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DERGİSİ

Üstyapı Projelerinin Kritik Yol Segmentleri (CPS) ve Kritik Yol Metodu (CPM) ile Çizelgelenmesi: Bir Vaka Çalışması

Gamze YALÇIN [a], **Savaş BAYRAM**[b,*]

[a]Erciyes Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği (Doktora), Kayseri, Türkiye
yalcinnn.gamze@gmail.com, ROR ID: https://ror.org/047g8vk19

[b]Erciyes Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Kayseri, Türkiye
sbayram@erciyes.edu.tr, ROR ID: https://ror.org/047g8vk19

Öz

Bir inşaat projesinin başarısı, uygulanan çizelgeleme yöntemine ve ne kadar iyi bir şekilde yürütüldüğüne bağlıdır. Planlama ve çizelgeleme teknikleri, başarılı projelerin gerçekleştirilmesi için çok önemlidir. Geleneksel kritik yol yöntemi (CPM), inşaat projelerinin çizelgelenmesi için yaygın olarak kullanılmasına rağmen bazı dezavantajlara sahiptir. Bu çalışmada, Nisan 2021'de başlayan ve Temmuz 2022'de tamamlanan Kayseri ilindeki bir konut projesine, her bir faaliyetin süresini ayrı zaman segmentlerine ayırarak daha ince bir ayrıntı düzeyine sahip kritik yol segmentleri (CPS) olarak adlandırılan bir teknik uygulanmıştır. Elde edilen sonuçlar CPM ile karşılaştırılmıştır. CPS'in CPM'e alternatif bir çizelgeleme aracı olup olamayacağı da değerlendirilmiştir. Literatürde CPS tabanlı çalışmaların sayısı sınırlıdır. Ayrıca yapılan çalışmalarda planlama aşaması dikkate alınmış, fiili aşama dikkate alınmamıştır. Bu nedenle bu çalışmada CPM ve CPS kullanılarak oluşturulan çizelgeler planlanan ve gerçekleşen aşamalar için değerlendirilmiştir. Sonuçlar, bireysel olarak CPS'in ağ gösterimini basitleştirme ve kritik yolu doğru bir şekilde tanımlama yeteneğini kısmen de olsa göstermiştir. Ancak CPM ile kıyaslandığında, kayda değer bir avantaj sunmadığı tespit edilmiştir. Bununla birlikte, CPS, kısmen kritik faaliyetlerde anormal bolluklar ortaya çıkarmıştır.

Anahtar Kelimeler
İnşaat Sektörü, Proje Yönetimi, Çizelgeleme, CPM, CPS

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Scheduling Superstructure Projects with Critical Path Segments (CPS) and Critical Path Method (CPM): A Case Study

Gamze YALÇIN [a], Savaş BAYRAM[b,*]

[a]Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Türkiye
yalcinnn.gamze@gmail.com, ROR ID: https://ror.org/047g8vk19

[b]Erciyes University, Faculty of Engineering, Department of Civil Engineering, Kayseri, Türkiye
sbayram@erciyes.edu.tr, ROR ID: https://ror.org/047g8vk19

Abstract

The success of a construction project depends on the scheduling method applied and how well it is executed. Planning and scheduling techniques are essential to the delivery of successful projects. The traditional critical path method (CPM), although widely used for scheduling construction projects, has some disadvantages. In this study, a technique known as critical path segments (CPS), which divides the duration of each activity into distinct time segments and has a finer level of detail, was applied to a housing project in Kayseri province of Türkiye. The project was started in April 2021 and was completed in July 2022. The obtained results were compared with CPM. It was also evaluated whether CPS can be an alternative scheduling tool to CPM. The number of CPS-based studies is limited in the literature. Moreover, in the studies conducted, the planning phase was considered, and the actual phase was not considered. Therefore, this study evaluates the schedules created using CPM and CPS for planned and actual phases. The results demonstrated CPS's ability to simplify network representation and accurately identify the critical path individually. However, when compared to CPM, it was found no significant advantage. Moreover, abnormal floats were observed for partially critical activities for CPS.

Keywords
Construction Industry, Project Management, Scheduling, CPM, CPS

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Introduction

The construction industry is one of the leading sectors of the world economy and is of great importance for the economy, especially in developing countries (Gurcanli, Mahcicek, Serpel & Attia, 2021). The creation of numerous direct and indirect jobs as well as the fact that it has an impact on many other industries that produce goods, equipment, and services in the production process make the construction industry a well-known major contributor to the economic and social development of a nation. In both periods of economic expansion and contraction, it is frequently one of the first industries to offer a snapshot of a region's financial health (Paz, Lafayette & Sobral, 2020). The construction industry, which accounts for around 30% of the gross domestic product (GDP) and employs around 1.5 million people, plays a crucial role in the economic development of Turkiye (Bayram, 2017). The Turkish construction industry has been undertaking an increasing amount of international contracts in recent years (Bilgin, Bilgin, Dikmen & Birgonul, 2019). Recently in August 2022, in the "Top 250 International Contractors" list released by "Engineering News Record", one of the leading publications in the industry, Turkiye is ranked second after China with 42 companies. The construction industry is more challenging than others due to its unique nature, the uniqueness of each project, the coexistence of many disciplines, the time, cost, and quality constraints of projects, and the high risk involved (Elbeltagi, 2009). Additionally, Eshtehardian et al. (2009) note that the environment in which construction projects are frequently carried out is typically unpredictable. Examples include changing weather and site conditions, equipment issues, delayed material deliveries, low labor productivity, etc. Several objectives need to be pursued to achieve a well-executed project (Elbeltagi, Ammar, Haytham & Kassab, 2016; Panwar & Jha, 2019). Cost and schedule are two essential objectives that need to be quantified and sustained (El-kholy, 2013). In order to successfully finish a project, an ideal balance between these goals must be struck.

Schedules are important management tools for building projects. The start date, length, end date, and resource requirements for each activity or production within the project are determined by the project schedule. The project team may deploy resources to the incorrect locations at the incorrect times as a result of scheduling errors, and/or the project manager may be unable to determine if the project is on or off schedule (Ackley, Baker & Lowe, 2007). When faced with problems, scheduling helps project managers reorganize project tasks and resources to meet key objectives such as time, cost, and quality under resource and budget constraints (Menesi, 2010). The planning phase of a construction project focuses on creating the logic for how the project will be built, whereas scheduling entails integrating the plan with a calendar or a specific time frame (Hinze, 2012.

Scheduling is an important management tool in the construction industry. Project scheduling, also known as project time management, involves the processes required to manage the timely completion of projects. According to the PMBOK (2017), these processes can be broken down into six categories: planning schedule management, identifying activities, sequencing activities, estimating activity durations, developing the schedule, and controlling the schedule. When it comes to construction management, scheduling entails figuring out the deliverables, milestones, and dependencies between various tasks for a certain project (Nouban & Ghaboun, 2017). Project managers traditionally use management tools such as the Gantt chart (Bar chart), and the Critical Path Method (CPM) to determine the interrelationship of activities, the overall project duration, and the redundancy of activities. Such data provides important information on critical and non-critical activities as well as the degree of flexibility with respect to the project schedule. Moreover, although these techniques have been used by project managers for many years in planning, scheduling, and project control, projects are not realized according to the planned Schedule (Wagh, 2017).

1. Previous Studies

Few studies have focused on developing a model called CPS to overcome the disadvantages of the traditional CPM. In a pioneering study, Menesi (2010) aimed to develop an innovative scheduling model, CPS, which eliminates the existing CPM disadvantages. He stated that the proposed CPS model will overcome scheduling constraints such as project deadlines, resource constraints, corrective actions during construction, and accurate scheduling analysis during and/or after construction. It was also stated that by using different optimization techniques such as simulated annealing, ant colony optimization, and genetic algorithms, the results and processing time can be compared to find the most appropriate technique to be used in future research with CPS. The article published as a follow-up to this doctoral thesis, Hegazy and Menesi (2010)

stated that the CPM is useful for scheduling construction projects but has serious drawbacks that have prevented decades of practice and research from using it as a decision support tool. Therefore, they proposed a new more elaborate CPS mechanism by dividing the duration of each activity into separate time segments. According to the claim, CPS would support planning, corrective action, and schedule analysis decisions by assisting project managers in creating trustworthy schedules that more accurately reflect reality.
Hegazy and Menesi (2012) stated that the CPM is useful for project planning, but in the case of complex schedules, variable calculation errors limit its potential for decision support during project control. In this study, they used a small case to demonstrate the CPS technique for project control. It was stated that the CPS will assist project managers in preparing more reliable schedules for planning, corrective action, and timeline analysis decisions. Tang and Mukherjee (2012) aimed to identify critical changes in activities in the construction process. They combined the CPS technique and interactive simulation to capture changes in the criticality of activity and used the CPS technique to plan and simulate a highway reconstruction project. They proved by comparing planned and simulated critical activities that the production-based scheduling method is more capable of capturing criticality changes than the time-based scheduling method. Wagh (2017) stated that although management tools such as CPM and Gantt chart have been used for many years, they are insufficient for project tracking, monitoring, and reviewing projects. This study presented the CPS technique, which allows project schedules to be tracked, monitored, and reviewed on a daily basis rather than periodically. It was also mentioned that CPS will help achieve a better level of control over projects with better visualization, optimization, and decision support to ensure project success. Aboelmagd (2020) stated the disadvantages of CPM and discussed the CPS approach. To focus on the shortcomings of CPM, he examined case studies and demonstrated the calculations and analysis of the CPS technique. He stated that CPS is a beneficial tool that can be extensively studied by future researchers.

This study is an attempt to compare the performances of CPM and CPS for both planning and actual phases of a residential construction project, and to evaluate whether CPS can be used as an alternative promising scheduling tool to CPM.

2. Time-Oriented Problem Solving Methods

The use of rational planning and scheduling methods is one of the keys to ensuring the successful completion of a project (Zhang & Zou, 2015). There are various methods and techniques commonly used in scheduling construction projects. These methods can be categorized into three groups: classical methods, modifications of classical methods, and soft computing methods. The main topics of this study, CPM, which belongs to the group of classical methods, and CPS, which belongs to the group of modifications of classical methods, are discussed in more detail.

2.1. Critical Path Method (CPM)

Traditional network scheduling methods are used for scheduling and monitoring projects. The CPM, as a network scheduling method, was developed by James E. Kelley and Morgan R. Walker in the late 1950s (Kelley & Walker, 1959; Hinze, 2012). However, scientific studies on the use of CPM in the construction industry are limited (Taner, Parlak Biçer & Bayram, 2020). In order to achieve the best project completion time, CPM is a technique for allocating tasks based on priorities (Prakash & Vidjeapriya, 2020). CPM has remained unchanged for decades of use in the fields of scheduling and control of construction projects. It provides an easy calculation for creating a project schedule and evaluating the criticality of activities using the concepts of float and critical path, with a focus on time. The information obtained from the schedule informs the project managers about the criticality of the activities. CPM also allows them to plan in advance how to manage the project effectively (Zhang & Zou, 2015). Despite their extensive use, traditional network scheduling methods also have some shortcomings. Some of the disadvantages of CPM are as follows:

- Inaccurate schedule calculations arise because the abundances and critical path are inaccurate due to the widespread use of leading and lagging (Wickwire & Ockman, 2000) and because multiple calendars complicate the analysis of critical paths and abundances (Scavino, 2003).
- Due to their complexity, it is difficult to study project networks with a large number of activity relationships (e.g. start-to-finish and finish-to-finish with negative delays) using CPM (Lu &Lam, 2008; Mohamed 2018).
- There is no mechanism in CPM to react to parallel execution, resource loading, or even real progress barriers (Lowsley and Linnett 2006; Mohamed 2018).

- CPM does not guarantee continuity of work, which can lead to idle working teams (Adeli & Karim, 2001).
- Multi-team strategies are difficult to implement, and CPM is not suitable for monitoring the progress of a project (Adeli & Karim, 2001).

Therefore, these circumstances prevent the CPM from being used as a decision-support tool for corrective actions and forensic analysis required during project control (Hegazy & Menesi, 2012).

2.2. Critical Path Segments (CPS)

Although the equations for CPM are easy to understand, CPM-based scheduling is a difficult procedure. The CPM network may have intricate relationships at the planning stage, which makes scheduling more difficult. Additionally, the CPM algorithm lacks a formulation to take into consideration a project's many limitations, including as timelines and resource constraints. It is extremely harder to use CPM in the construction process. The bulk of as-built schedules are exceedingly challenging to analyze because they contain so many complicated relationships, execution events, resource issues, revisions, and delays. Because of this issue, CPM cannot be used as a decision support tool for forensic investigation and necessary remedial measures during project control. When using complex network relationships (end-end, start-start, and start-end), a restricted amount of resources, or numerous resource schedules, CPM can suffer from inaccuracies in total float computations (Mubarak, 2019).

To overcome the disadvantages of traditional scheduling techniques like CPM, Hegazy and Menesi (2010) developed the CPS method, which segments the duration of an activity to enable micro-scheduling. In this technique, each activity is divided into separate time segments to accurately identify all critical path floats, better allocate limited resources, avoid multiple schedule problems, and accurately analyze project delays (Menesi & Hegazy, 2011). CPS facilitates accurate chart analysis by simplifying complex relationships and avoiding potential leading and waiting. It is even stated that CPS will provide project managers with reliable schedules that better reflect reality and provide better support for planning, corrective action, and schedule analysis decisions (Joshi and Patil, 2015). However, the CPS method was less popular than classical work scheduling methods because it was introduced relatively recently, in 2010, and has not been the subject of sufficient studies.

CPS displays each activity as a series of discrete time segments that together make up the activity's overall duration, as opposed to the conventional portrayal of each activity as a continuous block of time (Wagh, 2017; Mubarak, 2019). It allows any complex logical relation (SS, FF) to be directly transformed into a simple FS relation the latencies that cause redundancy computation problems in traditional CPM (Hegazy & Menesi, 2010). As a result, all network calculations become significantly easier to understand and perform (Hegazy & Menesi, 2012).

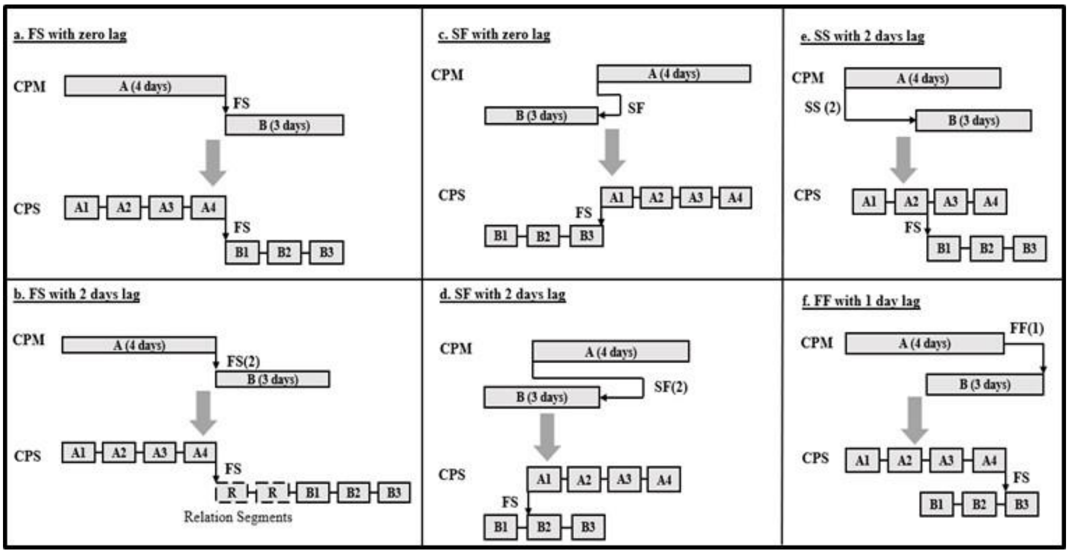

Figure 1. Representation of activity relationships in the CPS method. FS: Finish-to-start, SF: Start-to-finish, SS: Start-to-start, and FF: Finish-to-finish) [Menesi,2010; Hegazy & Menesi, 2010].

Figure 1 illustrates how easily SS and FF links can be transformed into FS ones. Lag times, a major cause of computational issues in classical CPM, are also unnecessary (Menesi, 2010). Figure 1’s caption describes the identified relationships.

(1) When there is zero lag time between the predecessor activity’s last time segment and the successor activity’s initial time segment, an FS relationship is established (Figure 1a).
(2) Period segments known as start-delay or relation segments are formed when an FS relationship has a lag period. These time intervals are equivalent in number to the lag time. These are connected to the successor's first-time segment. The end time segment of the predecessor activity and the beginning of the successor activity are then connected by an FS relationship (Figure 1b).
(3) When there is no lag time between the initial time segment of the predecessor action and the last time segment of the successor activity, an FS relationship is established (Figure 1c).
(4) A FS relationship is established between the first-time segment of the predecessor activity and the time segment number (L) counted from the end of the successor activity in the case of an SF relationship with a lag time (L) (Figure 1d).
(5) A FS relationship is established between the time segment number (L) of the predecessor activity and the first-time segment of the successor activity in the case of an SS relationship with a lag time (L) (Figure 1e).
(6) When an FF connection has a lag time (L), an FS relationship is formed between the final time segment of the predecessor activity and the number of time segments (L) counting backward from the conclusion of the successor activity (Figure 1f).

In addition to being time-based, the CPS can also be characterized as production-based in the relationship between activities. For example, the CPS allows the project manager to specify that every 20% of activity A is followed by 20% of activity B, rather than specifying that activity B can start two days after activity A starts, as seen in Figure 2.

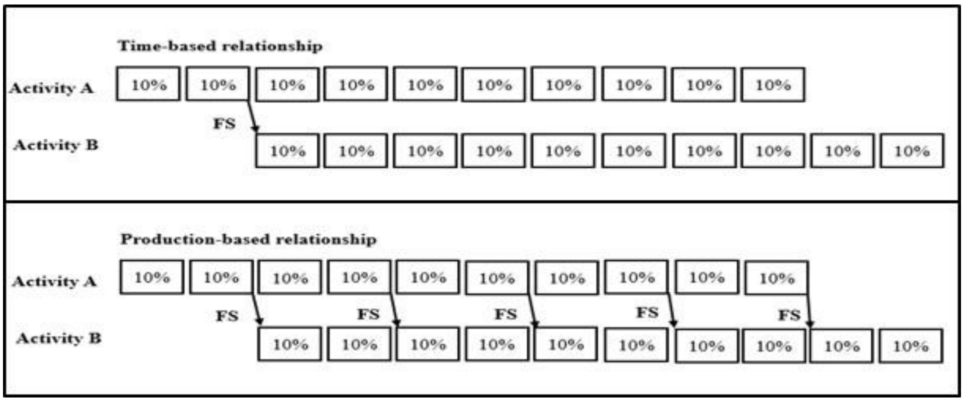

Figure 2. Time-based and production-based relationships in CPS [Menesi,2010; Hegazy & Menesi, 2010]

CPS uses a daily CPM analysis instead of an activity-based CPM analysis. Therefore, CPS also facilitates the daily monitoring of resources (Menesi, 2010).

3. Case Study and Discussion

This section presents CPM and CPS scheduling processes for both the planning and actual phases of a housing project, which started on April 2021 and was completed in July 2022. The housing project was completed in the Develi district of Kayseri province, Turkiye. The project consisted of four floors and 12 flats, as seen in Figure 3. The total construction area was 1,749.66 square meters. The data of the housing project, reported in the master thesis of Ayyarkın (2022) were used. It is a fact that it is difficult to access the data realized at the construction sites in Turkiye. The main reason for this is the lack of attention paid to the construction site books and/or reluctance to share.

Figure 3. The completed south facade of the housing project

A total of 38 activities were analyzed, 25 of which were fine works and 13 were rough works. The activity durations determined according to the Turkish Ministry of Environment, Urbanization and Climate Change data and the actual activity durations obtained during construction at the construction site were used. To create a work schedule with CPM and CPS for the productions with known activity durations, rough and fine works were detailed under work breakdown structures (WBS) as seen in Figure 4 and 5. Microsoft Office Project Professional 2007 (MS Project) software was used to define the activities and their details. The work schedule of the housing construction was created by taking into account criteria such as religious and national holidays, days that cannot be worked due to weather conditions, etc.

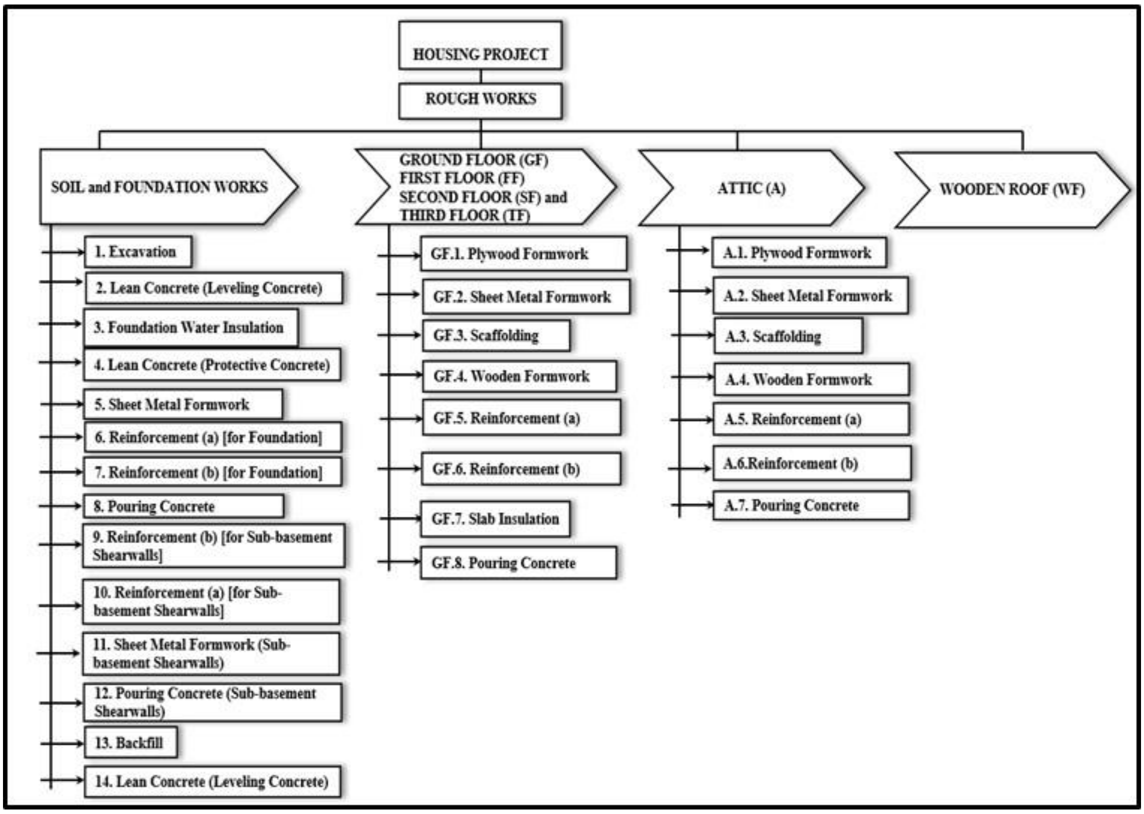

Figure 4. Work breakdown structure for rough works

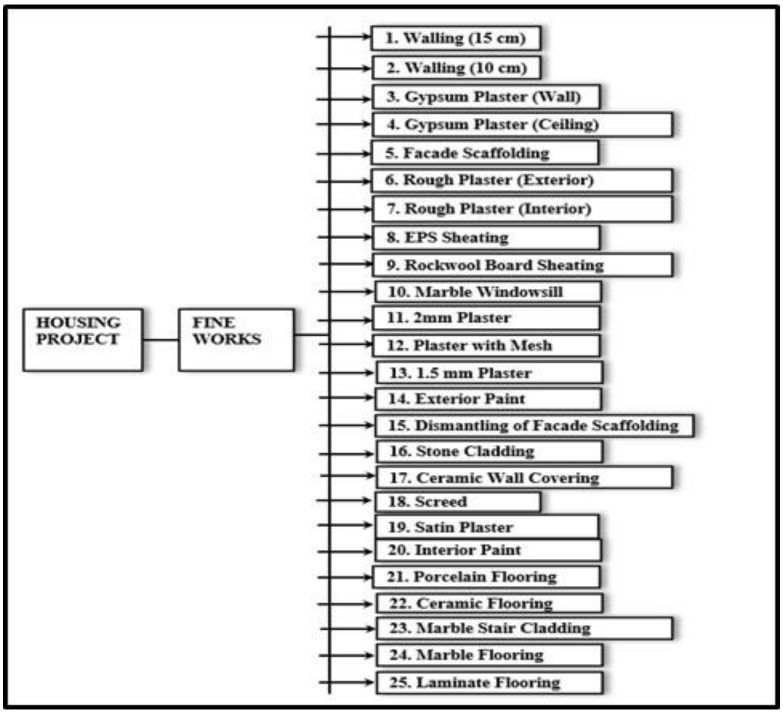

Figure 5. Work breakdown structure for fine works

3.1. The Principal Advantages of CPS

The work schedules that are created demonstrate how CPS may give greater representation and analysis than typical CPM, with one example being the ability to specify the critical path in more depth and another being the display of schedule-related faults.

3.1.1. The Ability to Define the Critical Path More Detailed

A more accurate critical path can be produced by using the CPS to partially define criticality in activities (Menesi, 2010). As shown in Figure 6 and 7, the project's work schedules were made using CPM and CPS. The crucial path is displayed on the MS Project chart, which highlights the actions in red. Each time segment in the CPS representation, as shown in Figure 7, represents its own MS Project activity. Without employing delays, CPS just depicts the linkages between activities as FS relationships. Although the program is difficult to use for CPS representation, it clearly demonstrates that only the first six days of the sheet metal formwork activity in Figure 7 are crucial rather than the entire activity. Figure 7 also demonstrates that delays and start-to-start (SS), start-to-finish (SF), and finish-to-finish (FF) interactions are not necessary to represent CPS using simply finish-to-start (FS) relationships.

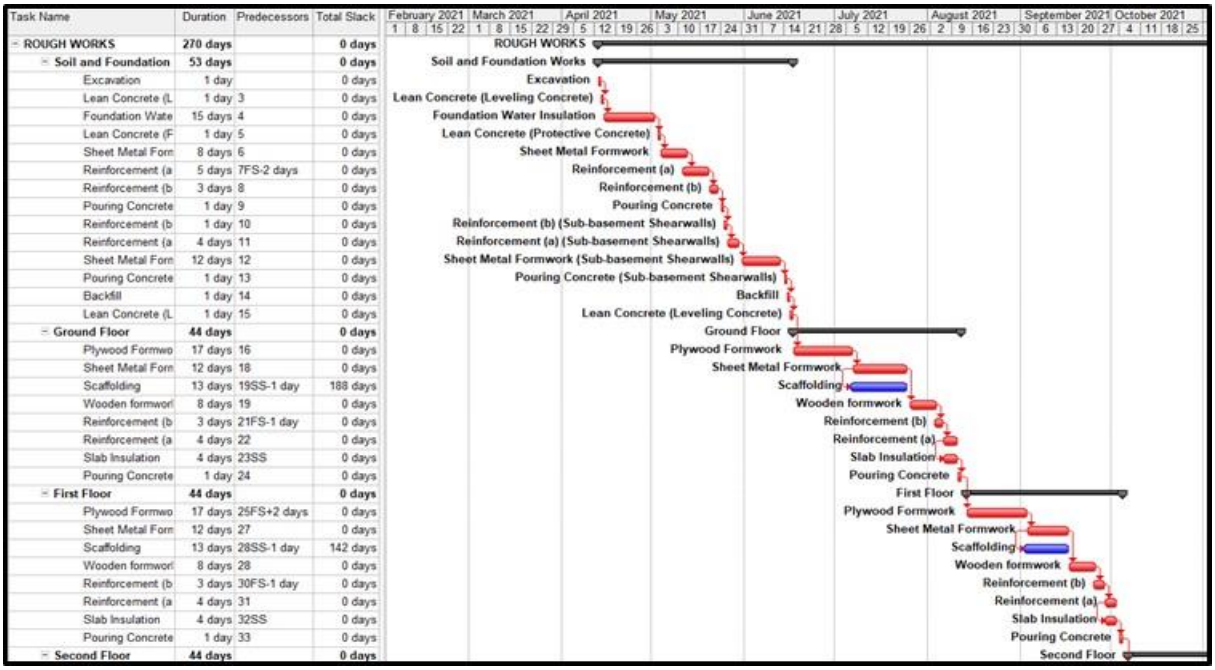

Figure 6. CPM work schedule of the housing project

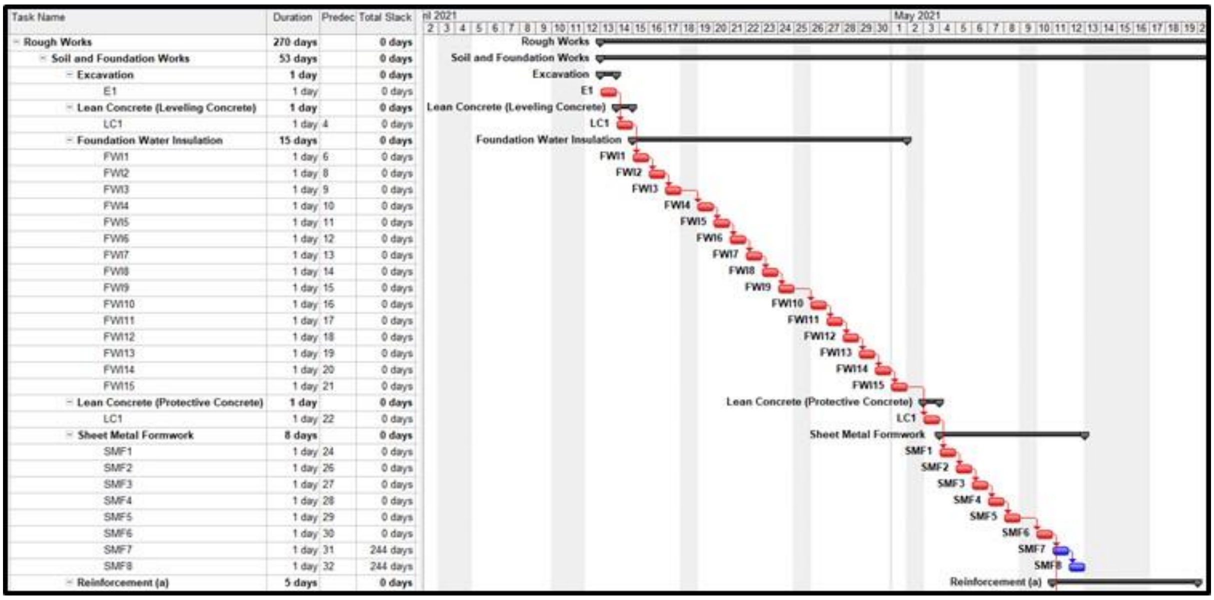

Figure 7. CPS work schedule of the housing project

3.1.2. Display of Calendar-Related Errors

In MS Project software, the ‘1.5 mm plaster’ activity within the scope of CPM includes days that are not suitable for working according to weather conditions, and in this case, the activity duration cannot be seen correctly, as seen in Figure 8. When the activity is simulated in MS Project using CPS, it can be seen that no work is done for the ‘1.5 mm plaster’ activity on non-working days, as seen in Figure 9.

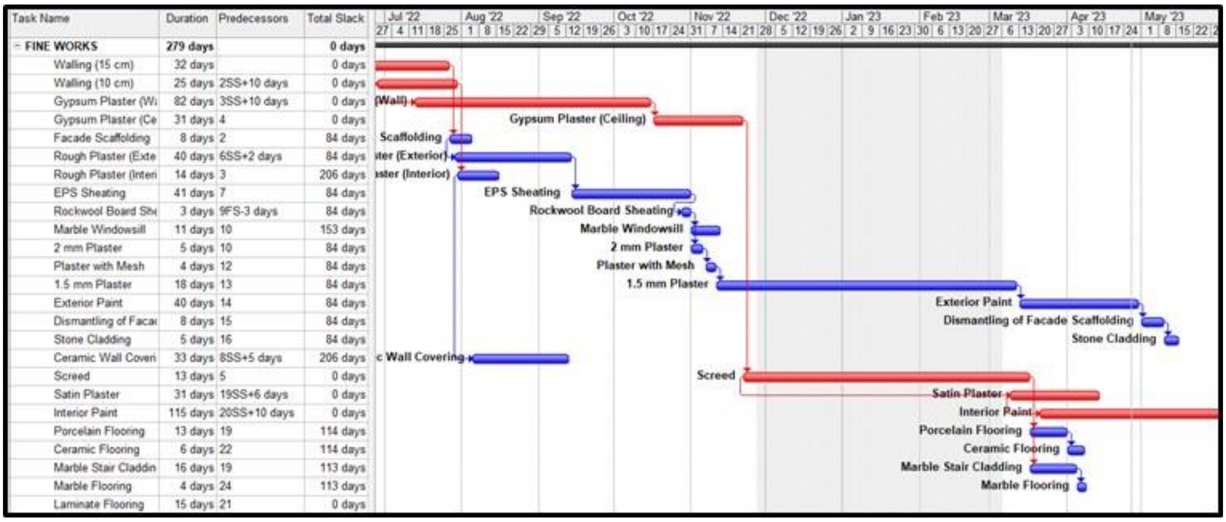

Figure 8. Incorrect Display of Non-Working Days via CPM

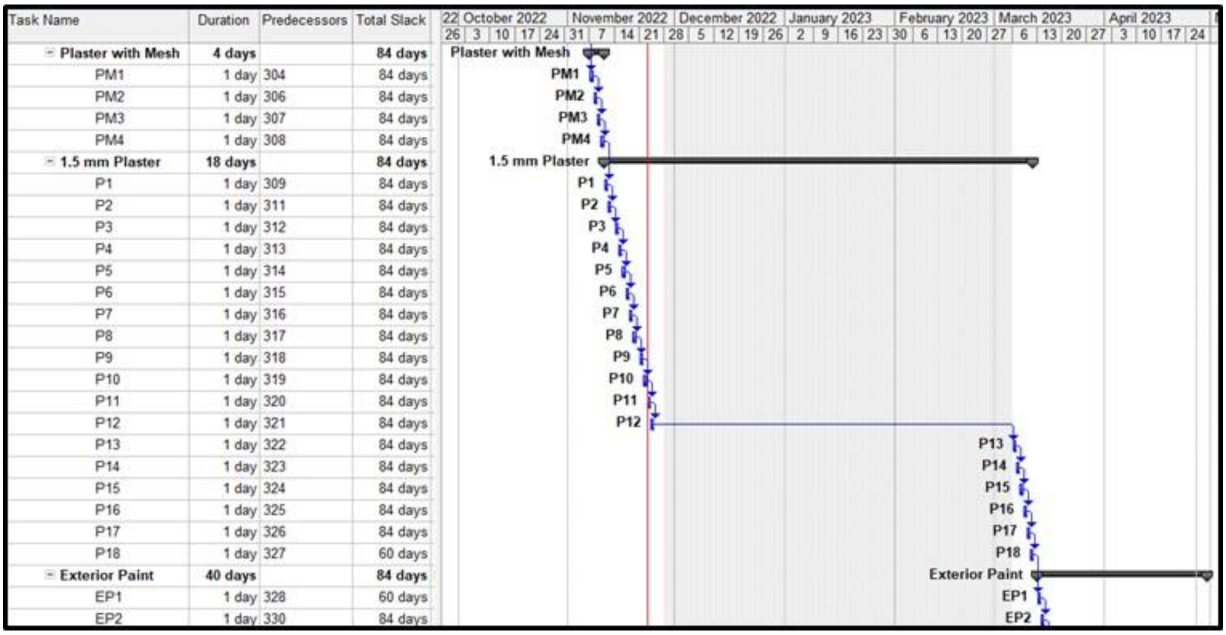

Figure 9. Correct Display of Non-Working Days via CPS

3.2. The Principal Disadvantages of CPS

3.2.1. Increase in the Number of Activities

In defining activities under the CPS approach, it is necessary to create time segments equal to the sum of activity durations. This constitutes a disadvantage in terms of number. While defining the activities within the scope of the work schedule prepared in MS Project for the planned fine works of the project; a total of 26 lines were used for CPM, while 639 lines were used for CPS. For the planned rough works, a total of 61 lines were used for CPM, while 409 lines were used for CPS. For large-scale construction projects, it is therefore impractical to convert activities into time segments.

3.2.2. Dummy Activity-like Start Delay and Relation Segment Usage

A dummy activity is an activity with a duration of zero that represents a logical connection between network pathways rather than a real task to be performed (Li, Zheng & Zhu, 2023). However, some dummy activities do not fit this definition. For example, a building project may require waiting while the concrete is curing. No real work is being done and the use of a dummy activity can make the network logically correct. But the time it takes for the concrete to cure is of course important and this activity must be given a deadline. This kind of activity is called “real-time dummies” (Carson, Oakander & Relyea, 2014).

In the CPS scheduling technique, in order to transform the relationships between activities into FS relationships, it is necessary to add dummy activity-like activities that represent the logical link. For example, in the case of FS with lag time, “start-lag time segments” or “relation segments” (e.g. start delay) should be added at the beginning of the successor activity. The number of relation segments is equal to the lag time, and the last time segment of the predecessor activity is associated with the first relation segment of the successor activity. Once the project has started, activity progress may be interrupted by uncertain events, such as weather and unforeseen geological conditions that can change the relationships between activities. Therefore, dummy activities can be used to identify such situations. Changes sometimes force non-critical activities to become critical, and vice versa. Moreover, critical path changes in the schedule can significantly affect the resource allocation plan (Tang & Mukherjee, 2012).

3.2.3. Emergence of Abnormal Floats in Partially Critical Activities

As a result of the preparation of the work schedule of the housing project using the CPS method in the MS Project, abnormal floats in partially critical activities have emerged. This situation can be observed in Tables 1, 3 for the planning phase and 2, 4 for the actual phase, with the results of CPM.

Table 1. The results of CPM and CPS for the planning phase (Rough works)

ID	CPM		CPS		Explanation
	Number of Critical Days	Total Float	Number of Critical Days	Total Float	
1	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
2	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
3	15 days	0	15 days	0	The same result was obtained for CPM and CPS.
4	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
5	8 days	0	First 6 days	0/244	CPS determines the critical path in more detail.
6	5 days	0	5 days	0	The same result was obtained for CPM and CPS.
7	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
9	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
10	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
11	12 days	0	12 days	0	The same result was obtained for CPM and CPS.
12	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
13	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
14	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
GF1	17 days	0	17 days	0	The same result was obtained for CPM and CPS.
GF2	12 days	0	12 days	0	The same result was obtained for CPM and CPS.
GF3	—	188	—	188	The same result was obtained for CPM and CPS.
GF4	8 days	0	First 7 days	0/180	CPS determines the critical path in more detail.
GF5	4 days	0	—	174	The difference can be associated with the micro-level computation of the CPS approach.
GF6	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
GF7	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
GF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
FF1	17 days	0	17 days	0	The same result was obtained for CPM and CPS.
FF2	12 days	0	12 days	0	The same result was obtained for CPM and CPS.
FF3	—	142	—	142	The same result was obtained for CPM and CPS.
FF4	8 days	0	First 7days	0/134	CPS determines the critical path in more detail.
FF5	4 days	0	—	128	The difference can be associated with the micro-level computation of the CPS approach.
FF6	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
FF7	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
FF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
SF1	17 days	0	17 days	0	The same result was obtained for CPM and CPS.
SF2	12 days	0	12 days	0	The same result was obtained for CPM and CPS.
SF3	—	96	—	96	The same result was obtained for CPM and CPS.
SF4	8 days	0	First 7 days	0/88	CPS determines the critical path in more detail.
SF5	4 days	0	—	82	The difference can be associated with the micro-level

					computation of the CPS approach.
SF6	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
SF7	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
SF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
TF1	17 days	0	17 days	0	The same result was obtained for CPM and CPS.
TF2	12 days	0	12 days	0	The same result was obtained for CPM and CPS.
TF3	—	50	—	50	The same result was obtained for CPM and CPS.
TF4	10 days	0	First 9days	0/40	CPS determines the critical path in more detail.
TF5	4 days	0	—	34	The difference can be associated with the micro-level computation of the CPS approach.
TF6	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
TF7	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
TF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A1	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
A2	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
A3	—	26	—	26	The same result was obtained for CPM and CPS.
A4	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
A5	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A6	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
WR	20 days	0	20 days	0	The same result was obtained for CPM and CPS.

Table 2. The results of CPM and CPS for the actual phase (Rough works)

ID	CPM		CPS		Explanation
	Number of Critical Days	Total Float	Number of Critical Days	Total Float	
1	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
2	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
3	5 days	0	5 days	0	The same result was obtained for CPM and CPS.
4	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
5[SMF1]	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
[SMF2]	1 day	0	—	102	The difference can be associated with the micro-level computation of the CPS approach.
6[R1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[R2]	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
7	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
11[SMF1]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[SMF2]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[SMF3]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
12	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
13	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
14	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
GF1[PF1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[PF2]	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
GF2	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
GF3[S1]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[S2]	—	82	—	82	The same result was obtained for CPM and CPS.
[S3]	—	80	—	80	The same result was obtained for CPM and CPS.
GF4[WF1]	—	86	—	86	The same result was obtained for CPM and CPS.
[WF2]	2 days	0	—	74	The difference can be associated with the micro-level computation of the CPS approach.
GF5	4 days	0	First 3 days	0/74	CPS determines the critical path in more detail.
GF6	2 days	0	First 1 day	0/77	CPS determines the critical path in more detail.
GF7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
GF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
FF1[PF1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[PF2]	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
FF2	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
FF3[S1]	—	71	—	71	The same result was obtained for CPM and CPS.
[S2]	—	65	—	65	The same result was obtained for CPM and CPS.
FF4[WF1]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[WF2]	—	59	—	59	The same result was obtained for CPM and CPS.
FF5	3 days	0	First 2 days	0/59	CPS determines the critical path in more detail.

FF6[R1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[R2]	—	61	—	61	The same result was obtained for CPM and CPS.
FF7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
FF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
SF1[PF1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[PF2]	3 days	0	3 days	0	The same result was obtained for CPM and CPS.
SF2[SMF1]	—	49	—	49	The same result was obtained for CPM and CPS.
[SMF2]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
SF3[S1]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[S2]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
SF4[WF1]	—	54	—	54	The same result was obtained for CPM and CPS.
[WF2]	—	42	—	42	The same result was obtained for CPM and CPS.
SF5	3 days	0	First 2 days	0/42	CPS determines the critical path in more detail.
SF6	2 days	0	First 1 day	0/46	CPS determines the critical path in more detail.
SF7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
SF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
TF1[PF1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[PF2]	4 days	0	4 days	0	The same result was obtained for CPM and CPS.
TF2	4 days	0	First 1 day	0/28	CPS determines the critical path in more detail.
TF3[S1]	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
[S2]	2 days	0	First 1 day	0/29	CPS determines the critical path in more detail.
TF4[WF1]	—	38	—	38	The same result was obtained for CPM and CPS.
[WF2]	—	26	—	26	The same result was obtained for CPM and CPS.
TF5	4 days	0	First 3 days	0/25	CPS determines the critical path in more detail.
TF6	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
TF7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
TF8	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A1[PF1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[PF2]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A2	—	14	—	14	The same result was obtained for CPM and CPS.
A3[S1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[S2]	—	14	—	14	The same result was obtained for CPM and CPS.
A4	2 days	0	2 days	0	The same result was obtained for CPM and CPS.
A5	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
A6	—	14	—	14	The same result was obtained for CPM and CPS.
A7	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
WR[WR1]	1 day	0	1 day	0	The same result was obtained for CPM and CPS.
[WR2]	8 days	0	8 days	0	The same result was obtained for CPM and CPS.

During the construction project's planning phase (for rough works), differences in the float and criticality of the four activities were observed, namely, ground, first, second, and third-floor reinforcement activities. These activities are critical in CPM, whereas they are not in CPS. This situation is associated with CPS giving more detailed results due to the conversion of activities into time segments. In other activities, no difference was observed except for partial criticality.

During the construction project’s actual phase (for rough works) on the other hand, there was a difference in the float and criticality of the two activities observed, namely, foundation sheet metal formwork, and ground floor wooden formwork. Sheet metal formwork activity and wooden formwork activity were critical in CPM but not critical in CPS. This situation is associated with CPS giving more detailed results due to the conversion of activities into time segments. In other activities, no difference was observed except for partial criticality.

Table 3. The results of CPM and CPS for the planning phase (Fine works)

ID	CPM		CPS		Explanation
	Number of Critical Days	Total Float	Number of Critical Days	Total Float	
1	32 days	0	First 10 days	0/84	CPS determines the critical path in more detail.
2	25 days	0	First 10 days	0/206	CPS determines the critical path in more detail.
3	82 days	0	82 days	0	The same result was obtained for CPM and CPS.
4	31 days	0	31 days	0	The same result was obtained for CPM and CPS.
5	—	84	—	84/239	The difference can be associated with the micro-level computation of the CPS approach.
6	—	84	—	84	The same result was obtained for CPM and CPS.
7	—	206	—	206/230	The difference can be associated with the micro-level computation of the CPS approach.
8	—	84	—	84/164	The difference can be associated with the micro-level computation of the CPS approach.
9	—	84	—	84	The same result was obtained for CPM and CPS.
10	—	153	—	153	The same result was obtained for CPM and CPS.
11	—	84	—	84	The same result was obtained for CPM and CPS.
12	—	84	—	84	The same result was obtained for CPM and CPS.
13	—	84	—	84	The same result was obtained for CPM and CPS.
14	—	84	—	84	The same result was obtained for CPM and CPS.
15	—	84	—	84	The same result was obtained for CPM and CPS.
16	—	84	—	84	The same result was obtained for CPM and CPS.
17	—	206	—	206	The same result was obtained for CPM and CPS.
18	13 days	0	First 6 days	0/113	CPS determines the critical path in more detail.
19	31 days	0	First 10 days	0/109	CPS determines the critical path in more detail.
20	115 days	0	115 days	0	The same result was obtained for CPM and CPS.
21	—	114	—	114	The same result was obtained for CPM and CPS.
22	—	114	—	114	The same result was obtained for CPM and CPS.
23	—	113	—	113	The same result was obtained for CPM and CPS.
24	—	113	—	113	The same result was obtained for CPM and CPS.
25	15 days	0	15 days	0	The same result was obtained for CPM and CPS.

Table 4. The results of CPM and CPS for the actual phase (Fine works)

ID	CPM		CPS		Explanation
	Number of	Total	Number of Critical	Total Float	
1	—	237	—	237	
2	—	237	—	237	
3	—	237	—	237	
4	—	253	—	253	
5	—	207	—	207	
6	—	207/240	—	207/240	
7	—	240	—	240	
8	—	233	—	233	
9	—	207	—	207	
10	—	246	—	246	The same results were obtained for the total float
11	—	207	—	207	results and criticality states in CPM and CPS.
12	—	207	—	207	
13	—	207	—	207	
14	—	207	—	207	
15	—	207	—	207	
16	—	207	—	207	
17	—	231	—	231	
18	—	86	—	86	
19	—	86	—	86	
20	—	86	—	86	
21	—	66	—	66	
22	—	122	—	122	
23	—	96	—	96	
24	—	96	—	96	
25	6 days	0	6 days	0	

During the construction project's planning phase (for fine works), differences in the float of the three activities were observed, namely, facade scaffolding, rough plaster (interior), and EPS sheeting. These activities are not critical in CPM and CPS. However, the floats of these activities were the same on some days but differed on others. This situation is associated with CPS giving more detailed results due to the conversion of activities into time segments. In other activities, no difference was observed except for partial criticality. During the construction project's actual phase (for fine works) on the other hand, no differences were observed in the abundance and criticality of the activities.

The case study tested the applicability of the developed CPS scheduling technique by comparing it with CPM. It was observed that the planned activity durations of the Turkish Ministry of Environment, Urbanization, and Climate Change were not the same as the actual ones. This situation is thought to be due to the high labor force data of the Ministry. Moreover, it was observed that other reasons for the difference between the planned and actual stages of the construction project are the difficulties of working in the field and the interruptions of work, mostly due to the team.

The obtained results were also compared with the study of Hegazy and Menesi (2010), who developed the CPS approach. Hegazy and Menesi (2010) demonstrated the ability of CPS to simplify the network representation and accurately compute the critical path. However, a different situation has emerged in terms of the floats in this study. Abnormal floats occurred in activities where the criticality was partial (e.g. wooden formwork [GF4]; first 7 days 0, last 1 day 180), and where the activity abundance was variable (e.g. EPS sheeting [8]; first 38 days 84, last 3 days 164). However, no information was found related to abnormal floats in the literature.

In terms of methodological comparison, the simulation of the case study using CPS in MS Project reflects the days without work can be seen. For CPM on the other hand, activity durations cannot be seen accurately. The finding shows that present findings are consistent with Hegazy and Menesi (2010). At the actual stage of the construction project (for fine works), no differences were observed for the float and criticality of the activities. This finding is consistent with the results obtained from the simple case study using a few activities solved by Aboelmagd (2020) by applying CPM and CPS.

Conclusion

Construction managers often need to strike a balance between significant project objectives such as time, cost, and quality when scheduling construction projects. This paper focused on the CPS approach to avoid the disadvantages of CPM, which is a traditional scheduling method, and in use for 60 years in the global construction industry. Essentially, the CPS scheduling technique is a modified version of the CPM. It is the representation of the changed activities and the types of relationships. However, the number of scientific studies on CPS has remained limited. CPS is not a common method for planning and scheduling practitioners.

In this study, two different scheduling techniques, classical CPM and modification CPS, are used for project duration, critical path, and total float. For the planned and actual phases of construction, the observed findings were discussed by making an application on a sample housing construction project. As can be seen from the case study, no concrete findings could be identified regarding the positive aspects of this approach, except for the display of activity durations daily, the elimination of calendar-related errors, and the transformation of activity relationships into FS only. In addition, considering the serious increase in the number of activities, the use of dummy activity-like relationship segments in defining activity relationships, and the observation of abnormal float, it was observed that the method seemed simple but complicated the work schedule. The main reason for the observed abnormal abundances in the CPS method is thought to be that the 87 activities considered in the CPM method, increased to 1,048 in the CPS method including sub-activities, and thus increased abnormally. It was also observed impractical to convert activity durations into time segments, especially for large-scale construction projects. Moreover, difficulties in comparing the findings with the literature due to the lack of studies related to CPS have been experienced in this study. In this context, it was concluded that CPM is more practical and understandable, and CPS can only be used for scientific study purposes. Therefore, in this study, in case the CPS method was applied to a real project using MS Project for both planned and actual phases, the expected level of success in reaching the targeted result was not achieved.

For future studies, it can be verified whether the CPS technique can be applied in practice by considering its application to real construction projects. Besides, the results can be compared by integrating the CPS approach with the soft computing methods. Moreover, it can be better evaluated whether CPS can be an alternative to traditional scheduling techniques for more detailed construction projects.

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