**T.C.**
**İSTANBUL KÜLTÜR UNIVERSITY**
**INSTITUTE OF GRADUATE STUDIES**

# A COMPARATIVE ANALYSIS OF CRITICAL CHAIN AND CRITICAL PATH PROJECT MANAGEMENT METHODS

**Master Of Science Thesis**

**Saad ALNEHLAWI**
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**Department: Industrial Engineering**
**Program: Engineering Management**

**Supervisor: Assist. Prof. Zeynep GERGİN**

**JUNE 2022**

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I would like to express my gratitude to all those who gave me the possibility to complete this study. I want to thank my family, my teachers, and especially Assist. Prof. Zeynep GERGİN.

Date 03.06.2022 Saad ALNEHLAWI

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# ÖZET

## KRİTİK ZİNCİR VE KRİTİK YOL PEOJE YÖNETİM METODLARININ KARŞILAŞTIRMALI ANALİZİ

**Saad ALNEHLAWI**

Proje Yönetimi, zaman ve kaynak israfını azaltmaya yardımcı olan tüm prosedürlerdir. Ancak planlanan projelerin çoğu ayrılan kaynaklardan çok daha fazlasını kullanırlar. Bu prosedürler, ekip yönetimi, maliyet optimizasyonu, aktivite planlama, değerlendirme ve raporlamayı kapsar ve projenin başlangıcından sonuna kadar planlama, yönetim ve izleme süreçlerini içerir. En yaygın kullanılan proje çizelgeleme yöntemlerinden ikisi, Kritik Yol Metodu (CPM) ve Kritik Zincir Proje Yönetimi'dir (CCPM). Bu tez, kaynak bağımlı projelerle çalışırken her iki yöntemin artılarını ve eksilerini göstermek üzere, CPM ve CCPM yöntemleri arasında bir karşılaştırma sunar. CCPM kullanılarak elde edilebilecek yeni özellikleri ve neden yeni bir çizelgeleme yaklaşımı kullanıldığını gösterir. Bu çalışma ayrıca, CCPM'nin zaman tasarrufu ve bu tür bir projenin hedeflerine ulaşma açısından daha güvenilir ve verimli olabileceğini açıklamak için, bir tarımsal yatırım şirketi için gerçek bir vaka üzerinde her iki tekniğin de uygulamasını göstermektedir. Uygulamanın sonunda, CCPM'nin bu tür projelerde CPM'den daha uygun bir proje yönetimi planlama metodolojisi olduğu sonucuna varılmıştır.

**Anahtar Kelimeler:** Kritik Zincir Proje Yönetimi, Proje Yönetimi, Proje Çizelgeleme

| | |
|---|---|
| **University** | **: İstanbul Kültür University** |
| **Institttute** | **: Institute of Graduate Studies** |
| **Department** | **: Industrial Engineering** |
| **Program** | **: Engineering Management** |
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# ABSTRACT

## A COMPARATIVE ANALYSIS OF CRITICAL CHAIN AND CRITICAL PATH PROJECT MANAGEMENT METHODS

**Saad ALNEHLAWI**

PM is practically all procedures that help to reduce the waste of time and resources while most of the planned projects were using much more than what was assigned. These procedures include planning, managing, and monitoring processes of the project from its start to its end, covering the team management, cost optimization, activities scheduling, evaluating, and reporting. Two of the most commonly-used project scheduling methods are the Critical Path Method (CPM) and Critical Chain Project Management (CCPM). This thesis is presenting a comparison between CPM and CCPM showing the pros and cons of both methods when dealing with resource-depending projects. It shows the new features that can be achieved using CCPM, and the reasons that led to its use this new scheduling approach. This study also illustrates the application of both of the techniques in a real case study for an agricultural investment company, to explain how much CCPM can be more reliable and efficient in terms of time-saving and achieving the objectives of this kind of project. It is concluded that CCPM is a more suitable project management planning methodology to apply to this kind of project than CPM.

**Keywords**: Critical Chain Project Management, Project Management, Project Schedulin

# 1. INTRODUCTION

Since every project has its expectations related to cost, time, and quality which need to be achieved, the Project Management (PM) was created in the 1950s to help in getting these expectations professionally. PM is practically all procedures that help to reduce the waste of time and resources while most of the planned projects were using much more than what was planned. These procedures include planning, managing, and monitoring the project from its start to its end, covering the team management, cost optimization, activities scheduling, evaluating, and reporting.

From the 1960s till now many methods were used in project planning, such as the Project Network-based method which was one of the best solutions to save time and cost at that time especially CPM (Critical Path Method).

After that, in 1997 Dr. Eliyahu Goldratt proposed the new revolutionary project management method called Critical Chain Project Management (CCPM), first published in Goldratt's book Critical Chain 1997. CCPM was featured with the consideration of human behavior besides the algorithmic side. CCPM shares the main principles with CPM with one particular difference; CPM discusses the longest path of structural dependent activities, while CCPM discusses the dependency of resources between project activities. Each one of these methods has its advantages, and disadvantages, a different level of applicability and effectiveness, and different criteria to cover while managing projects.

Although the similarity in their names, there are many differences between them. Since the projects are getting more complex in this ever-changing world as time passing, these two project management methodologies' efficiency are not enough evaluated, nor deeply compared with each other in a way that enables project managers to decide correctly which method they need to choose according to the project's optimization objectives, such as minimizing time, cost, or other resources.

With this motivation, this thesis is presenting a comparison between CPM and CCPM showing the pros and cons of both project planning methods when dealing with resource-depending projects. It shows the new features that can be achieved using CCPM, and the reasons that led to its use it. The research also illustrates the application of both of the techniques in a real case study to explain how much CCPM can be more reliable and efficient in terms of time-saving and achieving the objectives of this kind of project.

Since the case study examined in this thesis is a resource-depending project, it is a hard decision to decide which method should be used for planning the project CPM or CCPM. Thus, this research is realized to help in clarifying the pros and cons for both of them in planning and managing this type of project, since the existing research that compares those two techniques are rare. This research will add value to the project management field academically and practically by comparing the two methodologies and presenting the numerical results after applying both of them on the real case study. In other words, the research will guide to use of the most suitable project planning method, taking into account the available resources together with the required objectives that need to be achieved.

In this research, a detailed explanation was made for both CPM and CCPM, after that a comparison was made between them in planning a feasibility study project for an agricultural investment company as a real case study. To achieve the mentioned research goals, this thesis was divided into the following six chapters:

1) Introduction: in which the research's aim, scope, significance, structure, and the questions to which the research is giving answers were explained.

2) General Information: in this chapter, basic information regarding the research topics was given such as project management, the commonly used methods (CPM, CCPM, PERT), the Theory Of Constraints, etc. in order to bring the reader to the point of discussion.

3) Literature Review: here, a full review of the academic history related to the discussed topic was provided, as well as a list of the previous works that compared CPM and CCPM.

4) Methodology: The steps of applying CPM and CCPM are provided.

5) Implementation and Results: This chapter contains the practical part of the research, which is the application of CPM and CCPM to the same real case study in order to compare the results.

6) Conclusion: in this last chapter, a brief conclusion was provided to illustrate the gained results of the comparison made, in addition to a summary of the research to present the final result that can be get from the work.

# 2. GENERAL INFORMATION

This section gives general information on Project Management and the two methods of Project scheduling such as Critical Path Method (CPM) and Critical Chain Project Management (CCPM)

## 2.1. Project Management (PM)

Project management is the process that uses all the skills, knowledge, techniques, and experiences in order to ensure that the project will achieve its objectives and get its expectations done in the best way. The project management approaches help professionals to work smarter in the dynamic world and quickly solve the problems over a determined period of time to get the needed outcomes.

From a historical perspective, the project manager has not been used formally until the mid of 20$^{th}$ century, when a group of future-thinking individuals from many different fields realized that the world is in need of new tools to be able for scheduling and manage the complex projects, at that time they started to standardize this new profession. And then the Project Management Institute (PMI) was born in 1969 as the world's leading authority on project management. From that time on, the growth of project management globally proves its importance as a strategic organizational skill, and so it needs to have it's own educating and training courses as a career path.

## 2.2. Critical Path Method (CPM)

CPM method is one of the most known planning techniques in project management, it was developed by both DuPont and Remington Rand in the 1950s. This technique helps in planning and modeling complicated projects step by step, defining the critical tasks and activities in order to solve problems such as the processes' critical activities, and calculating the required time for the project to be implemented without any time delay from the start to end.

### 2.3. Theory of Constraints (TOC)

The theory of constraints (TOC) was proposed by Dr. Eliyahu Goldratt in the 1980s. After publishing it, he explained the theory in many books later as The Goal and Theory of Constraints. In one of his lectures, Goldratt mentioned that TOC can be defined in one ward which is FOCUS defining the verb as: “Do what should be done, and don’t do what should not be done”. Goldratt said in his book that “TOC changed drastically the meaning of the verb to focus” (Goldratt, 1990).

TOC is basically a philosophy of management for any operation to reach the optimum solution. The greatest application of this theory is CCPM (Critical Chain Project Management), which is a project management method based on TOC.

The theory of constraints assumes that every operation consists of many dependent activities, and there is one activity with a low capacity affecting the performance of other activities called Constraint (Bottleneck). By elevating the constraint, the system will work better, and the operation will reach its goal more ideally. TOC concept description is in Figure 2.1 below.

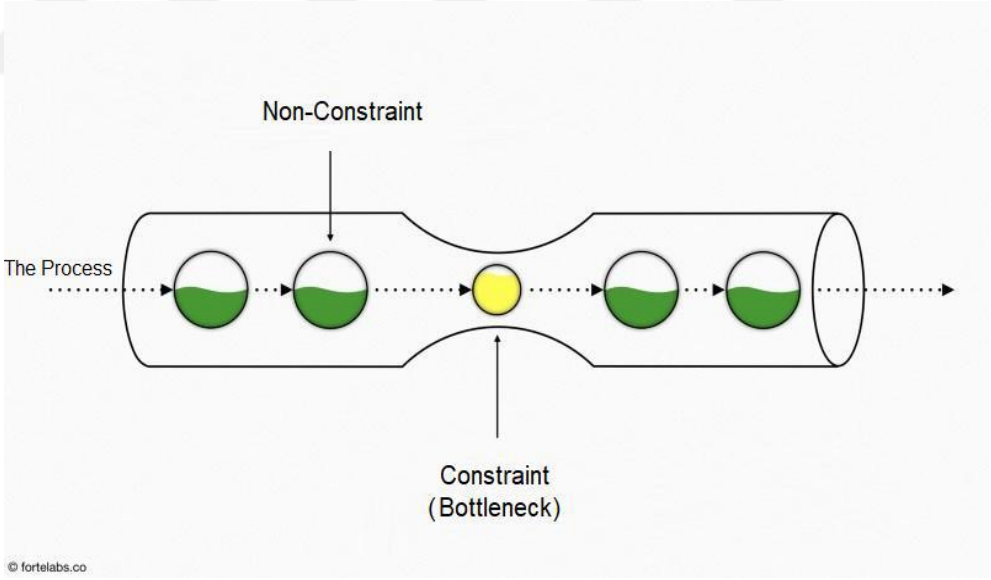


Figure 2.1 TOC concept description

### 2.3.1. The Five Focusing Steps

In TOC the steps of focusing have been identified to implement the theory, these five steps are:

1) Identify the system's constraint: in this step, the constraints must be identified and also prioritized according to their importance. The constraint should be identified first to show where to focus the improvement to get the best advantage.

2) Optimize the constraint: by deciding how can these constraints be managed and exploited, this can be done by using the full capacity of the constraint before adding more capacity (before elevating the constraint).

3) Subordinate the non-constraint: Since the activities are dependent on each other, the elevation of the constraint will improve the performance of all the systems (chain activities). Considering that all of the non-constraints should be subordinate to serve the need of the constraint. This will lead everything else to the previous decision, thus, whatever the constraints are, there must be a way to reduce their limiting impact.

4) Elevate the constraint: After the optimized constraint capacity is reached, it is time to expand the capacity by dealing with this constraint. This step should be done after the previous steps to minimize the constraint capacity expending cost. By this step, the process for the determined constraint can be ended because it will not be limiting the system anymore and there will be another constraint that is limiting the system and it must be elevated.

5) Return to step 1: After satisfying the needed capacity of the identified constraint, so the constraint has been broken by completing the previous four steps, then the process of finding the new constraint should take a place, and the cycle will be repeated.

## 2.4. Critical Chain Project Management (CCPM)

In Project Management (PM) many methods are designed to achieve the operational goal within the optimum time, cost, and resources. Different methods are taking different criteria into accounts such as time, cost, resources effect, and the team communication skills. When most common methods like CPM and PERT (Project

Evaluation Review Technique) are time-cost dependent project management methodologies, CCPM is one of the leading project management methodologies which care about resources.

The difference between the critical chain project management CCPM and the normal critical path method CPM is that in CCPM more attention is given to the available resources and the dependencies between them. In addition, CCPM uses “Buffers” in which the uncertain times be aggregated and kept at the end of the activities path, then the project evaluation will depend on how much this project used from the buffers. This method helps in improving project management and implementation in the shortest time (McKay& Morton, 1998).

CCPM considers the resource dependency between project activities based on the Theory of Constraints. Moreover, traditional project management methods assume fixed start and end dates, then a contingency time is added for each activity to avoid exceeding the planned deadline. Activities feeding buffer in Figure 2.2 and CCPM project buffer in Figure 2.3 below explains the addition of the contingency time to the estimated durations.

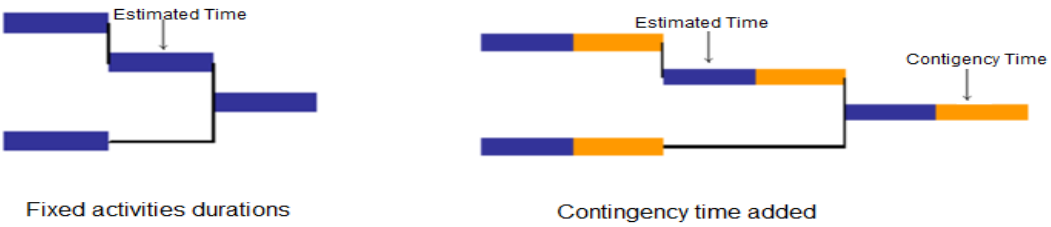


Figure 2.2 Activities feeding buffer

In CCPM all activities contingency times are summed to be added at the end of the project in time storage called "CCPM project buffer" as shown in Figure 2.3 below.

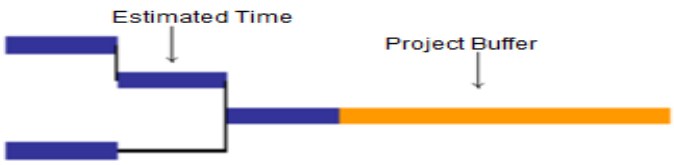


Figure 2.3 CCPM project buffer

### 2.4.1. CCPM Planning

In CCPM, planning starts with creating the project structure, then it goes from the end to the beginning of the project backward determining the latest start of each activity. Every activity is assigned to an estimated duration, these durations have a probability of 50% to happen at the time, assuming that half of the activities will finish before the deadline and the other half to finish after the deadline. After that a contingency time is added to the estimated activities durations, often taken as equal to the estimated time. This time addition raises the probability of happening at the time to almost 90%. The extra time added to each activity must be added at the end of the project in "buffers" which allows monitoring of the project performance better. Probability of task finishing at time in Figure 2.4 below shows the distribution of the probability by task duration and the probability of finishing the task at the estimated time with and without time addition.

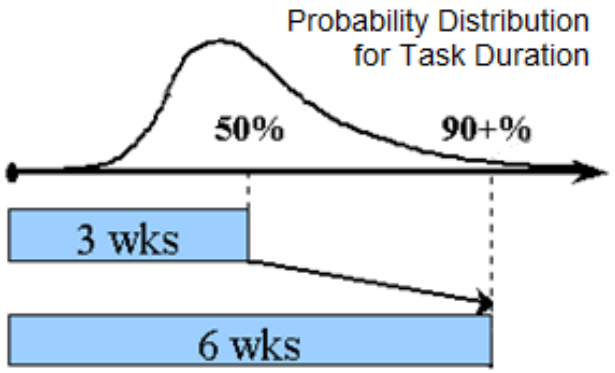


Figure 2.4 Probability of task finishing at time

Furthermore, one of the main goals of CCPM is to avoid multitasking, this phrase which is in project environments means switching back and forth among two or more concurrent tasks in one or multiple project/s. CCPM does not allow multitasking under any circumstances and keeps resources 100% dedicated to a task until it is completed, because multitasking means making the resource works on several unfinished tasks at the same time.

### 2.4.2. CCPM Execution

By identifying the priority of the project in all resources, any multitasking should be removed. Then the activities will run as fast as possible regardless of the deadlines working like a relay race. Because the plan is made with a probability of 50% that the activities will be done on time without consuming any buffers, the pressure will be high on the resources to finish the tasks as soon as possible, which overcomes the tendency to delay and laziness in the project activities.

### 2.4.3. CCPM Monitoring

Monitoring is the most important output of CCPM which includes specifically monitoring the buffer consumption rate. When the rate of consumption is high, the project manager should be alerted to make some improvements to correct the planned scheduling providing better alternative plans. And if the buffer is fully used before the project is finished the improvement plans should be implemented. Buffers' consumption rate is monitored using a graph with three colours: green, yellow, and red. As long as the rate line lies in the green area, the rate is good and no need to change, while the yellow area means observing and planning is necessary without any action, but if the rate becomes to be in the red zone, the plans made in the yellow area should be implemented and a change should be done. Project buffer status in Figure 2.5 below shows an example of CCPM monitoring of a project when the buffer rate shifts between the three areas.

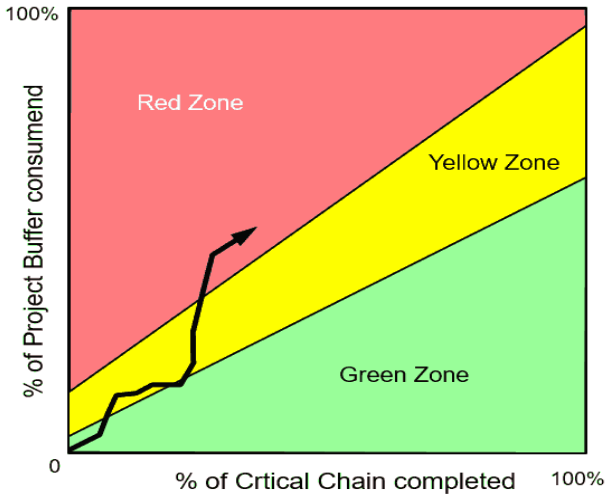


Figure 2.5 Project buffer status

### 2.4.4. Critical Chain Project Management and Theory of Constraints

Since CCPM is the adaption of the theory of constraints (TOC) to project management, thus CCPM is using literally the same five steps of focusing as TOC.

Table 2.1 below, shows the five steps of focusing on TOC and CCPM. In this table, the basic five steps were translated to be accommodated with the CCPM is a project management method.

Table 2.1 Five steps of focusing on TOC and CCPM

| TOC | CCPM |
|---|---|
| Identify the constraint | Identify the Critical Chain |
| Exploit the constraint | Save the Critical Chain activities: "Project Buffer", "Resources Buffer". |
| Subordinate everything else to the constraint | Prevent feeding chains to affect the critical chain "Feeding Buffer" |
| Elevate the constraint | Invest for resources |
| Control if constraint changes return to step 1 | Control if Critical Chain changes return to step 1 |

## 2.5. CPM versus CCPM

Despite the major theoretical and practical advances in the project management aspects, project-scheduling methods remained almost the same since CPM and PERT methods were introduced in the 1950s. It was thought that the reason for time and budget overruns for most projects is the inflexibility nature of the existed project management methods, that was what encouraged Eliyahu Goldratt to introduce CCPM as an alternative method for managing projects in 1990. After that, he decided to write the "Critical Chain" business novel in 1997. In his book, Goldratt extended the principles of the Theory of Constraints (TOC) to project management. At that time, the concept has become a well-known approach within project management.

Ghaffari and Emsley (2015) identified around twenty published case studies in different industries in which an average reduction of 40% in project durations was shown as well as improvements to productivity, transparency, communication and

collaboration, on-time delivery rate and control and monitoring of the projects. It has also been reported by the Project Management Institute PMI (2016) that CCPM is currently being used by the respective organizations of over one-third of 2428 project management practitioners who were surveyed globally. On the other hand, research on CCPM principles in multi-project environments is still extremely scarce

Although they share the main principles, Leach (2000) shows that CCPM has many main differences from CPM, these differences can be listed below:

I. Resource dependencies.

II. Looking for a good solution instead of an optimum solution.

III. Buffer's addition: (Time buffer, Feeding buffer, and Resources buffer).

IV. Monitoring and evaluating the project through the consumption rate of the buffer.

# 3. LITERATURE REVIEW

The literature review conducted show the lack of papers studying CCPM methodology in project management. Only 8 papers on average are discussing CCPM-related research since 1999, with a total of fewer than 400 articles. Most of those papers do not include a real case study implementation comparison using both CPM and CCPM methodologies. Although, some of the most related papers are listed below in Table 3.1 Past work about CCPM, and many are reviewed as well.

Table 3.1 Past work about CCPM

| Source | Work done in CCPM |
|---|---|
| Goldratt, 1990 | First introduction of CCPM as well as concept of CCPM was given. |
| Goldratt, 1997 | Business novel on 'Critical Chain' that explain principles of TOC and give 50% buffer sizing rule. |
| Leach, 1999 | Theory of CCPM and detail practice of CCPM. |
| The Product Development Institute, 1999 | Introduced RSEM for buffer sizing. |
| Graham K. Rand et al., 2000 | Introduced interlinks and inter connectivity between CPM & CCPM. |
| Steyn, 2002 | Derived how TOC helps in project scheduling using CCPM. |
| Wei, Liu, and Tsai, 2002 | Compared and derived the advantages and disadvantages of traditional method and TOC based method. |
| Goldratt, 2003 | Give TOC Insight project management programme. |
| Leach, 2003 | Introduces BPRSEM for buffer sizing. |

| | |
|---|---|
| Leach, 2004 | Introduce real and practical approach for continuous improvement of CCPM. |
| Herroelen and Leus, 2005 | Gave stochastic resource constrained project scheduling |
| Lechler et al., 2005 | Find that number of TOC ideas that can be used without implementing the whole concept of CC and benefited the project. |
| Shixin et al., 2006 | Presented a model of CCM considered work in process for product plan. |
| Rabbani et al., 2007 | Presented project-scheduling method by resource constraints for merging new and traditional resource management method by stochastic network. |
| Ashtiani et al., 2007 | Introduced High Confidence RSEM. |
| Tenera et. al., 2007 | Give highly sophisticated approaches using Computerized simulations. |
| Ohsato, 2008 | Fuzzy CCPM based scheduling developed. |
| Huang, 2009 | Explored the due-date performance problem using the concept of the aggregated time buffer in CCPM. |
| Zhen Yu Zhao, 2010 | He proposes an innovative critical chain method (ICCM) for project planning and control under resource constraints and uncertainty with an improved genetic algorithm. |
| Xue-mei et al., 2010 | Introduced Improved RSEM. |
| Srijit Sarkar, 2012 | He prepared CCPM as well as CPM using MS Project –a project management software and compared both networks. |
| Kaushik, 2013 | CCPM implementation related potential barriers were identified for Indian construction industry. |
| Yang and Fu, 2013 | Activity priority based multi project scheduling method introduced. |
| Repp & Wright, 2013 | They done identification of CCPM success factors. |

| | |
|---|---|
| Guofeng Ma et al., 2014 | CCPM framework to enhance the capabilities for project management practice. |
| Guofeng Ma et al., 2015 | Proposed Scenario-Based Proactive Robust Optimization for CCPM Scheduling. |
| Ghaffari and Emsley, 2015 | Suggest current status of research on CCPM approach from literature study as well as list of topics in CCPM that are still required research. |
| Poshdar et.al., 2016 | He discusses a probabilistic-based buffer allocation method (PBAL), which enables the final decision on buffer size to be made by the project planners based on their preferences about project completion time. |
| Kokoskie, G, 2001 | Recommending the alternatives of sizing buffers in specific scenarios. Many projects networks is discussed to as examples to find the results. |
| Newbold, R.C., 1998 | explains how constraints theory can be applied to arrive at effective innovative solutions in almost any setting.<br>Includes a comprehensive discussion of the critical chain scheduling approach designed by Eli Goldrat, the most important new development in project scheduling in the last 40 years! |
| Morris, P. W., & Pinto, J. K., 2007 | The book demonstrates how strategic project management and program management can be understood and used and linked to context and strategy in other activities and processes, such as quality management and statistical quality control. |

| | |
|---|---|
| Raz, T., Barnes, R., Dvir, D., 2003. | The paper concludes that although the CCPM contains many important principles, it does not provide a complete solution to project management needs, and that project managers should be careful about excluding traditional project management methods. |
| Tukel, O. I., et.al., 2006 | The paper presents two methods for measuring the size of the feed buffer in the CCPM scheduler.<br>One method involves resource constraints while the other uses network complexity.<br>The paper's conclusion shows that both methods generate smaller buffer sizes while providing adequate protection against delays at the time of project completion. |
| Westland, J., 2006 | The book emphasized the importance of true organizational commitment to the project, to a well-developed and executable project plan, to adequate resources and a high performing project team.<br>In conclusion, it turns out that project management is a complex industry, which is not just a set of competencies that can be taught from a manual, but rather requires flexibility, understanding and good judgment. |
| Wideman, R. M., 1995 | The paper states that the basis for project management is "getting things done", but the primary need is to address "the way people do it".<br>This illustrates the conflict between the scientific approach of 'reductionism' and the psychological disciplines that are more sensitive to the ecosystem approach to 'relationships'. |

| | |
|---|---|
| XM, X., et.al., 2010 | Based on CPM theory, this paper analyzes software development projects for problems with limited resources and offers solutions to them, and proposes Improved Root Square Error (IRSE), a method for setting up appropriate buffer sizes for software development projects. |

The research of Sinaga and Husin (2021) discusses the implementation of CCPM in the construction field in Indonesia and tries to solve the delivery delay problems related, by finding the best planning techniques for such projects, considering internal and external factors. Although the paper is about CCPM, the main difference it has with this studied thesis is that the paper focuses on construction projects, which have resources independent activities. Besides it does not discuss the CPM implementation on the project or its comparison with CCPM implementation results.

Shanlin and Fu (2004) discusses the implementation of project management methods to enhance the planning and execution of projects in automobile production in China. CCPM was implemented, and the buffers were calculated. In conclusion, the researchers found that implementing CCPM for automobile projects will enhance the planning and outcomes of the project.

Demeulemeester and herrolen (2002) introduced an important research handbook about project scheduling. Discussing the scheduling process, resources, estimating time for tasks, classifying project scheduling and analyses. Putting new definitions for project's scheduling especially related to CCPM as it discusses resources.

In terms of discussing CPM scheduling in different industries, Galloway (2007) discussed the use of CPM scheduling for construction industry projects, using many surveys with different positions like project managers, department heads, executive officers, staff positions and others. It was observed that CPM needs improvement to

cancel the risk of delay. And discusses the used softwares for the implementation of CPM and which is better.

Ghaffari and Emsley (2015) is a good reference to understand the current studies and possible evaluation of CCPM methodology in project management. It does not include a case study, implementation, or a comparison with other methods. Also, it is old now.

Trietsch and Baker (2012) discuss PERT technique in detail, showing the ability to develop the technique and its wide implementation variety. Also, this research discussed CCPM briefly in terms of risk modules. While CCPM methodology or implementation is not discussed, either the comparison with other methodologies.

Rand (2000) explains the CCPM as general information, with a quiet comparison with CPM as general information as well. Unlike this thesis, the research does not include any case studies or implementation comparisons between both methods.

Andyan et al. (2020) focuses on the analysis of the planning and scheduling of a construction project in Indonesia. It is discussing the implementation of CPM, PERT, and CCPM methodologies to solve the scheduling problems of the studied project. It also discusses the CPM Crashing method, giving more resources (more cost) to finish earlier (less time). The paper concluded that using the CCPM method in planning and scheduling is much better for construction projects.

Steyn (2002), introduces the theory of constraints and its relation to critical chain project management, implementation, resources management, risk management, and further work. It does not include a case study, implementation, or comparison as well.

Araszkiewicz (2017) compares the results of implementing both CPM and CCPM methodologies in a case study, to construct several marinas in north-western Poland. Important topics were covered in this research, also the comparison between CPM and CCPM was helpful in terms of further studies or real execution of the project. Although, construction projects are on a type of many of what a project may be. Thus, another type of projects needs to be studied as well.

The paper of Long and Ohsato (2008) is the discussion of the uncertainty of the resource's constraints of the activities of the project, and how CCPM can deal with

such a type of project. It is called the ‘Fuzzy Critical Chain Method’.By creating a deterministic schedule within the resource constraints, and adding the project buffer, in order of uncertainty, the method is practical in terms of planning projects with resource constraints as well as uncertainty.

Izmailov et al., (2016a) introduces a brief on CCPM methodology, including the TOC, Parkinson’s law, buffers, and chains. By discussing the buffers, times, and resources, this paper concluded the sensitivity of consuming buffers with time and proposed some steps to enhance the accuracy of the project planning using CCPM.

Feng et al. (2012) studies the creation of the portfolios of the project on the basis of the principle of similarity and provides a definition of priority in allocating multiple resources, based on quantitative analysis. It provides a useful model regarding the topics and is implemented for construction projects as a case study for the model used.

Izmaliov (2016b) introduces the CCPM method with its details in planning, implementation, and monitoring. It is a general brief about Critical Chain Project Management.

She et al. (2021) shows the CCPM methodology in terms of buffering and buffer sizing. It focuses on buffer calculations without looking for the project planning or the implementation using CCPM and other methodologies.

Li et al. (2022) focuses on the project buffer sizing in CCPM, it does not discuss other planning or implementation phases, or a case study. it also does not include a comparison with other project management methods.

Liu and Whangbo (2012), deeply studies CCPM and its implementation and buffering. Besides the cut and paste buffer calculating method and the root square error method, this paper introduces a new method to calculate the buffers using data statistical analysis. It concluded that, if the studied project and its activities have a known history and recorded data, it is much more accurate and reasonable to use the statistical analysis to calculate the buffers.

Taghipour (2020) investigates the methods used in project management in petrochemical industries and introduces the use of CPM and CCPM in this kind of

project as well, showing the advantages project managers may have considering CCPM as a project management methodology for petrochemical projects.

After discussing the general information of all methodologies, Narita et al. (2021) stated a case study to be studied as a project in all methods. Although the project studied was limited to a single, small activity network diagram, it concluded that CCPM is better in effectiveness than other studied techniques.

Montazeri (2017) stated the CPM and CCPM methods, starting with general information and literature review, then explaining the methodologies followed in the case study, and the findings and discussions of the case study. In the case study, it was shown that using CCPM gives more practical and effective in project planning and scheduling. Still, the paper did not show the difference between the methodologies for a different types of real-life case studies and projects.

Fan (2016) show the implementation of both CPM and CCPM techniques to plan a project of 20 activities, to construct a kitchen and a bedroom. After resources levelling, it was clear that CCPM is much suitable for scheduling such a project. The conclusion of the paper stated that because of the CPM's ignorance of resources which was proved by the computerized case study, using CCPM in such projects is a must to schedule the activities in a proper way.

Prajapati and Yadav (2017) introduced the comparison between CPM and CCPM, including their similarities and differences. The conclusion is that scheduling projects resources-based is more effective than task-based scheduling (no resources levelling). Thus, the researchers suggest using CCPM instead of CPM in private and governmental projects in their country.

Sung-Hwan et al (2018) discusses the implementation of CCPM method in EPC, Engineering, Procurement and Construction of mega oil and gas projects. Starting by defining the problem the paper discusses, and the application and methodology of implementation, then the application of the technique on the specific project in the case study. CPM was only compared to CCPM on the topic of how to deal with buffers, but

it was not applied as well to compare results. It was concluded that using CCPM provided 35% less time to complete the project than using PERT/CPM method.

Dürdar (2021) introduces both CPM and CCPM in detail, it also states the benefits of applying each of the methodologies in different types of projects, and the value it may bring to the project management field in turkey.

As it is proposed for a PhD, Ghafari (2016) covers most of the details related to CCPM and other project management techniques. As in conceptual background, principles and general information, Multitasking, and the methodology to implement it all to a specific case study project. After the discussion and the result of the implementation, the conclusion was introduced, showing that multitasking may be decided according to the resources and project type as well.

The paper of Sekreter (2009) is important regarding the definition of CCPM methodology and its implementation. After the detailed explanation of the technique, a construction case study is analyzed in the paper to show the ability of CCPM in enhancing the planning and scheduling of such projects. In the conclusion, the paper stated that proper project planning can be realized by using the resources in the most efficient way, by achieving the expected performance, and by planning the precious time in the most appropriate way, according to the methods offered by Project Management Science.

Davalu et al., (2019) discusses the project management techniques to construct a dam in Iran in the best way possible, it is discussing CCPM and its advantages in planning, scheduling and also in the economy. By applying four different hypotheses, it concludes that in all hypotheses applying CCPM in such a project is a benefit. And it is recommended.

In this thesis the contribution to the literature is firstly, the practical and theoretical comparison between the CPM and CCPM techniques. In this study going through the methodologies, the pros and cons, and application of both methods, the results, and the results reliability are discussed. The methods are also analysed through a non-common type of project, a feasibility analysis project for an agricultural investment company.

# 4. METHODOLOGY

The flowchart of the methodology in Figure 4.1 below shows the steps through which this thesis's objectives are implemented. Starting with the literature review, followed by presenting the differences between CPM and CCPM, then the implementation of both of them in the same case study.

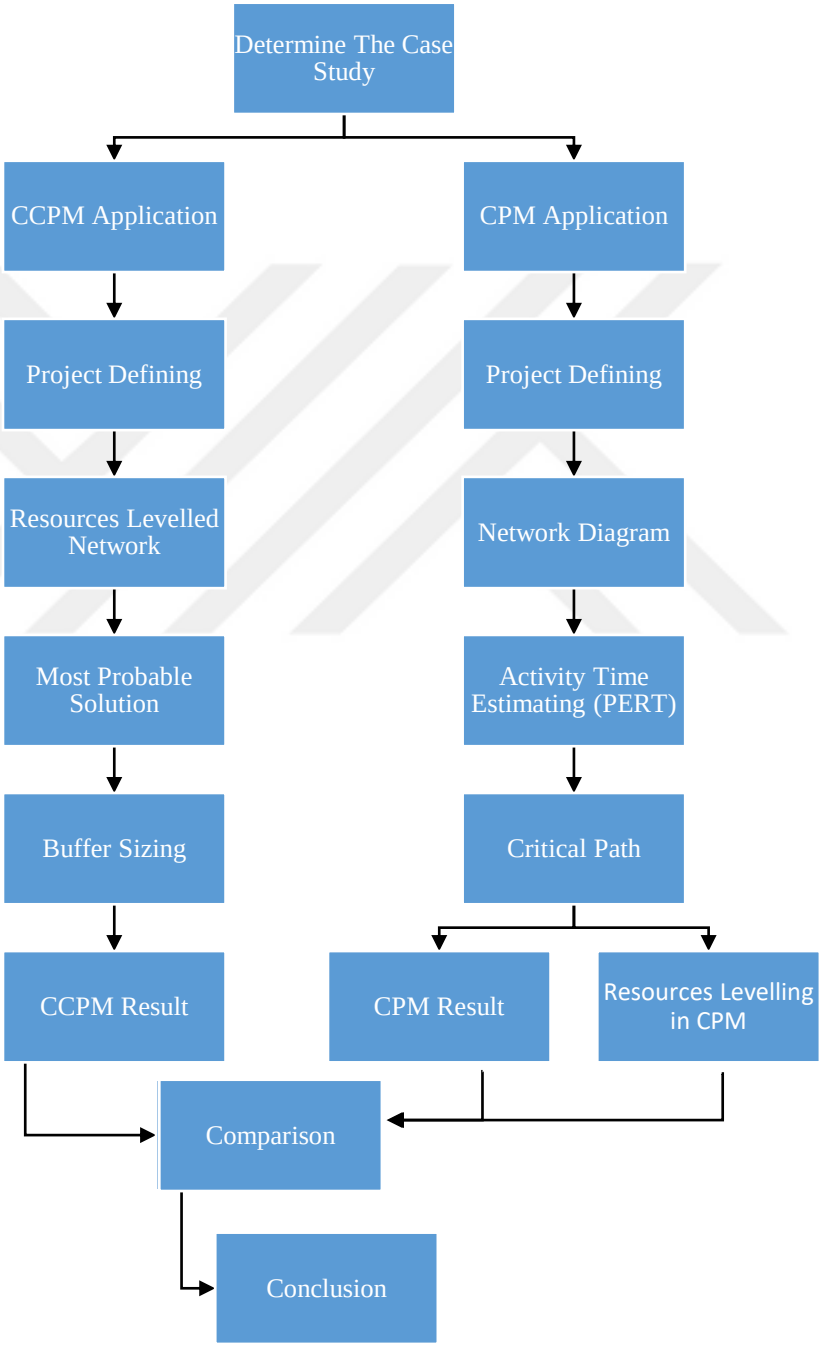


Figure 4.1 The flowchart of the methodology

### 4.1. Determine the Case Study

This section discusses the case study project, its definition, activities included, and the scope of the project as well. A table describing the project activities is introduced also, classified into main task groups. It will give a full image and a clear view of the case study project.

### 4.2. CPM Application

#### 4.2.1. Project Defining

When the project is identified, it is deeply understood to find out the relations between its activities. In this step project managers analyze the activities and identifies their predecessors as well. Defining the predecessors means, for each activity to determine which activities should be finished before this activity start. As End to Start relation. The Predecessors information is added to the activities table also, to help draw the network diagram in next step. A table of activities is provided showing the Number of Task, Outline Numbers, Task Names and Predecessors.

#### 4.2.2. Network Diagram

The network diagram is drawn after defining the project to show the activities flow and paths of the project. Since the project is being studied with software, it is enough to list the predecessors in the Gantt Chart table to get the network diagram drawn. Without the software the network diagram will be drawn by hand. A diagram showing the activities as Activity on Node is drawn with the number of activities on it.

#### 4.2.3. Activity Time Estimating (PERT)

Using PERT, with three-time values for each activity identifying pessimistic, optimistic, and most likely activity completion time. Activity time is to be determined using the PERT method as follows:

The average or expected time as approximated by the PERT formula is

$$\mu = t_e = \frac{t_0 + 4t_m + t_p}{6}$$

This formula is to be applied on each activity in the project. Since a software 'MS Project' is used, it is enough to list the three duration values for each activity in the Gantt Chart table, and the 'Expected' duration of the activity will be shown in a new column created and assigned with the formula above. Using the formula gives different numbers with fractions, thus all durations are rounded to 0.5 (half a day). This column is named 'Duration'. In this case an activity table is provided including Task Number, Task Name, Pessimistic Time, Most Likely Time, Optimistic Time, Expected Time and Duration.

### 4.2.4. Critical Path

Critical path is the longest path through the project's activities network diagram, The critical path can be identified by calculating using the earliest start and finish times, and the latest start and finish times for each activity. To identify the critical path, the critical activities should be identified first, to identify the critical activities, the slack duration should be calculated and should sum up to zero. Which is Slack = Late Finish – Early Finish. For each activity of the project.

Although, using the software MS Project, the critical path is identified automatically and can be shown on the network diagram and Gantt Chart on the software. No need for any calculation by hand. A table is provided showing the Number of tasks, Outline Number, Task Name, and Critical (yes/no). also, a network diagram showing the critical activities and slacks.

### 4.2.5. CPM Result

Applying CPM, and identifying critical path, will result in the project duration calculated in the duration unit used, as days or hours. The result of CPM without Resources Levelling will lead to a short duration but with resources conflict as well. And this result is to be compared with both: CPM with Resources Levelling and CCPM method. The start and finishing date of the project have resulted, the duration of the project in days, the number of activities and number of critical activities as well.

### 4.2.6. Resources Levelling in CPM

Usually, CPM does not deal with resources either in planning or scheduling the project. Although, to compare with CCPM, resources levelling is applied to the activities to examine CPM behaviour to resources. Each activity is assigned to the corresponding resource (team member), then all resources are considered as constraints just as the predecessors, and a new network is resulted, with different CPM result than before.

As MS Project software is used in this study, it is easy to assign resources to the activities through the software. The resources are automatically considered constraints and affect the network, the critical path and CPM result as well.

A brief about the resources is provided, with a table of activities showing the Task Number, Outline Number, Task Name and Resource Name. Also, the CPM result is calculated again under this constraint resulting the new starting and finishing dates and the duration of the projects in days as well. The results of resources levelled CPM and no-resources CPM is compared in this section showing the difference in the project duration.

## 4.3. CCPM Application

CCPM is more practical for performance improvement than traditional project management methods. By considering the resources available and the human behavior CCPM showed stability and effectiveness to reduce the consumption of resources and expand the capacity of the project making more benefits. In this case study, CCPM planning is introduced to compare with the CPM planning, with no monitoring or implementation details.

### 4.3.1. Project Defining

Planning CCPM starts with identifying the project, developing WBS, identifying the dependency between activities, and drawing the network diagram of the project. This step is used identically CPM. The project network diagram with no-resources is provided in this section defining the project before applying CCPM to it.

### 4.3.2. Resources Levelled Network

As resources are important in this project, and to avoid multi-tasking or activities conflict, the project network is levelled with resources, by assigning the right resources to each activity and redrawing the network diagram accordingly. The network diagram is provided showing the differences after resources levelling, the new critical activities, and the resources names on every activity on the diagram.

### 4.3.3. Most Probable Solution

When the resources levelled network is drawn, the project is to be solved using 'most probably finishing time' for each activity. Not applying the Beta distribution anymore in this method. Thus, instead of using three Time values in order to find the Duration to be used, only the Most Likely time value will be used as the duration of each activity. The network diagram with the Most Likely Time duration is provided with the project finishing date and project duration as the Most Probable Solution.

### 4.3.4. Buffers Sizing

The Project Buffer is to be added to the end of the critical chain, and it lies between the last task of the 'most probable solution' (aggressive schedule critical chain) and the committed end date (pessimistic finishing times). Also, feeding buffers are added to all non-critical activities (chains) that feed critical chains to protect them from being impacted by the non-critical activities. And it is placed at the end of each non-critical chain before they connect to the critical chain.

To calculate the buffers, the square root of the sum of squares is used (SSQ) since it is more effective. And buffer size using SSQ will be

$$Buffer\ Size = \sqrt{\sum Di^2}$$

Were,

*D:* the amount of shortened duration of an activity *i*

D is calculated as.

$$D = Pi - Mi$$

Were,

*Pi*: Pessimistic time of activity *i*

*Mi*: Most probable time of activity *i*

Then the '*D'* time of the tasks on the critical chain are used as Project Buffer, and the non-critical tasks have their feeding buffers.

The table of activities is provided showing the Task Number, Outline Number, Task Name, Pessimistic Time, Most Likely Time, and D values for all activities.

When the Critical Chain is identified, the Project Buffer is calculated as;

$$PB = \sqrt{\sum Di^2}$$

The size of the Project Buffer should not be less than 25 % of the size of the critical chain. Hence, if the calculation gives a value less than 25% of the chain, PB size is increased to this minimum amount.

The Feeding Buffer(s) is identified and the network diagram showing the buffers is provided. Feeding Buffers are calculated with the same formula using the activities on the non-critical paths.

$$FB = \sqrt{\sum Di^2}$$

If the number of activities on the paths(s) are less than 4, then Feeding Buffer is sized as *min (Di, Pi/2)* of longest activity duration on that feeding chain.

### 4.3.5. CCPM Results

The calculated buffers are added to the project Most Probable Solution, resulting the commitment duration to deliver the project in days.

## 4.4. Comparison

The results obtained from CPM application, with and without resources levelling, and the result of CCPM application are compared in term of the project duration and the reliability of applying the method to this kind of projects.

# 5. IMPLEMENTATION AND RESULTS

## 5.1. Case Study

In recent years, Turkey has opened widely to foreign investments, and official and popular encouragement to attract foreign investments to Turkey has become a priority for the Turkish economy.

Therefore, the investment services offices of the government, ministries and the presidency were also opened, and bridges of relations were built with other countries to pump capital into government and private projects inside Turkey.

These efforts were successful in attracting large foreign investments, both official and popular, and at the same time these investments needed more diversified services to expand and become more effective.

To meet these required services, private companies specializing in economic consultancy and project management have emerged, which provide economic feasibility studies and financial assessments, develop plans and effectively manage projects to serve foreign investments in Turkey to contribute to the stability and growth of the Turkish economy.

Since most investments are governmental-governmental or private-governmental, accuracy in data and investment details was an urgent necessity to conduct economic feasibility studies professionally, and because times are specific to seasons and linked to official relations between countries, and in governmental-governmental coordination often, the commitment to deliver feasibility studies on time Definitely without delay is an imperative that cannot be tolerated. Strict and expensive delay procedures and penalties have been set in the event that delivery is delayed on time, which makes one day a great value.

The case of one of the foreign investment services companies in Turkey, Nifa Consult, was studied, where different methodologies were applied to planning projects for preparing feasibility studies, to present offers with a realistic and real delivery time, and actually meet that time upon delivery.

This thesis is written to show the most proper project planning method for projects such as feasibility studies and business plans, the case study is a feasibility study of a new company working in agriculture investment management in Turkey.

The project includes market, legal, organizational, technical, and financial analysis. Each of these sections has many activities, the total project has a sum of 59 activities including start and finishes activities.

Since the case study is a resource-depending project, it is a hard decision to decide which method should be used for planning the project CPM or CCPM. Thus, this research is realized to help in clarifying the pros and cons for both of them in planning and managing this type of project. Project activities are provided below in Table 5.1.

Table 5.1 Project activities

| Task Number | Outline Number | Task Name |
|---|---|---|
| 1 | 1 | Start |
| 2 | **2** | **Market Analysis** |
| 3 | 2.1 | Analyzing agriculture revenue and statistics in turkey |
| 4 | 2.2 | Analyzing agriculture Import to total import |
| 5 | 2.3 | Agriculture Export to total export |
| 6 | 2.4 | Area analysis of agricultural lands |
| 7 | 2.5 | Agriculture Supply and demand in turkey |
| 8 | 2.6 | Walnut market review in turkey |
| 9 | 2.7 | Almond market review in turkey |
| 10 | 2.8 | Banana market review in turkey |
| 11 | 2.9 | Comparing agriculture statistics for USD and TL |
| 12 | 2.10 | Exchange rate effects analysis on the agriculture industry |
| 13 | 2.11 | Market analysis meeting and discussion |
| 14 | 2.12 | Market analysis final edits |
| 15 | **3** | **Legal Analysis** |
| 16 | 3.1 | Entity legal registration alternatives |
| 17 | 3.2 | Suggested registrations model and its specification |
| 18 | 3.3 | Licenses and documents needed to register |
| 19 | 3.4 | Taxes and legal finance procedure |
| 20 | 3.5 | Legal alternative methods to invest in the company's projects |
| 21 | 3.6 | Suggested legal investment method and its details |
| 22 | 3.7 | Agriculture investment projects government support |
| 23 | 3.8 | Legal analysis meeting and discussion |
| 24 | 3.9 | Legal analysis final edits |
| 25 | **4** | **Technical Analysis** |
| 26 | 4.1 | Preparing Company profile |

| | | |
|---|---|---|
| 27 | 4.2 | Business model (Canvas) Preparing |
| 28 | 4.3 | Categories of agriculture investment projects |
| 29 | 4.4 | Success factors analysis |
| 30 | 4.5 | Agriculture investment projects proposing and selection process |
| 31 | 4.6 | Operational workflow |
| 32 | 4.7 | Operational tasks analysis |
| 33 | 4.8 | Establishing tasks analysis |
| 34 | 4.9 | Establishing an action plan and preparing |
| 35 | 4.10 | Project's management fees, and contracting technical model |
| 36 | 4.11 | Establishing costs table |
| 37 | 4.12 | Operational costs table |
| 38 | 4.13 | Technical analysis meeting and discussion |
| 39 | 4.14 | Technical analysis final edits |
| 40 | **5** | **Organizational Analysis** |
| 41 | 5.1 | Organizational chart modelling |
| 42 | 5.2 | Job Descriptions preparing |
| 43 | 5.3 | Salaries table preparing |
| 44 | 5.4 | Rules and Regulations preparing |
| 45 | 5.5 | Organizational analysis meeting and discussion |
| 46 | 5.6 | Organizational analysis final edits |
| 47 | **6** | **Finance Analysis** |
| 48 | 6.1 | Financial model designing |
| 49 | 6.2 | legal establishing cost analysis |
| 50 | 6.3 | Technical establishing cost analysis |
| 51 | 6.4 | Operational cost analysis |
| 52 | 6.5 | Fixed and variable cost analysis |
| 53 | 6.6 | Revenue model designing |
| 54 | 6.7 | Revenue analysis |
| 55 | 6.8 | Tax Calculation |
| 56 | 6.9 | Depreciation analysis |
| 57 | 6.10 | Cash flow projection preparing for 8 years |
| 58 | 6.11 | Total Investment, Break even, and payback period calculation |
| 59 | 6.12 | Financial Ratio calculation |
| 60 | 6.13 | Financial ratio analysis |
| 61 | 6.14 | Financial feasibility analyzing and check |
| 62 | 6.15 | Financial analysis meeting and discussion |
| 63 | 6.16 | Financial analysis final edit |
| 64 | 7 | Finish |

## 5.2. CPM Application

### 5.2.1. Project Defining

As the project’s tasks and activities analysis is done, the activities' dependency is identified. Table 5.2 Activities predecessors below shows it.

Table 5.2 Activities predecessors

| Task Number | Outline Number | Task Name | Predecessors |
|---|---|---|---|
| 1 | 1 | Start | |
| 2 | **2** | **Market Analysis** | |
| 3 | 2.1 | Analyzing agriculture revenue and statistics in turkey | 1 |
| 4 | 2.2 | Analyzing agriculture Import to total import | 1 |
| 5 | 2.3 | Agriculture Export to total export | 1 |
| 6 | 2.4 | Area analysis of agricultural lands | 1 |
| 7 | 2.5 | Agriculture Supply and demand in turkey | 4,5,3 |
| 8 | 2.6 | Walnut market review in turkey | 1 |
| 9 | 2.7 | Almond market review in turkey | 1 |
| 10 | 2.8 | Banana market review in turkey | 1 |
| 11 | 2.9 | Comparing agriculture statistics for USD and TL | 3 |
| 12 | 2.10 | Exchange rate effects analysis on the agriculture industry | 11,3,7 |
| 13 | 2.11 | Market analysis meeting and discussion | 3,4,5,6,7,8,9,10,11,12 |
| 14 | 2.12 | Market analysis final edits | 13 |
| 15 | **3** | **Legal Analysis** | |
| 16 | 3.1 | Entity legal registration alternatives | 1 |
| 17 | 3.2 | Suggested registrations model and its specification | 16 |
| 18 | 3.3 | Licenses and documents needed to register | 17 |
| 19 | 3.4 | Taxes and legal finance procedure | 17,18 |
| 20 | 3.5 | Legal alternative methods to invest in the company's projects | 17 |
| 21 | 3.6 | Suggested legal investment method and its details | 20 |
| 22 | 3.7 | Agriculture investment projects government support | 16 |
| 23 | 3.8 | Legal analysis meeting and discussion | 16,17,18,19,20,21,22 |
| 24 | 3.9 | Legal analysis final edits | 23 |
| 25 | **4** | **Technical Analysis** | |
| 26 | 4.1 | Preparing Company profile | 1 |

| | | | |
|---|---|---|---|
| 27 | 4.2 | Business model (Canvas) Preparing | 26 |
| 28 | 4.3 | Categories of agriculture investment projects | 1 |
| 29 | 4.4 | Success factors analysis | 26,27 |
| 30 | 4.5 | Agriculture investment projects proposing and selection process | 28 |
| 31 | 4.6 | Operational work flow | 27,26 |
| 32 | 4.7 | Operational tasks analysis | 31 |
| 33 | 4.8 | Establishing tasks analysis | 27,26 |
| 34 | 4.9 | Establishing an action plan and preparing | 33 |
| 35 | 4.10 | Project's management fees, and contracting technical model | 27,24 |
| 36 | 4.11 | Establishing costs table | 34 |
| 37 | 4.12 | Operational costs table | 29,31 |
| 38 | 4.13 | Technical analysis meeting and discussion | 26,27,28,29,30,31,32,33,34,35,36,37 |
| 39 | 4.14 | Technical analysis final edits | 38 |
| 40 | **5** | **Organizational Analysis** | |
| 41 | 5.1 | Organizational chart modelling | 27,32 |
| 42 | 5.2 | Job Descriptions preparing | 41 |
| 43 | 5.3 | Salaries table preparing | 42,41 |
| 44 | 5.4 | Rules and Regulations preparing | 26,27,31,32,41,42 |
| 45 | 5.5 | Organizational analysis meeting and discussion | 41,42,43,44 |
| 46 | 5.6 | Organizational analysis final edits | 45 |
| 47 | **6** | **Finance Analysis** | |
| 48 | 6.1 | Financial model designing | 1 |
| 49 | 6.2 | legal establishing cost analysis | 15,48 |
| 50 | 6.3 | Technical establishing cost analysis | 36,48 |
| 51 | 6.4 | Operational cost analysis | 37 |
| 52 | 6.5 | Fixed and variable cost analysis | 51 |
| 53 | 6.6 | Revenue model designing | 27,35,28 |
| 54 | 6.7 | Revenue analysis | 53,2 |
| 55 | 6.8 | Tax Calculation | 19 |
| 56 | 6.9 | Depreciation analysis | 34,49,50 |
| 57 | 6.10 | Cash flow projection preparing for 8 years | 48,51,52,53,54,55,56,49,50 |
| 58 | 6.11 | Total Investment, Break even, and payback period calculation | 57 |
| 59 | 6.12 | Financial Ratio calculation | 57,58 |
| 60 | 6.13 | Financial ratio analysis | 59 |
| 61 | 6.14 | Financial feasibility analyzing and check | 60 |
| 62 | 6.15 | Financial analysis meeting and discussion | 51,52,53,54,55,56,57,58,59,60,61 |
| 63 | 6.16 | Financial analysis final edit | 62,14,24,39,46 |
| 64 | 7 | Finish | 1,13,24,39,46,63 |

### 5.2.2. Network Diagram

Project's network diagram (software aided) is developed in this stage considering the predecessor relationships given in Table 4, introduced in Figure 5.1.

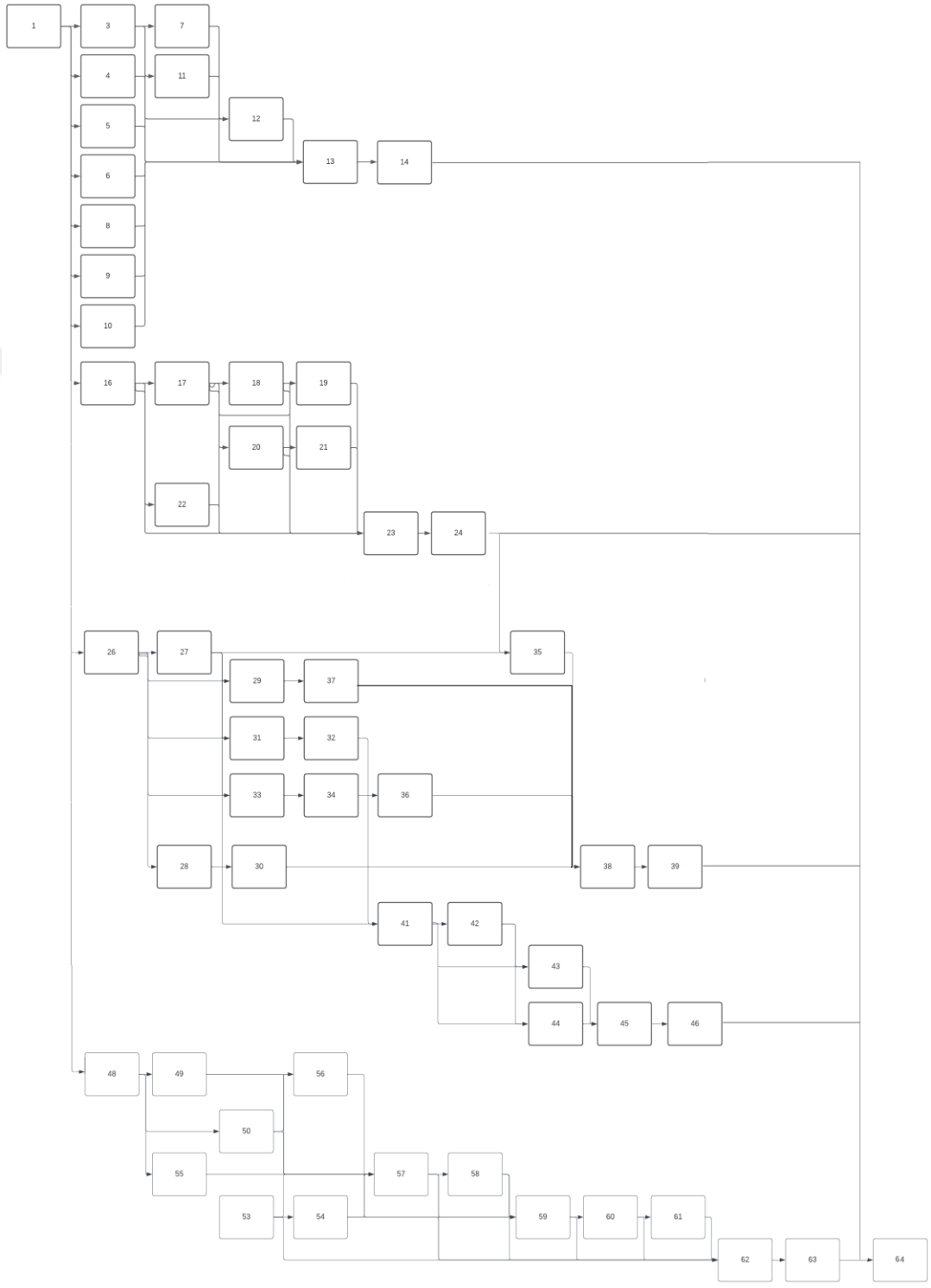


Figure 5.1 Project's network diagram

### 5.2.3. Activity Time Estimating (PERT)

Finding the time estimated to finish the project starts with identifying the finishing time as optimistic, pessimistic, and the most likely finishing time for each of the project activities, then applying the estimated time formula for each activity.

The durations used for calculations of the activities are the round-up of the expected duration, rounding up to half a day. The list with estimated activity times and the duration of the activities become as in Activities finishing times in Table 5.3 below:

Table 5.3 Activities finishing times

| Task No | Task Name | Pes. Time | Most likely | Opt. Time | Expected | Duration |
|---|---|---|---|---|---|---|
| 1 | Start | 0 | 0 | 0 | 0 | 0 |
| 2 | **Market Analysis** | 0 | **0** | 0 | **18.25** | **26** |
| 3 | Analyzing agriculture revenue and statistics in turkey | 2 | 1 | 1 | 1.17 | 1.5 |
| 4 | Analyzing agriculture Import to total import | 1.5 | 1 | 0.5 | 1 | 1 |
| 5 | Agriculture Export to total export | 1 | 1 | 0.5 | 0.92 | 1 |
| 6 | Area analysis of agriculture lands | 1.5 | 1 | 0.5 | 1 | 1 |
| 7 | Agriculture Supply and demand in turkey | 3 | 2 | 1 | 2 | 2 |
| 8 | Walnut market review in turkey | 4 | 2 | 1.5 | 2.25 | 2.5 |
| 9 | Almond market review in turkey | 4 | 2 | 1.5 | 2.25 | 2.5 |
| 10 | Banana market review in turkey | 4 | 2 | 1.5 | 2.25 | 2.5 |
| 11 | Comparing agriculture statistics for USD&TL | 2 | 1 | 0.5 | 1.08 | 1.5 |
| 12 | Exchange rate affects analysis on agriculture industry | 2 | 1 | 1 | 1.17 | 3 |
| 13 | Market analysis meeting and discussion | 1 | 1 | 1 | 1 | 2 |
| 14 | Market analysis final edits | 4 | 2 | 1 | 2.17 | 2.5 |
| 15 | **Legal Analysis** | 0 | **0** | 0 | **10.75** | **25** |
| 16 | Entity legal registration alternatives | 2 | 1 | 1 | 1.17 | 1.5 |
| 17 | Suggested registrations model and it's specification | 1 | 0.5 | 0.5 | 0.58 | 1 |
| 18 | Licenses and documents needed to register | 1 | 0.5 | 0.5 | 0.58 | 1 |
| 19 | Taxes and legal finance procedure | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 20 | Legal alternative methods to invest in the company's pojects | 2 | 2 | 1 | 1.83 | 2 |
| 21 | Suggested legal investment method and its details | 1 | 1 | 0.5 | 0.92 | 2 |
| 22 | Agriculture investment projects government support | 3 | 2 | 1 | 2 | 2 |
| 23 | Legal analysis meeting and discussion | 1 | 1 | 1 | 1 | 2 |
| 24 | Legal analysis final edits | 4 | 2 | 1 | 2.17 | 2.5 |
| 25 | **Technical Analysis** | 0 | **0** | 0 | **27.58** | **40** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 26 | Preparing Company profile | 4 | 4 | 2 | 3.67 | 4 |
| 27 | Business model (Canvas) Preparing | 3 | 1 | 1 | 1.33 | 1.5 |
| 28 | Categories of agriculture investment projects | 2 | 2 | 1 | 1.83 | 2 |
| 29 | Success factors analysis | 3 | 2 | 1 | 2 | 2 |
| 30 | Agriculture investment projects proposing and selection process | 2 | 2 | 1 | 1.83 | 2 |
| 31 | Operational work flow | 3 | 2 | 1 | 2 | 2 |
| 32 | Operational tasks analysis | 4 | 3 | 1.5 | 2.92 | 3 |
| 33 | Establishing tasks analysis | 2 | 1 | 1 | 1.17 | 1.5 |
| 34 | Establishing action plan preparing | 2 | 2 | 1 | 1.83 | 2 |
| 35 | Project's management fees, and contracting technical model | 3 | 2 | 1 | 2 | 2 |
| 36 | Establishing costs table | 1.5 | 1 | 0.5 | 1 | 1 |
| 37 | Operational costs table | 1.5 | 1 | 0.5 | 1 | 1 |
| 38 | Technical analysis meeting and discussion | 4 | 3 w`2s | 2 | 3 | 3 |
| 39 | Technical analysis final edits | 3 | 2 | 1 | 2 | 2 |
| 40 | **Organizational Analysis** | 0 | **0** | 0 | **17** | **20.5** |
| 41 | Organizational chart modelling | 2 | 2 | 1 | 1.83 | 2 |
| 42 | Job Descriptions preparing | 7 | 5 | 3 | 5 | 5 |
| 43 | Salaries table preparing | 1.5 | 1 | 0.5 | 1 | 1 |
| 44 | Rules and Regulations preparing | 6 | 4 | 3 | 4.17 | 4.5 |
| 45 | Organizational analysis meeting and discussion | 4 | 3 | 2 | 3 | 5 |
| 46 | Organizational analysis final edits | 3 | 2 | 1 | 2 | 2 |
| 47 | **Finance Analysis** | 0 | **0** | 0 | **23.5** | **49** |
| 48 | Financial model designing | 3 | 2 | 2 | 2.17 | 2.5 |
| 49 | legal establishing cost analysis | 1 | 0.5 | 0.5 | 0.58 | 1 |
| 50 | Technical establishing cost analysis | 1 | 0.5 | 0.5 | 0.58 | 1 |
| 51 | Operational cost analysis | 1.5 | 1 | 0.5 | 1 | 1 |
| 52 | Fixed and variable cost analysis | 1.5 | 1 | 0.5 | 1 | 1 |
| 53 | Revenue model designing | 3 | 2 | 1 | 2 | 3.5 |
| 54 | Revenue analysis | 3 | 2 | 1 | 2 | 2 |
| 55 | Tax Calculation | 1 | 1 | 0.5 | 0.92 | 1 |
| 56 | Depreciation analysis | 1 | 1 | 0.5 | 0.92 | 1 |
| 57 | Cash flow projection preparing for 8 years | 3 | 2 | 1 | 2 | 2 |
| 58 | Total Investment, Break even, and payback period calculation | 1.5 | 1 | 1 | 1.08 | 1.5 |
| 59 | Financial Ratio calculation | 2 | 2 | 1 | 1.83 | 2 |
| 60 | Financial ratio analysis | 2 | 1 | 1 | 1.17 | 1.5 |
| 61 | Financial feasibility analyzing and check | 1.5 | 1 | 1 | 1.08 | 1.5 |
| 62 | Financial analysis meeting and discussion | 4 | 3 | 2 | 3 | 3 |
| 63 | Financial analysis final edit | 4 | 2 | 1 | 2.17 | 2.5 |
| 64 | Finish | 0 | 0 | 0 | 0 | 0 |

### 5.2.4. Critical Path

In this case study, the critical path is found by the software MS Project. Critical activities are in red, and written 'Yes' for it as in Critical activities Table 5.4 below:

Table 5.4 Critical activities

| Task Number | Outline Number | Task Name | Critical |
|---|---|---|---|
| 1 | 1 | Start | Yes |
| 2 | **2** | **Market Analysis** | **No** |
| 3 | 2.1 | Analyzing agriculture revenue and statistics in turkey | No |
| 4 | 2.2 | Analyzing agriculture Import to total import | No |
| 5 | 2.3 | Agriculture Export to total export | No |
| 6 | 2.4 | Area analysis of agricultural lands | No |
| 7 | 2.5 | Agriculture Supply and demand in turkey | No |
| 8 | 2.6 | Walnut market review in turkey | No |
| 9 | 2.7 | Almond market review in turkey | No |
| 10 | 2.8 | Banana market review in turkey | No |
| 11 | 2.9 | Comparing agriculture statistics for USD and TL | No |
| 12 | 2.10 | Exchange rate effects analysis on the agriculture industry | No |
| 13 | 2.11 | Market analysis meeting and discussion | No |
| 14 | 2.12 | Market analysis final edits | No |
| 15 | **3** | **Legal Analysis** | **No** |
| 16 | 3.1 | Entity legal registration alternatives | No |
| 17 | 3.2 | Suggested registrations model and its specification | No |
| 18 | 3.3 | Licenses and documents needed to register | No |
| 19 | 3.4 | Taxes and legal finance procedure | No |
| 20 | 3.5 | Legal alternative methods to invest in the company's projects | No |
| 21 | 3.6 | Suggested legal investment method and its details | No |
| 22 | 3.7 | Agriculture investment projects government support | No |
| 23 | 3.8 | Legal analysis meeting and discussion | No |
| 24 | 3.9 | Legal analysis final edits | No |
| 25 | **4** | **Technical Analysis** | **Yes** |
| 26 | 4.1 | Preparing Company profile | Yes |
| 27 | 4.2 | Business model (Canvas) Preparing | Yes |
| 28 | 4.3 | Categories of agriculture investment projects | No |
| 29 | 4.4 | Success factors analysis | No |
| 30 | 4.5 | Agriculture investment projects proposing and selection process | No |
| 31 | 4.6 | Operational work flow | Yes |
| 32 | 4.7 | Operational tasks analysis | Yes |

| | | | |
|---|---|---|---|
| 33 | 4.8 | Establishing tasks analysis | No |
| 34 | 4.9 | Establishing an action plan and preparing | No |
| 35 | 4.10 | Project's management fees, and contracting technical model | No |
| 36 | 4.11 | Establishing costs table | No |
| 37 | 4.12 | Operational costs table | No |
| 38 | 4.13 | Technical analysis meeting and discussion | No |
| 39 | 4.14 | Technical analysis final edits | No |
| 40 | **5** | **Organizational Analysis** | **Yes** |
| 41 | 5.1 | Organizational chart modeling | Yes |
| 42 | 5.2 | Job Descriptions preparing | Yes |
| 43 | 5.3 | Salaries table preparing | No |
| 44 | 5.4 | Rules and Regulations preparing | Yes |
| 45 | 5.5 | Organizational analysis meeting and discussion | Yes |
| 46 | 5.6 | Organizational analysis final edits | Yes |
| 47 | **6** | **Finance Analysis** | **Yes** |
| 48 | 6.1 | Financial model designing | No |
| 49 | 6.2 | legal establishing cost analysis | No |
| 50 | 6.3 | Technical establishing cost analysis | No |
| 51 | 6.4 | Operational cost analysis | No |
| 52 | 6.5 | Fixed and variable cost analysis | No |
| 53 | 6.6 | Revenue model designing | No |
| 54 | 6.7 | Revenue analysis | No |
| 55 | 6.8 | Tax Calculation | No |
| 56 | 6.9 | Depreciation analysis | No |
| 57 | 6.10 | Cash flow projection preparing for 8 years | No |
| 58 | 6.11 | Total Investment, Break even, and payback period calculation | No |
| 59 | 6.12 | Financial Ratio calculation | No |
| 60 | 6.13 | Financial ratio analysis | No |
| 61 | 6.14 | Financial feasibility analyzing and check | No |
| 62 | 6.15 | Financial analysis meeting and discussion | No |
| 63 | 6.16 | Financial analysis final edit | Yes |
| 64 | 7 | Finish | Yes |

And as a Gantt chart, the critical path is shown in red, and the slack time for each non-critical activity (Blue) is written next to it, as in project's critical path in Figure 5.2.

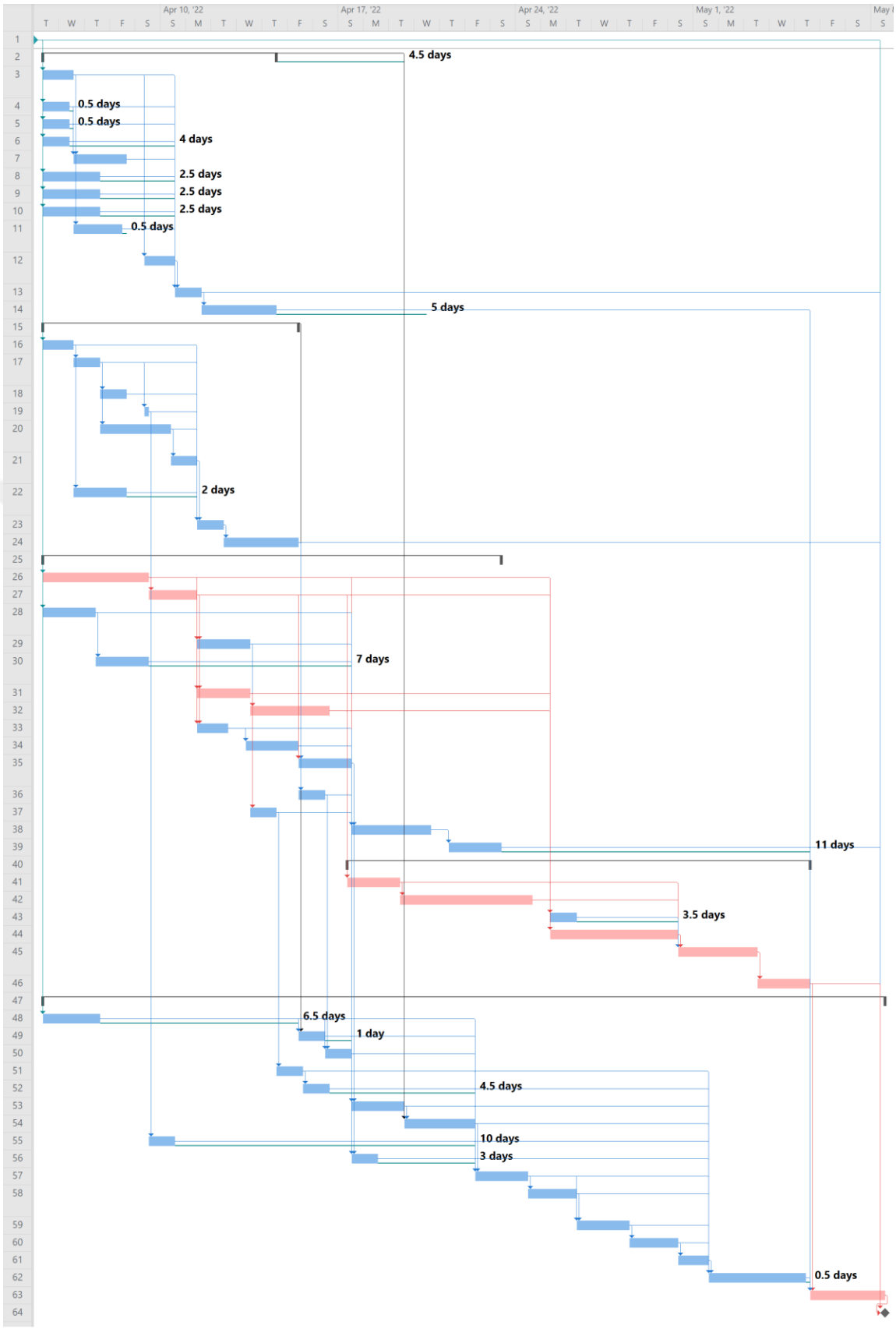


Figure 5.2 Project's critical path

### 5.2.5. CPM Result

The project in this case study has 59 activities, including start and finish activities. 18 of these activities form the critical path of the project. The total time needed to finish the project according to CPM planning is 29.5 days, starts on Tue 4/5/22, and finishes on Fri 5/8/22.

### 5.2.6. Resources Levelling in CPM

Although, planning using CPM is not accurate for such projects since it is resource independent. Like some tasks should be done by the same person. To find out the real effects of the resources assigned for all the activities, the responsible person was assigned to each activity, as a resource, and many activities had to be rescheduled. A team of 5 people will be working on the project, Saad: the project manager, Amjad: Market Researcher, Lolia: An organizational expert, Sami: Financial Analyst, and Malik: the legal expert. Table 7 below shows the resources assigned to activities.

Table 5.5 Resources of Project's Activities

| Task Number | Outline Number | Task Name | Resource Names |
|---|---|---|---|
| 1 | 1 | Start | |
| 2 | **2** | **Market Analysis** | |
| 3 | 2.1 | Analyzing agriculture revenue and statistics in turkey | Amjad |
| 4 | 2.2 | Analyzing agriculture Import to total import | Amjad |
| 5 | 2.3 | Agriculture Export to total export | Amjad |
| 6 | 2.4 | Area analysis of agricultural lands | Amjad |
| 7 | 2.5 | Agriculture Supply and demand in turkey | Amjad |
| 8 | 2.6 | Walnut market review in turkey | Amjad |
| 9 | 2.7 | Almond market review in turkey | Amjad |
| 10 | 2.8 | Banana market review in turkey | Amjad |
| 11 | 2.9 | Comparing agriculture statistics for USD and TL | Amjad |
| 12 | 2.10 | Exchange rate effects analysis on the agriculture industry | Saad, Amjad |
| 13 | 2.11 | Market analysis meeting and discussion | Amjad, Saad |
| 14 | 2.12 | Market analysis final edits | Amjad |
| 15 | **3** | **Legal Analysis** | |
| 16 | 3.1 | Entity legal registration alternatives | Malik |
| 17 | 3.2 | Suggested registrations model and its specification | Malik |
| 18 | 3.3 | Licenses and documents needed to register | Malik |
| 19 | 3.4 | Taxes and legal finance procedure | Malik |

| | | | |
|---|---|---|---|
| 20 | 3.5 | Legal alternative methods to invest in the company's projects | Malik |
| 21 | 3.6 | Suggested legal investment method and its details | Malik, Saad |
| 22 | 3.7 | Agriculture investment projects government support | Malik |
| 23 | 3.8 | Legal analysis meeting and discussion | Malik, Saad |
| 24 | 3.9 | Legal analysis final edits | Malik |
| 25 | **4** | **Technical Analysis** | |
| 26 | 4.1 | Preparing Company profile | Saad |
| 27 | 4.2 | Business model (Canvas) Preparing | Saad |
| 28 | 4.3 | Categories of agriculture investment projects | Saad |
| 29 | 4.4 | Success factors analysis | Saad |
| 30 | 4.5 | Agriculture investment projects proposing and selection process | Saad |
| 31 | 4.6 | Operational work flow | Saad |
| 32 | 4.7 | Operational tasks analysis | Saad |
| 33 | 4.8 | Establishing tasks analysis | Saad |
| 34 | 4.9 | Establishing an action plan and preparing | Saad |
| 35 | 4.10 | Project's management fees, and contracting technical model | Saad |
| 36 | 4.11 | Establishing costs table | Saad |
| 37 | 4.12 | Operational costs table | Saad |
| 38 | 4.13 | Technical analysis meeting and discussion | Saad |
| 39 | 4.14 | Technical analysis final edits | Saad |
| 40 | **5** | **Organizational Analysis** | |
| 41 | 5.1 | Organizational chart modeling | Lolia |
| 42 | 5.2 | Job Descriptions preparing | Lolia |
| 43 | 5.3 | Salaries table preparing | Lolia |
| 44 | 5.4 | Rules and Regulations preparing | Lolia |
| 45 | 5.5 | Organizational analysis meeting and discussion | Lolia, Saad |
| 46 | 5.6 | Organizational analysis final edits | Lolia |
| 47 | **6** | **Finance Analysis** | |
| 48 | 6.1 | Financial model designing | Sami |
| 49 | 6.2 | legal establishing cost analysis | Sami |
| 50 | 6.3 | Technical establishing cost analysis | Sami |
| 51 | 6.4 | Operational cost analysis | Sami |
| 52 | 6.5 | Fixed and variable cost analysis | Sami |
| 53 | 6.6 | Revenue model designing | Sami, Saad |
| 54 | 6.7 | Revenue analysis | Sami |
| 55 | 6.8 | Tax Calculation | Sami |
| 56 | 6.9 | Depreciation analysis | Sami |
| 57 | 6.10 | Cash flow projection preparing for 8 years | Sami |
| 58 | 6.11 | Total Investment, Break even, and payback period calculation | Sami |
| 59 | 6.12 | Financial Ratio calculation | Sami |

| | | | |
|---|---|---|---|
| 60 | 6.13 | Financial ratio analysis | Sami |
| 61 | 6.14 | Financial feasibility analyzing and check | Sami, Saad |
| 62 | 6.15 | Financial analysis meeting and discussion | Sami, Saad |
| 63 | 6.16 | Financial analysis final edit | Sami |
| 64 | 7 | Finish | |

In this situation, the difference between resources and no resources dependency is very clear, as all the critical paths, slack times, and project duration may change. The duration to finish the project became 49 days, while it was only 29.5 days. The project starts on Tue 4/5/22 and finishes on Tue 5/30/22.

Although it looks shorter and better to use CPM for planning the project with no resource levelling, it is not realistic or reliable when the project is implemented, and there will be challenges such as multi-tasking and late finishing.

## 5.3. CCPM Application

### 5.3.1. Project Defining

The project's tasks and their dependencies are shown in no resources project diagram in Figure 5.3 below:

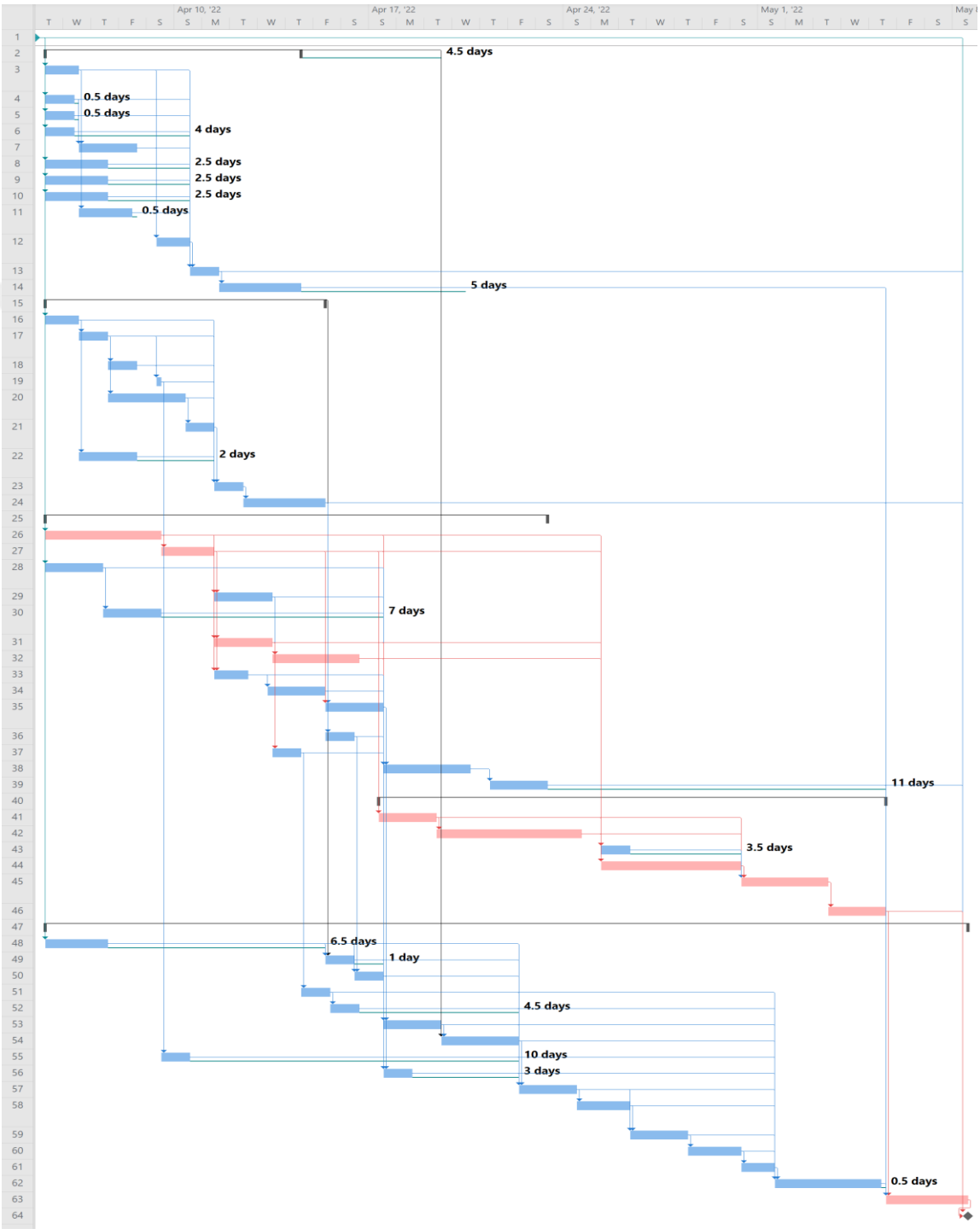


Figure 5.3 No resources project network

### 5.3.2. Resources Levelled Network

After assigning the corresponding resources to each activity using PERT durations, the network diagram becomes different, as drawn in resources levelled project network in Figure 5.4 below.

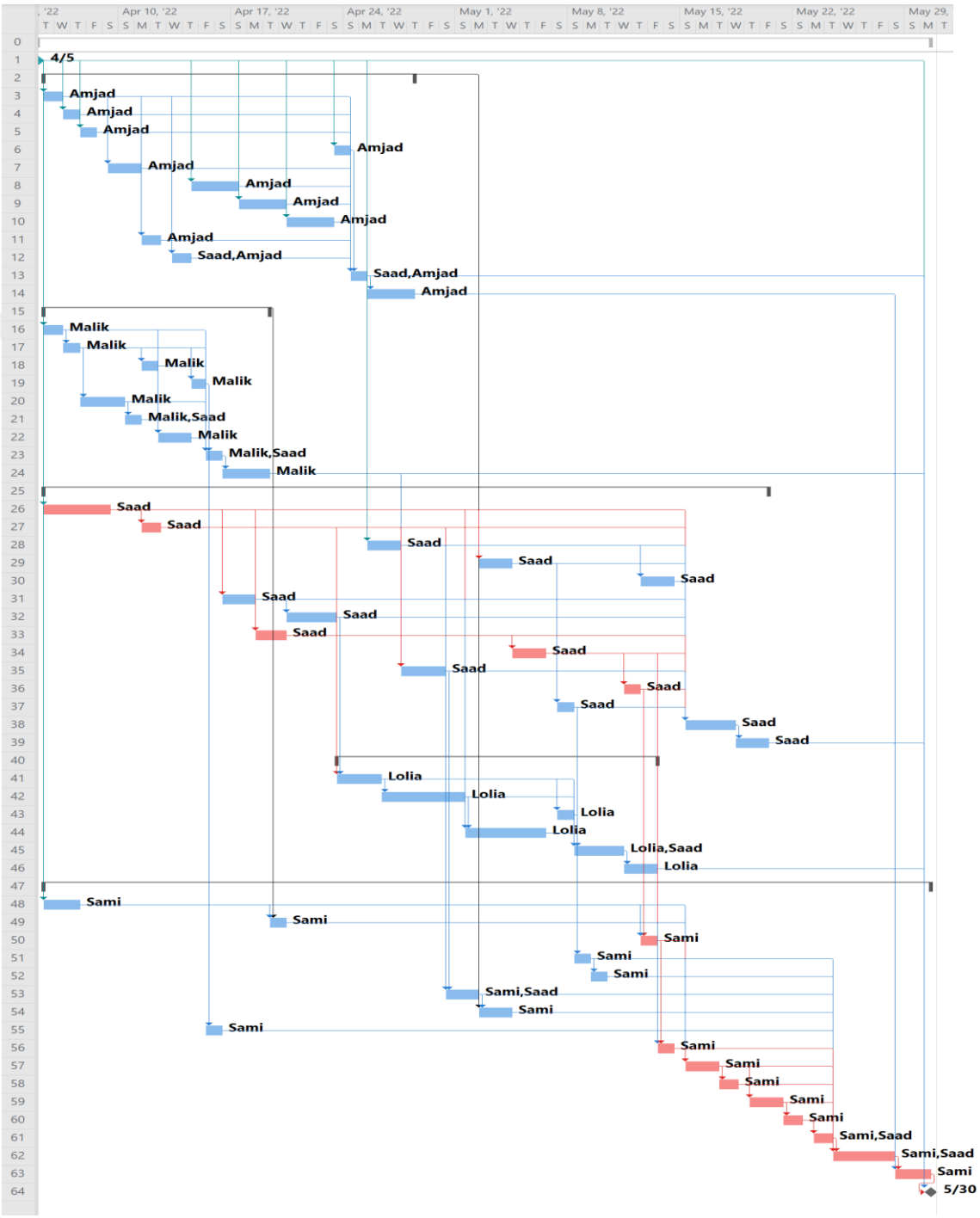


Figure 5.4 Resources levelled project network

### 5.3.3. Most Probable Solution

Solving for the most probable time, using MS Project software showed a significant change in the project's network. When the duration of the activities is the most probable finishing time (most likely), Most probable network is as Figure 5.5:

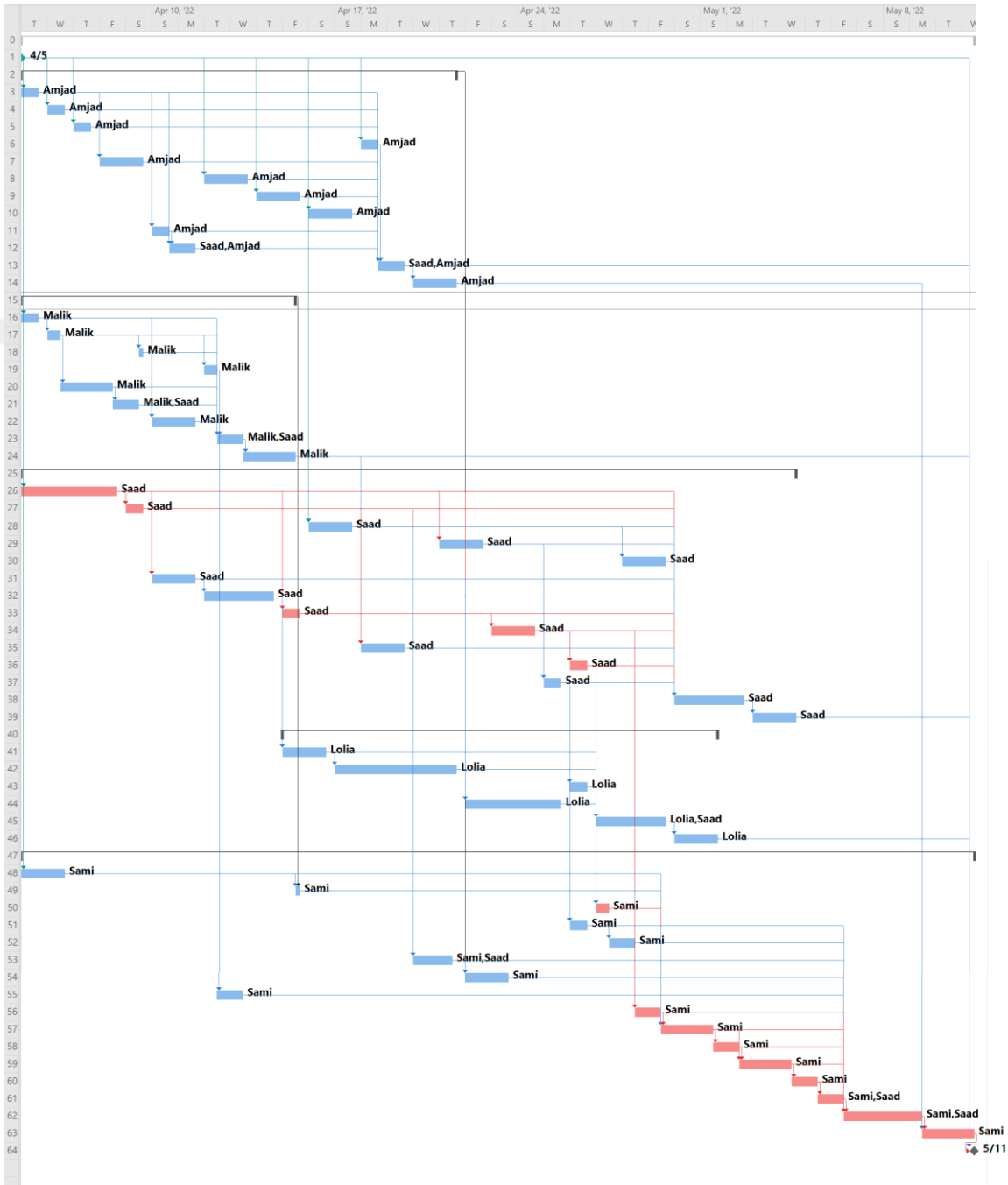


Figure 5.5 Most probable network

This solution has shown the finishing date of the project to be on 11th May, taking a total time of 36.5 days to finish the project.

### 5.3.4. Buffers Sizing

Project activities CCPM durations in Table 5.6 below shows the pessimistic and most likely durations of the activities, it shows the shortened durations (D values) for each activity as well. The critical chain is shaded in red also.

D = Pessimistic duration – Most likely duration.

Table 5.6 Project activities CCPM durations

| Task No | Task Name | P. Time | M. likely | D |
|---|---|---|---|---|
| 1 | Start | 0 | 0 | 0 days |
| 2 | **Market Analysis** | 0 | **0** | **0 days** |
| 3 | Analyzing agriculture revenue and statistics in turkey | 2 | 1 | 1 day |
| 4 | Analyzing agriculture Import to total import | 1.5 | 1 | 0.5 days |
| 5 | Agriculture Export to total export | 1 | 1 | 0 days* |
| 6 | Area analysis of agriculture lands | 1.5 | 1 | 0.5 days |
| 7 | Agriculture Supply and demand in turkey | 3 | 2 | 1 day |
| 8 | Walnut market review in turkey | 4 | 2 | 2 days |
| 9 | Almond market review in turkey | 4 | 2 | 2 days |
| 10 | Banana market review in turkey | 4 | 2 | 2 days |
| 11 | Comparing agriculture statistics for USD and TL | 2 | 1 | 1 day |
| 12 | Exchange rate effects analysis on agriculture industry | 2 | 1 | 1 day |
| 13 | Market analysis meeting and discussion | 1 | 1 | 0 days |
| 14 | Market analysis final edits | 4 | 2 | 2 days |
| 15 | **Legal Analysis** | 0 | **0** | **0 days** |
| 16 | Entity legal registration alternatives | 2 | 1 | 1 day |
| 17 | Suggested registrations model and it's specification | 1 | 0.5 | 0.5 days |
| 18 | Licenses and documents needed to register | 1 | 0.5 | 0.5 days |
| 19 | Taxes and legal finance procedure | 0.5 | 0.5 | 0 days |
| 20 | Legal alternative methods to invest in the company's projects | 2 | 2 | 0 days |
| 21 | Suggested legal investment method and its details | 1 | 1 | 0 days |
| 22 | Agriculture investment projects government support | 3 | 2 | 1 day |
| 23 | Legal analysis meeting and discussion | 1 | 1 | 0 days |
| 24 | Legal analysis final edits | 4 | 2 | 2 days |
| 25 | **Technical Analysis** | 0 | **0** | **0 days** |
| 26 | Preparing Company profile | 4 | 4 | 0 days |
| 27 | Business model (Canvas) Preparing | 3 | 1 | 2 days |
| 28 | Categories of agriculture investment projects | 2 | 2 | 0 days |
| 29 | Success factors analysis | 3 | 2 | 1 day |
| 30 | Agriculture investment projects proposing and selection process | 2 | 2 | 0 days |
| 31 | Operational work flow | 3 | 2 | 1 day |

| | | | | |
|---|---|---|---|---|
| 32 | Operational tasks analysis | 4 | 3 | 1 day |
| 33 | Establishing tasks analysis | 2 | 1 | 1 day |
| 34 | Establishing action plan preparing | 2 | 2 | 0 days |
| 35 | Project's management fees, and contracting technical model | 3 | 2 | 1 day |
| 36 | Establishing costs table | 1.5 | 1 | 0.5 days |
| 37 | Operational costs table | 1.5 | 1 | 0.5 days |
| 38 | Technical analysis meeting and discussion | 4 | 3 | 1 day |
| 39 | Technical analysis final edits | 3 | 2 | 1 day |
| 40 | **Organizational Analysis** | 0 | **0** | **0 days** |
| 41 | Organizational chart modelling | 2 | 2 | 0 days |
| 42 | Job Descriptions preparing | 7 | 5 | 2 days |
| 43 | Salaries table preparing | 1.5 | 1 | 0.5 days |
| 44 | Rules and Regulations preparing | 6 | 4 | 2 days |
| 45 | Organizational analysis meeting and discussion | 4 | 3 | 1 day |
| 46 | Organizational analysis final edits | 3 | 2 | 1 day |
| 47 | **Finance Analysis** | 0 | **0** | **0 days** |
| 48 | Financial model designing | 3 | 2 | 1 day |
| 49 | legal establishing cost analysis | 1 | 0.5 | 0.5 days |
| 50 | Technical establishing cost analysis | 1 | 0.5 | 0.5 days |
| 51 | Operational cost analysis | 1.5 | 1 | 0.5 days |
| 52 | Fixed and variable cost analysis | 1.5 | 1 | 0.5 days |
| 53 | Revenue model designing | 3 | 2 | 1 day |
| 54 | Revenue analysis | 3 | 2 | 1 day |
| 55 | Tax Calculation | 1 | 1 | 0 days |
| 56 | Depreciation analysis | 1 | 1 | 0 days |
| 57 | Cash flow projection preparing for 8 years | 3 | 2 | 1 day |
| 58 | Total Investment, Break even, and payback period calculation | 1.5 | 1 | 0.5 days |
| 59 | Financial Ratio calculation | 2 | 2 | 0 days |
| 60 | Financial ratio analysis | 2 | 1 | 1 day |
| 61 | Financial feasibility analyzing and check | 1.5 | 1 | 0.5 days |
| 62 | Financial analysis meeting and discussion | 4 | 3 | 1 day |
| 63 | Financial analysis final edit | 4 | 2 | 2 days |
| 64 | Finish | 0 | 0 | 0 days |

*Some activities D=0 because P. time = M. time since it is a fixed duration activity.

A Project Buffer is set after the Critical Chain, to the end of the project. And four Feeding Buffers are assigned based on four non-critical paths of the network.

Buffer sizing network diagram is shown in Figure 5.6.

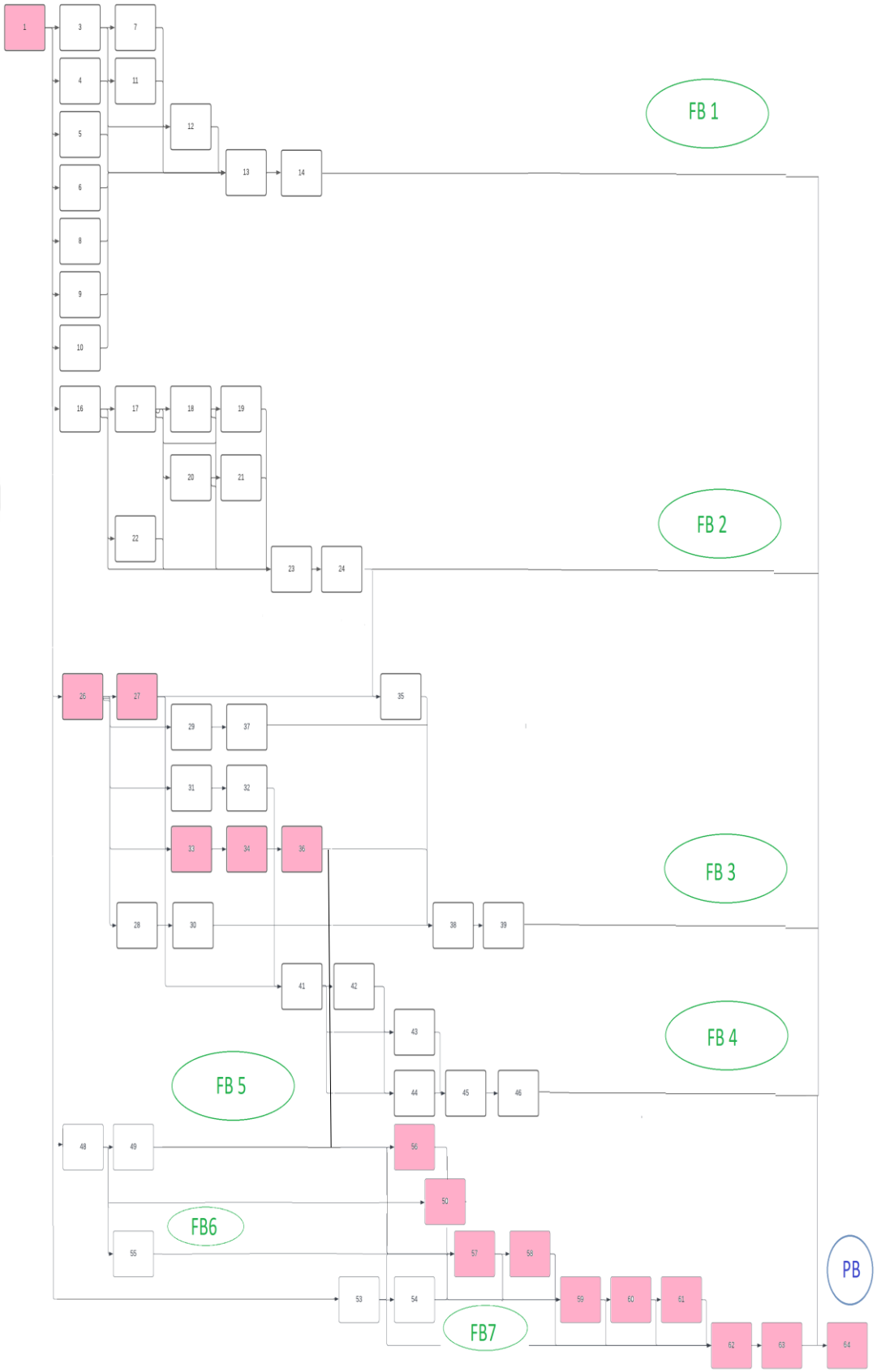


Figure 5.6 Buffer sizing network diagram

As seen from the network also, the critical chain is the path: Start-26-27-33-34-36-56-50-57-58-59-60-61-62-63-End; the length of the chain is 36.5 days.

The project buffer is calculated by SSQ for the buffers of each of these activities.

PB=$\sqrt{\sum Di^2}$

$$= \sqrt{D_{26}^2 + D_{27}^2 + D_{33}^2 + D_{34}^2 + D_{36}^2 + D_{56}^2 + D_{50}^2 + D_{57}^2 + D_{58}^2 + D_{59}^2 + D_{60}^2 + D_{61}^2 + D_{62}^2 + D_{63}^2}$$

$= \sqrt{0^2+2^2+1^2+0^2+0.5^2+0.5^2+0^2+1^2 + 0.5^2+0^2+1^2+0.5^2+1^2+2^2}$ = 3.6 days

Remembering that, the size of the Project Buffer should not be less than 25 % of the size of the critical chain, PB size must be increased to this minimum amount.

PB = 36.5 (0.25) = 9.125 days

And calculating for feeding buffers shows:

FB 1= $\sqrt{D_3^2 + D_4^2 + D_5^2 + D_6^2 + D_7^2 + D_8^2 + D_9^2 + D_{10}^2 + D_{11}^2 + D_{12}^2 + D_{13}^2 + D_{14}^2}$

$= \sqrt{1^2+0.5^2+0^2+0.5^2+1^2+2^2+2^2+2^2+1^2+1^2+0^2+2^2} = \sqrt{20.5}$ = 4.5 days

FB 2= $\sqrt{D_{16}^2 + D_{17}^2 + D_{18}^2 + D_{19}^2 + D_{20}^2 + D_{21}^2 + D_{22}^2 + D_{23}^2}$

$= \sqrt{1^2+0.5^2+0.5^2+0^2+0^2+0^2+1^2+0^2+2^2} = \sqrt{6.5}$ = 2.5 days

FB 3= $\sqrt{D_{28}^2 + D_{29}^2 + D_{30}^2 + D_{35}^2 + D_{37}^2 + D_{38}^2 + D_{39}^2}$

$\sqrt{1^2+0.5^2 + 1^2+0^2+0^2+1^2+1^2} = \sqrt{4.25}$ = 2 days

FB 4= $\sqrt{D_{31}^2 + D_{32}^2 + D_{41}^2 + D_{42}^2 + D_{43}^2 + D_{44}^2 + D_{45}^2 + D_{38}^2 + D_{39}^2}$

$\sqrt{1^2+1^2+0^2+2^2+0.5^2+2^2+1^2+1^2} = \sqrt{12.5}$ = 3.5 days.

FB5, FB6 and FB7 have less than 4 activities, and the buffers are calculated as follows.

FB5 = min *($D_{48}$, $P_{48}$/2) = min (1, 3/2) = 1 day*

FB6 = *min ($D_{55}$, $P_{55}$/2) = min (0, 1/2) = 0 days*

FB7 = *min ($D_{54}$, $P_{54}$/2) = min (1, 3/2) = 1 days*

### 5.3.5. CCPM Results

Adding the project buffer after the duration of the project provides the project committed duration as 36.5 + 9.125 = 45.625 days (approximately 46 days), while none of feeding buffers became critical as well.

## 5.4. Comparison

In the case study three solutions were discussed to solve the project scheduling: (1) CPM no-resources scheduling; (2) CPM resources levelled scheduling; (3) CCPM scheduling.

In first solution, the project duration resulted as 29.5 days. However, it is neither practical nor real, since the project is limited to resources and this will cause multitasking situation in the project, many tasks will be assigned to the same resources at the same time. On the other hand, levelling resources on CPM is applicable, it will avoid multitasking, and it resulted 49 days for the project to complete. Applying CCPM, resulted 36.5 days as critical chain duration, and with Buffers adding, the CCPM Solution became approximately 46 days. Being the best methodology to follow avoiding multitasking and saving time.

It's also shown the critical activities and critical path/s is changed when CPM is applied and when CCPM is applied, as shown in Result comparison Table 5.7 below.

Table 5.7 Results comparison

| | Critical Path / Chain Activities | Project duration |
|---|---|---|
| CPM | Start, 26, 27, 31, 32, 41, 42, 44, 45, 46, 63, End | 49 days |
| CCPM | Start, 26, 27, 33, 34, 36, 56, 50, 57, 58, 59, 60, 61, 62, 63, End | 46 days |

# 6. CONCLUSION

This study discussed project planning and scheduling using the critical path method (CPM), and the critical chain method (CCPM) on the same project. The study aimed to highlight the projects whose activities are dependent to resources while multitasking should be avoided in planning and implementation.

The study compared both techniques CCPM and CPM in project planning in terms of realism, accuracy, and the best result as well. First the general information and literature review about CPM and CCPM are introduced. Then the methodology of the research is shown by the study flowchart and the implementation detailed steps, at the end the case study implemented the methodology and showed its results and their comparison as well.

The comparison was made between CPM and CCPM when dealing with resource-depending projects such as Feasibility Study preparing projects. Applying CPM to Feasibility studies preparing projects was resulting a nonreliable result, on execution the deadline was always crossed which led to problems with delivery commitments. Also, when resources levelling was done to CPM activities, the delivery commitment time given was too long and not acceptable. This led to using CCPM and showing the way this method solves those problems in this kind of projects.

Comparative results showed that using CPM with no resources levelling results 29.5 days as delivery time for the project, although, it is not reliable result since multitasking occurred on the resources at the same time. Levelling resources in CPM made the result more reliable but less practical, the project duration became 49 (66% more longer duration) days to deliver which is too long.

When CCPM is applied, the Critical Chain Duration is 36.5 days to complete the project (35% less time than CPM levelling resources), and after adding buffers, the commitment delivery became 46 days (3 days – 7 % - less than CPM levelling resources).

While the comparison showed that Critical Chain Project Management is more suitable and appropriate for this type of projects and can be used in planning projects related to resources and where multitasking is a real problem.

CCPM has proved its worth in the field of work and other similar projects, it is recommended to implement this method to improve the planning accuracy and outcome in more and more sectors especially feasibility studies and research projects.

Considering the accomplishment in this research, many recommendations can be suggested for future research. Firstly, to apply the comparison between both project management methods in many different work fields and different types of projects, especially the resources limited projects. Secondly, to focus more on CCPM monitoring techniques rather than buffer sizing and scheduling. Last, to compare both CPM and CCPM in terms of project Crashing (time/cost trade-off).

# BIBLIOGRAPHY


Andiyan, A., Putra R M., Rembulan, G. D., and Tannad, H. (2020). *Construction Project Evaluation Using CPM Crashing, CPM-PERT and CCPM for Minimize Project Delays.* Conf. Ser. 1933- 012096.

Araszkiewicz, K. (2017). Application of Critical Chain Management in Construction Projects Schedules in a Multi-Project Environment: a Case Study. *Procedia Engineering* 182. 33 – 41.

Davalu, B., Khosravi, M. J., Pezeshki, B. and Estelaji, F. (2019). Descriptive Statistics Analysis of CPM and CCPM Methods for Dam Construction Projects from Experts' Standpoint. *Humanities & Management*, Vol (37), No 1 (1), 11-25.

Demeulemeester, E and Herroelen, W. (2002) *Project Scheduling: A Research Handbook.* Kluwer Academic Publishers; 2002.

Dürdar, V. (2021). *Approaches in Project Management Activities and Critical Chain Project Management.* Department of management information systems, Yeditepe university.

Fan, Z. (2016). A Study on Computerized Simulation of difference between CPM and CCPM. *ICMEMTC* 2016.

Feng, J., Yang, l., Hong, Y., Pang, M., Xiong, Y. and Wang, l. (2012). Critical Chain Construction with Multi-Resource Constraints Based on Portfolio Technology In South-To-North Water Diversion Project. *Water Science and Engineering*, 4(2): 225-236.

Galloway, P. D. (2006). Survey of the construction industry relative to the use of CPM scheduling for construction projects. *Journal of construction engineering and management*, 132(7), 697-711.

Ghaffari, M., & Emsley, M. W. (2015). Current status and future potential of the research on Critical Chain Project Management. *Surveys in Operations Research and Management Science*, 20(2), 43-54.

Ghaffari, M. (2016). *The Impact of Multitasking on Critical Chain Portfolios.* Doctor of Philosophy in the Faculty of Science and Engineering, University of Manchester.

Goldratt, E. M. (1990). *Theory of constraints,* Croton-on-Hudson: North River.

Goldratt, E. M. (1997). *Critical chain,* Routledge.

Goldratt, E. M., & Cox, J. (2003). *Production the TOC way*. Great Barrington: North River Press.

Graham K. R. (2000). Critical chain: the theory of constraints applied to project management. *International Journal of Project Management* 18. 173-177.

Herroelen, W. and Leus, R. (2001) On The Merits And Pitfalls Of Critical Chain Scheduling. *Journal of Operations Management;* 19:559–77.

Izmailov, A., Korneva, D. and Kozhemiakin, A. (2016). Effective Project Management with Theory of Constraints. Procedia - *Social and Behavioral Sciences* 229. 96 – 103.

Izmailov, A., Korneva, D. and Kozhemiakin A. (2016). Project Management Using the Buffers of Time and Resources. Procedia - *Social and Behavioural Sciences* 235. 189 – 197.

Kerzner, H. (2009). *Project management: A systems approach to planning.* Scheduling, and Controlling, 7. Wiley: 10th edition.

Kokoskie, G (2001). *A comparison of critical chain project management (CCPM) buffer sizing techniques*. Fairfax: George Mason University.

Leach, L. P. (1999). Critical chain project management improves project performance. *Project Management Journal*, *30*(2), 39-51.

Leach, L.P. (2014) *Critical Chain Project Management*. 3rd ed. USA: The Artech House Publishers.

Li, H., Cao, Y., Lin, Q. and Zhu, H. (2022). Data-Driven Project Buffer Sizing in Critical Chains. *Automation in Construction* 135, 104134.

Liu, J. and Whangbo, T. (2012). *A Study on the Buffer Sizing Method of CCPM Technique Using Statistical Analysis*. ICHIT 2012. 310 Berlin.

Long, D. L. and Ohsato, A. (2008). Fuzzy Critical Chain Method For Project Scheduling Under Resource Constraints And Uncertainty. *International Journal of Project Management* 26. 688–698.

McKay, K. N., & Morton, T. E. (1998). Review of: "Critical Chain" Eliyahu M. Goldratt The North River Press Publishing Corporation, Great Barrington, MA, 1997. *IIE Transaction*s, 30(8), 759-762.

Morris, P. W., & Pinto, J. K. (2007). *The Wiley guide to project, program, and portfolio management (Vol. 3).* John Wiley & Sons.

Montazeri, B. (2017). *Comparing Critical Chain Project Management with Critical Path Method: Case Study*. Masters Theses & Specialist Projects. Paper 1935.

Narita, T., Alberconi, C. H., Souza, F. B. and Ikeziri, L. (2021). Comparison of PERT/CPM and CCPM Methods in Project Time Management. *Gepros: Gestão da Produção, Operações e Sistemas;* 3. 16-1.

Newbold, R.C. (1998). Project Management in The Fast Lane *–Applying The Theory Of Constraints.* USA: CRC Press.

O'Brien, J., & Plotnick, F. (2016). *CPM in construction management*. McGraw-Hill Education.

Patrick, F. (1998). *Critical chain scheduling and buffer management*. Pennsylvania: Project Management Institute.

Peng, W. L. & Xu, H. (2012). The scheduling problem of active critical chain method. *Information Technology Journal, 11,* 829.

Prajapati, M. and Yadav, N. B. (2017). Buffer Based CCPM Scheduling: A Modern Approach for Indian Constraints. *Kalpa Publications in Civil Engineering* 1, 291-300

Raz, T., Barnes, R., Dvir, D. (2003). A Critical Look at Critical Chain Project Management. *Project Management Journal* (34)4, 24-32

Sekreter, E. B. (2009). Kritik Zincir Yöntemi Ile Proje Planlama: Inşaat Sektöründe *Bir Uygulama.* Department of Business Administration. Unpublished Master Thesis. Akdeniz University.

She, B., Chen, B. and Hall, G. (2021). Buffer Sizing in Critical Chain Project Management by Network Decomposition. *ACS Omega* 102. 102382.

Siemens, N. (1971). A simple CPM time-cost tradeoff algorithm. *Management Science, 17(6),* B-354.

Sinaga, T. and Husin, H. (2021). Analysis of Time Efficiency with CCPM Method and BIM in Construction Projects Construction of High-Rise Residential Building Basement. *Civil Engineering and Architecture,* 9(5), 1465 - 1477.

Steyn, H. (2002), Project Management Applications of The Theory of Constraints Beyond Critical Chain Scheduling. *International Journal of Project Management* 20. 75-80.

Sung-Hwan, J., Lee, E., and Pyo, K. (2018). Integrating a Procurement Management Process into Critical Chain Project Management (CCPM): A Case-Study on Oil and Gas Projects, the Piping Process, Sustainability 10, 6: 1817.

Taghipour, M., Seraj, F., Amin, M. and Delivand, C. (2020). Evaluating CCPM Method Versus CPM in Multiple Petrochemical Projects. *CITS* Volume 3, Issue 3, 2617-4596.

Tukel, O. I., Rom, W. O. & Eksioglu, S. D. (2006). An investigation of buffer sizing techniques in critical chain scheduling. *European Journal of Operational Research*, 172.

Westland, J. (2006). The Project Management Life Cycle: A Complete Step-by-step Methodology for initiating, planning, executing& closing a project successfully, *Kogan Page, p.3-6*

Wideman, R. M. (1995). Criteria for a project management body of knowledge. *International Journal of Project Management,* 13(2), 71-75.

XM, X., Guang Y., and Chuang L. (2010) Software development projects IRSE buffer set- tings and simulation based on critical chain. *J China Univ Posts Telecommun*; 17:100–6.

Yang, S. and Fu, L. (2014). Critical Chain and Evidence Reasoning Applied to Multi-Project Resource Schedule in Automobile R&D Process. *International Journal of Project Management* 32. 166 – 177.