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EVALUATION OF MANAGERIAL FLEXIBILITIES IN CRITICAL PATH METHOD BASED CONSTRUCTION SCHEDULES

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Abstract
Scheduling of a construction project can be done by using the Critical Path Method (CPM) in case the project is composed of interrelated activities that can be combined through a network. Given uncertainties nowadays and the related need for project schedule adaptations, the question is raised whether and how "traditional" CPM based schedules allow for flexibility in project planning and management.

In order to give an answer to this question, firstly the managerial flexibilities provided by CPM were evaluated at three levels, i.e. activity, path, and project. Afterwards, the CPM schedules of two different projects were examined. Finally, the first conclusion arrived was that, in spite of its criticized deterministic features, CPM contains various flexible aspects from a managerial viewpoint. Second, potential flexibilities in CPM are mainly associated with resource levelling, uncritical activities, uncritical paths, activity float times, activity float types, and float times of uncritical paths. Third, CPM contains complete flexibility through independent floats and resource levelling capability.

Investigating the flexible features of CPM in its traditional form, this study aims to open the way to develop a more flexible scheduling approach based on CPM and its extensions, which future self-organizing teams can adjust or apply.

Keywords: Activity criticality, Activity float times, Activity float types, Critical path method, Flexible schedule management.

1. Introduction

Construction projects are required to be completed in planned time, envisaged budget and predetermined scope along with ensuring the expected quality, safety and stakeholder satisfaction. These are the basic criteria of success in almost all kinds of projects [2, 18], although different importance is given to such criteria based on the stakeholders involved [3]. The "time" portion of this multilateral trade-off problem is tried to be kept under control through well-prepared schedules. These schedules are generally prepared at the beginning of projects and updated as the projects progress.

Critical Path Method (CPM) has been the method of time scheduling in construction projects since it was first developed in the 1950's [5]. This method has found application in all sectors. In case a project can be defined through a series of interrelated activities or tasks from top to bottom and these activities can be combined through a network, CPM could be used.

In construction projects, various resources are used to realise the tasks constituting the CPM schedules. Resources can be expressed in terms of time, cost, labour, equipment or materials. As a result, CPM turns into a tool not only for managing time but also for managing the other resources.

The success and popularity of this traditional, old, activity network scheduling method is probably related to the information it provides to its users like project managers, owners, contractors, engineers, foremen, workers or even lawyers. The information that CPM provides includes, but is not limited to [12, 13];

- Shortest possible project completion time
- Critical path(s), critical activities
- Uncritical path(s), uncritical activities
- Activity float times
- Precedence relationships between activities
- Early/late start/finish times of activities

However, CPM also has limitations [1, 8, 11, 16, 19]:

- CPM is deterministic, therefore it is unable to reflect the uncertainty effect on schedules and it is not capable of modelling the dynamic character of projects.
- CPM ignores the correlations that might exist between activities and between risk-factors, which causes greater uncertainty on activity durations and in turn on project duration.
- CPM assumes unlimited availability of resources.
- CPM has limited flexible features, therefore it is not adaptable enough to changing conditions and it is unable to reflect the ever changing dynamic nature of projects.
- CPM has limited capability in scheduling linear or repetitive type of projects such as multi-storey building, highway, railway, and canal construction projects. Besides ensuring the network logic within each unit, also the resource continuity is required to be provided along the repetitive parts in this type of projects.

Literature also contains studies proposing ways of overcoming CPM's shortcomings. These studies mostly focus on the application of probabilistic methods, risk analysis procedures and optimisation methods on traditional CPM [10, 16, 17, 19]. Besides, the literature includes studies that propose the integration of CPM into linear scheduling methods [1, 15]. None of these studies disregards CPM, but it is tried to expand and improve CPM in compliance with the uncertain, complex and dynamic character of real life construction projects.

Given uncertainties nowadays and the related need for project schedule adaptations, the question is raised whether and how "traditional" CPM based schedules allow for flexibility in project planning and management. In order to give an answer to this question, the managerial flexibilities of CPM were investigated in this study.

The literature on project management brings a number of different definitions for "flexibility" [9]:

- "uncommitted potentiality for change [4]"
- "the capability to adjust the project to prospective consequences of uncertain circumstances within the context of the project [7, 14]"
- "a way of making irreversible decisions more reversible or postponing irreversible decisions until more information is available [14]"
- "the ability and readiness to deal with dynamics in a project [9]"

Taking into account these definitions, "flexibility" in projects can be considered as the adaptability of a project to complex, uncertain and dynamic conditions. A paradigm change in traditional project management seems needed for achieving such flexibility. Obviously, flexibility can be realised by benefiting from existing managerial flexibilities. Exploration of inherent flexibilities in traditional methods of construction, such as CPM, gains importance in order to open the way into developing new flexible managerial approaches.

This paper is structured as follows. First, in Section 2, how flexibility can be linked to different characteristics of the CPM at the three different levels, i.e. activity, path, and project levels, is evaluated. In order not to get stuck into theoretical expressions, two different example CPM applications are used which are described in Section 3 and Section 4. The findings are discussed, conclusions are drawn and recommendations for further research are given in Section 5.

2. Managerial Flexibilities Provided by CPM

In this section, managerial flexibilities of CPM are evaluated with respect to the activity, path, and project levels. The links that can be set between flexibility and different characteristics of the CPM are discussed.

2.1 Flexibility at Activity-Level

Flexibility at activity level in a CPM schedule can be evaluated based on float times belonging to uncritical activities. Activity float times provide various potential flexibilities during managing a CPM schedule. Basic definitions of activity float types are given below [12, 13]. Furthermore, the flexibilities associated with these floats are discussed.

Total float time is the difference between activities' late start time and early start time or late finish time and late start time. It represents the amount of total flexibility of an activity that can be consumed in case of any possible delay or disruption in that activity. A delay in an activity as far as the amount of delay stays within the limits of total float time does not cause delay on the envisaged project completion time. However, total float should not be considered as an absolute flexibility for an activity because some portion of it may be shared by some of the successor activities [12]. Besides, total float times can be consumed as time buffers to take limited resources into account as in the case of Critical Chain Method, which is proposed as an extension of CPM [6]. As a result, total float times do not provide full flexibility and therefore they should be consumed consciously. Furthermore, it should be emphasized that unlike the uncritical activities, critical activities have no flexibility with respect to total float time in CPM applications because they have no float time by definition.

Free float time is the float amount up to which an uncritical activity can be delayed without causing any delays on the early start times of any of its successor activities. Furthermore, the consumption of the free float does not cause a delay on the project completion time if it does not contain any shared float. In that sense, free float represents a kind of partial flexibility in CPM schedules.

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

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

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

And what about the critical activities? Don't they have any flexibility from a management point of view? In the end, they have no total float as well as no other types of float. The awareness CPM brings to a project manager through the information "those activities are critical, so be careful while executing them, take the necessary precautions in advance" can also be considered as a kind of managerial flexibility. Furthermore, the critical activities, along with the uncritical activities that may turn into critical during execution of the project, can be utilised for shortening the project duration through the project crashing capability of CPM and this gives flexibility of changing the predetermined project duration if required, but in expense of increase in project costs.

2.2 Flexibility at Path-Level

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

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

2.3 Flexibility at Project-Level

CPM provides the shortest possible project completion time of a project, which is mostly important from the management point of view. Is there any flexibility on the calculated completion time? Traditional application of CPM can calculate only one single project duration at a time because of its deterministic nature [10, 17]. However, CPM's updating capability brings some flexibility. As far as the flow of accurate data is ensured for completed parts of projects and the estimations for the remaining parts are updated realistically taking into account the actual data, completion times of projects would be calculated more precisely each time through a more flexible approach. Depending on the outcomes, project managers could take precautions in order to overcome deviations from the estimated project duration.

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

- levelling resources through consuming activity float times in order to keep under the maximum available resource limit,
- skipping resources from uncritical activities to critical activities in order to avoid schedule overruns,
- optimising time against costs (i.e. time-cost trade-off analysis).

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

2.4 From ideas to practical applications

So far, the notion of flexibility is described on three levels from a theoretical perspective: activity level, path level and project level. The following sections introduce a more detailed evaluation of the managerial flexibilities of CPM at these three levels using two examples. Firstly, a sewer line project is used to evaluate the flexibility at activity and path levels, see Section 3. Subsequently, the flexibility of CPM at project level is discussed in terms of its resource levelling capability through another example project specifically constituted for the sake of simplicity in Section 4.

3. Example 1: a sewer pipeline construction project

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

The time schedule of the project was prepared through CPM's forward/backward pass algorithm (the reader is referred to Newitt [12] and Oberlender [13] for detailed explanations on the algorithm and computation procedures). The resulting activity-on-node network diagram is shown in Fig.1. The representation of the data in the quadrilaterals is indicated by the "activity label notation" in Fig.1. The CPM application revealed that:

- Activities 1, 2, 6, 8, 9, 11 and 12 are the critical activities having no float times,

- Activities 3, 4, 5, 7 and 10 are the uncritical activities having float times,
- Path 1 (1–2–6–8–9–11–12) and Path 2 (1–2–6–8–11–12) are the critical paths,
- Path 3 (1–2–6–8–10–12) and Path 4 (1–2–3–4–5–7–9–11–2) are the uncritical paths.

The total, free, shared, and independent float times of the activities, float sharing activities, float times of the paths, and the criticality of the activities and the paths are given in Table 2. As shown in Fig. 1, the late finish time of the last activity represents the resulting project completion time, which is 62 days.

Next, the flexibility is evaluated on activity level and on path level.

3.1 Evaluation of Flexibility at Activity Level

When the float times given in Table 2 are examined, it is observed that each uncritical activity does not have to possess free, shared and independent float necessarily at the same time. However, by definition, each activity has a total float time. This is the starting point for determining the management strategy. As previously mentioned, a manager who is not fully aware of the flexibilities that CPM provides in terms of float times at activity level might mistakenly use the total floats carelessly as if they were only under the pure possession of uncritical activities. This is clarified below.

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

Next to the flexibility created by “activity 10”, the flexibilities associated with the other uncritical activities of the project, i.e. activities 3, 4, 5, and 7, should be discussed together because these activities are located subsequently on the same path. As given in Table 2, these activities have 2 days of total float each. However, the float they each possess is the shared float at the same time. In other words, they share the 2 days of float. Therefore, the cumulative flexibility of these four activities sequentially lined up as shown in Fig. 1 is as much as their shared float amount, i.e. 2 days, rather than the cumulative of their total floats, i.e. 8 days.

3.2 Evaluation of Flexibility at Path Level

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

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

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

Table 1 Activities and network information of example application 1 – hypothetical sewer pipeline project

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

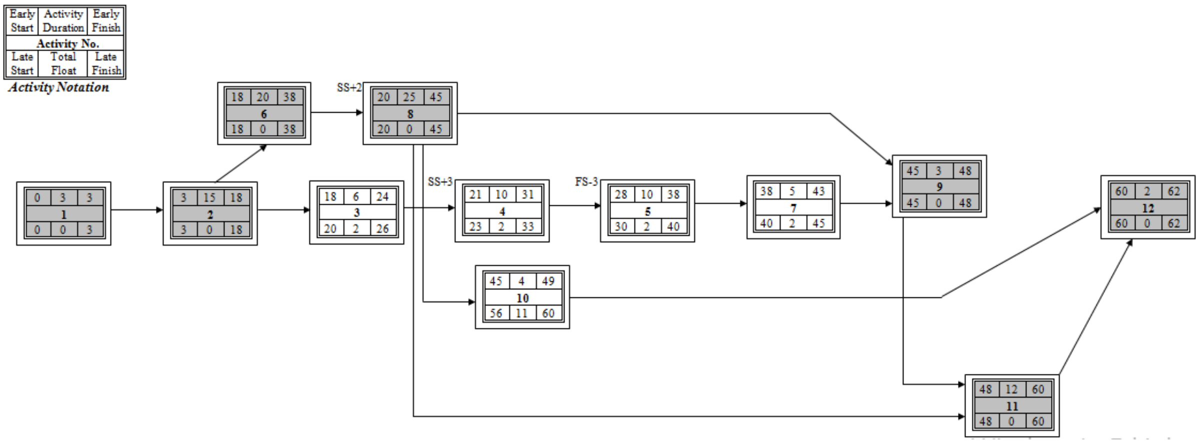

Fig. 1 Activity-on-node network diagram of example application 1 – Hypothetical sewer pipeline project.

Table 2 Float times and criticalities of the activities and paths of example application 1 – hypothetical sewer pipeline project

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

*All time values in this table are in ‘days’.

4. Example Application 2

In this section, the flexibility of CPM at project level is discussed in terms of its resource levelling capability through another example illustrative project. The project data used in this application is given in Table 3. The activities of the project are represented with letters and all the network relationships between the activities are assumed to be finish-to-start (FS) without any lag times. Table 3 also includes the information about the activities, activity durations, predecessor activities, network relationships between the activities and the number of workers required for each activity. This data was used in the implementation of CPM, in the preparation of time and labour schedules, and in levelling the labour requirement. For the sake of simplicity, only one type of resource was taken into account.

Firstly, in accordance with the information given in Table 3, a time schedule was created with forward/backward CPM calculations. The schedule is given in Table 4 and shown as an activity-on-node network diagram in Fig. 2. According to the schedule;

- Activities A, C, F, I, and J are the critical activities,
- Activities B, D, E, G, and H are the uncritical activities,
- Path A-C-F-I-J is the critical path,
- Paths A-B-F-H-J, A-C-F-H-J, A-D-J, A-E-J, and A-G-J are the uncritical paths.
- The completion time of the project is 24 days.

Subsequently, labour charts showing the labour requirements along the project were prepared by the data given in Tables 3 and 4. It is assumed that the maximum number of workers that can be employed throughout the project is 9. In other words, there is a workforce of 9 workers available for this job. Therefore, a labour shortage is assumed to occur when more than 9 workers are needed on any working day, and some of the workers will remain idle when less than 9 workers are required.

Table 3 Activity network information and labour requirement of Example Application 2

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

Table 4 CPM solution of Example Application 2

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

*All time values in this table are in 'days'.

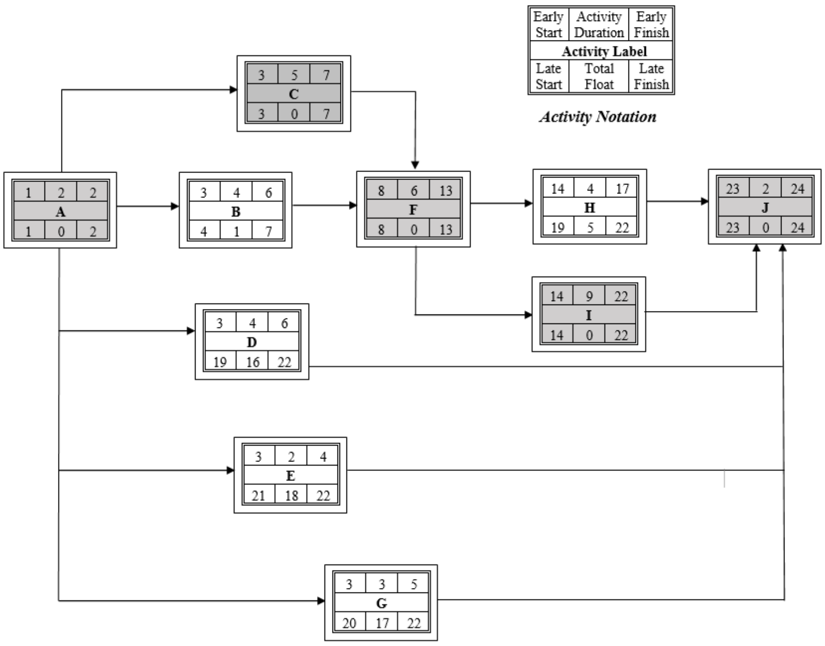

Fig. 2 Activity-on-node network diagram of Example Application 2.

Labour requirement schedules can be prepared by a stepwise procedure consisting of three stages. In the first stage, a labour schedule is prepared according to the early start and early finish times of the activities. In this schedule, it is determined on which dates labour shortage and on which dates excess labour problems will occur. Then, a second labour schedule is prepared according to the late start and late finish times of the activities. In this schedule, again it is determined on which dates labour shortage and on which dates excess labour problems will occur. Then, by using these two labour schedules and shifting the required activities over the total float times of the uncritical activities, a levelled or optimized labour schedule is constituted. This process is called “resource levelling” [12, 13]. In this final labour schedule, the need for labour generally increases at the beginning of the project, follows a regular course in the middle and begins to decrease towards the end of the project. The number of workdays with labour shortage or excessive labour problems is minimized or eliminated.

Using the values in Tables 3 and 4, taking into account the maximum allowable labour assumption, i.e. maximum 9 workers daily, and following the three-stage resource levelling procedure described above, the labour requirement charts (i.e. labour schedules) of the example project were prepared. The charts are given in Figs. 3 - 5. Fig. 3 and Fig. 4 show that we are facing an over-requirement problem in terms of labour force. This problem can be resolved through benefitting from the flexibilities provided by CPM at project level, as described below.

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

Fig. 5 illustrates the labour requirement chart prepared according to the late start and late finish time values. Now only 12 workers are needed on the 21st and 22nd days. In other words, labour shortage will still occur due to the need for more workers than the maximum worker capacity of 9, but the number of days with labour shortage has decreased from 4 to 2 compared to Fig. 5. Also the number of extra workers needed has decreased significantly. Apart from this, the need for workers increases slowly at the beginning of the 24-day total work period, the need drops rapidly with a sudden leap towards the end, after following a regular course. In other words, the labour schedule prepared according to the late start and late finish times still needs to be levelled due to the sudden leap after the 21st day though it is superior with respect to the labour schedule prepared by the early start and early finish times. We need additional flexibility.

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

Fig. 3 Labour requirement chart prepared based on early start and early finish times.

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

Fig. 4 Labour requirement chart based on late start and late finish times.

In order to overcome this problem, we can benefit from the resource levelling capability of CPM. The labour requirement chart obtained by resource levelling is given in Fig. 5. According to the levelled chart, there is no day left with labour shortage. The need for workers follows a regular and balanced course throughout the 24-day period. In order to create this levelled schedule, uncritical activities were shifted over their total float times for eliminating the days of labour shortage, hence creating more balanced labour requirements. In other words, we actually did benefit from the flexibility capacity of CPM to overcome the aforementioned over-requirement problem in terms of labour.

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

Fig. 5 Levelled labour requirement chart.

5. Discussion and Conclusions

This paper investigated the flexibilities that traditional CPM provides during the management of construction projects. The managerial flexibilities provided by CPM were evaluated at three levels, i.e. activity, path, and project, first conceptually, then through two different example CPM applications. The results of the study have introduced three important findings. Firstly, CPM, in spite of its criticized deterministic features, contains various flexible aspects from a managerial viewpoint. Secondly, potential flexibilities in CPM are mainly associated with resource levelling, uncritical activities, uncritical paths, activity float times, activity float types, and float times of uncritical paths. Thirdly, CPM contains complete flexibility through independent floats and resource levelling capability.

Such a study is assumed to be a starting point towards the creation of advanced and flexible project scheduling approaches utilizable in complex, dynamic and uncertain conditions of today’s construction sector. In this regard, the subject is open to development through investigating the ways of incorporating managerial flexibilities into the extensions of CPM such as the Critical Chain Method, CPM based schedule risk analysis models and CPM integrated linear scheduling methods. This topic is the next step and a recommendation for future studies.

Obviously, trying to manage the CPM schedules without being aware of the managerial flexibilities will not contribute to the aim of successfully completing complex construction projects. One purpose of this study is to raise such an awareness. The discussion in this study has revealed that CPM is not as rigid as it is assumed as far as the manager using it is aware of the means of benefitting from its flexible features. For instance, it is important to make the distinction between the activity float types in a CPM network schedule, i.e. total, free, shared, and independent. While total float times belonging to uncritical activities are probably the most well known aspect of CPM to the practitioners, the free, shared and independent floats that the total floats contain should be taken into account during the schedule applications in order to avoid any wrong usage of the activity float times. Otherwise, the number of critical activities would increase and the schedules would face the risk of overrunning the target durations. Such critical points regarding the correct utilisation of the flexibilities provided by CPM have been discussed within the paper.

The authors believe that being aware of the managerial flexibilities already existing in traditional approaches of project management will make contributions to the managing capabilities of future self-organizing teams who will be involved in the projects that are getting more complicated day by day. Furthermore, traditional methods of project management, when they are utilised in full through their flexible features, will empower the managerial skills of practitioners during the practical applications of modern project management approaches.

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