while minimizing costs. Unlike previous models, this one focused on resource constraints and usage. The time-cost trade-off was addressed for the first time alongside the finance-based scheduling approach. However, their model did not account for different types of financing. Only line-of-credit was used as a financing option in the studies mentioned.

Furthermore, none of the developed models took into account scenarios that involved the simultaneous execution of multiple projects. To fill this gap, Elazouni (2009) proposed a model. However, considering multiple projects presented computational challenges that were addressed with a heuristic algorithm-based model. This study also failed to consider the use of various financing alternatives.

Ali and Elazouni (2009) identified a gap in models that needed to take into account linear scheduling and proposed a model for linear scheduling projects. Their model sought to identify the optimal work schedule that maximizes profit by taking into account construction methods, work interruptions, and crew sizes. Unlike previous models, it considered various types of relationships between activities. Liu and Wang (2009) proposed a model that improved existing models for linear scheduling projects by taking into account work continuity and various activity relationship types. Although resource utilization and concurrent execution of multiple projects were addressed in these studies, evaluating multiple financing alternatives has been missed.

The above-mentioned studies should have considered cash and resource priorities for various projects. To address the shortcomings of their previous model, Liu and Wang (2010) proposed a model aimed at maximizing total project profit in a multi-project environment. In this model, where each project is carried out under different contract terms, there needs to be a recommendation for prioritizing and allocating the necessary funds for project completion. Other neglected aspects of the model included resource management approaches and the use of various financing alternatives. The model presented by Gajpal and Elazouni (2015) did not make any progress in determining how to prioritize available cash among multiple projects.

Existing studies in the finance-based scheduling literature have only considered the required amount of cash to finance construction projects as a constraint. However, Abido and Elazouni (2009) developed a model to reduce the financing costs associated with obtaining the required cash. Fathi and Afshar (2010) proposed a new model for minimizing financing cost and borrowed money. Abido and Elazouni (2011) presented a multi-project optimization model. This model used an Evolutionary Algorithm to reduce the project group's overall duration. The model sought to obtain optimal values for variables such as the required borrowing amount and financing cost. However, these studies, which assess project financing from a different perspective, have yet to address issues such as resource management and the use of various financing types.

Jiang et al. (2011) included both short-term and long-term loans, which are commonly used in construction project financing but should be taken into account in existing finance-based scheduling research. Their Pareto Optimality Efficient Network Model aims to reduce financing cost by considering a variety of financing alternatives. Although this study contributed significantly to the literature by examining various financing alternatives, it fell short in terms of resource management. Algazi et al. (2012) used the Shuffled Frog-Leaping Algorithm to maximize project profits. The performance of the algorithm used in their model was compared to algorithms used in existing finance-based scheduling models, and the algorithm's success was demonstrated through a case study. Elazouni et al. (2015) compared the Genetic Algorithm, Simulated Annealing, and Shuffled Frog-Leaping Algorithm, concluding that simulated annealing produced better results.

Another gap in the literature is the need to include factors that ensure efficient resource management in the developed models. To address this gap, Elazouni and Abido (2014) used the parameter number of "resource idle days" in their models with the goal of minimizing idle days and financing costs. However, various financing alternatives were not utilized, and the possibility of a construction company managing multiple projects was not considered. El-Abbasy et al. (2016) added the "release and rehire" parameter, as well as "resource idle days." This study went into greater detail about resource management than previous works. The proposed model's objective function included maximum resource demand and leveling parameters. The model also took into account factors such as the project duration, total project cost, project profit, financing cost, and required additional cash amount. Despite taking into account many factors when compared to existing models, their research overlooked using multiple financing alternatives. El-Abbasy et al. (2017) argued that the lack of resource management approaches in existing models reduced their effectiveness. They proposed a model with multiple parameters to represent real-world scenarios. Considering network diagrams with multiple resource types made a unique contribution to the literature, allowing for realistic cash flows and efficient resource utilization. The study's limitation was the lack of use of various financing alternatives. Another area for improvement was the failure to provide flexible work schedules, which needed to be addressed in the model developed by El-Abbasy et al. (2020), who evaluated multiple projects.

Alavipour and Arditi's (2018a) model overcomes this shortcoming by considering different financing alternatives. Their model provides an optimal financing schedule while avoiding extending the project duration. However, Alavipour and Arditi's (2018b) assertion is that it can be further improved by adding time-cost trade-off analysis. Integrating different financing alternatives and time-cost trade-off analysis provides an opportunity to increase contractor profits while minimizing financing costs. The shortcomings of Alavipour and Arditi's (2019a) model are that it considers only the early start and early finish times of activities and ignores cases where the project duration has to be extended beyond the contract duration. In order to overcome these shortcomings, Alavipour and Arditi (2019b) proposed a finance-based scheduling model that allows shifting start times of activities and minimizing the extension of the project duration beyond the duration specified in the contract while increasing contractor profits and minimizing financing cost via time-cost trade-off analysis. However, the need for resource management techniques and further investigation for schedule flexibility is neglected in these studies.

Recent research has primarily focused on selecting the best method to achieve the ideal solution rather than adding a new objective function or financing option to the model. Al-Shihabi and AlDurgam (2020a) proposed a mathematical algorithm-based model in response to the optimal solutions provided by analytical methods. The proposed model can assess various activity execution modes. Furthermore, Al-Shihabi and AlDurgam (2020b) proposed a model that employs crashing techniques to shorten the completion time of multiple projects. This model, like the previous work, was created using mathematical algorithms. The authors' studies did not include any elements related to different financing alternatives or resource management techniques. He et al. (2021) proposed a model for minimizing the required financing amount under cash constraints. The model generated various cash flows for multiple projects by changing activities' start and completion times within certain limits. Despite considering resource management techniques for multiple projects, different financing options should have been explored. Abido and Elazouni (2021) used a multi-objective evolutionary programming algorithm in their models to calculate the required financing amount while also addressing the resource leveling problem. The proposed model incorporates approaches to resource management and activities with multiple execution modes, but it only considers cash flow for a single project and one resource type. Liu et al. (2021) proposed a heuristic-based Genetic Algorithm model that maximizes profit while accounting for the relationships between activities, cash limits, and resource constraints. However, the model only considers one type of financing.

2.2 Overview of the Parameters, Methods, Constraints, and Objective Functions Considered in Existing Studies in the Finance-Based Scheduling Literature

In this study, a systematic and detailed review of the finance-based scheduling literature is conducted to determine the parameters, methods, constraints, and objective functions considered in existing studies in the literature. Furthermore, the methodologies and techniques used in previous studies to solve finance-based scheduling problems are identified and presented in Tables 2.1, 2.2, and 2.3. The existing finance-based scheduling literature is reviewed using a systematic literature review following the steps defined in the studies by Amer et al. (2021) and Akin et al. (2022). The steps of the systematic literature review can be seen in Figure 2.1. In this study, Scopus is selected as the database for the literature review. The following search query is used in this study: {"finance-based" AND "scheduling"} OR {"financing cost" AND "scheduling"} OR {"finance cost" AND "optimization"}. These keywords yielded a total of 367 publications. They were screened based on their titles, with those that were irrelevant being excluded. This step resulted in the selection of 60 publications for abstract-based screening. Six publications were excluded when their abstracts were examined because they could not fully access them. In addition, eight publications were excluded because they were irrelevant to finance-based scheduling. The selected publications' full texts are then screened. After the full-text screening, 39 publications were determined to be relevant. The references to each publication were then examined, resulting in an addition of 15 publications to the existing list. In the next step, an author knowledge-based screening was carried out. It was discovered that four additional publications could be added to the existing group. All previous steps were repeated until no more relevant publications could be added to the current group.

Following a systematic literature review, 47 publications were discovered to be related to finance-based scheduling. These publications are classified according to their publication type. The majority of publications (35 out of 47) are journal papers. The remaining publications include three conference papers, one discussion article, one closure article, and one technical note. Nonetheless, the full text of the six publications could not be obtained. The discussion paper, closure paper, and six inaccessible publications were all excluded from future investigations. Figure 2.2 displays the names of the journals and conferences, as well as the number of publications associated with each.

When it comes to the algorithms used in the developed models, mathematical algorithms (e.g., Linear Programming, Integer Programming) were used in ten publications, heuristic algorithms in three, and meta-heuristic algorithms (e.g., Genetic Algorithm, Shuffled Frog-Leaping Algorithm, Max-Min Ant System) in 22 publications. Three publications used hybrid algorithms (e.g., Linear Programming/Genetic Algorithm and Mixed-Integer Linear Programming/Heuristic). The Pareto Optimality Efficiency Network was also used in one publication (Figure 2.2.3). This finding reveals that researchers frequently prefer meta-heuristic algorithms that can provide near-optimal solutions in a short period of time, as mathematical algorithms require more time to solve finance-based scheduling problems. However, it is important to note that the optimal solution may differ significantly from that provided by a meta-heuristic algorithm.

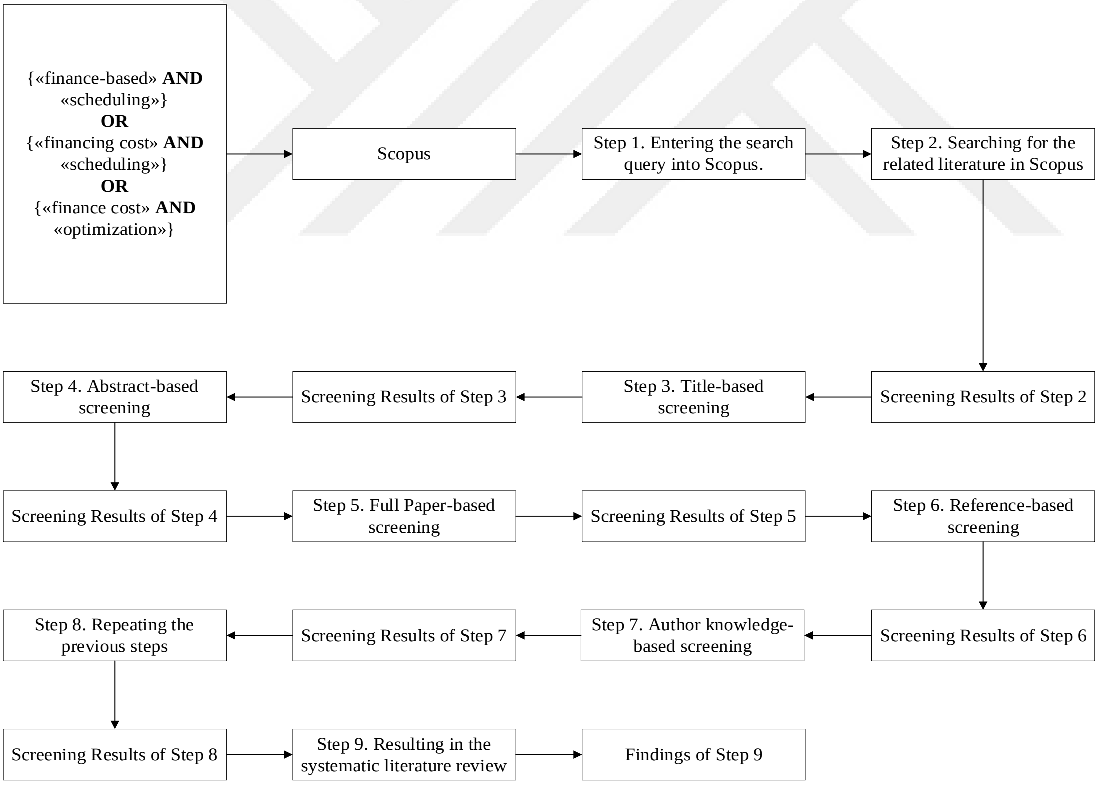

Figure 2.1 : Flowchart of the systematic literature review.

Table 2.1 shows that various factors are taken into account when developing finance-based scheduling models. While the majority of studies focus on portfolios with a single project, the literature review reveals a small number of studies that look at portfolios with multiple projects. Furthermore, some studies allow for changes to the original project duration if it is necessary to extend it due to financial constraints. On the other hand, studies have proposed models that keep the project duration fixed. Furthermore, some researchers have modified these finance-based scheduling models by including time-cost trade-off or crashing techniques that allow for activity duration changes.

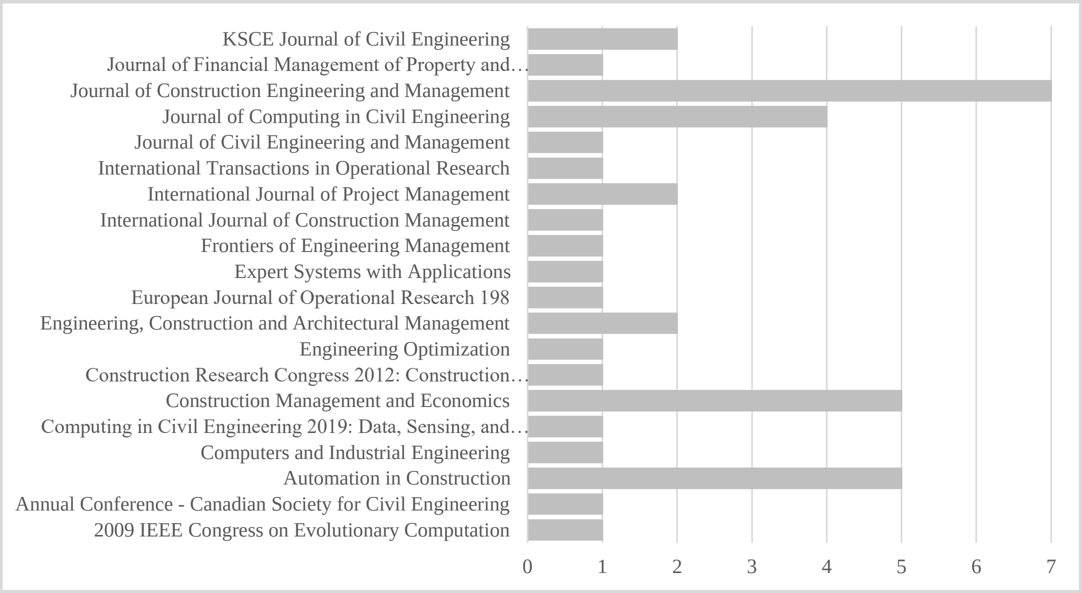

Figure 2.2 : Distribution of the published literature about finance-based scheduling.

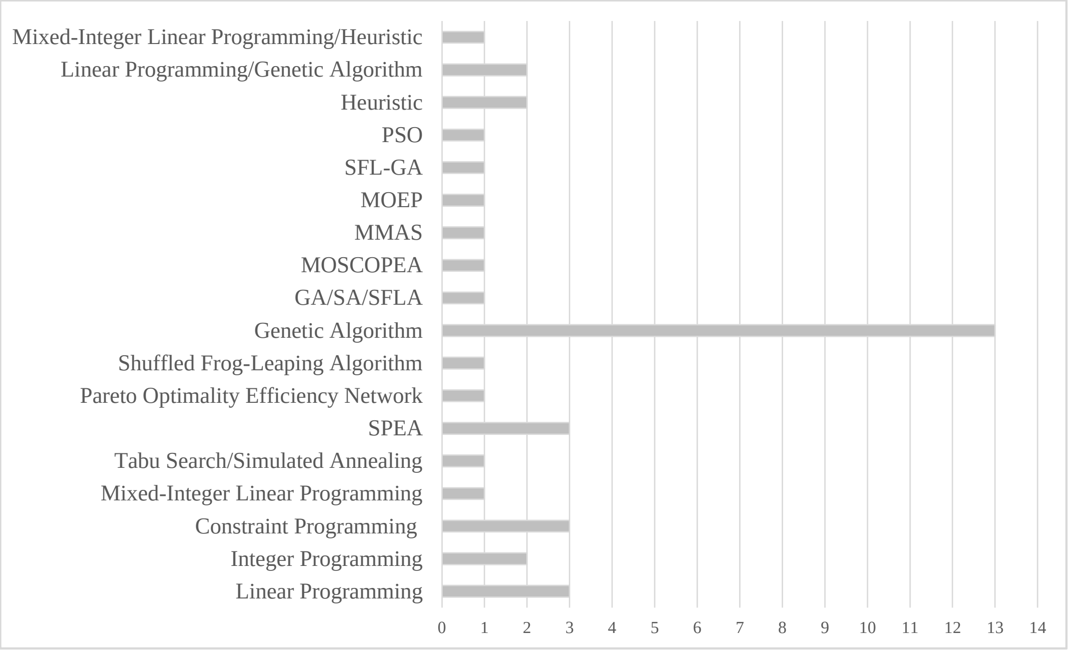

Figure 2.3 : Types of algorithms used in the developed models.

Nevertheless, it should be noted that in finance-based scheduling models that account for resource leveling, the original project duration and activity duration remain unchanged. Furthermore, finance-based scheduling models that consider non-cash resource management (e.g., by including resource leveling in the model) can consider only one or multiple resource types. To achieve the optimization goals, the literature uses various objective functions (see Table 2.2). The objective functions considered in the literature are divided into four major categories: (1) time, (2) cost and profit, (3) cash, and (4) resources other than cash. It was discovered that a significant number of finance-based scheduling models seek to reduce the increase in original project duration caused by the finance gap. The finance-based scheduling models aimed to reduce costs rather than lengthen the original project duration by minimizing the amount of borrowed money and finance costs.

Furthermore, the literature review reveals that maximizing project profit and net present value objectives have been used in a small number of finance-based scheduling models. Although most finance-based scheduling-related studies have ignored the optimization of resources other than cash, it should be noted that a number of studies have considered objectives (e.g., minimization of resource fluctuations, maximum resource demand) and included resource management in finance-based scheduling models (Table 2.2).

Table 2.3 shows the parameters and factors used in the finance-based scheduling models. It was discovered that the most commonly used methods in resource management (i.e., resource leveling and resource allocation) are also used in some finance-based scheduling models. For example, some finance-based scheduling models consider "release and re-hire" and "resource idle days" as optimization parameters for the efficient use of non-cash resources. Minimizing these two parameters results in a less fluctuated resource usage profile and reduces maximum resource demand. In terms of financing alternatives, the majority of finance-based scheduling-focused studies have only used line-of-credit. However, it should be noted that only a small number of finance-based scheduling models have considered short-term and long-term credits as financing alternatives.

Finance-based scheduling has been a topic of debate for the past two decades and is of great interest to professionals and researchers. Even though researchers have presented a large volume of academic work on finance-based scheduling, no attempt has been made to provide a comprehensive review that summarizes and critiques the existing literature on finance-based scheduling and makes recommendations for future research. This study used a systematic literature review to identify research gaps and potential areas for future research. Indeed, existing models have some flaws. For example, many developed models regard the line of credit as the sole financing option. However, there are numerous other ways to fund a construction project, including short-term loans (Alavipour and Arditi, 2018a), long-term loans (Alavipour and Arditi, 2018a), subcontracting (Tabyang and Benjaoran, 2016), and balloon loans. Furthermore, while a small number of finance-based scheduling models in the literature address resource management, none of the studies examined the use of different objective functions for resource-leveling. Finally, several researchers used mathematical algorithms to find an exact solution to their problems, as shown above. However, no one has looked into whether multiple schedules with low financing costs could exist. As a result, they failed to select the best schedule among those with the lowest financing costs. They also could have made more effort to address the issue of losing schedule flexibility when the activities' total floats are consumed to reduce a project's financing costs even further. Based on the systematic literature review, the parameters, methods, constraints, and objective functions are used in the study's proposed models to fill the research gaps mentioned above.

Table 2.1 : The methodologies and methods, portfolio types, project duration, activity duration, and resource type factors in the related literature.

Author Name / Publication Date	Methodologies/Methods	Project Type on Portfolio		Project Duration		Activity Duration		Resource Type	
		Single	Multiple	Fixed	Variable	Fixed	Variable	Single	Multiple
Elazouni and Gab-Allah (2004)	Mathematical / Integer Programming	✓			✓	✓			
Elazouni and Metwally (2005)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Metwally (2007)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Liu and Wang (2008)	Mathematical / Constraint Programming	✓			✓		✓		✓
Ali and Elazouni (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Afshar and Fathi (2009)	Meta-Heuristic / Genetic Algorithm		✓		✓	✓			
Elazouni (2009)	Heuristic Algorithm		✓		✓	✓			
Liu and Wang (2009)	Mathematical / Constraint Programming	✓			✓		✓	✓	
Senouci and Rayes (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Abido and Elazouni (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Liu and Wang (2010)	Mathematical / Constraint Programming		✓	✓		✓			
Fathi and Afshar (2010)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Abido (2011)	Meta-Heuristic / Strength Evolutionary Algorithm		✓		✓		✓		
Abido and Elazouni (2011)	Meta-Heuristic / Strength Evolutionary Algorithm		✓		✓		✓		
Jiang, Issa and Malek (2011)	Mathematical/Pareto Optimality Efficiency Network	✓		✓		✓			
EL-Abbasy, Zayed and Elazouni (2012)	Meta-Heuristic / Genetic Algorithm		✓		✓		✓		
Alghazi, Selim and Elazouni (2012)	Meta-Heuristic/Shuffled Frog-Leaping Alg. (SFLA)	✓		✍	✍	✓			
Alghazi, Elazouni and Selim (2013)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Abido (2014)	Meta-Heuristic / Strength Evolutionary Algorithm	✓			✓		✓		✓
Elazouni, Alghazi and Selim (2015)	Meta-Heuris./Genetic Algr.-Sim. Annealing and SFLA	✓			✓	✓			
Gajpal and Elazouni (2015)	Heuristic Algorithm		✓		✓	✓			
Tabyang and Benjaoran (2016)	Mathematical / Linear Programming	✓		✓		✓			
El-Abbasy, Elazouni and Zayed (2016)	Meta-Heuristic / MOSCOPEA	✓			✓		✓		✓
Elbeltagi , Ammar , Sanad and Kassab (2016)	Meta-Heuristic / Particle Swarm Optimization	✓			✓		✓		✓
Al-Shihabi and AlDurgam (2017)	Heuristic Algorithm / Max. Min. Ant Syst.	✓			✓	✓			
El-Abbasy, Elazouni and Zayed (2017)	Meta-Heuristic / Genetic Algorithm		✓		✓		✓		✓
Alavipour and Arditi (2018a)	Mathematical / Linear Programming	✓		✓		✓			
Alavipour and Arditi (2018b)	Mathematical / Linear Programming	✓		✓		✓			
Alavipour and Arditi (2019a)	Mathematical/Meta-Heuristic	✓			✓		✓		
Alavipour and Arditi (2019b)	Mat.-Meta-Heuristic / Linear Prog. - Genetic Alg.	✓			✓		✓		
Shiha and Hosny (2019a)	Meta-Heuristic / Genetic Algorithm	✓		✓		✓			
Shiha and Hosny (2019b)	Meta-Heuristic / Genetic Algorithm		✓	✓		✓			
Tavakolan and Nikoukar (2019)	Meta-Heuristic / SFLA ve Genetic Algorithm	✓			✓		✓		
El-Abbasy, Elazouni and Zayed (2020)	Meta-Heuristic / Genetic Algorithm		✓	✓			✓		
Al-Shihabi and AlDurgam (2020a)	Mathematical / Mixed-Integer Linear Programming	✓			✓		✓		

Table 2.1 (continued) : The methodologies and methods, portfolio types, project and activity duration, and resource type factors in the related literature.

Author Name / Publication Date	Methodologies/Methods	Project Type on Portfolio		Project Duration		Activity Duration		Resource Type	
		Single	Multiple	Fixed	Variable	Fixed	Variable	Single	Multiple
Al-Shihabi and AlDurgam (2020a)	Mathematical / Mixed-Integer Linear Programming	✓			✓		✓		
Al-Shihabi and AlDurgam (2020b)	Mat.-Heuristic/Mixed-Integer Linear Progr.-Heuris.		✓		✓		✓		
Liu, Zhang and Liu (2021)	Mathematical / Integer Programming	✓			✓		✓	✓	
Abido and Elazouni (2021)	Math. - Meta-Heuristic / Multi-Obj. Evolu. Progr.	✓			✓		✓	✓	
He, He and Wang (2021)	Meta-Heuristic/Tabu Search and Simulated Ann.		✓	✓		✓		✓	

Table 2.2 : Objective functions considered in the finance-based scheduling models.

Author Name / Publication Date	Objective Function										
	Duration		Cost and Profit				Cash			Resources other than cash	
	Min. of Total Project Duration	Min. of Extended Duration	Min. of Finance Cost	Min. of Total Project Cost	Min. of Required Credit	Max. of Profit	Min. of Max. Overdraft	Min. of Cash Fluctuations	Max. of Net Present Value	Min. of Resource Fluctuations	Min. of Peak Resource Demand
Elazouni and Gab-Allah (2004)	✓	✓									
Elazouni and Metwally (2005)	✓					✓					
Elazouni and Metwally (2007)				✓		✓					
Liu and Wang (2008)						✓					
Ali and Elazouni (2009)						✓					
Afshar and Fathi (2009)	✓	✓	✓		✓						
Elazouni (2009)	✓	✓									
Liu and Wang (2009)						✓					
Senouci and Rayes (2009)	✓					✓					
Abido and Elazouni (2009)			✓			✓					
Liu and Wang (2010)						✓					
Fathi and Afshar (2010)	✓	✓	✓		✓						
Elazouni and Abido (2011)	✓		✓		✓	✓					
Abido and Elazouni (2011)	✓		✓		✓	✓					
Jiang, Issa and Malek (2011)			✓			✓					
EL-Abbasy, Zayed and Elazouni (2012)	✓		✓				✓				
Alghazi, Selim and Elazouni (2012)						✓					
Alghazi, Elazouni and Selim (2013)						✓					
Elazouni and Abido (2014)			✓			✓				✓	
Elazouni, Alghazi and Selim (2015)	✓					✓					
Gajpal and Elazouni (2015)	✓	✓									
Tabyang and Benjaoran (2016)							✓				

Table 2.2 (continued) : Objective functions considered in the finance-based scheduling models.

Author Name / Publication Date	Objective Function										
	Duration		Cost and Profit				Cash			Resources other than cash	
	Min. of Total Project Duration	Min. of Extended Duration	Min. of Finance Cost	Min. of Total Project Cost	Min. of Required Credit	Max. of Profit	Min. of Max. Overdraft	Min. of Cash Fluctuations	Max. of Net Present Value	Min. of Resource Fluctuations	Min. of Peak Resource Demand
El-Abbasy, Elazouni and Zayed (2016)	✓		✓	✓	✓	✓				✓	✓
Elbeltagi , Ammar , Sanad and Kassab (2016)	✓		✓	✓				✓			
Al-Shihabi and AlDurgam (2017)	✓	✓									
El-Abbasy, Elazouni and Zayed (2017)	✓	✓	✓	✓	✓	✓				✓	✓
Alavipour and Arditi (2018a)			✓								
Alavipour and Arditi (2018b)			✓								
Alavipour and Arditi (2019a)	✓	✓	✓			✓					
Alavipour and Arditi (2019b)			✓			✓					
Shiha and Hosny (2019a)			✓			✓					
Shiha and Hosny (2019b)						✓	✓				
Tavakolan and Nikoukar (2019)	✓		✓			✓			✓		
El-Abbasy Elazouni and Zayed (2020)	✓	✓	✓		✓	✓					
Al-Shihabi and AlDurgam (2020a)	✓		✓		✓	✓					
Al-Shihabi and AlDurgam (2020b)	✓	✓									
Liu, Zhang and Liu (2021)						✓					
Abido and Elazouni (2021)						✓	✓	✓			
He, He and Wang (2021)							✓				

Table 2.3 : The parameters considered in the finance-based scheduling models.

Author Name / Publication Date	Resource Leveling / Resource Allocation					Financing Alternatives and Usages		
	Release and Re-Hire	Resource Idle Days	Moment	Resource Un-levelling Penalty	Max. Resource Demand	Evaluation of Different Financing Alternatives	Charges on Unused Portion of Credit	Float Usage
Elazouni and Gab-Allah (2004)								✓
Elazouni and Metwally (2005)							✓	✓
Elazouni and Metwally (2007)			✓	✓				✓
Liu and Wang (2008)					✓			
Ali and Elazouni (2009)					✓			✓
Afshar and Fathi (2009)								✓
Elazouni (2009)								
Liu and Wang (2009)								
Senouci and Rayes (2009)								
Abido and Elazouni (2009)								✓
Liu and Wang (2010)								✓
Fathi and Afshar (2010)								✓
Elazouni and Abido (2011)								✓
Abido and Elazouni (2011)								✓
Jiang, Issa and Malek (2011)						✓		
EL-Abbasy, Zayed and Elazouni (2012)								✓
Alghazi, Selim and Elazouni (2012)								✍
Alghazi, Elazouni and Selim (2013)								✓
Elazouni and Abido (2014)	✓	✓			✓			✓
Elazouni, Alghazi and Selim (2015)								✓
Gajpal and Elazouni (2015)								✓
Tabyang and Benjaoran (2016)						✓		
El-Abbasy, Elazouni and Zayed (2016)	✓	✓			✓			✓
Elbeltagi , Ammar , Sanad and Kassab (2016)			✓					✓
Al-Shihabi and AlDurgam (2017)								✓
El-Abbasy, Elazouni and Zayed (2017)	✓	✓			✓			✓
Alavipour and Arditi (2018a)						✓		
Alavipour and Arditi (2018b)						✓		✓
Alavipour and Arditi (2019a)						✓		✓
Alavipour and Arditi (2019b)						✓		
Shiha and Hosny (2019a)						✓		✓
Shiha and Hosny (2019b)						✓		✓
Tavakolan and Nikoukar (2019)						✓		
El-Abbasy Elazouni and Zayed (2020)								✓
Al-Shihabi and AlDurgam (2020a)								
Al-Shihabi and AlDurgam (2020b)								✓
Liu, Zhang and Liu (2021)					✓			✓
Abido and Elazouni (2021)		✓						
He, He and Wang (2021)								✓

3. METHODOLOGY

In this study, the proposed finance-based scheduling models were created using an MS Excel-based approach that makes use of Visual Basic Programming Language. The primary reason for using an Excel-based approach in this study was that Excel is widely available and reliable. Each proposed finance-based scheduling model is made up of four standard modules: (1) scheduling, (2) cash flow forecasting, (3) financing cost optimization, and (4) optimal work schedule selection (the third model does not contain this module). These modules have been designed to work together in harmony. The sections that follow describe the computational processes that take place in these modules. It should be noted that these four modules are used in each of the models as standard modules. However, each model requires adjustments to these modules and additional modules to be integrated with the standard ones by considering the characteristics of the finance-based scheduling problem. These adjustments and additional models are explained in other sections, along with the development of the proposed models.

3.1 Scheduling Module

In this module, basic critical path method (CPM) calculations are used to generate a schedule. The scheduler first enters information about activity names (A_j), the total number of activities (n), the duration of each activity (d_j), and the precedence relationships between the activities. The scheduling module calculates the early start (T_{esj}), early finish (T_{efj}), late start (T_{lsj}), and late finish (T_{lfj}) times, as well as the total floats (TF_j) for the activities (j). The scheduling module performs basic CPM calculations when shifting noncritical activity start times forward or backward to generate alternative schedules. During this process, the precedence relationships between activities are never violated.

3.2 Cash Flow Forecasting Module

This module forecasts the project’s cash flow. A modified version of Alavipour and Arditi's (2018b) and Akin et al. (2024) models are used as a road map for formulating a forecast of the project cash flow, which includes (1) model parameters, (2) project cash inflows, (3) project cash outflows, (4) financing cash inflows and outflows, and (5) the cumulative cash flow balance. Together with project cash inflow forecasting (owner progress payments to the contractor) and project cash outflow forecasting (contractor payments to material dealers, subcontractors, etc.), this module also forecasts financing cash inflow (money borrowed from financial institutions) and financing cash outflow (interest on the loan and repayment of the loan). First, the cash inflow and outflow parameters are established. Next, the project's cash inflows and outflows are computed. The project's financing cash inflows and outflows are computed using the project inflows and outflows previously determined in the Cash Flow Forecasting Module and the CPM outputs of the Scheduling Module. Subsequent subsections provide a detailed description of this process in the same sequence as the above.

3.2.1 Setting up the basic parameters

As can be seen from Eq. 3.1, the total cost of a construction project is the sum of its direct and indirect costs, excluding the cost of financing.

$$Total\ Cost = Direct\ Cost + Indirect\ Cost \qquad (3.1)$$

Materials, equipment, labor, and subcontractors' costs make up the direct cost (Alavipour and Arditi, 2018b; Hinze, 2012). The working week was selected as the unit of activity duration in the first and third models, and the working day was selected as the unit of activity duration in the second model. Therefore, adding up the direct costs of all the activities completed in week k yields the contractor's weekly direct cost. Using Eq. 3.2, the direct cost is computed by adding up all weekly direct costs for the project's duration:

$$Direct\ Cost = \sum_{k=1}^{Project\ Duration} Direct\ Cost_k\ ; k = 1, 2\ , \ldots\ldots, Project\ Duration \qquad (3.2)$$

Projecting the project's indirect costs is the next stage. Adding the fixed overhead, variable overhead, mobilization cost, and bonding cost can forecast the indirect cost using Eq. 3.3 (Alavipour and Arditi, 2018a; Peterson, 2013). The accuracy of the cash flow forecast is increased when the indirect cost of a project is determined using the company's historical records (Peterson, 2013). Each of the previously mentioned costs is predicted separately in this study's Cash Flow Forecasting Module.

$$\begin{aligned}Indirect\ Cost = {} & Fixed\ Overhead\ + Variable\ \ Overhead \\ & +\ Mobilization\ Cost\ +\ Bonding\ Cost\end{aligned} \tag{3.3}$$

First, the fixed overhead is computed by multiplying the project duration, given in weeks, by the average fixed overhead per week using Eq. 3.4.

$$Fixed\ Overhead = Weekly\ average\ fixed\ overhead \times Project\ Duration \tag{3.4}$$

Next, a forecast is made for the variable overhead. The project insurance premiums, taxes, site utility costs, and management expenses comprise the variable overhead (Alavipour and Arditi, 2018a; Peterson, 2013). Although Alavipour and Arditi (2018a) and Fathi and Afshar (2010) suggest that the fixed and variable overheads can be forecasted separately, Liu and Wang (2008) and Ali and Elazouni (2009) express the variable overhead as a percentage of the direct cost. In this study, the direct cost and a percentage of the direct cost are used to forecast the variable overhead using Eq. 3.5, following the methodologies of Liu and Wang (2008) and Ali and Elazouni (2009). The percentage of the direct cost allocated to variable overhead is displayed. This percentage is established by consulting the data in the construction company's historical records and is contingent upon the nature and scope of the project.

$$\begin{aligned}& Variable\ Overhead \\ & \qquad = Direct\ Cost \\ & \qquad \times\ Variable\ overhead\ as\ percent\ of\ Direct\ Cost\end{aligned} \tag{3.5}$$

The mobilization cost, which includes the cost of tasks like clearing the area, grading the land, and installing utilities, is the indirect cost in Eq. 3.3 that needs to be estimated. The percentage of the direct cost that is used to express the mobilization cost. Numerous researchers use this percentage, which the construction company sets, to estimate the mobilization cost (e.g., Alavipour and Arditi, 2018a; Elazouni and Abido, 2011; Alghazi et al., 2013). The mobilization cost is determined by multiplying the total direct cost and variable overhead by a percentage of these two parameters in Eq. 3.6. This percentage is established by consulting the data in the construction company's historical records. It is contingent upon the nature and scope of the project.

$$Mob.Cost = (Direct\ Cost + Variable\ Overhead) \times Mobilization\ Cost\ as\ percentage \tag{3.6}$$

The profit that the contractor determines is appropriate for a project is the final term in the project’s parameters. As a percentage of (Direct Cost + Fixed Overhead + Variable Overhead + Mobilization Cost), it is expressed in Eq. 3.7. The contractor sets this percentage considering the bidding environment, the contractor's workload, and the level of market competition.

$$Profit = (Direct\ Cost + Fixed\ Overhead + Variable\ Overhead + Mobilization\ Cost) \times Profit\ expressed\ as\ a\ percentage \tag{3.7}$$

The bonding cost, which is the final variable in Eq. 3.3, is finally predicted in the Cash Flow Forecasting Module by multiplying the total of the direct cost, fixed overhead, variable overhead, mobilization cost, and profit by a percentage that corresponds to the bonding cost using Eq. 3.8. This percentage is determined by the risk an insurance company takes when it agrees to issue a financial instrument (a surety bond) that protects against a construction company's possible default. The size of the premium that the construction company pays to the surety company for the bond is reflected in this percentage, which is set by the surety company (Clough et al., 2015).

$$Bonding\ Cost = (Direct\ Cost + Fixed\ Overhead + Variable\ Overhead + Mobilization\ Cost + Profit) \times Bonding\ Cost\ expressed\ as\ a\ percentage \tag{3.8}$$

The direct cost, fixed overhead, variable overhead, mobilization cost, bonding cost, and profit are added up to determine the bid price in Eq. 3.9. The bid price is the offer made in the bid that the bidder submits to the owner, so it must be determined. When the project's cash inflows are anticipated, the bid price will be utilized subsequently to calculate the progress payments.

$$\begin{aligned} Bid\ Price = {} & Direct\ Cost + Fixed\ Overh. + Variable\ Overhead \\ & + Mobilization\ Cost + Bonding\ Cost + Profit \end{aligned} \tag{3.9}$$

These fundamental variables are used to forecast the project and financing cash flows, as well as to determine the best optimal work schedule considering financing cost.

3.2.2 Setting up the project cash inflows

The contractor's project cash inflows are established by calculating the owner's interim payments. Typically, the contractor requests these payments approximately every four weeks or at the end of each month (Alavipour and Arditi, 2018a; Hinze, 2012). It should be mentioned, though, that usually, the contractor does not receive the interim payment right away following the submission of the payment request. The time elapsed between the contractor submitting a payment request and the contractor receiving the payment could be as much as one month. Furthermore, it should be mentioned that, in accordance with the common practice, the private owner may choose to withhold retainage. After the contractor addresses the punch list items just before final completion, the owner is entitled to use the accumulated retainage to correct the contractor's defective work, complete any omissions, and settle any debts the contractor may have to third parties. At final completion, the contractor receives their entire retainage, which was withheld from them (or what has been left over after the owner pays for any defective work, omissions, or debts). This module takes into account the owner's percentage of the payment retained, the contractor's frequency of submitting payment requests, the owner's lag in responding to the contractor’s payment requests, and the delay in the final payment, which includes the owner's return of any money retained during the project. The model can more accurately represent project conditions when these factors are taken into account when setting up project cash inflows. The interim and final payments made by the owner to the contractor make up the project cash inflow. Eq. 3.10 is used to calculate the interim payments. This formula incorporates expenses other than direct costs using the bid price to direct cost ratio. Additionally, the bid price is multiplied by a percentage of the bid price that represents the advance payment if the contractor receives payment in advance from the owner. In order to distribute the advance payment evenly over the project's duration, it is forecasted in this manner and then divided by the project's duration, expressed in 4-week periods. The contractor's cash inflow is made up of the interim payments.

$$\begin{aligned}&\text{Project Cash Inflow}_{\text{t + Lag in Interim Payments}}\\ &\quad = \left[\begin{array}{l}\text{(1 - Retainage as a percentage of bid price)}\\ \qquad \times \dfrac{\text{Bid Price}}{\text{Direct Cost}} \times \text{Direct Cost}_t\end{array}\right] - \\ &\quad \frac{\text{(Bid Price} \times \text{Advance Payment as a percentage of bid price)}}{\text{Project Duration expressed in 4-week periods}}\\ &\text{t = 1, 2, ..., (T - 1) (expressed in 4-week payment periods)}\end{aligned} \tag{3.10}$$

where T is the time of the final payment at final completion.

It should be mentioned that the interim payment is calculated without taking the final payment into account. The determination of the final payment at the end of the project's duration, using the owner's late payment and return of any money retained during the project's duration, is the final step in the second section of the Cash Flow Forecasting Module. Eq. 3.11 can be used to calculate the return on retainage.

$$Final\ Payment\ = Last\ Payment + (Bid\ Price \times Retainage\ Percent) \tag{3.11}$$

3.2.3 Setting up the project cash outflows

The method of Alavipour and Arditi (2018a) is employed to predict the cash outflows for the project. In this method, the mobilization and bonding costs are considered separately from other overheads. The reason for this is that while other overheads are incurred throughout the execution of the construction project, mobilization and bonding costs are incurred at the start of the project. The periodic disbursements (*Project Cash Outflow*$_t$) after four-week periods t are calculated using Eq. 3.12, as the owner's payments to the contractor are typically made every four weeks. The mechanism of project cash inflow and outflow is presented in Figure 3.1.

$$\left\{\begin{array}{l}\text{Project Cash Outflow}_{\text{t = 0}} \text{ = Mobilization Cost + Bonding Cost}\\ \text{Project Cash Outflow}_{\text{t}} \text{ = (Direct Cost}_{\text{t}} \text{ + Fixed Overhead}_{\text{t}} \text{ + Variable Overhead}_{\text{t}}\text{)}\\ \text{t = 1, 2, 3, ..., Project Duration (expressed in 4-week periods)}\end{array}\right\} \tag{3.12}$$

3.2.4 Setting up the financing cash inflow and outflow

The retainage that the owner withholds results in a steady decrease in the contractor's project cash inflow while the outflow stays constant. Contractors need to consider this and keep a close eye out for negative cash flows, as they could prevent the project from completing on time if they do not have the necessary funds for project disbursements. To prevent their project cash flow from going negative, contractors frequently borrow money from financial institutions or draw credits from their funds. There are non-trivial financing costs associated with both options.

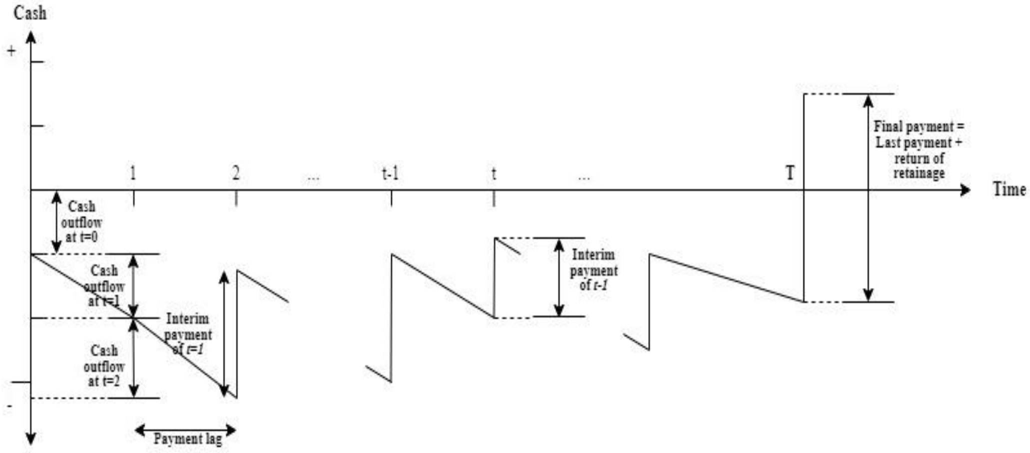

Figure 3.1 : Typical cash flow diagram of a construction project.

The financing cash inflows and outflows need to be forecasted after the project's cash inflows and outflows. Financing cash outflows include paying interest and returning borrowed money to lenders, whereas financing cash inflows consist of money borrowed from financial institutions. Eqs. 3.13 and 3.14 are used to calculate the financing cash inflows and outflows, respectively. The Financing Cost Optimization Module presents detailed calculations about financing cash inflows and outflows. Eq. 3.13 illustrates that the financing cash inflow comprises the total amount borrowed from lenders.

$$Financing\ Cash\ Inflow_t = \sum_{t=1}^{T-1} Borrowed\ money_t \qquad (3.13)$$

The financing cash outflow equals the total of the financing cost plus the amount of principal that is returned to the lenders, as shown in Eq. 3.14.

$$Financing\ Cash\ Outflow_t = \sum_{t=1}^{T} Financing\ Cost_t + \sum_{t=1}^{T} Repaid\ Money_t \qquad (3.14)$$

3.2.5 Setting up the cumulative balance of the cash flow

The cash inflows and outflows associated with the project and the financing account for the contractor's cash flow. The cumulative cash flow balance can be computed after project and financing cash inflows and outflows have been forecasted. In the Cash Flow Forecasting Module, the cumulative balance of the cash flow is computed using Eq. 3.15. The total cash flow, or inflow-outflow, for period *t* should exceed the contractor's minimum specified cumulative cash flow balance. This includes both project cash inflow and project cash outflow, financing cash inflow, and financing cash outflow. Depending on the contractor's level of risk tolerance, the minimum cumulative balance of the cash flow can be zero or greater than zero. A value of zero indicates that it is certain that the projected cash flows will not change. In contrast, a positive value indicates that additional funds should be borrowed to handle unforeseen changes in the cash flows. Alavipour and Arditi (2019) state that, in other words, the contractor should always be able to pay its creditors. This implies that the cumulative net balance of the cash flow should never go below zero but may exceed zero to account for unforeseen expenses. It should be noted that the contractor will be more likely to incur higher financing costs if they choose to have a minimum cumulative balance of cash flow that is greater than zero than if they prefer a minimum cumulative balance of cash flow that is equal to zero. The degree of reliability of the cash flow forecasts determines the trade-off between these two options.

$$\begin{aligned} &\text{Cumulative balance of the cash flow}_t \\ &\quad = \text{Cumulative balance of the cash flow}_{t-1} + \text{Project Cash Inflow}_t \\ &\quad\quad - \text{Project Cash Outflow}_t + \text{Financing Cash Inflow}_t - \text{Financing Cash Outflow}_t \qquad (3.15) \\ &t = 1, 2, 3, \ldots\ldots, T \end{aligned}$$

The contractor's cash flow balance may alter dramatically upon acquiring an external fund from a financial institution. Borrowing money can help avoid negative cash balances, as shown in Figure 3.2. However, the principal and interest must also be considered while establishing the cumulative cash flow balance. The total amount borrowed must be sufficient to pay off the borrowed funds' interest and the negative cash flow balance.

3.3 Financing Cost Optimization Module

The Financing Cost Optimization Module's goal is to find multiple work schedules that can be finished for the lowest possible financing cost. The time and amount of the loan, the principal and interest repayment schedule, and other factors are all determined by applying a linear programming algorithm to minimize the financing cost. Apart from changing the start times of the activities, the quantity and timing of these parameters are also regarded as variables of the problem. For each financing option in this study, a number of schedules with various combinations of the borrowing periods for the necessary funds, the periods for the repayment of the principal for each loan, and the interest payments of these loans can be provided.

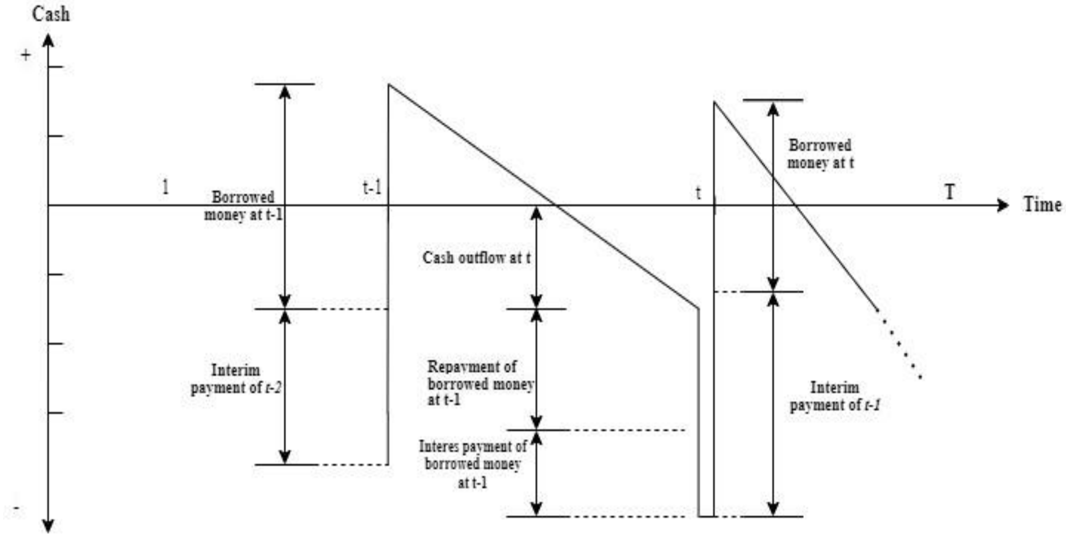

Figure 3.2 : Cash flow diagram with the financial flow.

The Optimization Module, which calculates the project's financing cost for various combinations of these variables, takes into account the timing and amount of (1) borrowing the necessary additional funds, (2) repayment of the principal, and (3) interest payments in the process of selecting financing alternatives for borrowing additional cash to maintain the positive cash flow. Table 3.1 illustrates the utilization of three distinct financing options in the Financing Cost Optimization Module: short-term loans, long-term loans, and credit lines. There are differences in the terms of borrowing money, repaying borrowed funds, and paying interest for every financing option shown in Table 3.1.

During project execution, if the cumulative net balance of the cash flow falls below zero or the user-specified minimum limit, the best available financing option is chosen to borrow the required amount of money to keep the balance from falling below zero.

To predict how much money will be borrowed, Eq. 3.16 can be used. Three variables make up Eq. 3.16: the total amount borrowed as a line of credit at the end of period *t*, the total amount borrowed as a long-term loan at the start of the project, and the total amount borrowed as short-term loans at the end of period *t*.

$$\begin{aligned} &Total\ Borrowed\ Money_t \\ &\qquad = BM_{STL_t} + BM_{LTL_t} + BM_{LC_t}\ ;\ t = 0, 1, 2, \ldots., (T\text{-}1) \end{aligned} \tag{3.16}$$

where *BM* represents borrowed money, *SLT* represents short-term loans, *LTL* represents long-term loans, and *LC* represents line-of-credit.

Short-term loans can be taken out in this study every month or on an irregular basis (i.e., every two, three, or four months). However, a long-term loan can only be taken out once at the start of the project. In contrast to these two financing options, the line-of-credit is an account that permits the contractor to use the allotted credit limit whenever they see fit, provided that they repay the borrowed money regularly. The data on the alternative financing methods utilized in this study is shown in Table 3.1 and includes financing alternatives, interest payment schedules, total credit limits, and credit limits in each period.

The other aspects of the issue are the repayment of the principal and the interest of the borrowed money. To find the amount of money that has been repaid, Eq. 3.17 can be used. Eq. 3.17 has three variables that indicate how much money will be used to repay short-term loans at the end of period *t*, how much money will be used to repay long-term loans at the end of period *t*, and how much money will be used to repay a line of credit at the end of period *t*.

Regarding the schedules showing the timings and amounts of the repayment of the loans, it is anticipated that a short-term loan may be repaid 1, 2, 3, or 4 months after the funds are borrowed, and a long-term loan will be returned either monthly or after the project.

Table 3.1 : Information about financing alternatives.

Financing method	Altern.	Time of taking money	Time of repaying (After)	Time of repaying interest	Financing code	Total credit limit ($)	Credit limit-each period ($)	Monthly interest	APR (%)
Short-term	1	Every month STL1	One month	Monthly or at the time of repaying principal money	$STL1_1$	CL_{STL1_1}	CL'_{STL1_1}	i_{STL1_1}	18%
	2		Two months		$STL1_2$	CL_{STL1_2}	CL'_{STL1_2}	i_{STL1_2}	15%
	3		Three months		$STL1_3$	CL_{STL1_3}	CL'_{STL1_3}	i_{STL1_3}	15%
	4		Four months		$STL1_4$	CL_{STL1_4}	CL'_{STL1_4}	i_{STL1_4}	14%
	5	Every 2 mnths STL2	One month		$STL2_1$	CL_{STL2_1}	CL'_{STL2_1}	i_{STL2_1}	16%
	6		Two months		$STL2_2$	CL_{STL2_2}	CL'_{STL2_2}	i_{STL2_2}	13%
	7		Three months		$STL2_3$	CL_{STL2_3}	CL'_{STL2_3}	i_{STL2_3}	13%
	8		Four months		$STL2_4$	CL_{STL2_4}	CL'_{STL2_4}	i_{STL2_4}	15%
	9	Every 3 mnths STL3	One month		$STL3_1$	CL_{STL3_1}	CL'_{STL3_1}	i_{STL3_1}	17%
	10		Two months		$STL3_2$	CL_{STL3_2}	CL'_{STL3_2}	i_{STL3_2}	13%
	11		Three months		$STL3_3$	CL_{STL3_3}	CL'_{STL3_3}	i_{STL3_3}	10%
	12		Four months		$STL3_4$	CL_{STL3_4}	CL'_{STL3_4}	i_{STL3_4}	10%
	13	Every 4 mnths STL4	One month		$STL4_1$	CL_{STL4_1}	CL'_{STL4_1}	i_{STL4_1}	14%
	14		Two months		$STL4_2$	CL_{STL4_2}	CL'_{STL4_2}	i_{STL4_2}	8%
	15		Three months		$STL4_3$	CL_{STL4_3}	CL'_{STL4_3}	i_{STL4_3}	9%
	16		Four months		$STL4_4$	CL_{STL4_4}	CL'_{STL4_4}	i_{STL4_4}	16%
Long-term loan	17	t=0	Monthly or T		LTL	CL_{LTL}	-	i_{LTL}	8.5%
Line of	18	After 1 months	Any time	Monthly	LC_1	CL_{LC1}	CL'_{LC1}	i_{LC}	12%
	19	After 2 months	Any time	Monthly	LC_2	CL_{LC2}	CL'_{LC2}		
	20	After 3 months	Any time	Monthly	LC_3	CL_{LC3}	CL'_{LC3}		
	21	After 4 months	Any time	Monthly	LC_4	CL_{LC4}	CL'_{LC4}		
	22	After 5 months	Any time	Monthly	LC_5	CL_{LC5}	CL'_{LC5}		

Because of the nature of a line of credit account, there is no set repayment schedule; however, this study offers a schedule for managing it. The various options for repaying a line of credit and short-term loans are also shown in Table 3.1.

$$Total\ Repaid\ Money_t \ = RM_{STL_t} + RM_{LTL_t} + RM_{LC_t}; \quad t = 0, 1, 2, ..., T \qquad (3.17)$$

where RM represents the repaid money. Setting up a schedule for borrowed and returned monies is the next stage. The schedules that are used to show when borrowed and repaid funds are due from the start of the project until the last payment is represented by the matrices in Eqs. 3.18 and 3.19. If a financial alternative is chosen, the total amount borrowed—abbreviated as "*BM*" for "borrowed money"—is computed in the Financing Cost Optimization Module and shown in the matrix that depicts the borrowing schedule in Eq. 3.18. Any other cell that does not show borrowed money has a value of zero. This matrix's rows display the borrowing schedule, and its columns list all available financing alternatives according to their type (such as lines of credit, long-term loans, and short-term loans). This data is consistent with the data presented in Table 3.1.

When a financing alternative is chosen to obtain the required funds, the repayment of the principal for that additional money is also displayed in a matrix that serves as a schedule of repaid money in Eq. 3.19, where "*RM*" stands for "Repaid Money." For instance, choosing *STL₃₂* as the financing option, as shown in Table 3.1, means that the funds are borrowed as a short-term loan with a three-month repayment period after the project's second month.

The three financing alternatives, their borrowing and repayment schedules, and the total forecasted project cash inflows and outflows are all considered when deciding how much and when to borrow money.

$$Schedule\ of\ Borrowed\ \ Money$$
$$= \left(\begin{array}{cccc|c|c}
\mathrm{BM}_{\mathrm{STL1}_0} & \mathrm{BM}_{\mathrm{STL2}_0} & \mathrm{BM}_{\mathrm{STL3}_0} & \mathrm{BM}_{\mathrm{STL4}_0} & \mathrm{BM}_{\mathrm{LTL}_0} & \mathrm{BM}_{\mathrm{LC}_0} \\
\mathrm{BM}_{\mathrm{STL1}_1} & \mathrm{BM}_{\mathrm{STL2}_1} & \mathrm{BM}_{\mathrm{STL3}_1} & \mathrm{BM}_{\mathrm{STL4}_1} & \mathrm{BM}_{\mathrm{LTL}_1} & \mathrm{BM}_{\mathrm{LC}_1} \\
\mathrm{BM}_{\mathrm{STL1}_2} & \mathrm{BM}_{\mathrm{STL2}_2} & \mathrm{BM}_{\mathrm{STL3}_2} & \mathrm{BM}_{\mathrm{STL4}_2} & \mathrm{BM}_{\mathrm{LTL}_2} & \mathrm{BM}_{\mathrm{LC}_2} \\
\mathrm{BM}_{\mathrm{STL1}_3} & \mathrm{BM}_{\mathrm{STL2}_3} & \mathrm{BM}_{\mathrm{STL3}_3} & \mathrm{BM}_{\mathrm{STL4}_3} & \mathrm{BM}_{\mathrm{LTL}_3} & \mathrm{BM}_{\mathrm{LC}_3} \\
\mathrm{BM}_{\mathrm{STL1}_4} & \mathrm{BM}_{\mathrm{STL2}_4} & \mathrm{BM}_{\mathrm{STL3}_4} & \mathrm{BM}_{\mathrm{STL4}_4} & \mathrm{BM}_{\mathrm{LTL}_4} & \mathrm{BM}_{\mathrm{LC}_4} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\mathrm{BM}_{\mathrm{STL1}_T} & \mathrm{BM}_{\mathrm{STL2}_T} & \mathrm{BM}_{\mathrm{STL3}_T} & \mathrm{BM}_{\mathrm{STL4}_T} & \mathrm{BM}_{\mathrm{LTL}_T} & \mathrm{BM}_{\mathrm{LC}_T}
\end{array}\right) \qquad (3.18)$$

$$Schedule\ of\ Repaid\ Money$$

$$= \left(\begin{array}{cccc|c|c} \mathrm{RM}_{\mathrm{STL1}_0} & \mathrm{RM}_{\mathrm{STL2}_0} & \mathrm{RM}_{\mathrm{STL3}_0} & \mathrm{RM}_{\mathrm{STL4}_0} & \mathrm{RM}_{\mathrm{LTL}_0} & \mathrm{RM}_{\mathrm{LC}_0} \\ \mathrm{RM}_{\mathrm{STL1}_1} & \mathrm{RM}_{\mathrm{STL2}_1} & \mathrm{RM}_{\mathrm{STL3}_1} & \mathrm{RM}_{\mathrm{STL4}_1} & \mathrm{RM}_{\mathrm{LTL}_1} & \mathrm{RM}_{\mathrm{LC}_1} \\ \mathrm{RM}_{\mathrm{STL1}_2} & \mathrm{RM}_{\mathrm{STL2}_2} & \mathrm{RM}_{\mathrm{STL3}_2} & \mathrm{RM}_{\mathrm{STL4}_2} & \mathrm{RM}_{\mathrm{LTL}_2} & \mathrm{RM}_{\mathrm{LC}_2} \\ \mathrm{RM}_{\mathrm{STL1}_3} & \mathrm{RM}_{\mathrm{STL2}_3} & \mathrm{RM}_{\mathrm{STL3}_3} & \mathrm{RM}_{\mathrm{STL4}_3} & \mathrm{RM}_{\mathrm{LTL}_3} & \mathrm{RM}_{\mathrm{LC}_3} \\ \mathrm{RM}_{\mathrm{STL1}_4} & \mathrm{RM}_{\mathrm{STL2}_4} & \mathrm{RM}_{\mathrm{STL3}_4} & \mathrm{RM}_{\mathrm{STL4}_4} & \mathrm{RM}_{\mathrm{LTL}_4} & \mathrm{RM}_{\mathrm{LC}_4} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \mathrm{RM}_{\mathrm{STL1}_\mathrm{T}} & \mathrm{RM}_{\mathrm{STL2}_\mathrm{T}} & \mathrm{RM}_{\mathrm{STL3}_\mathrm{T}} & \mathrm{RM}_{\mathrm{STL4}_\mathrm{T}} & \mathrm{RM}_{\mathrm{LTL}_\mathrm{T}} & \mathrm{RM}_{\mathrm{LC}_\mathrm{T}} \end{array}\right) \tag{3.19}$$

The three different financing alternatives, namely line-of-credit, short-term loans, and long-term loans require different calculation steps to determine the financing cost of each loan type. The Financing Cost Optimization Module computes the financing cost for each financing option after the schedules for borrowed and repaid money are established.

Line-of Credit

A line of credit is the most common financing alternative for contractors since it allows them to borrow money when they need it. However, the interest rate on a line of credit is typically higher than that of other financing options. It should be emphasized that a contractor may borrow only the amount specified by the lender. The contractor has the option of repaying the loan in full or in installments. On the other hand, the contractor might pay the interest on a monthly basis.

In this study, it was agreed that the interest payment would be calculated monthly. In addition, it has been determined that the contractor must pay the money that was borrowed in one lump sum payment. Eq. 3.20 can be used to compute the interest payment on a line of credit.

$$Financing\ Cost_{LC_t} = BM_{LC_t} \times i_{LC_t};\ \ t = 1, 2, 3, \ldots\ldots, T \tag{3.20}$$

where *i* represents the monthly effective interest rate.

Short-Term Loans

It is important to remember that interest payments for short-term loans can be made either monthly (Eq. 3.22) or at the time of repayment of the borrowed money (Eq. 3.22). This choice is based on the aim of minimizing financing cost. Short-term loans allow the contractor to borrow varying amounts of money at different stages of the project. In this study, contractors can obtain monthly or periodic short-term loans (see Table 3.1). A contractor may use as many short-term loans as necessary to complete the project as long as the borrowed funds do not exceed the lender's limit. The money can be borrowed for one, two, three, or four months. Interest payments can be made either monthly or when the principal is repaid. In this study, interest payments are made on a monthly basis because delaying interest payments can be more expensive in terms of financing for the contractor. The proposed models in this study, on the other hand, allow the user to select one of the two possibilities. If the contractor pays the interest monthly, Eq. 3.21 can be used to calculate the financing cost, otherwise Eq. 3.22 can be used.

Interest payments on the short-term loan due each month:

$$Financing\ Cost_{LC_t} = BM_{LC_t} \times i_{LC_t};\ \ t = 1, 2, 3, \ldots\ldots, T \tag{3.21}$$

where *i* represents the monthly effective interest rate.

Interest payments of the short-term loan at the time of the payment:

$$\text{Financing Cost}_{\text{STLt}} = \text{BM}_{\text{STLt}} \times \hat{\imath}_{\text{STL}} \tag{3.22}$$

where *i* is the monthly effective interest rate, and *î* is the effective interest rate for period *T* (i.e., final completion).

Long-Term Loans

A long-term loan can only be borrowed once at the beginning of the project. It should not exceed the limit specified by the lender. The advantage of a long-term loan is that the contractor can fund the project from the start to cover initial costs such as mobilization and bonding. Long-term loans often have lower interest rates than lines of credit and short-term loans. Thus, taking out a long-term loan as a lump payment at the start of the project allows the contractor to achieve a reduced financing cost. Like short-term loans, long-term loans can have monthly interest payments (Eq. 3.23) or lump sum payments at the project's completion (Eq. 3.24). The decision to minimize the long-term loan's financing cost led to this choice. A long-term loan might be repaid on a monthly basis or in full at the completion of the project. Furthermore, the contractor and lender must agree on an interest payment schedule. Interest payments can be made on a monthly basis or in one lump sum at the end of the project. However, similar to short-term loans, deferring the interest payment may result in higher financing costs for the contractor. In this study, interest payments and the repayment of a portion of the long-term loan are made monthly. However, the user of the proposed model has the option of making a different decision about the project's characteristics. Eq. 3.23 can be used to compute the monthly interest payment on a long-term loan. On the contrary, Eq. 24 can be used.

Monthly interest payments of the long-term loan:

$$\text{Financing Cost}_{\text{LTLt}} = \frac{\left[\text{BM}_{\text{LTL}} \times \left(\text{i}_{\text{LTL}} \times \left(1 + \text{i}_{\text{LTL}}\right)^{\text{T}}\right)\right]}{\left[\left(1 + \text{i}_{\text{LTL}}\right)^{\text{T}} - 1\right]} - \frac{\text{BM}_{\text{LTL}}}{\text{T}} \tag{3.23}$$

Interest payments of the long-term loan at the time the principal is repaid:

$$\text{Financing Cost}_{\text{LTL}_{\text{T}}} = \text{BM}_{\text{LTL}} \times \hat{\text{i}}_{\text{LTL}} \tag{3.24}$$

In Eq. 3.25, where ‘’*FC*’’ stands for Financing Cost, there is a schedule that illustrates the interest payment schedule for each financing alternative over the project. Since the total of these interest payments equals the project's financing cost, the matrix that shows the interest payment schedule is crucial.

$$\mathit{Schedule\ of\ Interest\ Payment}$$

$$= \left(\begin{array}{cccc|c|c}
\text{FC}_{\text{STL1}_0} & \text{FC}_{\text{STL2}_0} & \text{FC}_{\text{STL3}_0} & \text{FC}_{\text{STL4}_0} & \text{FC}_{\text{LTL}_0} & \text{FC}_{\text{LC}_0} \\
\text{FC}_{\text{STL1}_1} & \text{FC}_{\text{STL2}_1} & \text{FC}_{\text{STL3}_1} & \text{FC}_{\text{STL4}_1} & \text{FC}_{\text{LTL}_1} & \text{FC}_{\text{LC}_1} \\
\text{FC}_{\text{STL1}_2} & \text{FC}_{\text{STL2}_2} & \text{FC}_{\text{STL3}_2} & \text{FC}_{\text{STL4}_2} & \text{FC}_{\text{LTL}_2} & \text{FC}_{\text{LC}_2} \\
\text{FC}_{\text{STL1}_3} & \text{FC}_{\text{STL2}_3} & \text{FC}_{\text{STL3}_3} & \text{FC}_{\text{STL4}_3} & \text{FC}_{\text{LTL}_3} & \text{FC}_{\text{LC}_3} \\
\text{FC}_{\text{STL1}_4} & \text{FC}_{\text{STL2}_4} & \text{FC}_{\text{STL3}_4} & \text{FC}_{\text{STL4}_4} & \text{FC}_{\text{LTL}_4} & \text{FC}_{\text{LC}_4} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\text{FC}_{\text{STL1}_\text{T}} & \text{FC}_{\text{STL2}_\text{T}} & \text{FC}_{\text{STL3}_\text{T}} & \text{FC}_{\text{STL4}_\text{T}} & \text{FC}_{\text{LTL}_\text{T}} & \text{FC}_{\text{LC}_\text{T}}
\end{array}\right) \tag{3.25}$$

The financing cost at the end of each period *t* are determined using Eq. 3.26, which leads in Eq. 3.27 to the objective function of minimizing the total of the financing costs incurred at the end of each period *t*. This completes the setup of the net financing cash flow.

$$Financing\ Cost_t = Financing\ Cost_{STL_t} + Financing\ Cost_{LTL_t} + Financing\ Cost_{LC_t} \tag{3.26}$$

The objective function is expressed in Eq. 3.27.

$$Minimum\ Financing\ Cost = MIN \sum_{t=1}^{T} Financing\ Cost_t \tag{3.27}$$

Five constraints are considered in the optimization model.

The first constraint (Eq. 3.28) ensures that the total amount borrowed through short-term loans does not exceed the overall limit set by the lender.

$$\sum_{t=1}^{T-1} \text{Borrowed Money}_{\text{STLt}} \leq \text{ Limit for Borrowed Money}_{\text{STL}} \tag{3.28}$$

The second constraint (Eq. 3.29) prevents the total amount borrowed for short-term loans after period *t* from exceeding the maximum amount the lender has set for each period t of loans.

$$\text{Borrowed Money}_{\text{STLt}} \leq \text{ Limit for Borrowed Money}_{\text{STLt}} \tag{3.29}$$

The third constraint, found in Eq. 3.30, ensures that the total amount borrowed for a long-term loan does not surpass the upper limit given by the lender for such loans.

$$\text{Borrowed Money}_{\text{LTL}} \leq \text{ Limit for Borrowed Money}_{\text{LTL}} \tag{3.30}$$

The constraint placed on a line-of-credit by a financial institution is the subject of the fourth constraint (Eq. 3.31). It ensures that the total amount borrowed under a line of credit does not surpass the credit limit set by the financial institution.

$$\sum_{t=1}^{T-1} \text{Borrowed Money}_{\text{LCt}} \leq \text{ Limit for Borrowed Money}_{\text{LC}} \tag{3.31}$$

The fifth constraint (Eq. 3.32) keeps the total amount taken out of the credit line after each period from going over the credit limit that the financial institution has set for that particular period.

$$\text{Borrowed Money}_{\text{LCt}} \leq \text{ Limit for Borrowed Money}_{\text{LCt}} \tag{3.32}$$

Linear programming models need a linear objective function, linear constraint equations, and continuous decision variables. The problem of financing cost optimization meets each of these prerequisites, so linear programming is a good fit for resolving it.

Linear programming models have the distinct advantage of allowing for "what if" analysis. The model user can compute the sensitivity of the optimal solution to modifications in the parameters used in the objective function and the constraint equations.

(1) As can be seen in Eq. 3.26, the financing cost makes up the objective function in Eq. 3.27. In this case, the coefficients of the variables are either 0 or 1 (e.g., the coefficient may be one (1) if the general contractor uses a line of credit and zero (0) if it does not). This financing cost is the sum of any short-term, long-term, and line-of-credit loans, if any. As a result, sensitivity analysis—referred to in this instance as "productivity analysis"—can be carried out by the user of the proposed model.

(2) Similarly, the user of the proposed model can once more conduct sensitivity analysis because the coefficients of the variables on the left-hand side of all five constraint equations (Eqs. 3.28–3.32) are always 0 or 1.

(3) Lastly, the financial institution's limits on the maximum amount of money that the general contractor can borrow are represented by the right-hand sides of each of the five constraint equations. It is possible for the user of this linear programming model to carry out sensitivity analysis—referred to in this case as "Specification Analysis"—to determine whether adjustments to these limits affect the optimal solution.

3.4 Optimal Work Schedule Selection Module

The first and second models include the use of total floats of noncritical activities to shift the activities' start times and obtain several work schedules to minimize the financing cost of the contractors further. When it is considered that there can be multiple schedules with the minimum financing cost, it becomes necessary to have a selection process to determine the best optimal schedule among the optimal schedules with the minimum financing cost. Although all three developed models in this study use the previously mentioned modules with slight readjustments, the use of the Optimal Work Schedule Selection Module varies greatly. Each proposed model in this study aims to fill a different gap in the finance-based scheduling literature. Each model has a different approach to selecting the best optimal schedule for a construction project.

The first and second proposed models involve the Optimal Work Schedule Selection Module to identify the best optimal schedule. However, the third proposed model aims to minimize the financing cost of the contractor by considering multiple financing methods that have never been considered in the finance-based scheduling literature. The third model does not consider using total floats to minimize the financing cost of the project further. Hence, only one optimal work schedule can be found by using the third model of this study. However, several financing schedules can be found using different combinations of financing alternatives. Contrary to the first and second proposed models, the third model does not involve the Optimal Work Schedule Selection Module. The details of the calculations for this module are explained in the following sections.

4. DEVELOPMENT AND ILLUSTRATIVE CASE OF THE FIRST MODEL

4.1 Development of the First Model

The Scheduling Module, the Project Cash Flow Forecasting Module, the Financing Cost Optimization Module, and the Optimal Work Schedule Selection Module, which were explained in the previous section, are used in the development of this study's first model. No adjustments or additional steps are made during the development of the first model in addition to the steps in the Methodology section. The flowchart that explains the steps followed in the first model is presented in Figure 4.1.

4.1.1 Optimal work schedule selection in the first proposed model

The optimal Work Schedule Selection module in the first model considers the cost of float consumption to determine which solutions are found by executing the three previous modules, which is the best work schedule. One of the main claims made in this model is that float consumption also has a cost, which is explained in the Introduction section. Furthermore, while using the total float of the activities may help minimize financing costs, there is a chance it will increase the likelihood of a project not being finished on time. In other words, it increases the possibility of establishing a network of numerous critical and near-critical tasks, thereby enabling the contractor to evade late completion.

The project manager can also use this feature to choose the work schedule with the lowest financing cost among those with the same cost. Float is a commodity, and moving an activity within its float—that is, using this commodity—may make it more expensive, according to de la Garza et al. (1991).

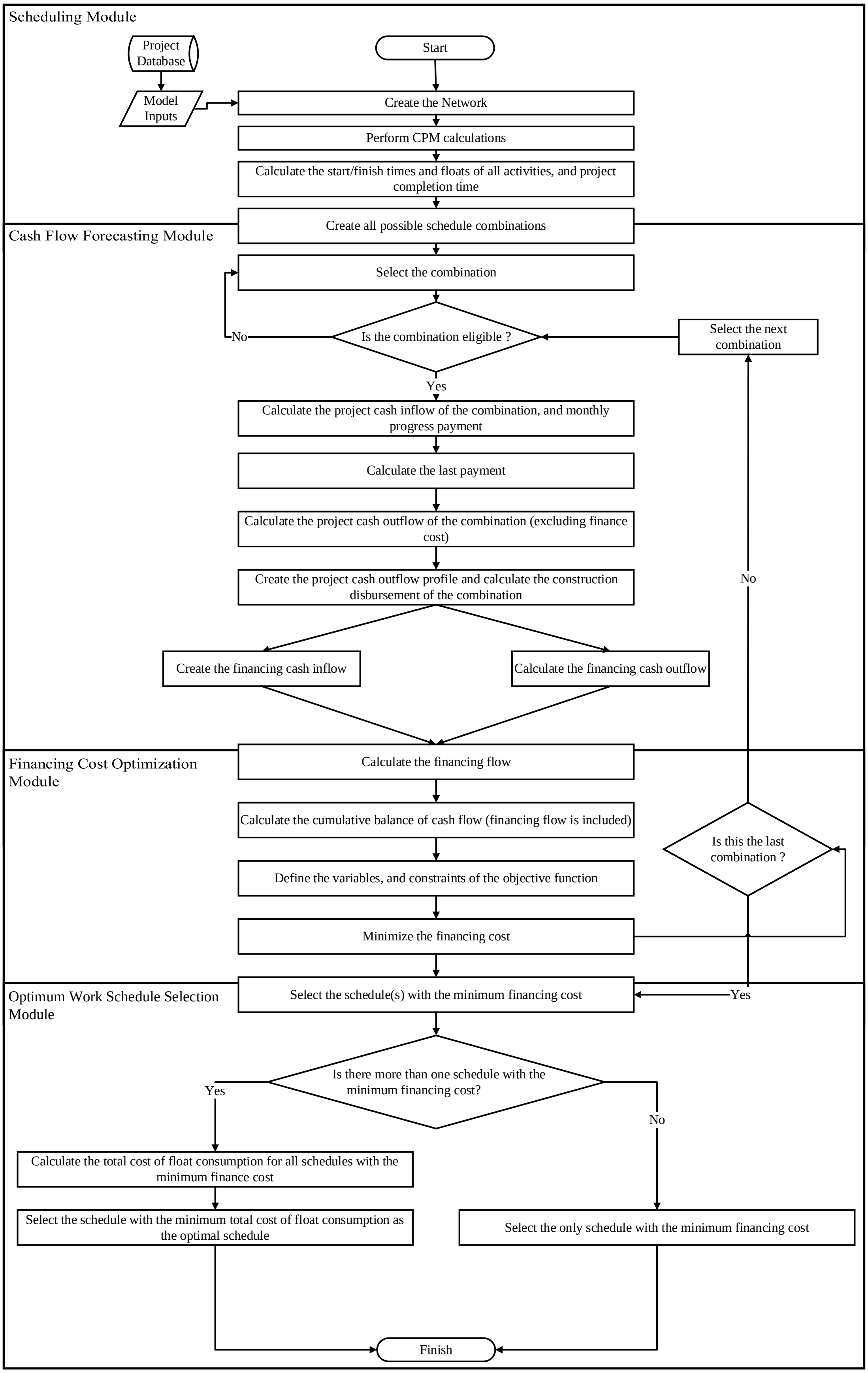

Figure 4.1 : The flowchart of the first proposed model.

The value of an activity's total float can be determined by a variety of factors, such as the activity's type, relation to other activities, timing (i.e., how early or late in the project it is completed), significance concerning other activities, and amount of total on the activity's path. There may be a difference in the value of each float time. One could argue that, for instance, using one week of total float out of ten weeks of available float would be less expensive than using one week of total float out of two weeks of available float because the former has a more negligible impact on the possibility of causing a project delay than the latter. Put another way, using a week of float is less expensive, as more float is available in an activity.

This module in the first model computes the cost of float consumption to determine which work schedule, out of several with the same financing cost, is best. This module uses the weekly float consumption costs of the activities to determine the cost of float consumption when the start times of the activities are changed to minimize the financing cost. The project's optimal work schedule can be identified as the one with the lowest float consumption cost (Eq. 4.1).

$$\begin{aligned}&\text{Minimum Cost of Float Consumption}\\&= \text{Min}\left\{\begin{array}{l}\sum_{j=1}^{n} \text{Cost of Float Consumption}_j \times \text{ total float used in activity j ;}\\ \text{for all schedules with the minimum financing cost}\end{array}\right\}\end{aligned} \tag{4.1}$$

where n represents the total number of activities.

In the first model, a different method has been used to compute the cost of float consumption. It is well-known that very few construction projects are completed on schedule, even with the best-intentioned project managers. As a result, owners impose liquidated damages for each week that contractor-caused delays in essential activities cause the project to be delayed, thereby pressuring contractors to complete it on time or sooner. Project delays are more likely when the total float is used because there is a greater chance of a network of numerous critical and near-critical activities being created. In other words, employing total float raises the possibility that the contractor will be required to reimburse the owner for liquidated damages at project completion due to delays caused by the contractor, such as delaying the start of an activity. It follows that the contractor may incur costs if they choose to use total float to reduce financing costs. The cost of float consumption in the proposed model is determined in

Eq. 4.2 by multiplying the normalized total float of the activities by the weekly liquidated damages. According to the basic rule of supply and demand theory, the price of a scarce good is higher than that of an abundant good. As a result, the value of total float is higher for activities with fewer weeks of available float than for activities with many weeks of available float. Eq. 4.3 is used to determine each activity's normalized total float. According to this equation, an activity with two weeks of available float will probably impact project completion more than one with ten weeks, as indicated by $1/TF_j$.

$$\text{Cost of Float Consumption}_j = \text{Weekly Liquidated Damages} \times \text{NTF}_j \tag{4.2}$$

$$\text{NTF}_j = \frac{\frac{1}{\text{TF}_j}}{\sum_{j=1}^{n} \frac{1}{\text{TF}_j}} \tag{4.3}$$

where *j* denotes the activity, and NTF_j is the normalized total float.

The total costs of using floats to account for delays caused by contractors are the cost of float consumption in each work schedule with minimum financing cost.

4.2 Illustrative case of the first model

The network utilized by Damci et al. (2020) is chosen to demonstrate the value of the suggested finance-based scheduling model. Eleven activities are included in it (Figure 4.2). Table 4.1 provides the details for every activity, such as the ID number, precedence relations, and duration (in weeks). The early/late start times, early/late finish times, and total floats of activities in the Scheduling Module are computed using these values, which are input by the scheduler. The scheduler additionally enters the cost information and the contract terms indicated in Table 4.2, which are approximated based on comparable data from earlier studies (e.g., Alghazi et al., 2013; Alavipour and Arditi, 2018a). The Cash Flow Forecasting Module uses this data to forecast the project cash inflows and outflows.

The Financing Cost Optimization Module uses the project cash inflows and outflows as well as the financing cash inflows and outflows as inputs to determine the schedules with the lowest financing costs.

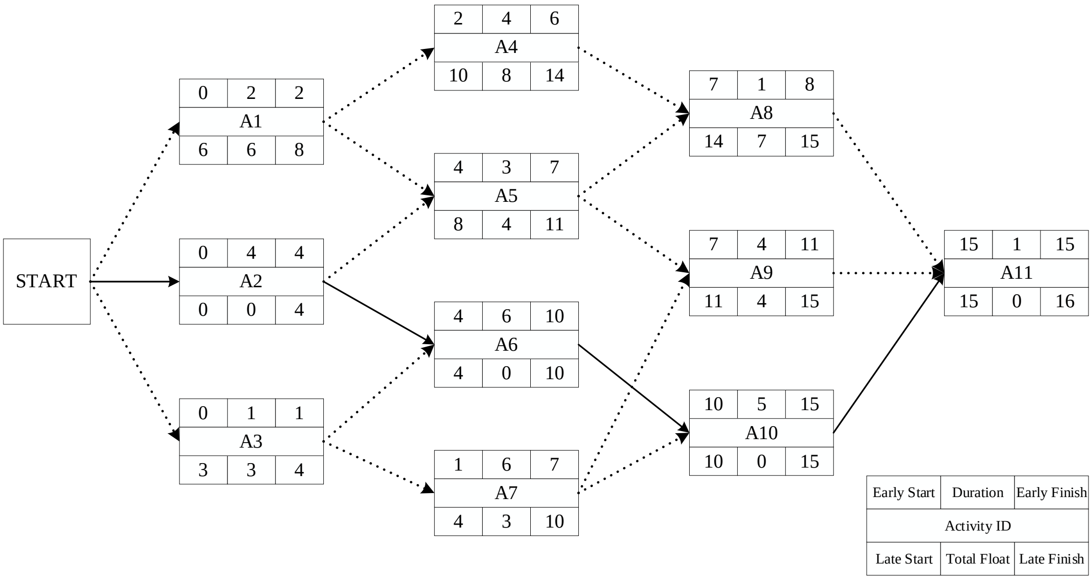

Figure 4.2 : Network of the first case example.

Table 4.1 : Information about activities in the first illustrative case.

Activity ID	Predecessor Activities	Duration (weeks)	Direct Cost ($/Week)	Cost of Float Consump ($/week)	CPM Calculations (Weeks)				
					Early Start	Early Finish	Late Start	Late Finish	Total Float
Start (S)	-	-	-	-	0	0	0	0	0
A_1	S	2	200,000	5,204	0	2	6	8	6
A_2	S	4	125,000	-	0	4	0	4	0
A_3	S	1	130,000	10,409	0	1	3	4	3
A_4	A_1	4	245,000	3,903	2	6	10	14	8
A_5	A_1, A_2	3	175,000	7,807	4	7	8	11	4
A_6	A_2, A_3	6	100,000	-	4	10	4	10	0
A_7	A_3	6	150,000	10,409	1	7	4	10	3
A_8	A_4, A_5	1	300,000	4,461	7	8	14	15	7
A_9	A_5, A_7	4	120,000	7,807	7	11	11	15	4
A_{10}	A_6, A_7	5	130,000	-	10	15	10	15	0
A_{11}	A_8, A_9, A_{10}	1	135,000	-	15	16	15	16	0

The proposed model was used in this case in two distinct scenarios. All available financing alternatives, including line-of-credit, long-term loan, and short-term loan, may be used concurrently in Scenario 1. The line of credit has a $100,000 maximum limit, but there is no limit on the short- and long-term loans in the first scenario. These financing options have monthly interest payments; however, the line of credit has two possibilities for interest payments: either monthly interest payments or interest payments compounded over a more extended period of time. In the suggested model, the right choice is chosen automatically to ensure that interest payments are made at the ideal time (considering the minimization of the financing cost). Scenario 2 allows for using a line-of-credit and short-term loans as financing options, but not long-term loans. The remaining circumstances are the same as they were in Scenario 1. Table 3.1 displays the annual percentage rates (APRs) for the financing options utilized in Scenarios 1 and 2.

Table 4.2 : Cost data and the contractual terms of the project in the first illustrative case.

Data Type	Item	Amount
Cost data	Weekly fixed overhead cost	\$25.000/week
	Variable overhead (percentage of direct cost)	10%
	Mobilization cost (percentage of direct cost + variable	5%
	Profit (percentage of total cost)	6%
	Bond premium (percentage of total cost + profit)	1%
Contract Terms	Advance payment (percentage of the contract bid price)	0%
	Retained percentage of interim payment	10%
	Liquidated Damage	\$50.000/week
	Number of weeks between submitting pay requests	4
	Lag in interim payments (weeks)	4
	Lag in making the final payment (weeks)	4

One of this study's main claims is that there is a cost associated with float use. The cost of float consumption in Scenarios 1 and 2 was considered while running the final module of the suggested model, known as the Optimal Work Schedule Selection Module. This method assists in demonstrating the benefit as well as the impact of taking the cost of float use into account in finance-based scheduling. In summary, the four modules operate simultaneously under the constraints when executing the proposed finance-based scheduling model. Using Eqs. 3.32–3.34, the costs of float consumption are shown for each activity in Table 4.1. Table 4.2 contains the contractual data about liquidated damages.

4.2.1 Findings and discussions of the illustrative case of the first model

As it can be seen in (Table 4.3), Schedules A, B, and C have the lowest financing cost (\$81,065) when the suggested model is run without accounting for the cost of float consumption used in Scenario 1. Even though these three schedules have the same project completion time and minimum financing cost, some of the activities on the schedule have different early start times. Different early start times for different activities result in varied cash flows but do not impact the minimum financing cost. Table 4.4's results indicate that Activity A8's start times in Schedules A, B, and C are 9, 10, and 11, yet the financing cost for each of these schedules is the same.

Table 4.3 : Comparison of financial parameters for scenarios 1 and 2.

Financial parameters ($)	Scenario 1	Scenario 2
	Schedules A, B, and C	Schedules D, E, F and G
Amount of Borrowed Money	3,871,182	3,664,373
Amount of Repaid Money	3,871,182	3,664,373
Financing Cost	81,065	83,397

Furthermore, Schedules D, E, F, and G have the lowest financing costs of $83,397 according to the results in Scenario 2 (Table 4.3). Table 4.4 demonstrates that, despite having the lowest financing costs in Scenario 2, Activities A1 and A3 cause distinct cash flows for schedules. As previously indicated, only short-term loans and a credit line are the financing alternatives used in Scenario 2, with the long-term loan being removed as a financing alternative. It should be mentioned that, as Table 4.3 illustrates, a larger number of schedules with the lowest financing cost resulted from considering fewer financing alternatives. Alavipour and Arditi's (2018a) claim that taking into account a more significant number of financing alternatives yields better results in terms of financing cost is further supported by the fact that the lowest financing cost is higher than the one calculated in Scenario 1, where three financing alternatives were used rather than just two.

At this stage, there are multiple schedules (three in Scenario 1 and four in Scenario 2) with the lowest financing cost, making it difficult for the scheduler to choose the best optimal schedule. Considering the cost of float consumption protects the owner from the drawbacks of float consumption (such as reducing the ability to prevent late completion) and aids in choosing the best work schedule among those with the lowest financing costs. The final module of the suggested model was applied to Schedules A, B, and C, taking into account the cost of float consumption in Scenario 1, and to

Schedules D, E, F, and G, taking into account the cost of float consumption in Scenario 2.

Table 4.4 : Schedules with the lowest financing cost in scenarios 1 and 2.

Activity ID	Early Start Times (Week)						
	Scenario 1			Scenario 2			
	Schedule A	Schedule B	Schedule C	Schedule D	Schedule E	Schedule F	Schedule G
Start (S)	0	0	0	0	0	0	0
A_1	0	0	0	0	0	1	1
A_2	0	0	0	0	0	0	0
A_3	0	0	0	0	1	0	1
A_4	2	2	2	3	3	3	3
A_5	6	6	6	4	4	4	4
A_6	4	4	4	4	4	4	4
A_7	1	1	1	2	2	2	2
A_8	9	10	11	7	7	7	7
A_9	9	9	9	8	8	8	8
A_{10}	10	10	10	10	10	10	10
A_{11}	15	15	15	15	15	15	15
Cost of Float Cons.($)	40,149	44,610	49,071	22,119	32,528	27,323	37,732

The cost of float consumption varies for schedules A, B, and C in Scenario 1 when the cost of float consumption is considered when the model is run. Eqs. 3.32–3.34 are used to compute the costs of float consumption in the various work schedules, which are shown in Table 4.4 for both scenarios. It is evident that when attempting to minimize financing costs, Schedule A in Scenario 1 and Schedule D in Scenario 2 benefit from taking the cost of float consumption into account since they have the lowest costs of float consumption in Scenarios 1 and 2, respectively. As a result, the project manager is not forced to choose one of the schedules randomly but is given an optimal work schedule at the lowest financing cost. The above-mentioned results show that considering the cost of float consumption enables the project manager to effectively differentiate between schedules with the same minimum financing cost.

Additionally, this model includes financing schedules showing the amount and timing of borrowed money, repaid money, and interest payments for all financing alternatives. The proposed model provides a distinct financing schedule for each work schedule with a varied combination of early start times. The financing schedules of the optimal work schedules in Scenarios 1 and 2 are presented in Tables 4.5, 4.6, and 4.7, which provide the financing schedules for Work Schedules A and D, including the amount and timing of borrowed money, repaid money, and interest payments. These tables match the matrices shown in Eqs. 3.18, 3.19, and 3.24.

4.2.2 Conclusion of the illustrative case of the first model

In today's competitive construction sector, changing activity start times to acquire the lowest financing cost appeals to contractors. However, changing the start times of activities within the limits of their total floats to minimize financing costs may result in many work schedules with the same minimum financing cost. Existing studies in the finance-based scheduling literature neglect this possibility because the metaheuristic algorithms used by the researchers in finance-based scheduling literature do not provide multiple optimal solutions but a near-optimal solution. A solution for this problem is demonstrated by an exact mathematical algorithm in this study. The question is which of the potential schedules with the minimum financing cost is the best. This paper argues that using float to change the start times of activities has a cost and that a paradigm shift from minimizing the financing cost alone to minimizing the financing cost as well as the cost of float consumption is required because float needs to be used to change the start times of activities and activity start times need to be changed to minimize financing cost.

This study proposes a finance-based scheduling model that considers the cost of float consumption in light of published literature that ignores this cost. With this model, the user may quickly determine the one schedule that will save the most money on the contractor's financing cost. An illustrative example is used to demonstrate the usefulness of the first model. The results showed that the first model of this study has the capability to identify the best optimal schedule among the schedules with the minimum financing cost by considering the cost of float consumption. Moreover, the results proved Alavipour and Arditi’s (2018a) statement that considering a larger number of financing alternatives helps contractors obtain a lesser amount of financing costs.

Table 4.5 : Borrowed money schedules for scenarios 1 and 2.

Month	Scenario 1 Schedule A					Scenario 2-Schedule D				
	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	LTL($)	LC ($)	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	STL-D3 ($)	LC ($)
0				3,201,203	-	-	-	-	2,128,643	-
1					100,000	-	-	-	-	100,000
2	161,806	23,571			100,000	518,837	452,255	-	-	100,000
3			84,603		100,000	-	-	164,638	-	100,000
4					100,000	-	-	-	-	100,000
5					-	-	-	-	-	-
Borrowed Money	161,806	23,571	84,603	3,201,203	400,000	518,837	452,255	164,638	2,128,643	400,000

Table 4.6 : Repaid money schedules for scenarios 1 and 2.

Month	Scenario 1-Schedule A					Scenario 2-Schedule D				
	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	LTL($)	LC ($)	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	STL-D3 ($)	LC ($)
0					-	-	-	-	-	-
1				640,241	-	-	-	-	-	-
2				640,241	-	-	-	-	-	-
3				640,241	-	-	-	-	2,128,643	-
4	161,806			640,241	-	518,837	-	-	-	-
5		23,571	84,603	640,241	400,000	-	452,255	164,638	-	400,000
Repaid Money	161,806	23,571	84,603	3,201,203	400,000	518,837	452,255	164,638	2,128,643	400,000

Table 4.7 : Interest payment schedules for scenarios 1 and 2.

Month	Scenario 1-Schedule A					Scenario 2-Schedule D				
	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	LTL($)	LC ($)	STL-B2 ($)	STL-B3 ($)	STL-C2 ($)	STL-D3 ($)	LC ($)
0										
1				13,162					15,342	
2				13,162	949				15,342	949
3	1,656	241		13,162	1,898	5,311	4,630		15,342	1,898
4	1,656	241	866	13,162	2,847	5,311	4,630	1,685		2,847
5		241	866	13,162	3,796		4,630	1,685		3,796
Repaid Money	3,313	724	1,732	65,808	9,489	10,623	13,889	3,371	46,025	9,489

5. DEVELOPMENT AND ILLUSTRATIVE CASE OF THE SECOND MODEL

5.1 Development of the Second Model

The Scheduling Module, the Project Cash Flow Forecasting Module, the Financing Cost Optimization Module, and the Optimal Work Schedule Selection Module, which were explained in the Methodology section, are used in the development of this study's second model. Another module is added to the modules in the Methodology section when developing the second model. The Resource-leveling Module is added to help contractors to have smoother resource usage histograms. This study presents an optimization model that examines the effects of various resource-leveling methods on finance-based scheduling problems. By considering various resource-leveling objective functions, the second optimization model suggests a work schedule among the multiple schedules with the lowest financing cost. This model is not just a theoretical construct but a practical tool that can be used to make informed decisions in project management. Ultimately, resource-leveling and finance-based scheduling are founded on the same premise, which is adjusting the start times of the activities by using their total floats. Resource-leveling and finance-based scheduling use the same float available in a project. Therefore, they are interdependent processes that aim to minimize resource fluctuation and minimize financing costs. In order to do this, this model put forward in this study shifts the early starts of the activities using total floats and considers various financing alternatives to minimize the project's financing cost. When this method yields more than one optimal work schedule, the optimal work schedule with the lowest resource fluctuation value (the least amount of resource variation) associated with these schedules with the lowest financing cost—is selected as the best one. Furthermore, the suggested model uses total floats to decrease the project's resource fluctuation values by delaying the start times of the activities. Like the previous procedure, the optimal work schedule can be determined by taking the schedule with the lowest financing cost from among the schedules with the lowest resource fluctuation value.

By taking into account their needs and priorities, model users can employ one of these two approaches. If a contractor prioritizes minimizing finance costs over minimizing resource variations, the first procedure must be used to identify the schedule with the lowest resource fluctuation value among those with the lowest financing costs. However, the contractor must use the second procedure if minimizing resource fluctuations is more crucial than minimizing finance costs. Both procedures can produce the best possible schedule considering the contractor's needs. This flexibility empowers the user to make decisions aligning with their project's requirements. Nine distinct resource-leveling methods are considered in this model to produce smoother resource utilization histograms. Contractors can determine the optimum schedule for resource-leveling by considering nine distinct objective functions, as opposed to just one, as most research in the literature did. Selecting the schedule with the smoothest resource usage histogram is ensured for the contractor by considering various resource-leveling objective methods. The flowchart explains the steps followed in the second proposed model of this study in Figure 5.1.

5.1.1 Resource-Leveling Module

The Resource-leveling Module is intended to reduce fluctuations in resource utilization during the project. This module generates resource utilization histograms based on information from the Scheduling module. After creating the histograms, nine resource-leveling methods extensively utilized in the resource-leveling literature are applied to minimize fluctuations. The nine resource-leveling methods are represented by nine objective functions, which estimate the minimum fluctuations while considering the research constraints. This comprehensive approach ensures that the methods used are valid and reliable. Table 5.1. shows the definitions and formulations for these resource-leveling methods.

At the end of this module, using Eqs. 5.1 and 5.2, the minimum resource fluctuation considering all nine resource-leveling methods is calculated.

$$RF_l = Minimize\ \sum_{t=1}^{T} RF_{l_t}\ ;\ \ t\ =\ 0, 1, 2, \ldots., T\ \ and\ \ l = 1, 2, \ldots., 9\ objective\ functions\ of\ resource\ leveling\ methods \qquad (5.1)$$

$$RF = Minimize\ RF_l; \quad l = 0, 1, 2, \ldots., 9\ methods\ of\ resource\ leveling \tag{5.2}$$

where *RF* is the resource fluctuation, and *l* is the resource-leveling method.

Table 5.1 : Resource-leveling objective functions (from Damci and Polat, 2014).

Obj. Func. No	Optimization Criteria	Formulas
1	Minimization of the sum of the absolute deviations in daily resource usage	$RF = min \sum_{u=1}^{PD} \lvert Rdev_u \rvert$
2	Minimization of the sum of only the increases in daily resource usage from one day to the next	$RF = min \sum_{u=1}^{PD} \lvert Rinc_u \rvert$
3	Minimization of the sum of the absolute deviations between daily resource usage and the average resource usage	$RF = min \sum_{u=1}^{PD} \lvert R_u$
4	Minimization of the maximum daily resource usage	$RF = min[max(R_u)]$
5	Minimization of the maximum deviation in daily resource usage	$RF = min[max \lvert Rdev_u \rvert]$
6	Minimization of the maximum absolute deviation between daily resource usage and the average resource usage	$RF = min[max \lvert R_u - A_{rr} \rvert]$
7	Minimization of the sum of the square of daily resource usage	$RF = min \sum_{u=1}^{PD} (R_u)^2$
8	Minimization of the sum of the square of the deviations in daily resource usage	$RF = min \sum_{u=1}^{PD} (Rdev_u)^2$
9	Minimization of the sum of the square of the deviations between daily resource usage and the average resource usage	$RF = min \sum^{PD} (R_u - A_{rr})^2$

Note: *RF* = Resource fluctuation, *u* = Day under consideration, *PD* = Project duration, R_{dev_u} = Deviation between resources required on day *u* and *u+1*, R_{inc_u} = Increase in resources required on day *u* and *u+1*, R_u = Resources required on day *u*, A_{rr} = Average resource usage over the project.

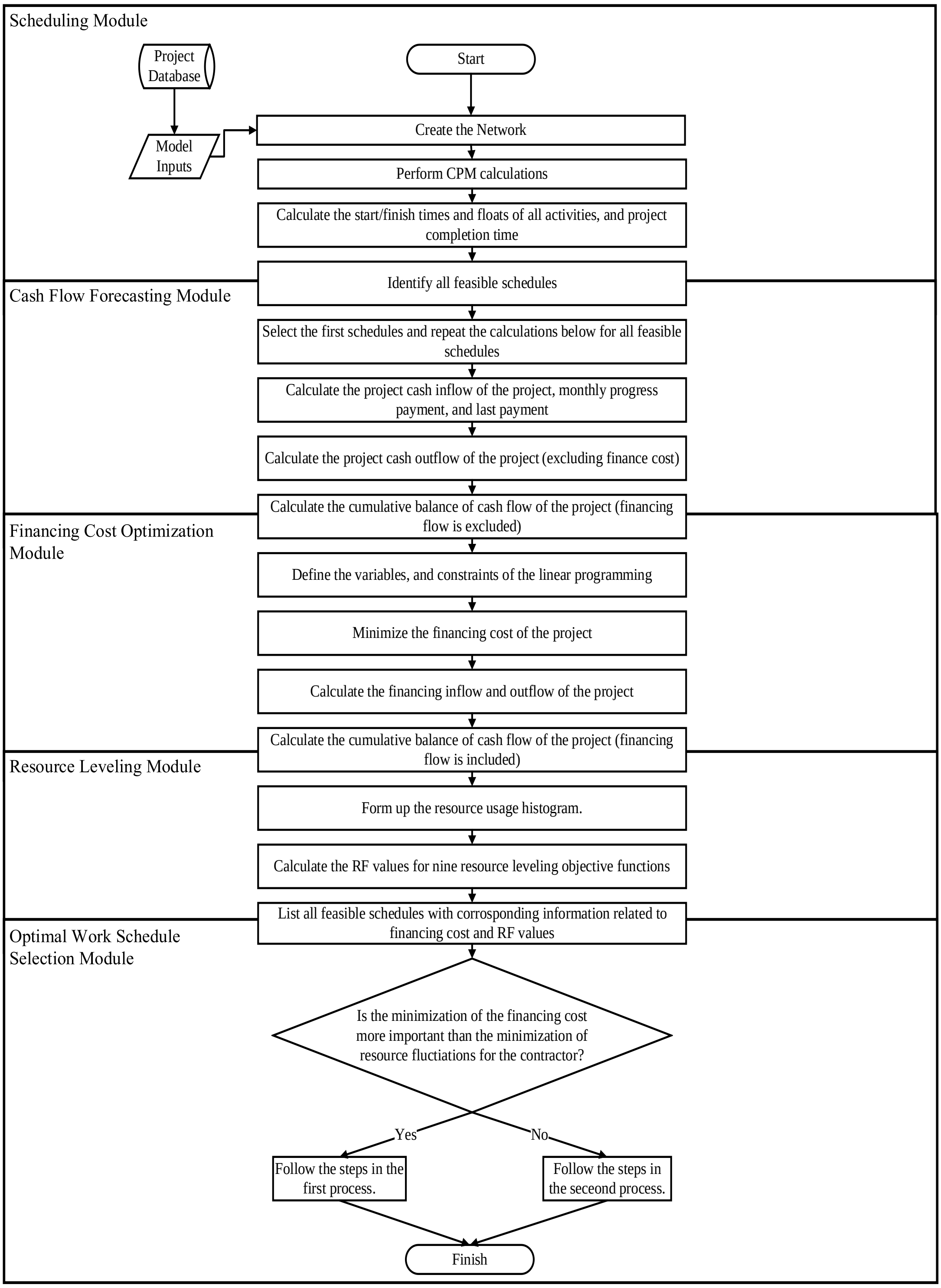

Figure 5.1: The flowchart of the second proposed model.

5.1.2 Optimal work schedule selection module in the second proposed model

The Optimum Work Schedule Selection Module in the second proposed model consists of two distinct processes. The contractor must follow the steps in the first process to find the best solution for minimizing the financing cost. The first step minimizes the financing cost for all feasible schedules using various financing alternatives. The best optimum schedule with the lowest financing cost is selected among the schedules with the lowest resource fluctuation value. In order to determine the schedules with the lowest resource fluctuation value, nine different resource-leveling methods are considered in this study; therefore, additional computations are required to determine the optimal selection procedure. This is due to the fact that various resource-leveling techniques employ various goal functions. There are considerable differences in the resource fluctuation value scales between the different resource-leveling objective functions. Therefore, choosing the best schedule should not be done by comparing the resource fluctuation values. Because of this, an additional step is included in the first process to determine which optimal schedule has the lowest resource fluctuation values by considering nine distinct objective functions. The best optimal schedule is the one that has the greatest number of lowest resource fluctuation values among the schedules with the lowest financing cost, based on nine resource-leveling objective functions.

If minimizing resource fluctuations is the contractor's top priority, then the second process has to be followed. In contrast to the first process, resource fluctuations are reduced in the second process by minimizing the financing cost of the schedules with the lowest resource fluctuation values after determining the resource fluctuation values for each early feasible schedule. Since the second part of the process (minimization of financing cost) only considers one metric—the financing cost—no additional calculations are required. In addition, the flowcharts that explain the steps followed in the second model for both approaches are presented in Figure 5.2 and Figure 5.3.

5.2 Illustrative Case of the Second Model

A network used by Damci et al. (2020) is selected and modified to demonstrate the application of the second proposed model of this study. There are eleven activities in the network (Figure 5.4). Each activity's ID number, precedence relationship, and duration (in days) are displayed in Table 5.2. There are six working days in a week in this network. This data is entered into the Scheduling Module by the scheduler. The early start/end timings, late finish times, and total floats of activities are computed by the Scheduling Module using this data.

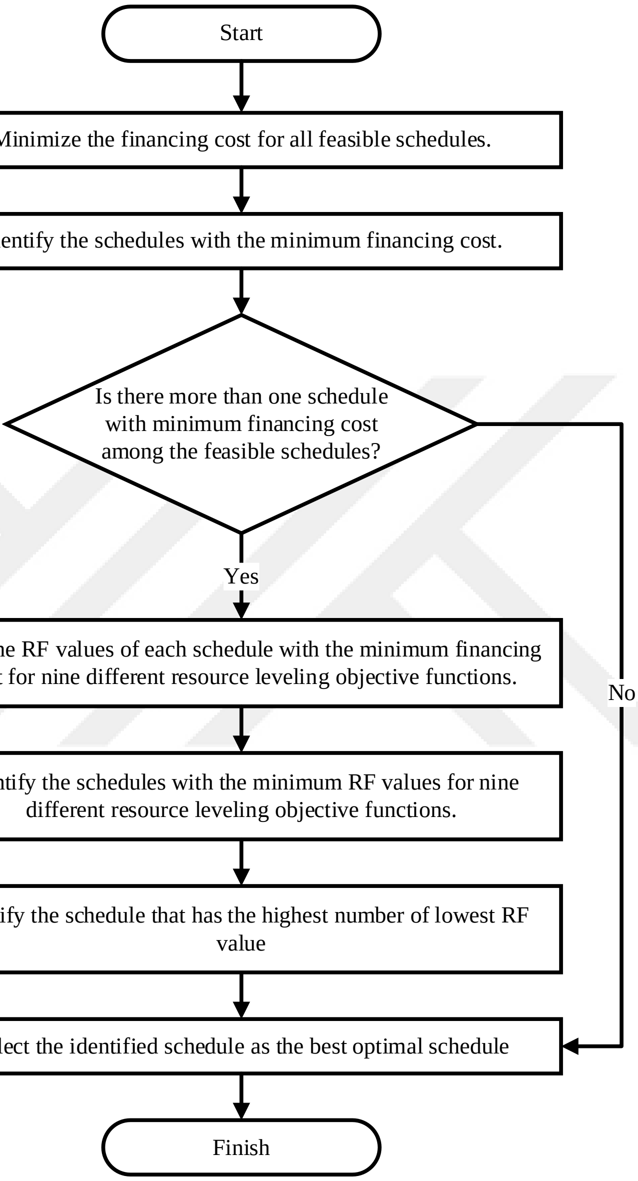

Figure 5.2: The flowchart of the first process.

In addition, the scheduler inputs the terms of the contract and cost information (Table 5.3). The Cash Flow Forecasting Module of the suggested model generates project cash inflows and outflows using this data. Using financing alternatives such as line-of-credit, short-term loans, and long-term loans, the Financing Cost Optimization Module determines the most satisfactory financing schedule that gives the minimum financing cost based on the results of the Cash Flow Forecasting Module. Information about the financing alternatives in the second model is given in Table 5.4. Moreover, Table 5.5 displays the financing cash inflow/outflow schedules for the initial schedule as well as the cumulative balance of the cash flow. Schedulers can use the suggested approach to get these financing cash flow schedules for each project schedule. The Resource-leveling Module creates the resource utilization histograms utilizing the data gathered from the Scheduling Module. Using the Resource-leveling Module of the proposed model, the resource fluctuation values for all viable schedules are calculated considering the nine different resource-leveling objective functions.

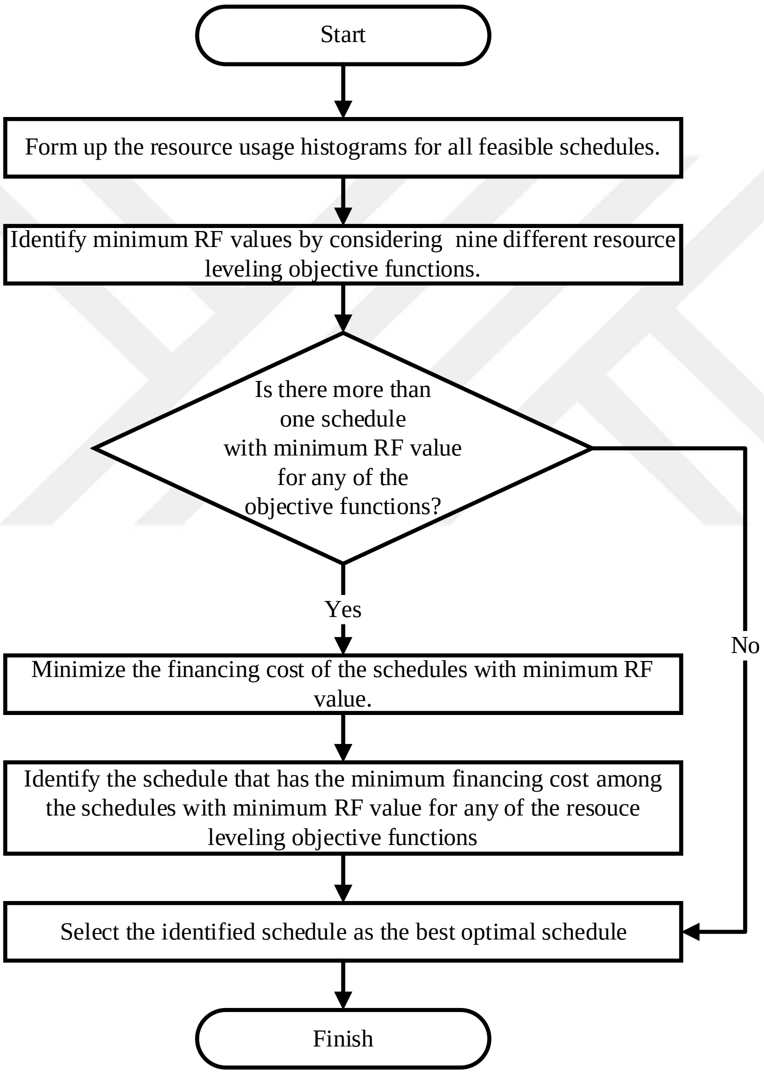

Figure 5.3: The flowchart of the second process.

Table 5.2 : Information about activities in the second illustrative case.

Activity ID	Predecessor Activities	Duration (days)	Daily Resource Usage	Direct Cost ($/day)	CMP Calculations (Days)				
					Early Start	Early Finish	Late Start	Late Finish	Total Float
A1	-	13	60	40,000.00	0	13	10	23	10
A2	-	19	60	35,000.00	0	19	3	22	3
A3	-	22	70	6,000.00	0	22	0	22	0
A4	A1	26	85	50,000.00	13	39	27	53	14
A5	A1, A2	28	50	19,000.00	19	47	23	51	4
A6	A2, A3	25	45	24,000.00	22	47	22	47	0
A7	A3	20	145	55,000.00	22	42	27	47	5
A8	A4, A5	18	100	23,000.00	47	65	53	71	6
A9	A5, A7	20	160	29,000.00	47	67	51	71	4
A10	A6, A7	24	55	27,000.00	47	71	47	71	0
A11	A8, A9, A10	19	33	10,000.00	71	80	71	90	0

Note: Direct cost of the project = $6,681,000; fixed overhead (15 weeks × $60,000/week = $900,000); variable overhead (10% of direct cost = $668,100); mobilization cost (10% of (direct cost + variable overhead) = $734,910); profit (6% of (direct cost + fixed overhead + variable overhead + mobilization cost) = $539,041); bond premium (2% of (direct cost + fixed overhead + variable overhead + mobilization cost + profit) = $190,461; bid price (direct cost + fixed overhead + variable overhead + mobilization cost + profit + bond premium = $9,713,512); contract bid price (total cost/direct cost = $9,713,512/$6,681,000 = 1.4539).

Table 5.3 : Cost data and the contractual terms of the project in the second illustrative case.

Data	Item	Amount
Cost data	Weekly fixed overhead cost	$60.000/week
	Variable overhead (percentage of direct cost)	10%
	Mobilization cost (percentage of direct cost +	10%
	Profit (percentage of total cost)	6%
	Bond premium (percentage of total cost + profit)	2%
Contract Terms	Advance payment (percentage of the contract bid	0%
	Retained percentage of interim payment	10%
	Number of weeks between submitting pay requests	4
	Lag in interim payments (weeks)	4
	Lag in making the final payment (weeks)	4

5.2.1 Findings and discussions of the illustrative case of the second model

The suggested model's outcomes show that the contractor may utilize it to determine the most advantageous schedule, considering the priority of their projects. There are multiple schedules with the lowest resource fluctuation value, at least in one resource-leveling objective function, when the first method that prioritizes the minimization of financing cost is employed to determine which of the schedules with the same financing cost is the optimal schedule. Therefore, to determine the most optimal schedule, further procedures are taken. Even though nine different resource-leveling objective functions are taken into account in this instance, the outcomes do not include objective functions 1, 2, 4, and 6. It is hard to distinguish between the schedules with the lowest financing costs as all of their resource fluctuation values in these objective functions (Table 5.6) are the same. Table 5.6 shows that out of all the schedules with the lowest financing cost, Schedule 32 is the best optimum work schedule since it has the lowest resource fluctuation value in four different resource-leveling objective functions (Objective Functions 3, 5, 6, and 9).

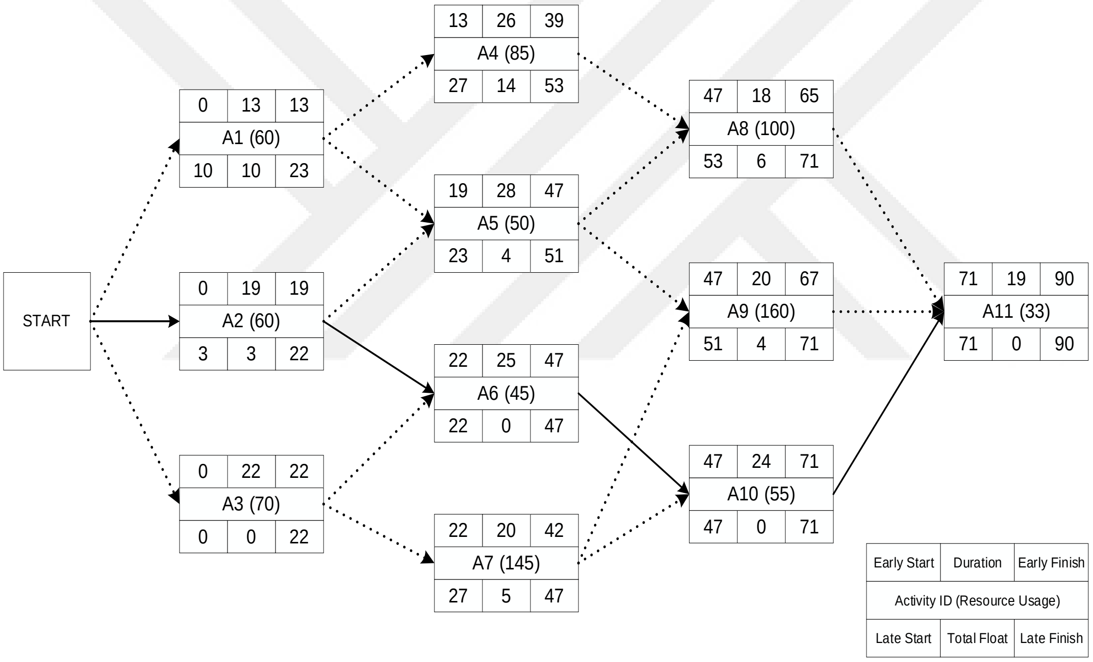

Figure 5.4: Network of the second illustrative case.

Schedule 180 is determined as the best optimum work schedule when resource-leveling is prioritized using the second approach in the illustrated case (refer to Table 5.7). Similar to the procedure, the financing cost values for all schedules with the smallest resource fluctuation value for these objective functions are the same. Hence, some of the objective functions (Objective Functions 4, 5, and 6) are eliminated from the study. As demonstrated in Table 5.7, three resource-leveling objective functions—Objective Functions 3, 7, and 9—identified Schedule 180 as the best optimum work schedule. This finding validates the idea that the contractor gains from Schedule 180, which lowers finance costs and produces a smoother resource histogram.

Table 5.4 : Information about financing alternatives for the second illustrative case.

Methods for Minimizing the Financing Cost	Time of borrowing the money	Time of repaying the money	Time of repaying the interest	Total credit limit ($)	Credit limit-each period ($)	APR (%)
Short-term loans	Every one, two, three, and four months	After one, two, three, and four months	Monthly	-	-	The same values from Akin et al. (2024a)
Long-term loan	Beginning of the Project	Monthly	Monthly	-	-	8.5%
Line-of -credit	Anytime	Any time	Monthly	$500,000	$100,000	15%

5.2.2 Conclusion of the illustrative case of the second model

Scheduling requires financing and resource management in order to generate effective project schedules. Finance-based scheduling takes into account both financing and scheduling at the same time, however previous research has revealed areas for improvement. The majority of studies considered finance and cash flow constraints, but they excluded financing alternatives other than the line of credit. Furthermore, just a few studies have addressed resource management in addition to financing, although the use of multiple objective functions for resource-leveling must be addressed.

The second model developed in this study proposes a new finance-based scheduling model to assist contractors in minimizing financing costs by taking into account different financing alternatives and employing several objective functions to build the smoothest resource consumption histogram. A linear programming-based approach is used to discover the lowest financing cost for all viable work schedules. The resource fluctuations are calculated using nine resource-leveling objective functions, and resource utilization histograms are generated for all feasible work schedules. An exemplary example from Damci et al.'s (2020) study is used to demonstrate how the suggested methodology can be used in a case study and shown beneficial. Based on the results of the illustrative scenario, it is possible to conclude that the proposed model in this study can efficiently select the best optimal schedule while considering the contractors' preferences to avoid finance costs or resource variations.

Table 5.5 : Cumulative balance of the cash flow and schedules of financing cash inflow/outflow of the initial work schedule.

Month	Cumulative balance of the cash flow before financing flow ($)	Borrowed Money ($)				Repayed Money ($)				Financing Cost ($)			
		Short-Term Loan ($)	Short-Term Loan ($)	Long-Term Loan ($)	Line-of-Credit ($)	Short-Term Loan ($)	Short-Term Loan ($)	Long-Term Loan ($)	Line-of-Credit ($)	Short-Term Loan ($)	Short-Term Loan ($)	Long-Term Loan ($)	Line-of-Credit ($)
0	-925,371		815,584	3,000,000									
1	-3,497,371				300,000			600,000			5,878	12,334	
2	-4,052,128	875,816			300,000			600,000			5,878	12,334	2,847
3	-2,348,130						815,584	600,000	255,543	8,966	5,878	12,334	5,693
4	-667,842					875,816		600,000	179,903	8,966		12,334	3,268
5	539,041							600,000	164,554			12,334	1,561
	SUM ($)	875,816	815,584	3,000,000	600,000	875,816	815,584	3,000,000	600,000	17,931	17,635	61,672	13,370

Table 5.6 : The results of the first process.

Schedule Number	Financing Cost	Resource-leveling Objective Functions								
		Objective Function 1	Objective Function 2	Objective Function 3	Objective Function 4	Objective Function 5	Objective Function 6	Objective Function 7	Objective Function 8	Objective Function 9
7	111.334,27	967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
8		967	405	8.650	325	160	168	4.765.566	116.659	1.120.548
9		967	405	8.450	325	160	168	4.733.566	116.659	1.088.548
10		967	405	8.250	325	182	168	4.701.566	123.699	1.056.548
12		967	405	8.850	325	160	168	4.797.566	116.659	1.152.548
13		967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
14		967	405	8.650	325	160	168	4.765.566	116.659	1.120.548
15		967	405	8.450	325	182	168	4.733.566	123.699	1.088.548
17		967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
18		967	405	8.850	325	160	168	4.797.566	116.659	1.152.548
19		967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
20		967	405	8.650	325	182	168	4.765.566	123.699	1.120.548
22		967	405	8.650	325	160	168	4.765.566	116.659	1.120.548
23		967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
24		967	405	8.850	325	160	168	4.797.566	116.659	1.152.548
25		967	405	8.850	325	260	168	4.797.566	155.699	1.152.548
27		967	405	8.450	325	160	168	4.733.566	116.659	1.088.548
28		967	405	8.650	325	160	168	4.765.566	116.659	1.120.548
29		967	405	8.850	325	260	168	4.797.566	148.659	1.152.548
30		967	405	8.850	325	182	168	4.797.566	123.699	1.152.548
32		967	405	8.250	325	160	168	4.701.566	121.059	1.056.548
33		967	405	8.450	325	160	168	4.733.566	121.059	1.088.548
34		967	405	8.650	325	160	168	4.765.566	121.059	1.120.548
35		967	405	8.850	325	282	168	4.797.566	160.099	1.152.548

Table 5.7 : The results of the second process.

Resource-Leveling Objective Function	Schedule Number	Resource Fluctuation Value	Finance Cost ($)
Obj1	4.741	597	113.840
Obj2	4.741	220	113.840
Obj3	180	7.200	111.841
	206	7.200	111.852
Obj7	180	4.546.316	111.841
	206	4.546.316	111.852
Obj8	4.741	65.259	113.840
Obj9	180	901.298	111.841
	206	901.298	111.852

6. DEVELOPMENT AND ILLUSTRATIVE CASE OF THE THIRD MODEL

6.1 Development of the Third Model

The third model in this study is developed using the Scheduling Module, the Project Cash Flow Forecasting Module, and the Financing Cost Optimization Module, which were discussed in the Methodology section. However, the cash inflow calculations are adjusted because this model uses the front-loading method as a financing tool. The financing schedules related to borrowed money, repayment of the principal of the borrowed money, and the interest payment for the balloon loans are adjusted. When developing the third model, another module is added to the modules in the Methodology section. The Financing Alternative Selection Module is added to help contractors use different financing methods to obtain lower financing costs. This study presents an optimization model examining the impact of various financing methods on the contractor's financing cost in this chapter. Having multiple financing methods allows the contractor to be more flexible in selecting the loan option with the lowest financing cost. In the third model, two additional financing methods are included as an improvement in the finance-based scheduling literature. As a result, multiple financing methods must be considered in a construction project to achieve better results in finance-based scheduling.

Even though balloon loans (Halpin and Senior, 2009) are a commonly used financing method for contractors seeking a smoother cash flow profile and lower financing costs, studies in the finance-based scheduling literature overlooked this financing method. Additionally, contractors can further reduce financing costs by front-loading the bid. This research offers a model that improves on Alavipour and Arditi's (2018a) model in two ways: (1) by front-loading the contractor's bid and (2) by utilizing balloon loans in addition to lines of credit, short-term loans, and long-term loans. The flowchart of the third proposed model is presented in Figure 6.1.

6.1.1 Adjusted cash inflow calculations

For the project cash inflow calculations, the steps outlined in Alavipour and Arditi's (2018a) and Akin et al.'s (2024) studies are followed. The interim payments from the owner to the contractor make up the contractor's project cash inflows. The contractor requests interim payments every month at the end (or every four weeks). However, after submitting the payment request, the owner paid the contractor one month later. By computing the earned value of the tasks completed during the payment periods, the contractor figures out how much money to ask the owner for at the end of the term. The contractor's request for interim payments is calculated using Eq. 6.1.

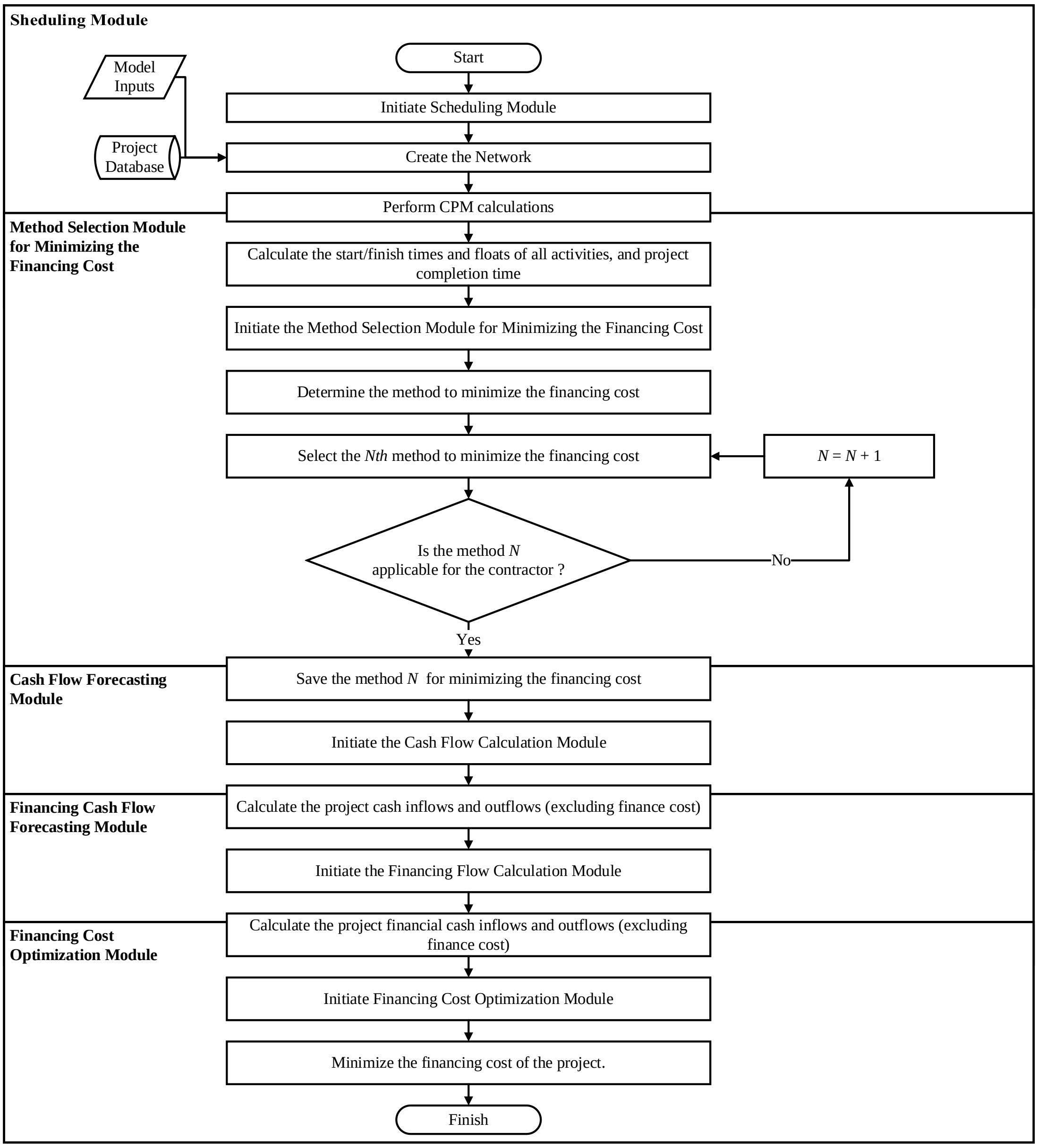

Figure 6.1 : Flowchart of the third model.

$$\text{Project Cash Inflow}_{\text{t + Lag in Interim Payments}} = \left[(1 - Retainage\ \%) \times \sum_{j=1}^{n} Earned\ Value_{j_t}\right] - \frac{(\textit{Bid Price} \times \textit{Advance Payment as a percentage of bid price})}{\textit{Project Duration expressed in 4-week periods}} \tag{6.1}$$

$$t = 1, 2, \ldots\ldots, (T - 1)\ (\textit{expressed in 4-week payment periods})$$

The first part of Eq. 6.1 calculates the earned value of activities *j* completed during the payment period t. The second part of Eq. 6.1 allocates the advance payment (if any) equally for each project period. It should be mentioned that the computations for the final payment are different from those for the interim payment.

6.1.2 Additional financing alternatives

Since the equations and steps of line-of-credit, short-term loans, and long-term loans are explained in the Methodology section, this section explains only the mechanisms, equations, and steps of two additional financing methods: balloon loans and front-loading.

6.1.2.1 Balloon loans

In order to finance their projects more conveniently, contractors can choose balloon loans, which have higher repayment periods that are longer than the project's completion date. These loans are paid back over an extended period of time, with the contractor repaying the principal in smaller monthly installments during the Project duration. Contractors may receive financial relief from smaller monthly payments made during project execution, but they will be required to repay the remaining loan balance in one lump sum (known as a balloon payment) at the project's completion (Halpin and Senior, 2009).

By incurring lower financing costs, contractors can use a balloon loan to lessen their financial burden while the project is being completed. For the repayment schedule, the contractor either pays only the interest monthly during the project's execution and repays the entire amount borrowed in one lump sum at the project's completion date, or the contractor repays the interest with a small portion of the principal during the project's execution phase on a monthly basis, paying the remaining principal as a balloon payment at the project's completion date. An interest-only balloon loan is the first choice. Considering the project's requirements, the user of the proposed model in this study can easily use any two types of balloon loans. The lender sets the maximum amount to be borrowed as a balloon loan. Eq 6.2 and Eqs. 6.3, 6.4, and 6.5 can be used to determine the financing cost of an interest-only balloon loan and a balloon loan with monthly installments.

$$Financing\ Cost_{BL_t} = BM_{BL} \times i_{BL_t};\ t = 1, 2, 3, \ldots\ldots, T\ (expressed\ in\ 4\text{-}\ week\ periods) \tag{6.2}$$

$$PMT = BM_{BL}\ (\frac{A}{P}, i\ , M) \tag{6.3}$$

$$RM_{BL} = \left(BM_{BL} - \left(\sum_{r=1}^{T} \left(\frac{PMT}{(1+i)^r} \right) \times (1+i)^T \right) \right) \tag{6.4}$$

$$Financing\ Cost_{BL_t} = \left(\left(BM_{BL} - \sum_{r=1}^{t} \left(\frac{PMT}{(1+i)^r} \right) \right) \times (1+i)^t \right) \times i_{BL} \tag{6.5}$$

Where BL_t represents the balloon loan at period t, PMT represents the payment of the monthly installment, M is the number of monthly installments to repay the loan, A/P represents the capital recovery factor, and RM_{BL} is the balloon payment amount at T.

6.1.2.2 Front-loading the project

By front-loading a bid, competitors can keep the total bid price the same while increasing the prices of early line items and lowering the prices of late line items (Akin et al., 2024a). When a contractor frontloads a bid, their primary goal is to mitigate the effects of significant costs that they incur early in the project, like setup and mobilization costs. However, when the time value of money is taken into account, the owner ends up paying more for the same activities when a contractor frontloads a bid, making it unbalanced (Arditi and Chotibhongs, 2009). Owners, therefore, typically have the ability to recognize and reject front-loaded bids. The ethical consideration of front-loading becomes debatable because contractors and owners view the practice entirely from different perspectives (Hyari, 2024). On the other hand, contractors frequently front-load their bids since they can improve their cash flow by front-loading their bids. It is typical for contractors to frontload their bids and obtain additional funding up front, especially if they do not receive an advance payment from the owner. Front-loading a bid may prevent the contractor from borrowing money, lowering the project's financing costs. Although owners may reject a front-loaded bid when they detect it because it may result in unjustified cost increases for the owner, they may tolerate the front-loaded bid if the project's final cost does not exceed the offer made by another bidder (Hyari, 2024). In other words, contractors can use the front-loading method to improve their cash flow and reduce the project's financing costs. However, they must exercise caution when front-loading their bids, as severe imbalances could result in the bid being rejected. The proposed model also looks into the trade-off between the degree of unbalancing and financing cost by increasing the line items' price limits for front-loading by five percent. The proposed model uses this method, in conjunction with other financing alternatives, to minimize project financing costs and provide contractors with financial relief. To unbalance the contractor's bid, a linear programming algorithm parallel to Nassar's (2004) is employed in this study. The algorithm's primary goal is to maximize the net present value of the cash flow by adjusting the bid prices of some line items within established limits while also ensuring that the project's total cost does not go over the anticipated bid from a competitor (Eq. 6.6).

If an unbalanced bid is detected, the owner may reject it, or the contractor may lose money if it is altered too much. For this reason, adjustments in line item prices are restricted to the lower and higher limits (Eq. 6.7). After the present value of the net present value of the cash flow is maximized (Eq. 6.6), the final constraint of the algorithm guarantees that the bid price stays equal to the balanced bid price (Eq. 6.8).

Objective function

$$Max\left\{Net\ Present\ Value\ of\ the\ Project = \sum_{LI=1}^{n'} Line\ Item\ Price_{LI} \times \left(\frac{P}{F}, i\ , t\right)\right\} \qquad (6.6)$$

Constraint equations

$$Line\ Item\ Price_{Lower\ Limit_{LI}} \leq Line\ Item\ Price_{LI} \leq Line\ Item\ Price_{Upper\ Limit_{LI}} \qquad (6.7)$$

$$Bid\ Price_{before\ front-loading} = Bid\ Price_{after\ front-loading} \tag{6.8}$$

where i is the interest rate, LI represents the line item, n' is the total number of line items, t is the time of payment of the line item relative to the present time, and P/F represents the single payment present worth factor.

6.1.3 Financing method selection module

Using the Financing Alternative Selection Module, users of the proposed model can select one or more financing methods, such as a balloon loan, short-term loan, long-term loan, or line of credit, to reduce their financing costs. They can also use this module to front-load their bid. It should be mentioned that front-loading the bid is possible even without external funding. Using Eq. 6.9, contractors can choose to use a front-loading bid in the project. The project cash inflow at any payment period t is updated, if the contractor chooses to front-load the bid in Eq. 6.9.

$$\left\{ Project\ Cash\ Inflow_t = \begin{cases} Project\ Cash\ Inflow_t'; after\ front-loading & = 1 \\ Project\ Cash\ Inflow_t; without\ front-loading & = 0 \end{cases} \right\} \tag{6.9}$$

Line-of-credit, short-term loans, long-term loans, and balloon loans are examples of financing alternatives that involve borrowing money from financial institutions in exchange for paying interest, whereas front-loading the bid directly improves project cash flow while indirectly lowering financing costs.

6.1.4 Adjusted financing cash inflow and outflow calculations

Since the balloon loan is considered in addition to the line-of-credit, short-term, and long-term loans, an adjustment for calculating the borrowed money, repayment of the borrowed money, and interest payment is needed. Eqs. 6.10, 6.11, and 6.12 can be used to adjust the financing schedules mentioned above while including the balloon loans in the finance-based scheduling problem.

$$Total\ BM_t = BM_{LC_t} + BM_{STL_t} + BM_{LTL} + BM_{BP};\ t = 0, 1, 2, \ldots, (T-1) \tag{6.10}$$

where BM represents the borrowed money.

$$Total\ RM_t = RM_{LC_t} + RM_{STL_t} + RM_{LTL_t} + RM_{BP_t};\ t = 0, 1, 2, \ldots, (T-1) \tag{6.11}$$

where *RM* represents the repaid money.

$$Total\,FC_t = FC_{LC_t} + FC_{STL_t} + FC_{LTL_t} + FC_{BP_t};\ t = 0, 1, 2, \ldots, T \qquad (6.12)$$

6.2 Illustrative Case of the Third Model

The usefulness of the proposed finance-based scheduling model is illustrated with a network (Figure 6.2) from Damci et al.'s (2020) study. Table 6.1 displays the details for the activities, including ID number, precedence relationship, duration (in weeks), line item prices, and higher and lower limits on line item prices. In the Scheduling Module, this input is used to determine the early/late start and finish times. The scheduler also inputs the contract terms and cost information displayed in Table 6.2. The information in Table 6.2 is also utilized in the computations to determine the model parameters. The Cash Flow Forecasting Module uses all of this data along with the parameters to forecast the project's cash inflows and outflows. Afterward, the financing cash inflows and outflows are computed using the project's cash inflows and outflows as input. Lastly, the Financing Cost Optimization Module uses the financing cash inflows and outflows as inputs to determine the project's financing cost.

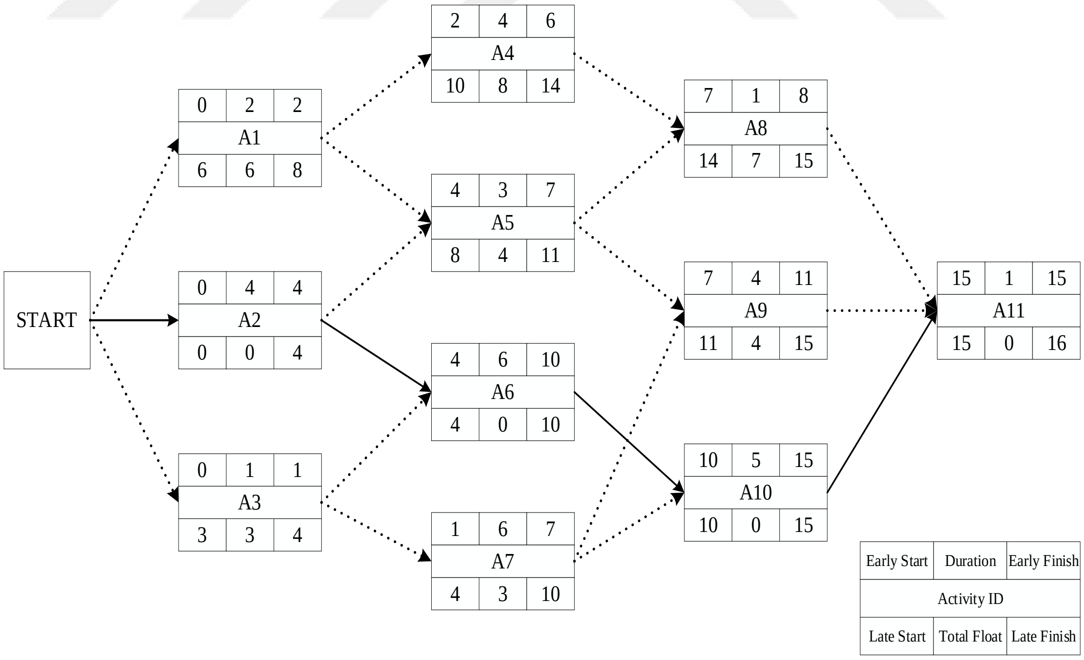

Figure 6.2 : Network of the third example case.

Table 6.1 : Information about activities in the third illustrative case.

Activity ID	Predecessor Activities	Dur. (weeks)	Direct Cost ($/week)	Lower Limit of Item Price ($/week)	Item Price (UP) ($/week)	Upper Limit of Item Price ($/week)
A_1	-	2	200,000	200,000	300,000	300,000
A_2	-	4	125,000	110,000	250,000	250,000
A_3	-	1	130,000	105,000	275,000	275,000
A_4	A_1	4	245,000	250,000	350,000	350,000
A_5	A_1, A_2	3	175,000	195,000	255,000	255,000
A_6	A_2, A_3	6	100,000	101,000	145,000	145,000
A_7	A_3	6	150,000	106,000	205,000	205,000
A_8	A_4, A_5	1	300,000	250,000	425,000	425,000
A_9	A_5, A_7	4	120,000	55,000	84,470	175,000
A_{10}	A_6, A_7	5	130,000	70,000	70,000	190,000
A_{11}	A_8, A_9, A_{10}	1	135,000	100,000	100,000	175,000

To illustrate the usefulness of each financing method, the proposed model is used in this study in five different scenarios. Furthermore, Alavipour and Arditi (2018a) assert—which is tested in each scenario—that employing a larger number of financing alternatives yields better outcomes in terms of financing cost. The finance-based scheduling problem is solved solely by adding a line of credit in the first scenario. In the second scenario, in addition to the line of credit, short-term and long-term loans are used, which is similar to Alavipour and Arditi's (2018a) study. In the third case, in addition to the line of credit, short-term, and long-term loans, an interest-only balloon loan is taken into account. In addition to the line of credit, short-term, and long-term loans, a balloon loan with monthly installments and a 48-month repayment schedule is taken into consideration in the fourth scenario. The purpose of Scenarios 3 and 4 is to test the individual impacts of two distinct types of balloon loans on the project's financing cost.

Moreover, in the fifth scenario, the line of credit, short-term, long-term, and interest-only balloon loans with the front-loading method are used to assess the impact of these financing methods on the project's financing cost. In the sixth scenario, the line of credit, short- and long-term loans, and a balloon loan with monthly installments are all included with the use of the front-loading method to assess their impact on the project's financing cost altogether. To further test the effect of front-loading on financing costs, the lower and upper limits for item prices for use with front-loading are increased by five percent, from five to fifty percent.

The financing methods for financing cost optimization are subject to a number of cash limits. In this study, the line of credit has a $100,000 limit, all short-term loans have a $400,000 limit, and the long-term loan has a $1,000,000 limit in all scenarios. An additional $2,000,000 is permitted for balloon loans. Regarding the balloon loan, there is no prepayment penalty. Monthly interest payments are made for line-of-credit, long-term, and short-term loans. Table 6.3 displays the annual percentage rates (APRs) for the line of credit, short-term, long-term, and balloon loans that are utilized in each scenario.

Tables 6.4 and 6.5 present the results of the example case obtained by using the third model. The findings in this section confirm the assertion made by Alavipour and Arditi (2018a) that considering a larger number of financing methods can lead to better financing cost outcomes. The first scenario's use of a line of credit as the sole funding source was unsuccessful in providing a feasible solution due to the limitations of the linear programming algorithm. However, the user of the suggested model can get a result for a $84,653 financing cost by considering the line of credit with the long-term and short-term loans together. The interest-only balloon loan and the balloon loan with monthly installments add up to $63,477 and $63,164, respectively, in the project's financing cost, as shown in Table 6.4 as is seen by investigating the results so far, better results in terms of financing cost can be achieved by involving any balloon loan types in addition to those in the second scenario.

6.2.1 Findings and discussions of the illustrative case of the third model

A detailed analysis of Table 6.5 reveals that the financing cost is significantly reduced when the front-loading method is considered in addition to the financing methods used in the third and fourth scenarios. The financing cost is significantly reduced each time the lower and upper limits for an item's price are raised by five percent. Therefore, it can be said that the contractors can effectively use the front-loading method to minimize the project's financing cost. However, they should be aware of the possibility of rejection when front-loading their bid for the reasons as mentioned earlier.

Additionally, this model can give information on the amount and timing of loans borrowed and repaid and interest payments related to line-of-credit, short-term loans, long-term loans, and balloon loans. Any combination of financing alternatives can result in a different financing schedule. Using the proposed model, contractors can use various financing alternative combinations regarding the project's characteristics. For the scenario that involves the use of the interest-only balloon loan with a line of credit, short-term, and long-term loans, Table 6.6 provides the financial schedules, including borrowed money, repaid money, and interest payments.

Table 6.2 : Cost data and the contractual terms of the project in the third illustrative case.

Data Type	Item	Amount
Cost data	Weekly fixed overhead cost	$25.000/week
	Variable overhead (percentage of direct cost)	10%
	Mobilization cost (percentage of direct cost + variable	5%
	Markup (percentage of total cost)	6%
	Bond premium (percentage of total cost + profit)	1%
Contract Terms	Advance payment (percentage of the contract bid price)	0%
	Retained percentage of interim payment	10%
	Number of weeks between submitting pay requests	4
	Lag in interim payments (weeks)	4
	Lag in making the final payment (weeks)	4

Table 6.3 : Information about financing alternatives for the third illustrative example.

Methods for Minimizing the Financing Cost	Time of borrowing the money	Time of repaying the money	Time of repaying the interest	Total credit limit ($)	Credit limit-each period ($)	APR (%)
Short-term loans	Every one, two, three, and four months	After one, two, three, and four months	Monthly	$400,000	-	The same values from Akin et al.
Long-term loan	Beginning of the Project	Monthly	Monthly	$1,000,000	-	7%
Balloon Loan	Beginning of the Project	Monthly	Monthly	$2,000,000	-	6%
Balloon Loan Interest Only	Beginning of the Project	At the End of the Project	Monthly	$2,000,000	-	6%
Line of credit	Any time	Any time	Monthly	$500,000	$100,000	15%

Table 6.4 : The amounts of borrowed money, repaid money, profit, and financing cost for four different scenarios.

	LC	LC + STL + LTL	LC + STL + LTL + BL (Interest Only)	LC + STL + LTL + BL (Monthly Ins.)
Borrowed Money ($)	Optimization constraints cannot be met	3.619.501	2.760.505	2.805.995
Repaid Money ($)		3.619.501	2.760.505	2.805.995
Profit		327.427	348.603	348.916
Financing Cost ($)		84.653	63.477	63.164

Table 6.5 : The amounts of borrowed money, repaid money, profit, and financing cost by considering different item price limits for front-loading.

	5%		10%		15%		20%	
	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.
Borrowed Money ($)	2.760.672	2.784.798	2.760.839	2.782.918	2.761.006	2.781.038	2.760.977	2.779.077
Repaid Money ($)	2.760.672	2.784.798	2.760.839	2.782.918	2.761.006	2.781.038	2.760.977	2.779.077
Profit ($)	349.816	350.128	351.028	351.314	352.241	352.501	353.425	353.675
Financing Cost ($)	62.264	61.952	61.052	60.766	59.839	59.579	58.655	58.405

	25%		30%		35%		40%	
	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.
Borrowed Money ($)	2.760.433	2.777.115	2.759.698	2.775.739	2.758.947	2.774.363	2.706.003	2.735.352
Repaid Money ($)	2.760.433	2.777.115	2.759.698	2.775.739	2.758.947	2.774.363	2.706.003	2.735.352
Profit ($)	354.536	354.758	355.627	355.840	356.717	356.922	357.771	357.977
Financing Cost ($)	57.544	57.322	56.453	56.240	55.363	55.158	54.309	54.103

	45%		50%	
	Interest Only	Monthly Ins.	Interest Only	Monthly Ins.
Borrowed Money ($)	2.658.713	2.672.769	2.658.908	2.675.421
Repaid Money ($)	2.658.713	2.672.769	2.658.908	2.675.421
Profit ($)	358.789	358.987	359.509	359.768
Financing Cost ($)	53.291	53.093	52.571	52.312

6.2.2 Conclusion of the illustrative case of the third model

Even though researchers have developed multiple models to address the finance-based scheduling problem, the line of credit remains the primary financing alternative to borrow money. While few researchers have combined the line of credit with short-term and long-term loans, balloon loans have been overlooked. Furthermore, none of the earlier studies in the finance-based scheduling literature have considered financing methods like front-loading and balloon loans to minimize the project's financing cost. In order to fill these gaps in the body of research on finance-based scheduling, a model is provided in this study.

Table 6.6 : Financing cash inflow/outflow schedules of the third scenario.

Month	Borrowed Money ($)					
	STL ($)	STL ($)	STL ($)	STL ($)	LC ($)	BL ($)
0		400.000	6.161	400.000		1.354.345
1	400.000				100.000	
2					100.000	
3						
4						
5						
Total	400.000	400.000	6.161	400.000	200.000	1.354.345
Month	Repayed Money ($)					
	STL ($)	STL ($)	STL ($)	STL ($)	LC ($)	BL ($)
0						
1						
2			6.161			
3	400.000	400.000		400.000	200.000	
4						
5						1.354.345
Total	400.000	400.000	6.161	400.000	200.000	1.354.345
	Financing Cost ($)					
Month	STL ($)	STL ($)	STL ($)	STL ($)	LC ($)	BL ($)
0		3.190	40	2.883		
1	4.686	3.190	40	2.883		6.592
2	4.686	3.190		2.883	949	6.592
3					1.898	6.592
4						6.592
5						6.592
Total	9.372	9.569	79	8.649	2.847	32.962

The results showed that considering a greater number of financing methods leads to better financing cost outcomes. Since none of the previous models included five different financing methods, it can be said that the proposed model is more effective than the others. Hence, the proposed model in this study covers a significant improvement in the finance-based scheduling literature.

7. CONCLUSION

This study introduces three innovative models to assist contractors in addressing various finance-based scheduling issues. All these models utilize four modules: scheduling, cash flow forecasting, financing cost optimization, and optimal work schedule selection modules (except the third model). As detailed in the Methodology Section, these modules play a crucial role in finance-based scheduling. However, each model requires specific adjustments and additional modules, as they are designed to fill distinct gaps in the finance-based scheduling literature.

The first model considers the cost of float consumption and how it affects choosing the best work schedule because it is not considered in any of the current studies published in the literature on finance-based scheduling. Using the float could be detrimental to a project, making it harder to avoid completion delays. However, using float could make it easier for contractors to minimize the financing cost by choosing a work schedule from among the various schedules. Thus, it is reasonable to draw the conclusion that finance-based scheduling models need to take the cost of float consumption into account. The example case solved in this study for the demonstration of the first model utilizing an exact mathematical approach proves that this possibility is valid. This model contends that using float to adjust activity start times has a cost. A paradigm shift is required from minimizing only the financing cost to minimizing the financing cost and, later, the cost of float consumption.

The case study presented here not only introduces the proposed model but also demonstrates its practical application in construction projects. The model, unlike previous research, takes into account the cost of float consumption, providing contractors with a high level of confidence in determining the best optimal work schedule among the schedules with the minimum financing costs. This practical demonstration reassures the users of the model's effectiveness and its potential to inspire further in-depth studies in the construction industry.

The second model considers the efficient management of the resources other than cash. Financing and resource management are necessary to establish successful project schedules. In order to help the contractors minimize financing costs, the second model developed in this study presents a new finance-based scheduling model that uses multiple objective functions to generate the smoothest resource usage histogram while accounting for various financing alternatives. Nine resource-leveling objective functions are used to calculate the resource fluctuations, and resource usage histograms are produced for each feasible work schedule. A similar example to the one used in the first model demonstrates how the second proposed model can be used in a case study and shown beneficial. Based on the results of the illustrative case, it is possible to conclude that the proposed model in this study can efficiently select the best optimal schedule while considering the contractors' preferences to avoid higher financing costs or resource fluctuations. The two distinct processes of the second model allow contractors to prioritize either of these goals and select the best optimal work schedule.

In the second proposed model, the Optimum Work Schedule Selection Module comprises two separate processes. To determine the optimal work schedule for minimizing the financing cost, the contractor has to follow the first process's steps. Using a variety of financing alternatives, the first process minimizes the financing cost for all feasible schedules. Among the schedules with the lowest resource fluctuation value, the best optimal schedule with the lowest financing cost is chosen. Nine different resource-leveling methods are taken into consideration in this study in order to identify the schedules with the lowest fluctuation value. The second procedure must be followed if the contractor's main goal is to minimize resource fluctuations. Unlike the first procedure, the second process minimizes the financing cost of the schedules with the lowest fluctuation value values once the fluctuation value values for each feasible schedule have been determined. This reduces resource fluctuations.

The line of credit remains to be the primary source of funding for borrowing money, even though scholars have created several models to handle the finance-based scheduling problem. Scholars have disregarded Balloon loans, even though few have linked the line of credit with both short-term and long-term loans. Moreover, no prior study in the literature on finance-based scheduling has considered financing methods to minimize the project's financing cost, such as front-loading and balloon loans. The last model of this study considered two financing methods, balloon loans and front-loading a bid, which have been neglected in the finance-based scheduling literature. This study’s third model involves five different financing methods simultaneously to minimize the financing cost of the contractor, which is an essential improvement in the finance-based scheduling literature. An optimization model that focuses on how different financing methods affect the contractor's financing cost is presented in this study. The contractor can choose the financing methods that provide the minimum financing cost with greater flexibility. An example case is used to illustrate the effectiveness of the proposed model. The findings demonstrated that considering a larger variety of financing methods improves financing cost results. It might be argued that the proposed model is more effective than the others because none of the earlier models included five distinct financing methods.

Although the three different models presented in this study fill several gaps in the finance-based scheduling literature, there are still several limitations to the proposed models. Some of these limitations are unique to one model, while the other models do not have any of them. First, none of the models considered the possibility of multiple projects in the contractor’s portfolio. When it is considered that contractors in the construction industry usually take responsibility for several projects in their portfolios, there is a need for improvement in the proposed models to include this feature. Secondly, none of the models presented in this study assumes a stochastic approach to predict the uncertain environment of the construction industry. There is a need for further research to fill this gap. As a third limit, the proposed models do not include any time-cost tradeoff analysis, which can help contractors minimize the financing cost further. Future research must consider these analyses to improve the effectiveness of the proposed models. Fourth, all the models can include a greater number of financing alternatives used by contractors in the construction industry but have never been covered in the current finance-based scheduling literature. Fifth, several more parameters can be included in those proposed models to efficiently manage resources in addition to the resource-leveling methods in the second proposed model. Finally, the proposed models apply to unit price and lump-sum contract types. The models can be adjusted to be applied in cost-plus contracts as a future improvement.

REFERENCES

Abido, M. A., and Elazouni, A. M. (2009, May). Improved crossover and mutation operators for genetic-algorithm project scheduling. *In 2009 IEEE Congress on Evolutionary Computation* (syf. 1865-1872). IEEE. DOI: 10.1109/CEC.2009.4983168

Abido, M. A., and Elazouni, A. M. (2011). Multiobjective evolutionary finance-based scheduling Entire projects' portfolio. *Journal of Computing in Civil Engineering*, *25*(1), 85-97. https://doi.org/10.1061/(ASCE)CP.1943-5487.000007

Abido, M. A., and Elazouni, A. M. (2021). Modified multi-objective Evolutionary Programming algorithm for solving project scheduling problems. *Expert Systems with Applications*, 115338. https://doi.org/10.1016/j.eswa.2021.115338

Ahuja, H. N. (1976). Construction performance control by networks. New York; Toronto: *Wiley*.

Akin, F. D., Damci, A., and Arditi, D. (2024b). Optimum Finance-Based Scheduling. *Journal of Construction Engineering and Management*, 150(9), 04024104. https://doi.org/10.1061/JCEMD4.COENG-1510

Akin, F. D., Damci, A., Arditi, D., and Demirkesen, S. (2024a). An advanced decision-support system for ranking unbalanced bids. *Construction Management and Economics*, 1-14. https://doi.org/10.1080/01446193.2024.2303158

Alavipour, S. R., and Arditi, D. (2018a). Optimizing finance cost in construction projects with fixed project duration. *Journal of Construction Engineering and Management*, 144(4), 04018012. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001451

Alavipour, S. R., and Arditi, D. (2018b). Impact of contractor's optimized finance cost on project bid price. *International Journal of Project Management*, 36(5), 808-818. https://doi.org/10.1016/j.ijproman.2018.03.001

Alavipour, S. R., and Arditi, D. (2019a). Time-cost tradeoff analysis with minimized project financing cost. *Automation in Construction*, 98, 110-121. https://doi.org/10.1016/j.autcon.2018.09.009

Alavipour, S. R., and Arditi, D. (2019b). Maximizing expected contractor profit using an integrated model. *Engineering, Construction and Architectural Management*, *26*(1), 118-138. https://doi.org/10.1108/ECAM-04-2018-0149

Alghazi, A., Elazouni, A., and Selim, S. (2013). Improved genetic algorithm for finance-based scheduling. *Journal of Computing in Civil Engineering*, 27(4), 379-394.https://doi.org/10.1061/(ASCE)CP.1943-5487.000022

Alghazi, A., Selim, S. Z., and Elazouni, A. (2012). Performance of shuffled frog-leaping algorithm in finance-based scheduling. *Journal of computing in civil engineering*, *26*(3), 396-408. https://doi.org/10.1061/(ASCE)CP.1943-5487.00001

Ali, M. M., ve Elazouni, A. (2009). Finance-based CPM/LOB scheduling of projects with repetitive non-serial activities. *Construction management and economics*, *27*(9), 839-856. https://doi.org/10.1080/01446190903191764

Al-Shihabi, S. T., and AlDurgam, M. M. (2017). A max-min ant system for the finance-based scheduling problem. *Computers and Industrial Engineering*, *110*, 264-276. https://doi.org/10.1016/j.cie.2017.06.016

Al-Shihabi, S., and Aldurgam, M. (2020a). Multi-objective optimization for the multi-mode finance-based project scheduling problem. *Frontiers of Engineering Management*, *7*(2), 223-237. https://doi.org/10.1007/s42524-020-0097-1

Al-Shihabi, S., and AlDurgam, M. M. (2020b). The contractor time–cost–credit trade-off problem integer programming model, heuristic solution, and business insights. *International Transactions in Operational Research*, *27*(6), 2841-2877. https://doi.org/10.1111/itor.12764

Arditi, D., and Chotibhongs, R. (2005). Issues in subcontracting practice. *Journal of Construction Engineering and Management*, *131*(8), 866-876. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:8(866)

Arditi, D., and Chotibhongs, R. (2009). Detection and prevention of unbalanced bids. *Construction Management and Economics*, *27*(8), 721-732. https://doi.org/10.1080/01446190903117785

Arditi, D., Koksal, A., and Kale, S. (2000). Business failures in the construction industry. *Engineering, Construction and Architectural Management*, *7*(2), 120-132. https://doi.org/10.1108/eb021137

Clough, R. H., Sears, G. A., Sears, S. K., Segner, R. O., and Rounds, J. L. (2015). Construction contracting: A practical guide to company management. *Eighth Edition, John Wiley & Sons.*

Damci, A., and Polat, G. (2014). Impacts of different objective functions on resource leveling in construction projects: a case study. *Journal of civil engineering and management*, *20*(4), 537-547. https://doi.org/10.3846/13923730.2013.801909

Damci, A., Polat, G., Akin, F. D., and Turkoglu, H. (2020). Use of float consumption rate in resource leveling of construction projects. Frontiers of Engineering Management, 1-13. https://doi.org/10.1007/s42524-020-0118-0

de la Garza, J. M., Vorster, M. C., and Parvin, C. M. (1991). Total float traded as commodity. *Journal of Construction Engineering and Management*, *117*(4), 716–727. https://doi.org/10.1061/(ASCE)0733-9364(1991)117:4(716

El-Abbasy, M. S., Elazouni, A. M., and Zayed, T. (2016). MOSCOPEA Multi-objective construction scheduling optimization using elitist non-dominated sorting genetic algorithm. *Automation in Construction*, *71*, 153-170. https://doi.org/10.1016/j.autcon.2016.08.038

El-Abbasy, M. S., Elazouni, A., and Zayed, T. (2017). Generic scheduling optimization model for multiple construction projects. *Journal of Computing in Civil Engineering*, 31(4), 04017003. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000659

El-Abbasy, M. S., Elazouni, A., and Zayed, T. (2020). Finance-based scheduling multi-objective optimization: Benchmarking of evolutionary algorithms. *Automation in Construction*, *120*, 103392. https://doi.org/10.1016/j.autcon.2020.103392

Elazouni, A. M. (2009). "Heuristic method for multi-project finance-based scheduling." *Construction Management and Econo*nmics, *27*(2), 199–211. https://doi.org/10.1080/01446190802673110

Elazouni, A. M., and Abido, M. A. (2011). Multiobjective evolutionary finance-based scheduling: Individual projects within a portfolio. *Automation in Construction*, *20*(7), 755-766. https://doi.org/10.1016/j.autcon.2011.03.010

Elazouni, A. M., and Abido, M. A. (2014). Enhanced trade-off of construction projects Finance-resource-profit. *Journal of Construction Engineering and Management*, *140*(9), 04014043.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000880

Elazouni, A. M., and Abido, M. A. (2014). Enhanced trade-off of construction projects Finance-resource-profit. *Journal of Construction Engineering and Management*, *140*(9), 04014043.https://doi.org/10.1061/(ASCE)CO.1943-7862.000088

Elazouni, A. M., and Gab-Allah, A. (2004). Finance-based scheduling of construction projects using integer programming. *Journal of Construction Engineering and Management*, *130*(1), 15–24. https://doi.org/10.1061/(ASCE)0733-9364(2004)130:1(15)

Elazouni, A. M., and Metwally, F. G. (2005). Finance-based scheduling Tool to maximize project profit using improved genetic algorithms. *Journal of Construction Engineering and Management*, *131*(4), 400-412. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:4(400)

Elazouni, A. M., and Metwally, F. G. (2007). Expanding finance-based scheduling to devise overall-optimized project schedules. *Journal of Construction Engineering and Management*, *133*(1), 86-90. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:1(86)

Elazouni, A., Alghazi, A., and Selim, S. Z. (2015). Finance-based scheduling using meta-heuristics: discrete versus continuous optimization problems. *Journal of Financial Management of Property and Construction*. DOI: 10.1108/JFMPC-07-2014-0013

Elbeltagi, E., Ammar, M., Sanad, H., and Kassab, M. (2016). Overall multiobjective optimization of construction projects scheduling using particle swarm. *Engineering, Construction And Architectural Management*, *23*(3), 265-282. DOI: 10.1108/ECAM-11-2014-0135

Eshtehardian, E., Afshar, A., and Abbasnia, R. (2008). Time–cost optimization: using GA and fuzzy sets theory for uncertainties in cost. *Construction Management and Economics*, *26*(7), 679-691. https://doi.org/10.1080/01446190802036128

Fathi, H., and Afshar, A. (2010). GA-based multi-objective optimization of finance-based construction project scheduling. *KSCE Journal of Civil Engineering*, *14*(5), 627-638. https://doi.org/10.1007/s12205-010-0849-2

Gajpal, Y., ve Elazouni, A. M. (2015). Enhanced heuristic for finance-based scheduling of construction projects. *Construction Management and Economics*, *33*(7), 531-553. https://doi.org/10.1080/01446193.2015.1063676

Halpin, D. W., and Senior, B. A. (2009). Financial management and accounting fundamentals for construction. *John Wiley and Sons*.

He, Y., He, Z., and Wang, N. (2021). Tabu search and simulated annealing for resource-constrained multi-project scheduling to minimize maximal cash flow gap. *Journal of Industrial and Management Optimization*, 17(5), 2451. doi:10.3934/jimo.2020077

Herroelen, W., De Reyck, B., and Demeulemeester, E. (1998). Resource-constrained project scheduling: A survey of recent developments. *Computers & Operations Research*, *25*(4), 279-302. https://doi.org/10.1016/S0305-0548(97)00055-5

Hinze, J. W. (2012). Construction planning and scheduling, *Pearson Prentice Hall*, Upper Saddle River, NJ.

Hyari, K. H. (2024). An Owner’s Overview of Contractor’s Models for Unbalanced Bidding: Easing the Controversy over This Practice. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *16*(1), 04523037.Jiang, A., Issa, R. R., and Malek, M. (2011). https://doi.org/10.1061/JLADAH.LADR-1017

Jiang, A., Issa, R. R., and Malek, M. (2011). Construction project cash flow planning using the Pareto optimality efficiency network model. Journal of civil engineering and management, 17(4), 510-519. Nassar, K. (2004). Using spreadsheets to optimally unbalance a construction bid. *Cost engineering*, *46*(12), 28. https://doi.org/10.3846/13923730.2011.604537

Kastor, A., and Sirakoulis, K. (2009). The effectiveness of resource levelling tools for resource constraint project scheduling problem. *International Journal of Project Management*, *27*(5), 493-500. https://doi.org/10.1016/j.ijproman.2008.08.006

Lee, D. E., Lim, T. K., ve Arditi, D. (2012). Stochastic project financing analysis system for construction. *Journal of Construction Engineering and Management*, *138*(3), 376-389. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000432

Liu, S. S., and Wang, C. J. (2008). Resource-constrained construction project scheduling model for profit maximization considering cash flow. *Automation in Construction*, *17*(8), 966-974. https://doi.org/10.1016/j.autcon.2008.04.006

Liu, S. S., and Wang, C. J. (2009). Two-stage profit optimization model for linear scheduling problems considering cash flow. *Construction Management and Economics*, *27*(11), 1023-1037. https://doi.org/10.1080/01446190903233111

Liu, S. S., and Wang, C. J. (2010). Profit optimization for multiproject scheduling problems considering cash flow. *Journal of Construction Engineering and Management*, *136*(12), 1268-1278. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000235

Liu, W., Zhang, J., ve Liu, W. (2021). Heuristic Methods for Finance-Based and Resource-Constrained Project Scheduling Problem. *Journal of Construction Engineering and Management*, *147*(11), 04021141. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002174

Peterson, S. J. (2013). Construction accounting and financial management (Vol. 2). Upper Saddle River, *NJ Pearson*.

Preinitz, W., and Niedermaier, M. (2010). Intermediate Structured Finance Modeling: Leveraging Excel, VBA, Access, and Powerpoint. *John Wiley & Sons*.

Russell, J. S. (1991). Contractor failure analysis. *Journal of Performance of Constructed Facilities*, *5*(3), 163-180.

Senouci, A., and Mubarak, S. (2014). Time-profit trade-off of construction projects under extreme weather conditions. *Journal of Construction Engineering and Project Management*, *4*(4), 33-40. https://doi.org/10.6106/JCEPM.2014.4.4.033

Shiha, A., and Hosny, O. (2019, June). A Multi-Objective Model for Enterprise Cash Flow Management. *In Proceedings, Annual Conference-Canadian Society for Civil Engineering* (2019).

Tabyang, W., and Benjaoran, V. (2016). Modified finance-based scheduling model with variable contractor-to-subcontractor payment arrangement. *KSCE Journal of Civil Engineering*, *20*(5), 1621-1630. https://doi.org/10.1007/s12205-015-0581-z

Tavakolan, M., and Nikoukar, S. (2022). Developing an optimization financing cost-scheduling trade-off model in construction project. *International Journal of Construction Management*, 1-16. https://doi.org/10.1080/15623599.2019.1619439

CURRICULUM VITAE

Name Surname **:** Fırat Doğu AKIN

EDUCATION :

- **B.Sc.** **:** 2016, Istanbul Technical University, Civil Engineering Faculty, Civil Engineering Department
- **M.Sc.** **:** 2019, Istanbul Technical University, The Graduate School of Science Engineering and Technology Division of Civil Engineering, Construction Management Graduate Program

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2016-2018 Cost Engineering in ESAS Properties
- 2018-2024 Research Assistant at Istanbul Technical University

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Akin, F. D.**, Damci, A., and Arditi, D. (2024). Optimum Finance-Based Scheduling. Journal of Construction Engineering and Management, 150(9), 04024104. https://doi.org/10.1061/JCEMD4.COENG-15103
- **Akin, F.D.** et al. (October, 2022). Overview of Financed-Based Scheduling in Construction Management Research. In Proceeedings of the 7TH INTERNATIONAL PROJECT AND CONSTRUCTION MANAGEMENT CONFERENCE, Istanbul, pp. 534–544.

OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS:

- Polat, G., Turkoglu, H., Damci, A., and **Akin, F.D.** Improved Unbalanced Bid Detection Model, 06/2019, *Creative Construction Conference – CCC2019*, 29.06.2019 – 02.07.2019.
- Damci, A., Polat, G., **Akin, F.D.**, and Turkoglu, H., Resource Levelling with Float Consumption Rate, 06/2019, *Creative Construction Conference – CCC2019*, 29.06.2019 – 02.07.2019.
- Polat, G., Turkoglu, H., Damci, A., and **Akin, F.D**. (2020). Detecting unbalanced bids via an improved grading-based model. *Organization, technology & management in construction: an international journal*, *12*(1), 2072-2082. https://doi.org/10.2478/otmcj-2020-0004

- Polat, G., **Akin, F. D.**, Turkoglu, H., & Damci, A. (2020, July). A Project Crashing Strategy Considering Contract Clauses and Quality Considerations: An Illustrative Example. In Creative Construction e-Conference 2020 (pp. 7-13). Budapest University of Technology and Economics.
- Turkoglu, H., Polat, G., Damci, A., and **Akin, F. D**. (2020, July). Project Crashing with Crash Duration Consumption Rate: An Illustrative Example. In Creative Construction e-Conference 2020 (pp. 56-64). Budapest University of Technology and Economics.
- Tas, E. F., Bulğan, J., Turkyılmaz, A. H., Bozdemir, S., Akarcalı, G. Z., **Akin, F. D.**, ... and Ergin, A. (2020). An assessment of lean and agile principles in building life cycle phases. In e-IPCMC-2020.
- **Akin, F. D.**, Damci, A., Polat G., and Turkoglu, H. (2020). A Risk-Based Approach to Prevent Unbalanced Bids. In e-IPCMC-2020.
- **Akin, F. D.**, Damci, A., and Yaşar, S. (2021). Prevention of Unbalanced Bids: A Counter Strategy. In *Proceedings of the ACE 2020-21*, Istanbul.
- **Akin, F. D.**, Polat, G., Turkoglu, H., and Damci, A. (2021). A crashing-based time-cost trade-off model considering quality cost and contract clauses. International Journal of Construction Management, 23(6), 954-963. https://doi.org/10.1080/15623599.2021.1946899
- Damci, A., Polat, G., **Akin, F. D.**, and Turkoglu, H. (2022). Use of float consumption rate in resource leveling of construction projects. Frontiers of Engineering Management, 1-13. https://doi.org/10.1007/s42524-020-0118-0
- •Esvap, E., Damci, A., Yasar, S., **Akin, F. D.**, and Abdi, A. P. (2022). An integrated multi-criteria-decision-making approach for spare parts supplier selection. Paper presented at the 7th International Project and Construction Management Conference (IPCMC2022), Istanbul, Turkey.
- Turkoglu, H., Polat, G., and **Akin, F. D.** (2023). Crashing construction projects considering schedule flexibility: An illustrative example. International Journal of Construction Management, 23(4), 619-628. https://doi.org/10.1080/15623599.2021.1901559
- **Akin, F. D.**, Damci, A., Arditi, D., and Demirkesen, S. (2024). An advanced decision-support system for ranking unbalanced bids. Construction Management and Economics, 1-14. https://doi.org/10.1080/01446193.2024.2303158
- Çeküç, S., Gürcanlı, G. E., **Akın, F. D.**, and Kale, Ö. A. (2024). Determination of Subcontractor Selection Criteria from the View of Occupational Health and Safety in the Construction Industry. International Journal of Advances in Engineering and Pure Sciences, 36(1), 23-32. https://doi.org/10.7240/jeps.1351569