A Proposed Method for Specifying Effect the Dynamic of Critical Path in Delays Analysis

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□ ABSTRACT □

The use of Critical Path Method (CPM) has become an accepted standard in all major construction works. The boards and courts have a willingness to use network analysis techniques to identify delays and disruptions and their causes. The critical path must be kept current to reflect delays and frequently changes during the course of project. Many methods used CPM in delay analysis, some of which are based on final as-built critical path such as net working duration method. Other methods tried to reflect the changes in critical path periodically during project implementation such as window analysis, snapshot, time impact technique, and isolated delay type method. The reliability of results, in these methods, is a function of the number of periods used through analysis. These methods do not reflect the realistic changes in critical path during project progress.

In this paper, a proposed method, which reflects the dynamic changes in the critical path(s) during the course of project, is presented. Updating the as-planned schedule on an activity-by-activity (i.e. after the finish of changed activities) basis can realistically prove the dynamic nature of critical path. Delays and other changes are considered in the analysis and then the changes in critical path and project deadline is tested. The proposed method offers both the owner and contractor a clear knowledge about the effect of delays of each activity on the succeeding activities as well as project completion date. On the other hand, the analysis can be performed after the project finish retrospectively. An illustrative example problem is presented to implement the proposed method.

Keywords: Construction Management, CPM , Dynamic Critical Path.

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طريقة مقترحة لتحديد تأثير ديناميكية المسار الحرج في تحليل التأخيرات

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□ ملخّص □

أصبح استخدام طريقة المسار الحرج (CPM) معيارًا مقبولًا في جميع مشاريع التشييد الكبيرة حيث تستخدم مجالس التحكيم والمحاكم تقنيات تحليل المخطط الشبكي لتحديد التأخيرات وفض النزاعات. يجب أن تتم عملية تحديث للمسار الحرج بشكل دائم ليعكس التأخيرات والتغييرات التي تحصل أثناء تنفيذ المشروع. استخدمت العديد من الطرق المسار الحرج لتحليل التأخيرات فبعضها اعتمد على المسار الحرج النهائي كما في طريقة العمل الصافي وهناك بعض الطرق التي حاولت ان تعكس تغيرات المسار الحرج بشكل دوري مثل طريقة النافذة ، واللقطات ، وتقنية التأثير الزمني، وطريقة التأخيرات المعزولة. وقد اعتمدت دقة النتائج في تلك الطرق على عدد الفترات المستخدمة أثناء تحليل التأخيرات. معظم هذه الطرق لا تعكس ديناميكية المسار الحرج بشكل فعلي أثناء تنفيذ المشروع.

سوف يتم في هذا البحث اقتراح طريقة تعكس التغيرات الديناميكية في المسار الحرج أثناء التنفيذ، والتي من خلالها سوف يتم تحديث المخطط الزمني لكل مهمة على حدى (بعد انتهاء المهمة التي حصل فيها التأخير أو تغير العمل فيها) لنثبت بشكل واقعي الطبيعة الديناميكية للمسار الحرج ولتتم عملية التحليل نقوم بادخال هذه التأخيرات الى المهمة. توفر الطريقة المقترحة لكل من المالك والمقاول معرفة واضحة حول تأثير التأخير لكل مهمة على المهام التالية بالإضافة إلى تاثيرها على تاريخ الانتهاء من المشروع. من ناحية أخرى ، يمكن إجراء التحليل بعد انتهاء المشروع بأثر رجعي كما سيوضح المثال المعروض في البحث.

الكلمات المفتاحية: ادارة التشييد ، المسار الحرج، ديناميكية المسار الحرج.

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INTRODUCTION:

The use of Critical Path Method (CPM) for planning and scheduling has become an accepted standard in all major construction works. This management technique is recommended for use on almost all projects in order to:

1. Obtain information and data that are needed by project managers to identify, manage, and resolve project problems and make decisions,
2. Document, manage, and monitor job site progress to effectively minimize legal disputes on construction projects, and
3. Minimize and establish realistic construction project duration while maintaining overall cost and design requirements.

CPM is a tool that can help project managers to evaluate the cumulative effect of delays (Antill and Woodhead 1982, O' Brien 1984). It can be assumed that if there is any delay during project progress, then there is a change in the contract. This change may be instituted by the requirement of the owner or by the contractor or by any other cause beyond the control of either party. A CPM network can be drawn to show the effects of such changes on the duration of the rest part of the project (Arditi and Patel 1989).

One of the many apparent features of CPM is its ability to identify critical path(s), which makes CPM an important tool in delay analysis. Because of the changes in activities' durations, logic, or delays during project progress, the critical path(s) of the as-built schedule may differ completely from that of the as-planned schedule. In general, the final as-built critical path(s) is not the actual critical path(s) during project implementation (Kraiem and Diekmann 1987, Antill and Woodhead 1982). The critical path(s) changes continuously due to delays and work changes or acceleration through project execution. Many methods relied on CPM for the analysis of delays and tried to reflect the actual changes in critical path during project progress such as window analysis, snapshot, time impact technique, and isolated delay type method. These methods explain how periodic analysis of project network could be used to achieve timely delay compensations for project parties. Another method considers the analysis of concurrent delays with a chronological day-by-day methodology to update the as-planned schedule and to remark the changes of critical path(s).

In this paper, the reliability of CPM in the analysis and evaluation of delays and work changes is discussed. A practical proposed method for specifying the dynamic nature of critical path during project progress will be presented. The proposed method depends on updating CPM network after the finish of each activity which have been changed (delay, acceleration, logic, …etc) during project progress (activity-by-activity). As soon as the duration and logic of an activity is adjusted, changes of critical path(s) are shown as well as their effect on project completion. An illustrative example problem is presented to implement the proposed method.

IMPORTANCE OF CPM SCHEDULING IN DELAY ANALYSIS

A schedule of a project network represents the project strategy or plan, whose longest path is called the "critical path." By criticality definition, any delay in the critical activities will delay the project. CPM is very important tool in delay analysis and its importance can be briefed as Royer (1986) commented "…The CPM schedule is the method of determining facts and it is used as a basis of payment for delays." It is a standard approach for considering the effects of delays on a project (Wickwire and Smith 1974), and forms the basis for discussion of time extension claims (Rubin 1983).

Davis (1974) prepared a survey on top management in large United States construction companies, the objective of which was to establish the scope and nature of network-scheduling methods (especially CPM). The results of survey can be summarized as one of the executives in that survey commented: "CPM is a very effective tool in our company for getting the job completed on time in the most efficient manner."
Jaafari (1984) defended the criticism of whether or not CPM is a project planning tool that can meet the required function of planning in construction, including consideration of legal (allocation responsibilities) and contractual framework. Based on his field experience and from experiences published by other authors, Jaafari concluded that CPM schedule can be used to resolve both delay and change order disputes.
Eldosouky (1996) declared that CPM is a powerful and decisive tool that could be used by the Engineer to determine the responsibility of various parties towards various project delays and work changes.

BACKGROUND

CPM schedules have been grasped as the medium and method to prove delays in the United States and other countries (Callahan et al. 1992). It was used extensively because of limitation of bar charts for measuring and evaluation of delays. It is not exception to find the as-built critical path different from as-planned one. As-built critical path, in general, does not represent actual critical path during project progress. The critical path changes continually as a result of delays, work changes, acceleration, adding activities, logic, …etc. Almost all delay analysis methods are based on CPM techniques.
The net working duration method, as presented by Antill and Woodhead (1982), examines the net working duration of all apparent as-built critical paths. It is based solely on the analysis of the critical path(s) with maximum net working duration. The path net working duration is calculated as follow: Path net working duration = its total duration – all delay times lying on it.
In net working duration method, the responsibility of each party for the contract delayed completion is determined by the inspection of primary critical path(s). The primary critical path(s) is the path(s) with the longest net working duration, while secondary path(s) are those parallel to primary path(s) but don't control the contract duration.
Kraiem and Diekmann (1987) used CPM in the analysis of concurrent delays. They assumed that as-planned critical path(s) does not change during project progress. The responsibility of parties for project delays are determined depending on the as-planned critical paths and other paths are neglected. However, as-planned schedule seldom constitutes the criterion for measuring actual fulfillment of the work as the Kraiem and Diekmann claims (Bartholemew 1989, Logcher 1989). Likewise, this method ignores the changes in critical path during project progress.
The window analysis technique (Finke 1997, Finke 1999) examines the effect of delays over the life of a project by looking at gains and/or losses on the critical path(s) within each schedule update period. The analysis focuses on the as-built history through sequential periods of project performance. Window analysis examines all periodic schedule updates prepared by the contractor and submitted to the owner over the life of the project. Each schedule update should incorporate changes to-date, any necessary logic and duration revisions by the contractor, and all delays to the project during the analysis period. The accuracy of this technique is a function of the selected periods and their duration.
Snapshot technique used by Revay (1990) is based upon the as-planned, as-built, and revised schedules that have been implemented during project execution. The dates of

snapshots usually coincide with major project milestones, significant changes in planning, or when a major delay occurred. In all snapshots analysis, any alterations to the CPM logic should be incorporated into the extended duration schedule before progressing to the next snapshot.

Similar to the snapshot, the time impact technique examines the effects of delays at different periods of project and examines changes of critical path(s) in these periods. The time impact technique concentrates on a specific delay or delaying events, whose timings as the updating periods. The idea is to obtain a stop-action picture of the project before and after the occurrence of a major delaying event (Alkass et al. 1996).

Alkass et al. (1995) and Alkass et al. (1996) used the isolated delay type technique which is based on the systematic time impact and snapshot techniques. Time periods are determined based on either major delaying events or after the occurrence of a series of delays. The changes in critical path(s) before and after these delays are examined.

However, in all previous methods, the critical path(s) within the analysis periods are likelihood to change and some non-critical activities evolve to critical ones. On the other hand, selection of updating periods is very important and may generally affect the results of the analysis. There are no definite rules for selecting these updating periods. This is because some delays may be go on and some activities' durations may be increased or accelerated after the selection period.

The only exception is the method proposed by Ariditi and Robinson (1995) for analyzing concurrent delays, which depends on day-by-day updating. This method did not ignore the dynamic nature of critical path. They highlighted that one delay started on a non-critical activity may evolve it into a critical one. They claimed that the criticality of individual activities in a CPM network might change day-by-day, depending on delays and accelerations that occurred the day before. However, a large amount of information is required to accurately assess the impact of delay for each day. Practically, it is very difficult to constitute a decision for succeeding activities' alterations (accelerations, logic, …etc) according to day-by-day analysis of delay.

To investigate the causes of delay in Iranian construction projects Mohammad Khoshgoftar, Abu Hassan Abu Bakar and Omar Osman (2014) were conducted by questionnaire survey to solicit the causes of delay from the viewpoints of clients, consultants, and contractors. One hundred and twenty five sets of questionnaires were distributed to the respondents. The results demonstrate that finance and payments of completed work, improper planning, site management, contract management, and lack of communication between the parties are the key reasons for delay

Yogita Gajare , Pankaj Attarde , Dr. D. K. Parbat, (2015) present list of construction delays causes retrieved from literature. The feedback of construction experts was obtained through interviews. Subsequently a questionnaire survey was prepared .The questionnaire survey was distributed to owner, contractor, engineer, architect and consultant. Frequency index, importance index and severity index are calculated. The results of this research can be used as a reference by project owners, managers, and in various organizations in developing their project management strategies and minimizing construction delays.

Aydın, D., Mıhlayanlar, E. (2018). study the factors that may cause delay in the construction activities which accelerate by depending on increase in the house selling prices in Edirne in Trakya region in recent years. For this purpose, in order to identify the causes of delays and the delay effects in the city centre, a survey was conducted with the clients, consultants and contractors in Edirne. Relative Importance Index (RII) is used to determine the relative importance of both causes and effects. Findings of the survey differ from other studies due to a local case study.

Delay to projects is one of the foremost concerns of the construction industry in the India (Rahul Razdan & Dr. Akhil Goyal , 2019) evaluated the various types of delays and the reasons for those delays that are currently affecting the projects in the India. Measures from previous researches to reduce or eliminate these delays by methods of mitigation or acceleration are analyzed for the case studies considered for this research.

Ludwig Rivera , Hilario Baguec, Jr. and Chunho Yeom (2020) determined the ten principal causes of delay in road construction projects in 25 developing countries across the globe. The study involves two steps. First, the authors compiled information regarding the most frequent delays in a road construction project. Second, they analyzed the intensity of each cause of delay in these projects.

RESEARCH IMPORTANCE AND OBJECTIVES:

The presented study has been motivated from the shortcoming of presented techniques for analysis of delays and work changes. It attempts to introduce a simplified methodology for solving the delay analysis problem. It also aims to assist construction practitioners by providing them with practical method for analysis of construction delays. The main objectives of the present research are Developing a technique to analyze delays and work changes. This technique must overcome the problems of activity acceleration and near critical path which cannot be shown without dynamic critical path.

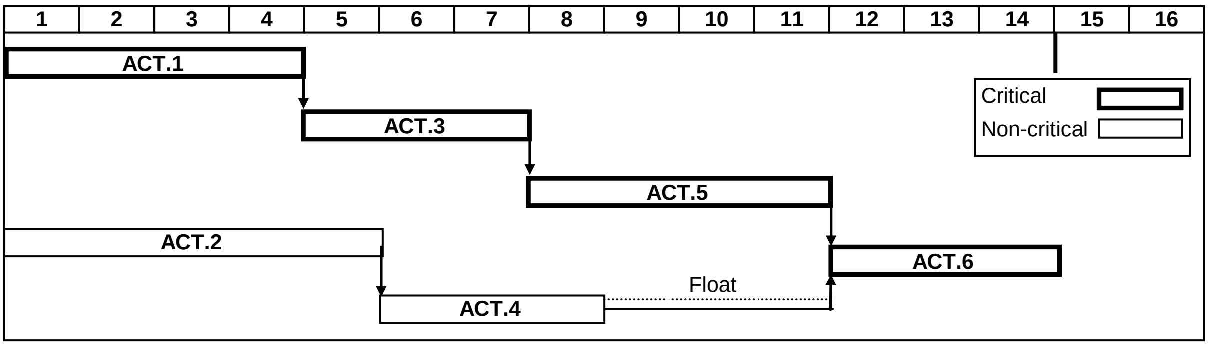
PROBLEMS OF CRITICAL PATH ANALYSIS

During project progress, some problems are usually encountered concerning critical path analysis. If such problems have not been considered in delay analysis they will cause disputes between different project parties. These problems include activity acceleration and near critical path.

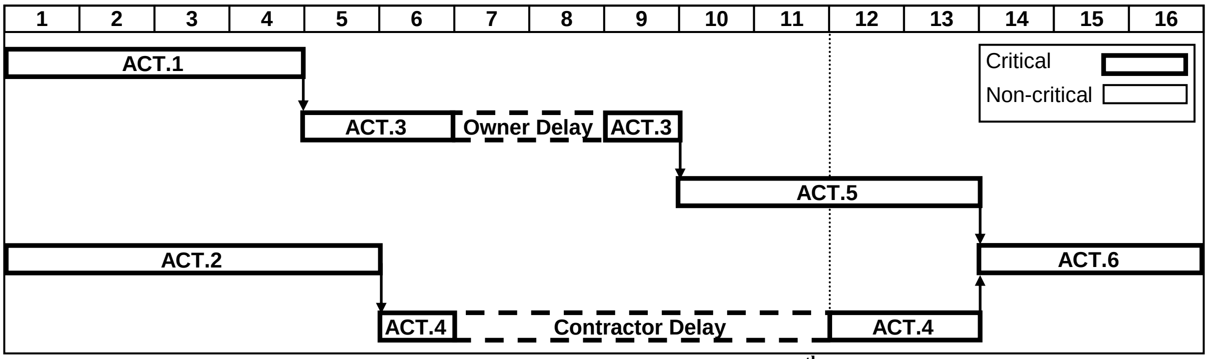
Activity Acceleration

Sometimes, when a delay in a critical activity is caused by the contractor, he may accelerate the remaining portion of the activity to avoid delayed project completion. In addition, owner may ask the contractor to accelerate certain activities when the preceding activities are delayed (Arditi and Patel 1989). Generally, the activity acceleration problem arises when the effects of delays disappear in the critical path(s) because of activity acceleration. This phenomenon will be demonstrated by the example problem shown in Fig.1, in which the network comprises only two paths.

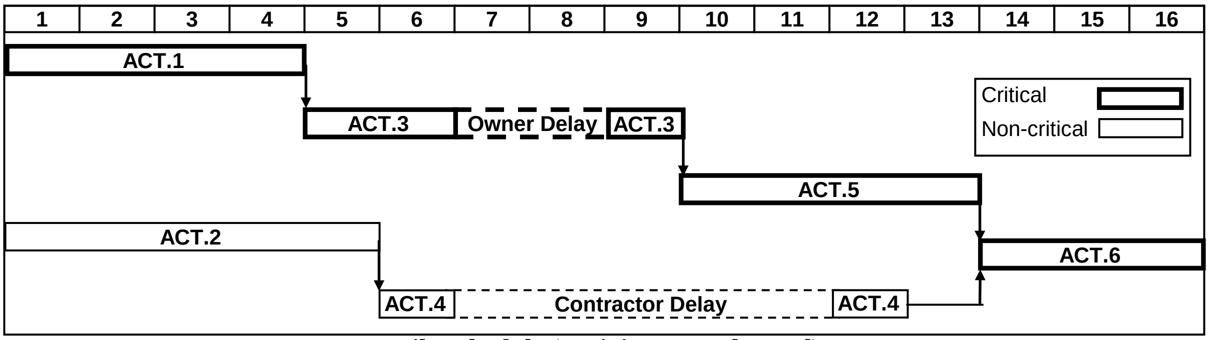
As shown in Fig.1.a, the as-planned schedule has only one critical path (activities 1, 3, 5, and 6), while the second non-critical path has a float of 3 days. During project execution, delays of 2, and 5 days have been reported for activities 3 and 4, respectively. Suppose that one of the techniques, which divide the project into many periods, are used in delay analysis as snapshot or isolated delay type. Suppose also that the delay analysis is performed from project start to the end of 11^{th} day, for instance, as shown in Fig.1. b. It reveals that another critical path is created (activities 2, 4, and 6). The contractor can accelerate the remaining portion of activity 4 and, as a consequence, the second critical path disappears as shown in Fig.1.c. It is, therefore, more realistic to analyze delays after finish of each affected activity, where its actual duration differs from as-planned duration.



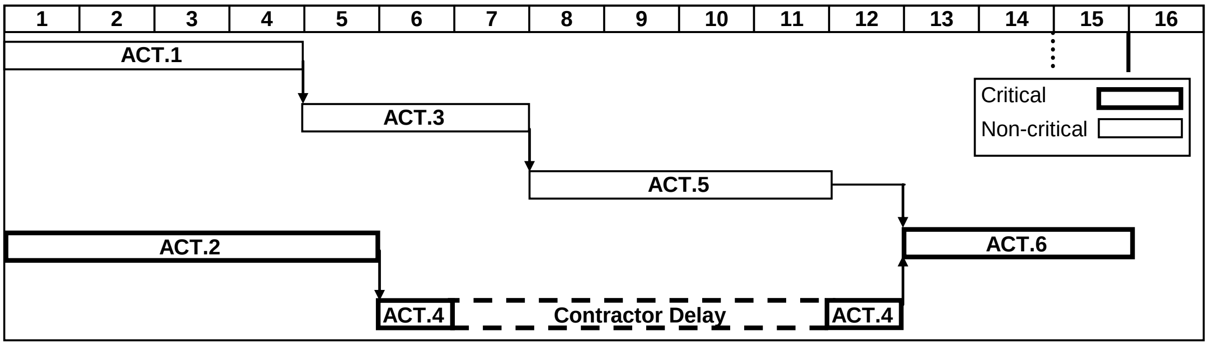
a. As-Planned Schedule



b. Schedule Update from Project Start to the 11th Day



c. As-Built Schedule (Activity 4 Accelerated)



d. As-Built Schedule after Updating Activity 4

Fig.1 Activity Acceleration Problem

If delay analysis is performed by one of the techniques, which divide the project into periods, then both the owner and the contractor are to be compensated for two days. When contractor delays are excluded from As-built schedule (Fig.1.b) then, the project completion date is delayed by two days upon owner responsibility. In the same way, when owner delays are excluded from As-built schedule (Fig.1.b) then, the project completion date is delayed by two days upon contractor responsibility.

If the net working duration technique is used in delay analysis, the owner will compensate the contractor for two days because the apparent critical path consist of activities 1, 3, 5, and 6, which is not equitable. If the owner's delays are excluded from Fig.1.c, then the project completion date is delayed by one day only because the contractor accelerated activity 4 by one day.

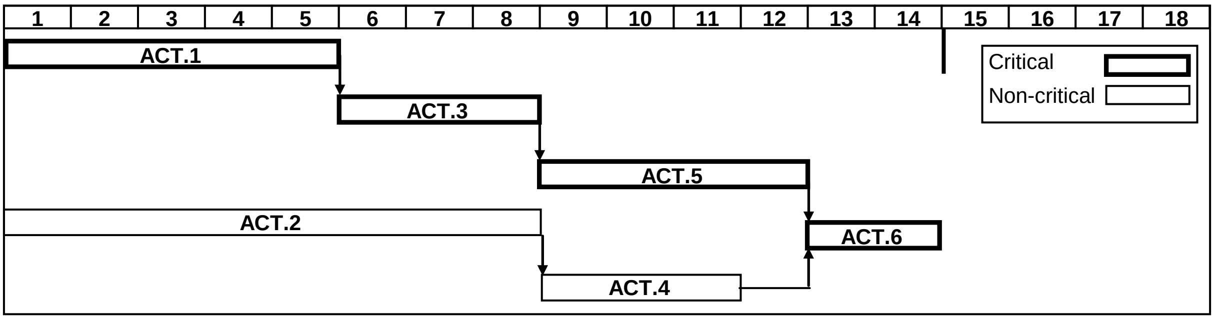
Based on the previous discussion, delay analysis should be performed after the finish of each affected activity during project progress. In the present example, the delays caused by the owner are inserted to activity 3, then the as-planned deadline is delayed by two days. If the delays caused by the contractor are inserted into activity 4 (after acceleration) then as-planned completion date is delayed by only one day (Fig.1.d).

Near Critical Path

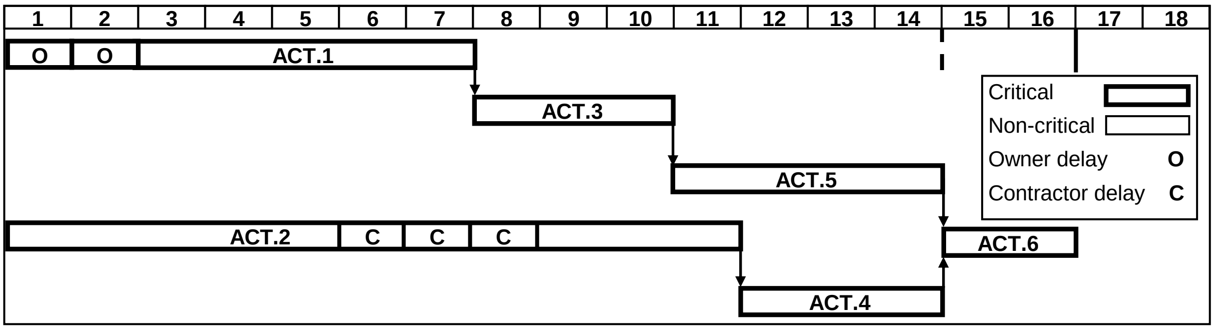
In delay analysis, the analyst can find a path(s), which is parallel to the primary critical path(s), whose length is little bit smaller than that of the critical path. This path is called near critical path. Delays caused by any party may be concentrated on a near critical path(s) and will not be considered because the path is not primary. If the net working duration concept is adopted in delay analysis, then different parties' payments are not fair.

To illustrate near critical path problem, consider the example problem shown in Fig.2.a. Suppose that activities 1 and 2 have been delayed by the owner and the contractor, respectively. The amount of delays, responsibility, and the critical path are shown in Fig.2.b. It can be noted that the as-planned non-critical path (activities 2, 4, and 6) evolves to a critical one. If the net working duration technique is used in delay analysis, two apparent critical paths are shown in the as-built schedule (Fig.2.b). The net working duration of path 1 (activities 1, 3, 5, and 6) and path 2 (activities 2, 4 and 6) are 14 and 13 days, respectively. Then, path 1 is primary and it will be used in calculating the entitlements. The owner will compensate the contractor for two days, despite the contractor caused a delay of two days on the as-planned schedule basis.

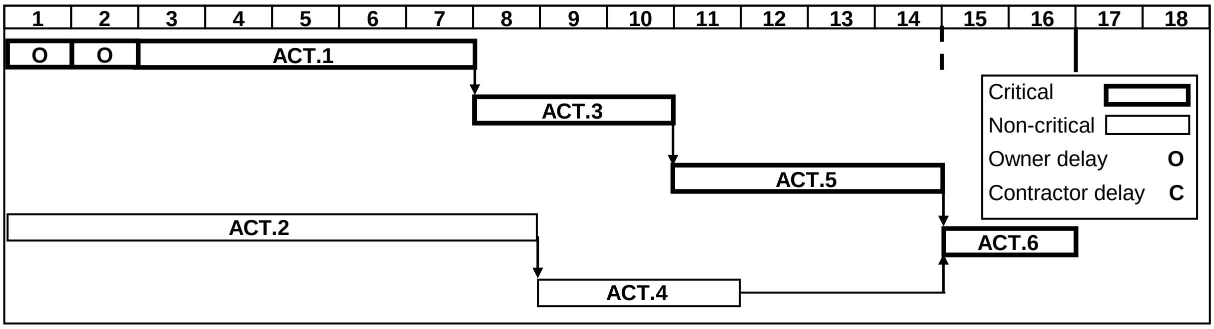
Let us consider delay analysis after finish of affected activities (activity-by-activity). First, the owner's delays are inserted to activity 1 and, consequently, the project is delayed by two days upon his responsibility, as shown in Fig.2.c. Second, the contractor's delays are inserted to activity 2, and the resulting project delay is two days upon his responsibility, as shown in Fig.2.d. It is clear that delay analysis using the activity-by-activity method is more equitable for both owner and contractor. It reflects the actual occurrence of activities during project progress.



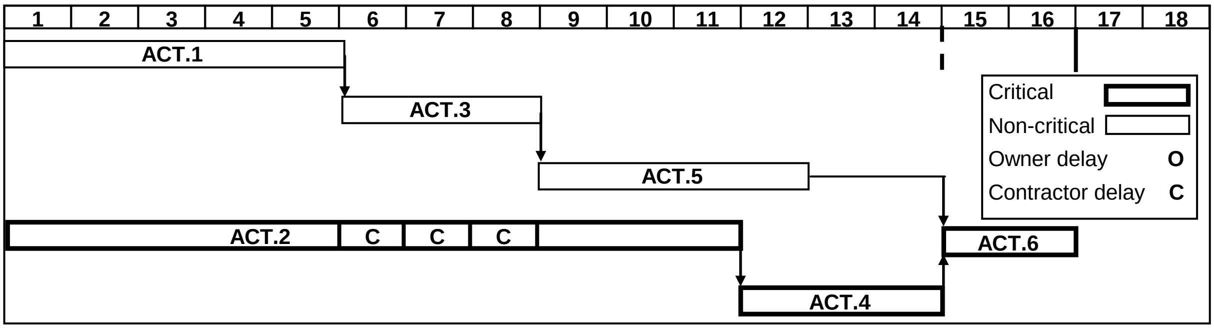
a. As-Planned Schedule



b. As-Built Schedule



c. As-Built Schedule after Updating Activity 1



As-Built Schedule after Updating Activity 2

Fig.2 Near Critical Path Problem of Project

PROPOSED TECHNIQUE FOR DYNAMIC CRITICAL PATH ANALYSIS

The use of CPM has become an accepted standard in all major construction work. The boards and courts have a willingness to use network analysis techniques to identify delays and disruptions and their causes (Kallo 1996). The critical path must be kept current and reflects delays and frequently changes during the course of project.

As described in the previous sections, many CPM-based methods have been used in delay analysis. Networking duration technique does not take into account any changes in the CPM schedule during the course of the project, which leads to inaccurate results in delay analysis. The potential error lies in the fact that delays may be on the as-planned critical path, but when the delay actually occurred, it was not a critical delay. In addition, this method cannot solve the near critical path problem because it depends solely on primary critical path. The other techniques are based on updating project schedule periodically, in which the reliability of results is a function of the number of periods used in the analysis. In each period, the analysis is performed twice from the contractor's point of view and from the owner's point of view to determine separately the owner and contractor responsibility, but the effect of each delayed activity on the project delay is not determined. In all methods, the problem of activity acceleration is not considered. On the other hand, the near critical path problem is overcome by dividing the as-built schedule into selected periods.

A new approach is proposed for critical path identification in delay analysis. This method checks the changes in each path during project implementation. The proposed technique reflects the dynamic nature of critical path by updating the as-planned schedule after the finish of each affected activity (activity-by-activity). Delays and other changes in activity duration will be inserted while the critical path and project deadline will be checked. The proposed method can be summarized in the following steps:

1. From field reports, determine those activities that have been changed or delayed during project progress and the causes of delays.
2. Revise as-planned schedule to reflect any changes in the as-planned plan (work change, acceleration, logic, adding activities, deleting activities, …etc).
3. Sort activities of as-built schedule according to their actual finish dates.
4. Update the revised as-planned schedule by adding any delays and/or changes that happened during project implementation. The updating is performed to reflect the changes of each affected activity (activity-by-activity) starting with 1st finished activity.
5. Check the changes in the revised as-planned critical path(s) and project completion date after each updating.
6. Compare the project completion date before and after activity updating. The difference between project deadline before and after activity updating is the project delay caused by this activity.
7. Repeat steps 4, 5, and 6 for all affected activities once they are finished through project execution.
8. The total project delay is the cumulative delays caused by all activities.

It should be noted that each type of delay must be determined before starting the activity-by-activity updating as owner delays, contractor delays, or concurrent delays.

ILLUSTRATIVE EXAMPLE PROBLEM

An example problem is used here to demonstrate the proposed method. Table 1 gives planning data and activity delays, while Table 2 gives start and finish dates of each delay. The as-planned schedule comprises three paths: path 1 (activities 1, 2, 7, and 9), path 2 (activities 3, 4, 7, and 9), and path 3 (activities 5, 6, 8, and 9). The as-planned deadline was 30 days while the as-built project completion date was 36 days as shown in Fig.3. The as-planned schedule contains one critical path (path 1) while as-built schedule contains two critical paths (paths 1 and 3). Fig.4 displays the changes on critical path after each updating, which is carried-out after the finish of each delayed activity. In this example problem, the contractor delays are considered only for comparison purpose. To compare the results of the proposed method with other existing techniques, updating is performed from the contractor's point of view, in which only delays caused by the owner and neither parties will be considered.

Table 1. Planning Data and Delays of the Example Problem

Activity	As-Planned Duration (Days)	Predecessors	Delays (Days), and Responsibility		
			Neither	Owner	Contractor
1	8	-	-	-	-
2	12	1	-	1	5
3	5	-	-	-	-
4	10	3	-	7	-
5	7	-	-	3	2
6	15	5	-	-	2
7	8	2, 4	-	-	-
8	2	6	-	-	3
9	2	7, 8	-	-	-

Table 2. Field Report of Delays

No.	Delay type	Activity Affected	Delay start	Delay finish	Delay Time
1	Contractor	5	1	2	2
2	Owner	4	6	12	7
3	Contractor	2	9	13	5
4	Owner	5	10	12	3
5	Owner	2	25	25	1
6	Contractor	6	25	26	2
7	Contractor	8	30	32	3

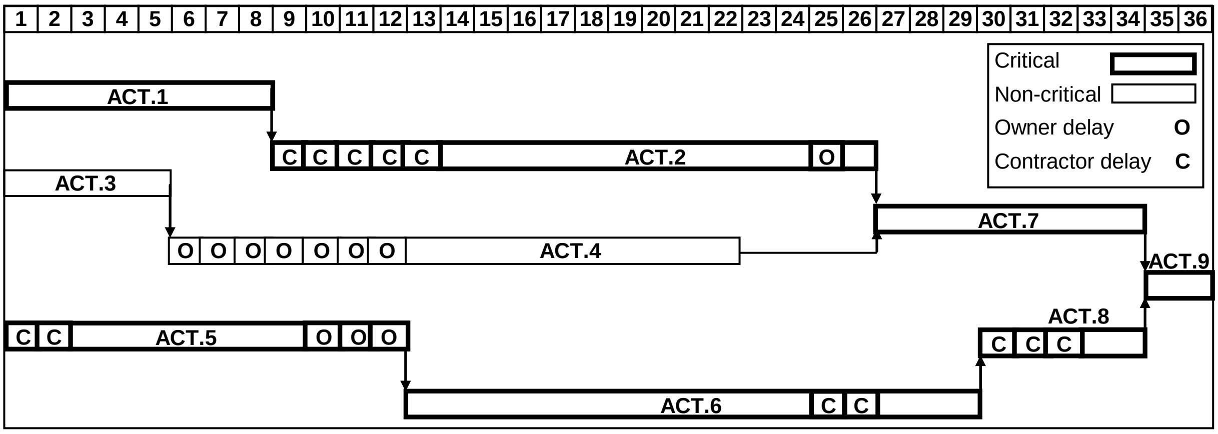
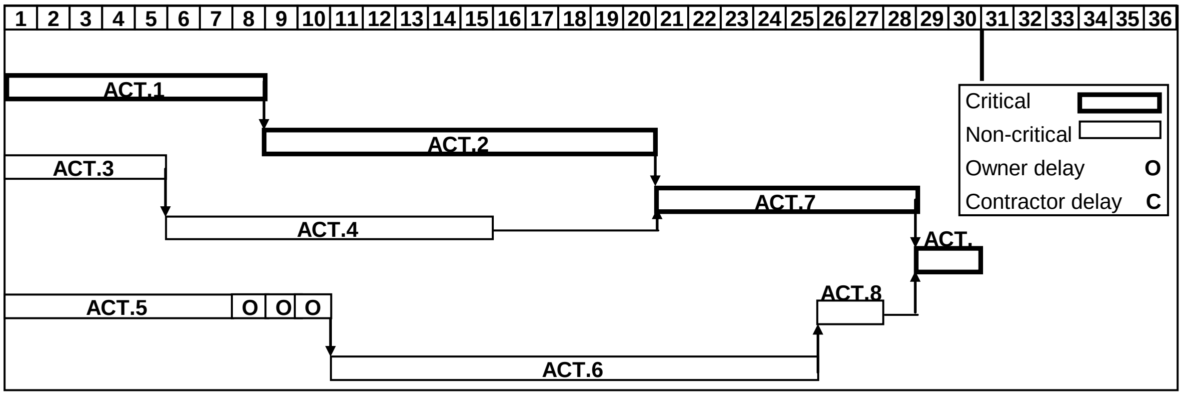


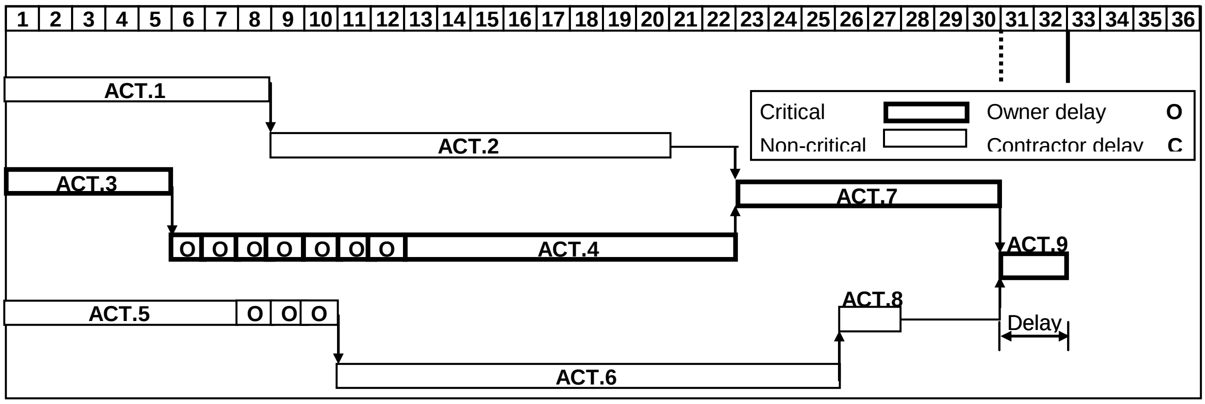
Fig.3 As-Built Schedule with Breakdown of Delays of the Illustrative Example

Project activities are sorted by their actual finish dates and then updating is performed according to their order. Therefore, updating will be performed for activities 5, 4, 2, 6, and 8 in order.

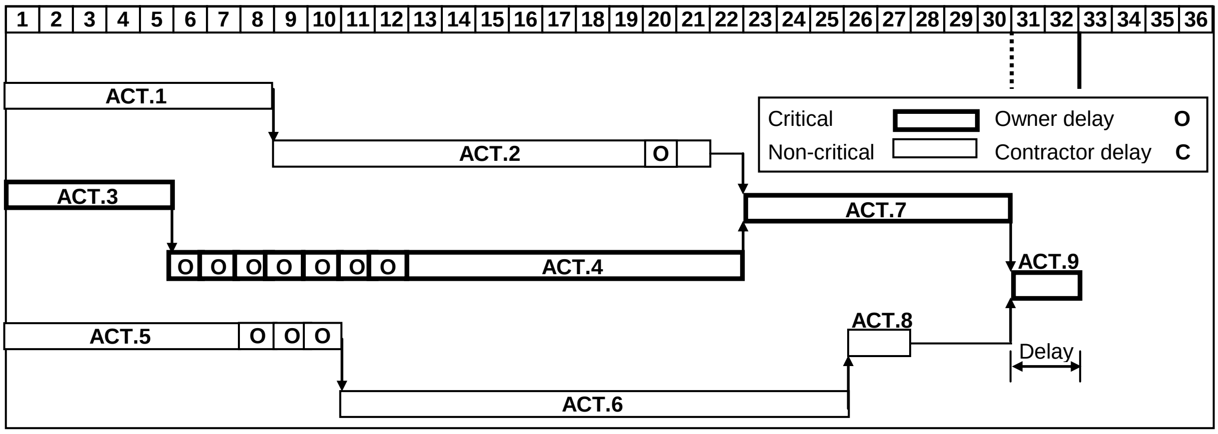
Fig.4.a, shows project status after the finish of activity 5, in which the as-planned critical path is not changed. On the other hand, the critical path is changed after updating activity 4 to another path (path 2), as shown in Fig.4.b. After updating activity 2, path 1 evolves again to critical path beside path2, as shown in Fig.4.c. It must be noted that delays of activities 6 and 8 are not considered, since these delays are caused by the contractor.



a. Project Schedule after Updating Activity 5 (from Contractor's Point of View)



b. Project Schedule after Updating Activity 4 (from Contractor's Point of View)



c. Project Schedule after Updating Activity 2 (from Contractor's Point of View)

Fig.4 Successive Updating After Activities' Completion

It is clear that the critical path(s) changes dynamically after each updating. Therefore, this analysis is referred to as Dynamic Critical Path Analysis. The effect of successive delays on critical path changes for this example problem is summarized in Table 3. The total project delay, which the contractor entitled for, is the commutative delays result form project updating from the contractor's point of view. In this example problem the contractor is entitled for 2 days.

Table 3 Critical Paths and Delays (form the Contractor's Point of View)

Updated Activity	Critical			Project Deadline		Project Delays Caused by an Activity
	Path 1	Path 2	Path 3	Before	After	
5	Yes	No	No	30	30	0
4	No	Yes	No	30	32	2
2	Yes	Yes	No	32	32	0
∑Delays caused by all updated activities						2

To compare the results of this illustrative example problem with other methods, which use CPM in delay analysis, the analysis is performed twice; from the contractor's point of view and from the owner's point of view. If updating is performed from the owner's point of view, only delays caused by the contractor are considered.

The corresponding changes in the critical paths after each updating (activity-by-activity) as well as resulting delays are given in Table 4. The contractor responsibility for project delay is the commutative delays caused by all updated activities from the owner's point of view. For this example problem, the contractor is responsible for delays of 5 days.

Table 4 Critical Paths and Delay (from the Owner's Point of View)

Updated Activity	Critical			Project Deadline		Project Delays Caused by an Activity
	Path 1	Path 2	Path 3	Before	After	
5	Yes	No	No	30	30	0
2	Yes	No	No	30	35	5
6	Yes	No	No	35	35	0
8	Yes	No	No	35	35	0
∑Delays caused by all updated activities						5

The illustrative example problem on hand is re-solved using various methods, which utilize CPM in delay analysis. The comparison between the proposed method and previous methods is given in Table 5. It is clear that the proposed method gives identical results except for net working duration method. This is because the net working duration method does not consider the dynamic nature of critical path in delay analysis. The net working duration method considers only the final apparent as-built critical path(s) while other paths are neglected.

Another important aspect of the proposed dynamic critical path approach is that the effect of each delayed activity on project delay can be obtained, while other methods can not. This is an apparent feature of dynamic critical path method over other methods used for delay analysis.

Table 5. Comparison of Existing Methods and Proposed Technique

Technique	Contractor Responsibility	Owner Responsibility
Net Working Duration	5 days	1 day
Isolated Delay Type	5 days	2 days
Snapshot Technique	5 days	2 days
Time Impact Technique	5 days	2 days
Dynamic Critical path	5 days	2 days

The proposed method offers both the owner and the contractor a clear knowledge about the effect of delays of each activity on the succeeding activities and project completion date. On the other hand, the analysis can be performed after the project finish retrospectively.

CONCLUSIONS AND RECOMMENDATIONS:

Critical path analysis is an extremely effective method for analyzing delays of complex projects. It helps the Engineer to calculate the minimum length of time in which the project can be completed, and which activities should be prioritized to complete on time. In addition, it reflects the actual progress of project. In this paper, a new proposed approach, which reflects and determines the dynamic nature of critical path during delay analysis, is presented. The new method depends on updating project network after the finish of each affected activity (i.e. activity-by-activity basis). The new features of the proposed method include:

1. It gives an effective basis for monitoring project progress after the finish of only affected activities, and helps us to focus on the succeeding critical activities to which attention and resources should be devoted,
2. It can be used as equitable compensation tool for both owner and contractor for delay analysis,
3. It gives realistic delay analysis when compared with other existing methods, and
4. It gives realistic delay analysis, especially when delays disappear through project progress due to dynamic nature of critical path.

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