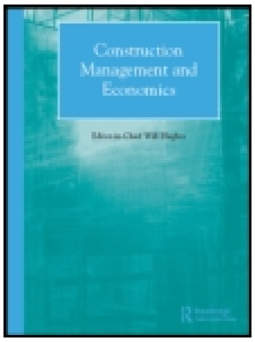

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Construction delay analysis techniques

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Construction projects continue to suffer delays. Things go wrong and the project's completion date gets pushed back, with someone to be blamed for it. In practice, attempts are made to identify the causes of delays and schedules are modified to incorporate revised duration and new project time. The analysis itself is usually complex and can be aided by a computerized approach. This paper discusses different delay analysis techniques that are currently used by practitioners in the construction industry. It also discusses a proposed new delay analysis technique called the Isolated Delay Type (IDT). These techniques were tested against a case example and their strengths and weaknesses highlighted. The new technique can be used as a stand-alone module for delay analysis or could be incorporated within a computer system for construction delay analysis and claims preparation called Computerized Delay Claims Analysis (CDCA) that integrates different software including an expert system and management software such as scheduling and a database or spreadsheet.

Keywords: Construction delays, claims, expert systems, computing, scheduling, construction management, construction planning, project control.

Introduction

Delays are the most common and costly problem encountered on construction projects. Analysing construction delays has become an integral part of the project's construction life. Even with today's technology, and management understanding of project management techniques, construction projects continue to suffer delays and project completion dates still get pushed back. There are many reasons why delays occur. They may be due to strikes, rework, poor organization, material shortage, equipment failure, change orders, act of God and so on. In addition delays are often interconnected, making the situation even more complex.

Delays are costly to all parties involved in the construction industry and often result in litigation. The time and expense incurred to prepare a claims document in itself is substantial. There is room for improvement in present practices for keeping track of delays. Therefore, introducing a flexible and more accurate delay analysis technique can be valuable.

The purpose of this paper is to examine and discuss the delay analysis techniques currently used by practitioners in the construction industry, and also to present a new and effective delay analysis technique called the Isolated Delay Type (IDT). The technique is tested against a case example and its advantages and shortcomings as compared to other techniques are highlighted. The new technique can be accommodated within the Computerized Delay Claims Analysis (CDCA) system (described in Alkass and Harris, 1991; Alkass *et al.*, 1993). This system could assist in improving the process of delay analysis, thus reducing the cost of claims preparation. CDCA uses existing software such as project management and database management. In addition to these, an expert system tailored to the specific expertise of construction claims is used to facilitate the decision making process.

In addition to the case example described in this paper, IDT has been tested against a real case study of a building project and demonstrated its effectiveness in determining the effect of delaying activities on the project duration (Mazerolle, 1993).

Construction delays

Construction delays and their classification have been discussed in the literature (Kraiem and Diekmann, 1987; Reams, 1989, 1990; Alkass *et al.*, 1991, 1993; Wickwire *et al.*, 1991; Mazerolle *et al.*, 1993). Generally they are classified according to liability into two major types, namely excusable or nonexcusable delays.

Excusable delays are those not attributable to the contractor's actions or inactions, and typically include unforeseen events. These events are beyond the contractor's control and are without fault or negligence on his/her part. Excusable delays, when founded, entitle the contractor to a time extension if the completion date is affected. This type of delay can also have an impact on noncritical activities which need a more detailed analysis to determine whether additional time extension is warranted, or if the reduction of float time can be justified. Excusable delays can be further classified into compensable and noncompensable delays.

Excusable compensable delays are caused by the owner's actions or inactions. When contractors encounter this type of delay, they are entitled to a time extension as well as monetary compensation due to the delay(s). An example of an excusable compensable delay would be when an owner denies access to the site once the notice to proceed is given.

Excusable noncompensable delays are delays where neither the owner nor the contractor is deemed responsible. When this type of delay is encountered, only a time extension will be warranted since there are no grounds for damages. Some examples of excusable noncompensable delays are unprovoked strikes, or any `act of God'.

Nonexcusable delays are delays which result from the contractor's or sub-contractor's actions or inactions. Consequently, this type of delay presents no entitlement to a time extension or delay damages for the contractor if the delay can be proved to have affected the whole project. The owner, however, could be entitled to liquidated damages. An example of a nonexcusable delay would be when a contractor fails to provide sufficient manpower to complete the job on time.

Concurrent delays refer to delay situations when two or more delays (regardless of the type) occur at the same time or overlap to some degree – either of which, had the delays occurred alone, would have affected the ultimate completion date (Rubin, 1983). Normally concurrent delays which involve any two or more excusable delays result in a time extension. When compensable and nonexcusable delays are concurrent, a time extension can be issued or the delay can be apportioned between the owner and the contractor.

In analysing concurrent delays, each delay is assessed separately and its impact on other activities and the project duration is calculated. Rubin (1983) suggested the following guidelines for classifying these kinds of concurrent delays:

1. If excusable and nonexcusable delays occur concurrently, only a time extension is granted to the contractor.
2. If excusable compensable and excusable noncompensable delays occur concurrently, the contractor is entitled to time extension, but not to damages.
3. If two excusable compensable delays occur concurrently, the contractor is entitled to both time extension and damages.

An example of a concurrent delay would be if the owner failed to supply detailed designs for specific machine installations (excusable compensable) while at the same time, the contractor who would have installed those machines was on strike (excusable noncompensable). In this scenario, since both excusable compensable and excusable noncompensable delays are present, the contractor would be entitled to a time extension, but not to damages.

Although such guidelines are useful for the purpose of carrying out delay analysis, it is in the best interest of all parties involved in a construction project to agree, at the beginning, the definitions of such delays and accommodate them throughout the contract language.

Schedules used in a delay analysis

Several types of schedule are used to determine the impact of delays. They are: as-planned, adjusted, as-built and entitlement schedules. The as-planned schedule represents the contractor's original plan for completing the work. There is no progress shown on this schedule, only planned activities which display one or more critical paths and the project start and finish dates.

The adjusted schedule reflects how the as-planned schedule has been impacted as a result of change orders, construction changes, delays, contractor-initiated changes, or acceleration. Starting with the as-planned schedule, the above mentioned delays are incorporated into the schedule. Upon updating the schedule, an adjusted schedule is generated. In this schedule, the critical path(s) and project start/finish dates may be different from that generated in the as-planned schedule.

The as-built schedule represents the final adjusted schedule which shows the actual sequence of activities as they occurred during the entire project. The activities shown are represented by actual dates. Similar to the adjusted schedule, the critical path(s) and the project start and finish dates may be different than that of the originally planned schedule.

Entitlement schedules are used to show the original contractual completion dates, how these completion dates have been impacted due to excusable delays, and the projected completion dates given the remaining work. They also depict the difference between the adjusted and the projected completion dates. Final entitlement schedules reflect the original, adjusted and actual completion dates used to establish the total time that the contractor or the owner is entitled to for compensation.

Delay analysis procedure

To quantify delays, the as-planned or the adjusted schedules at the time of impact are used as a baseline. Delays are inserted and the schedule is updated. It is important to note that the fuzzier the baseline, the less credible the claim becomes (McCullough, 1989).

Scheduling techniques (critical path methods or bar charts) are normally used to evaluate delays resulting from a specific impact. At the start of each project, a schedule is developed based upon the best estimates of achievable production and sequence of activities at that time. As the job progresses, new conditions appear and the schedule is updated. During this phase, any change to the project time is recalculated to determine whether the impacts have affected the project duration. This process is repeated throughout the project from the start date to completion. At the end of the project there should exist two schedules: the as-planned and the as-built. Comparing the as-planned with the as-built schedule, compensation of time and (to some degree) of cost for the delays can be determined. Figure 1 shows an example comparison between an as-built schedule (indicated by the rectangular boxes) and an as-planned schedule (indicated by the lines beneath the boxes). As shown, the as-built project completion date was 41 days, whereas the as-planned completion date was 23 days. The project had been delayed by 18 days.

The as-planned schedule illustrates the initial work plan to achieve the contract goal of constructing the project. The work plan includes activities, durations, relationships and any completion dates imposed by the contract documents. For this plan to be accepted for delay analysis, it must show: that the logic or relationships between activities are reasonably valid, that the activities' durations are realistic, that the planned resource allocation is feasible and that the schedule has allowed for foreseeable conditions such as weather, work restrictions, constraints and time for inspection and approvals (Reams, 1990).

The as-built schedule reflects the actual succession of events during the execution of the project. It can be established from the project's progress reports, data and documents.

Delay analysis techniques currently in use

Several techniques using the as-planned and as-built schedules for delay analysis have been utilized by experts in the domain of claim analysis to determine the impact of delaying events upon the overall project completion date. The following is a list of these techniques (Alkass *et al.*, 1991, 1993; Wickwire *et al.*, 1991; Reams; 1990; Leary and Bramble, 1988):

1. global impact technique
2. net impact technique
3. adjusted as-built CPM technique
4. 'but for' or collapsing technique
5. snapshot technique
6. time impact technique

These techniques have been examined for their effectiveness using an example case study.

Assessment of the delay analysis techniques

When dealing with delay analysis for construction claims, it is important that the technique used is a viable one. The techniques mentioned earlier range from simple date comparisons to tedious and time consuming detailed analyses, any of which can yield a wide variety of results. When the ultimate goal in preparing a delay analysis is to present the results in court as supportive documents, it is necessary to ensure that the technique used is sound. In order to assess the different delay analysis techniques previously mentioned, each technique was applied to a common test case using Primavera Project Planner scheduling software (Primavera Systems Inc., 1991).

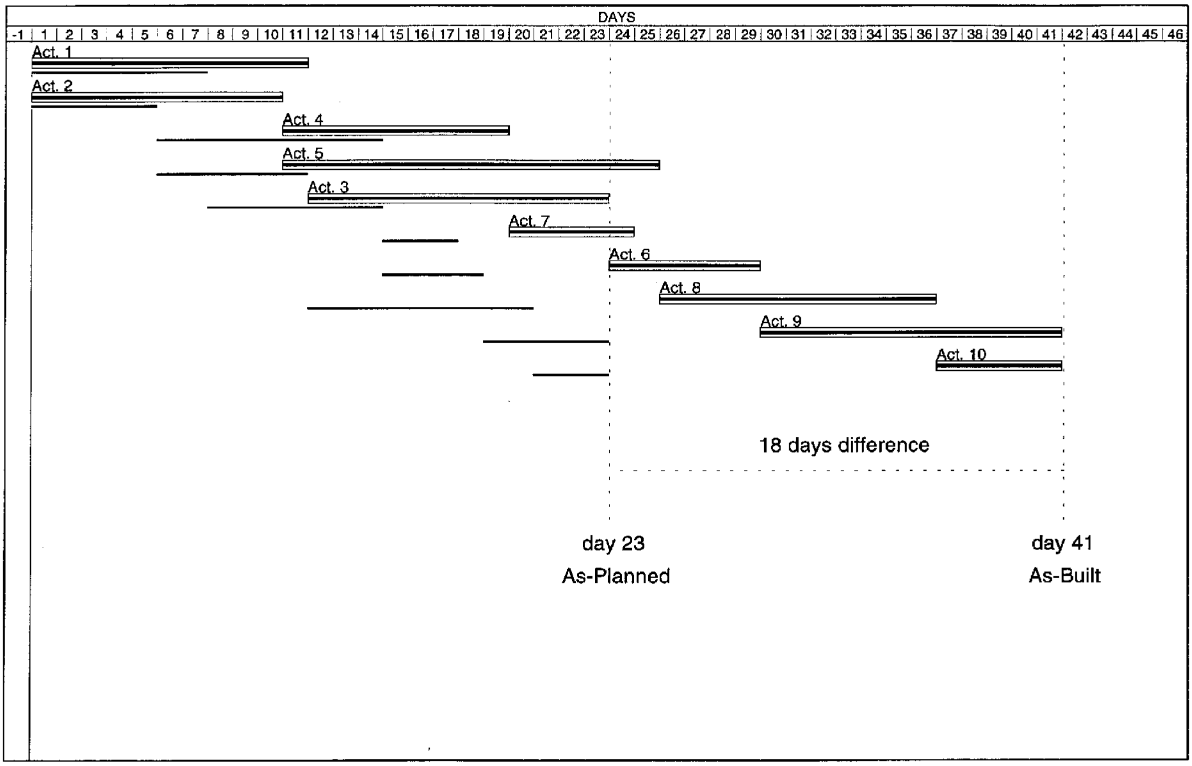

Figure 1 Comparison between as-planned and as-built critical schedules

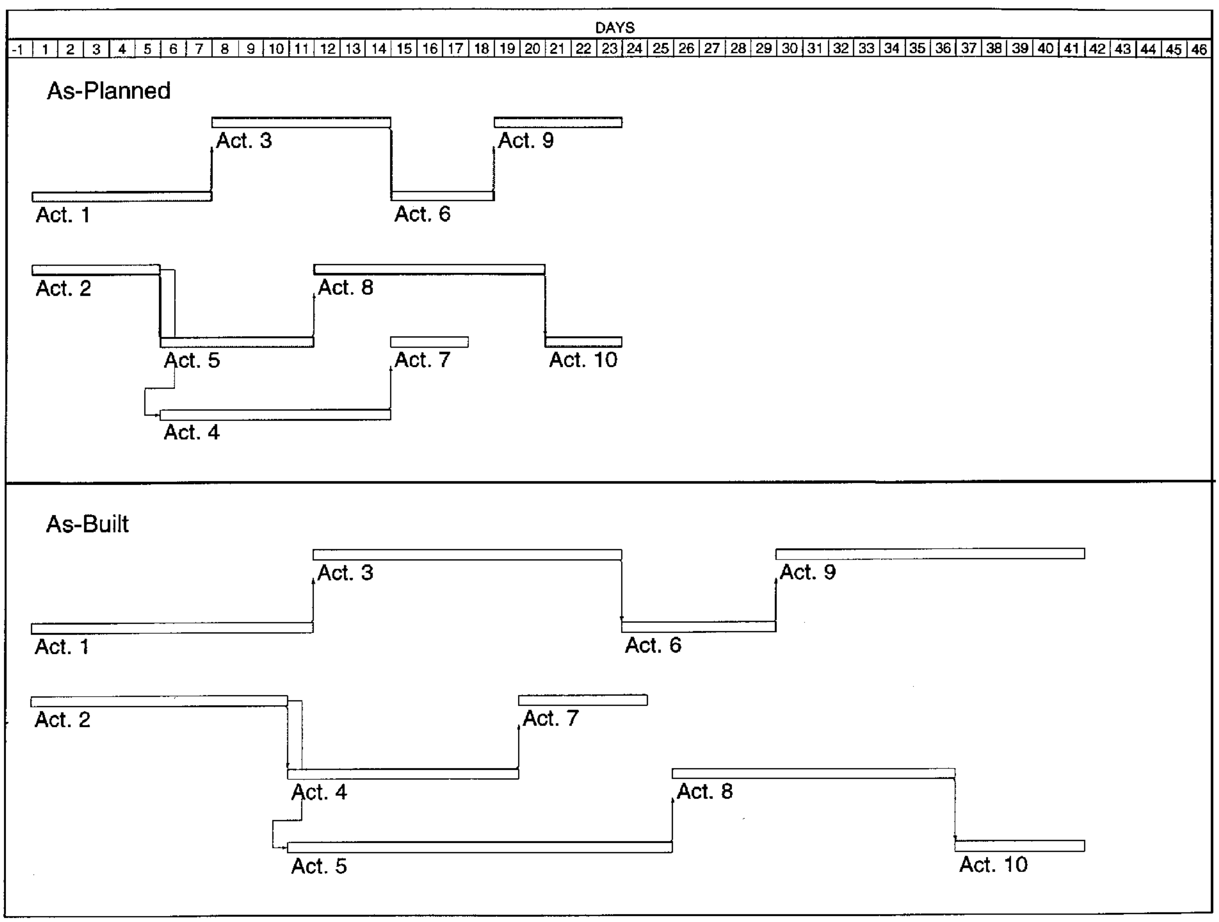

Figure 2 Example network and as-planned and as-built schedules – test case

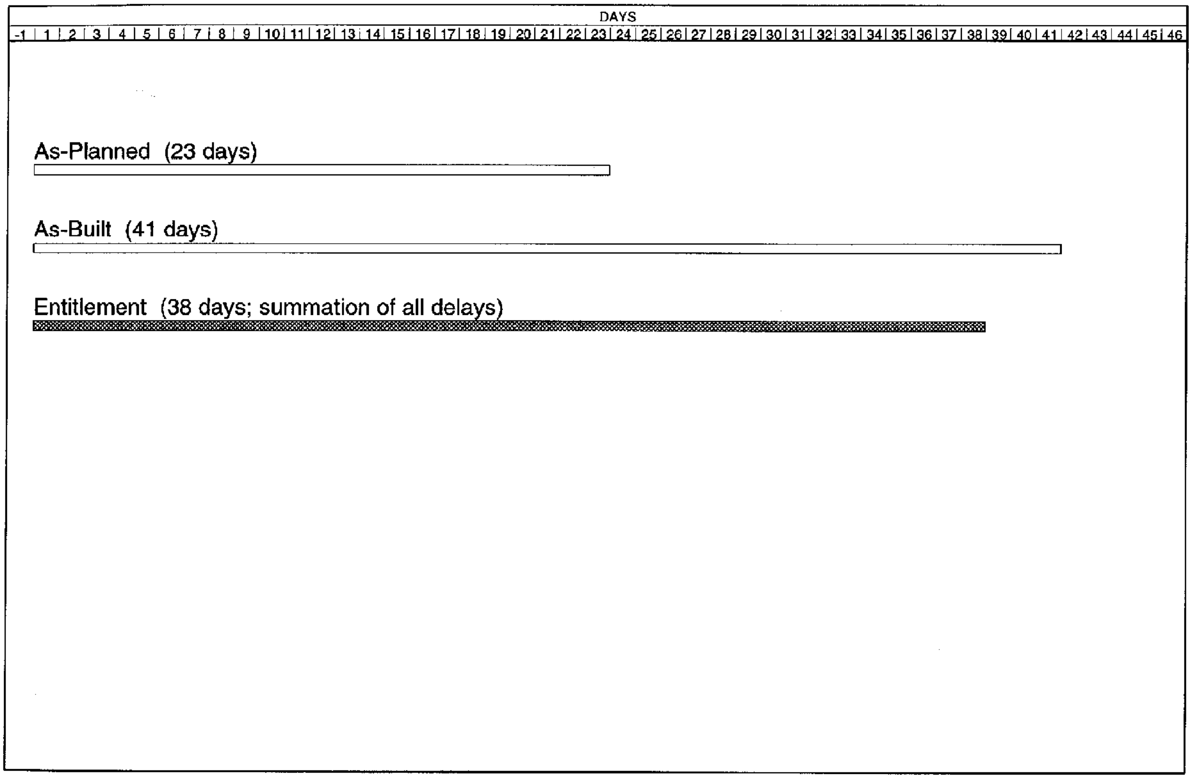

Figure 3 Global impact technique

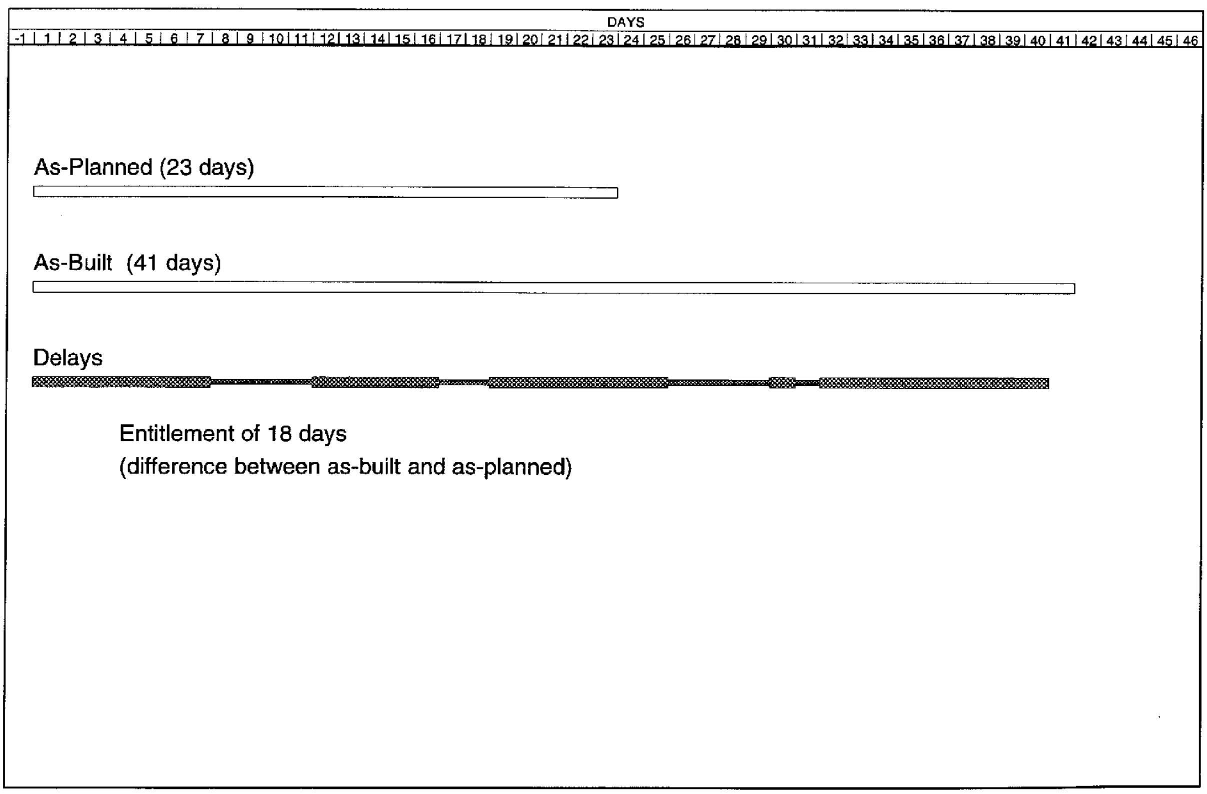

Figure 4 Net impact technique

Example case

A test case adopted from Kraiem and Diekmann (1987) was used in the assessment of delay analysis techniques. This case was found to be suitable for the assessment process, since it was a simple network and the delays used were well laid out. Figure 2 shows the as-planned and the as-built CPM schedules for the case example which each consist of ten activities split into three paths. For the assessment process a precedence diagram method (PDM) was used.

The PDM schedule, referred to here as the CPM (critical path method) schedule, is broken down as follows:

1. activities 1, 3, 6 and 9 – first critical path
2. activities 2, 5, 8 and 10 – second critical path
3. activities 2, 4 and 7 – noncritical path

The project's as-planned duration is 23 days from the start to the completion date. The as-built schedule maintains the same activities and relationships but contains many delays throughout the schedule, forcing the total project duration to 41 days. The delays identified in this test case are categorized into the three types; excusable noncompensable (EN), excusable compensable (EC) and nonexcusable (NE). The following is a breakdown of the delays:

1. Activity 1: EN 1 day, NE 3 days;
2. Activity 2: EN 3 days, NE 1 day, EC 1 day;
3. Activity 3: NE 3 days, EC 2 days;
4. Activity 4: no delay;
5. Activity 5: EN 5 days, NE 1 day, EC 3 days;
6. Activity 6: EC 2 days;
7. Activity 7: NE 1 day, EC 1 day;
8. Activity 8: EN 1 day, EC 1 day;
9. Activity 9: EN 2 days, NE 3 days, EC 2 days;
10. Activity 10: EN 2 days.

All the previously mentioned delay analysis techniques were used during the assessment process. Each technique was applied to the same case example using the same delays.

Global impact technique

The global impact technique is a simplistic way to depict the impact of delay-causing events. In this method, all the delays and disruptions are plotted on a bar chart. The delay start and finish dates are determined for each event. The total delay to the project is calculated to be the sum total of the durations of all delaying events.

In applying this technique to the example, the durations of all the delaying activities were summed to determine the total delay to the project. Using a bar chart which shows the as-planned and as-built schedules as summary bars, an additional summary bar representing the total delay was simply included on the bar chart. Figure 3 illustrates the bar chart showing all the delays. The total amount of delays is 38 days with a project completion date overrun of only 18 days. The contractor argues that the difference between the 38 days compensable time and the actual project overrun of only 18 days was due to acceleration of the project work.

There are many problems with the global impact technique. The issues that this technique disregards are: the effect of concurrent delays, scrutinizing delay types and assuming every delay has an equal impact on the project duration. This can and does lead to a gross overstatement of the entitlement due to delays. In some cases, the sum of the delays can exceed the project's as-built completion date; the rationale is that the difference between the entitlement completion date and the as-built completion date is the amount of time saved by accelerating the project.

Net impact technique

This method depicts only the net effect of all claimed delays on a bar chart. Using this technique all delays, disruptions, change orders and suspensions are plotted on an as-built schedule. Only the net effect of all the delays is calculated and the requested time extension is then the difference between the as-planned and the as-built completion dates. When using the net impact technique, all delaying activities identified in the test case were considered but only the net effect, taking into account the concurrency of the delays, was used. The as-planned and as-built schedules are plotted as summary bars on a bar chart where only the net impact of the delays is depicted, as shown in Figure 4. The difference between the as-built and the as-planned completion dates was 18 days. It is argued that the combined overwhelming effect of delays impacted the project, rather than the duration of each individual delay.

Although the net impact technique attempts to deal with the issue of concurrent delays, the method does not scrutinize delay types. As a result, the amount of delays having an effect on the project's completion date can be overstated. Also, since a network is not used, the true effect of a delay on the overall project completion date is difficult to determine.

Adjusted as-built CPM technique

This technique uses the CPM format to develop an as-built schedule. Delaying events are depicted as activities and linked to specific work activities. The critical

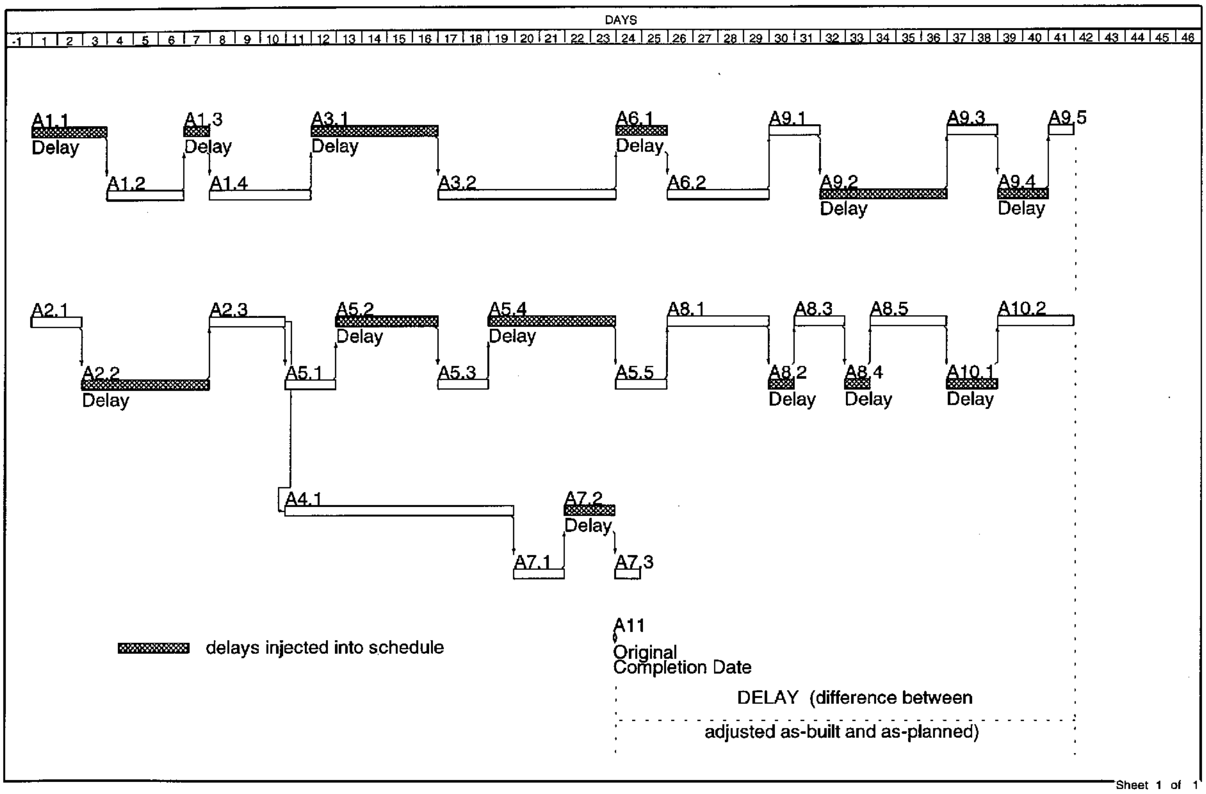

Figure 5 Adjusted as-built CPM technique

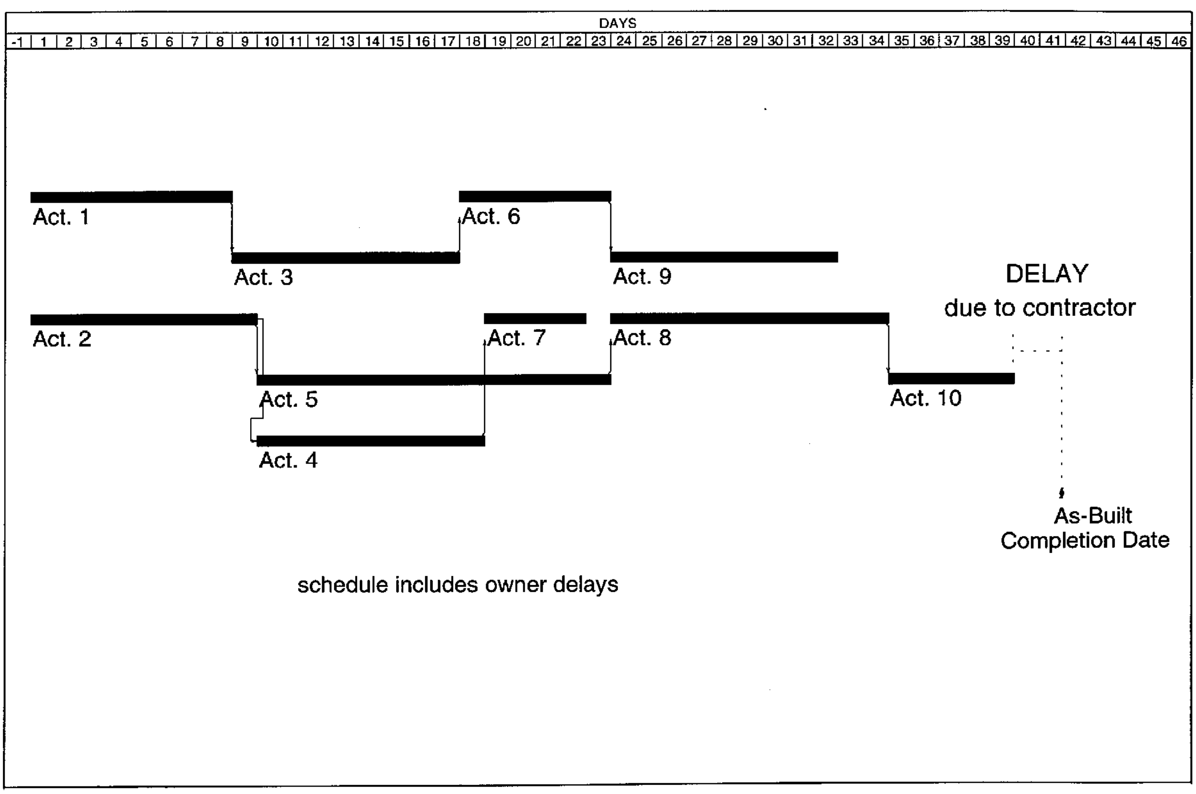

Figure 6 'But for' or collapsing contractor's delays technique

path(s) are identified twice, once in the as-planned schedule and once at the end of the project. The difference between the as-planned completion date and the adjusted as-built completion date is the amount of time for which the claimant would request compensation. This technique is similar to the net impact technique in that both techniques only show the net effect of all claimed delays on the project's completion date (Leary and Bramble, 1988).

Analysing the test case using this technique, a CPM of the as-planned schedule is used as the starting point. All delaying events are included and depicted as activities. Figure 5 illustrates the CPM schedule used for the adjusted as-built CPM technique. Linking all the delay 'activities' to their respective activities, the schedule was then updated. An adjusted completion date was found to be 41 days. The difference of 18 days between the as-planned and the as-built completion date would be the amount the contractor would claim for compensation.

The main problem with the adjusted as-built CPM technique is that even though it utilizes the CPM format which gives insight into the inter-relationships between activities, it still does not scrutinize delay types. It is not much better than the net impact technique, except that the CPM format gives a more sophisticated impression of an analysis. Another problem is that claimants invariably tie the delaying events to the critical path. Conversely, delaying events which are the responsibility of the claimant may be shown, but are more likely to be hidden in the schedule and not tied to the critical path.

'But for' or collapsing technique

The 'but for' technique (sometimes known as the collapsing technique) uses the CPM scheduling format, and entails one party taking the as-planned schedule and injecting all delays that they are willing to accept responsibility for. The updated schedule yields a revised project completion date and is compared against the as-built schedule. The conclusion thus drawn is that the difference between the as-built and the revised project completion dates is a result of delays that were beyond the claimant's control. For example, if the contractors were using this technique they would identify and include only nonexcusable (contractor's fault) delays into the as-planned schedule. As a result, an adjusted schedule would be generated with a revised completion date. The difference between this adjusted completion date and the as-built completion date is due to delays that are the owner's fault.

This technique was applied to the test case twice, first from the owner's point of view, and second from the contractor's point of view. In both cases, the as-planned schedule was used as the starting point of the analysis.

Figure 6 illustrates the 'but for' technique from the owner's point of view and contains the as-planned activities including delays the owner is taking responsibility for, those delays being excusable (EC, EN) delays. As a result, the adjusted completion date of the project was 39 days. 'But for' the contractor's delays, the project finished after 41 days, a difference of two days. Thus the owner could seek compensation (liquidated damages) from the contractor in the magnitude of two days.

Figure 7 illustrates the 'but for' technique from the contractor's point of view and contains the as-planned activities including delays the contractor is accepting responsibility for, those being nonexcusable (NE) delays. As a result, the adjusted completion date of the project was 32 days. 'But for' the owner's delays, the project finished after 41 days, a difference of nine days.

The 'but for' technique seems to provide a sound method for delay analysis. It addresses the issue of concurrent delays and scrutinizes delay types. The main problem, however, lies in the fact that it does not take into account any changes in the CPM schedule during the course of the project. Delays are applied in a 'one shot deal' to the as-planned schedule. This lends itself to inaccurate results since the critical path most certainly will change during the course of the project. 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.

Snapshot technique analysis

This technique is used to determine: the amount of delay that has occurred on a project, when the delay occurred and the cause(s) of the delay. When analysing delays, the conventional approach is to ask the question, 'This event occurred; what delay did it cause to the project?' However, the snapshot analysis asks, 'This delay occurred; what event or events caused it?' (Revay and Associates, 1990).

The snapshot technique is based upon the as-planned, as-built and any revised schedules that have been implemented during the execution of the project. The total project duration is divided into a number of time periods, or snapshots. The dates of these snapshots usually coincide with major project milestones, significant changes in planning or when a major delay or group of delays is known to have occurred. The relationships and duration of the as-built schedule within the snapshot period are imposed upon the as-planned schedule, while maintaining the relationships

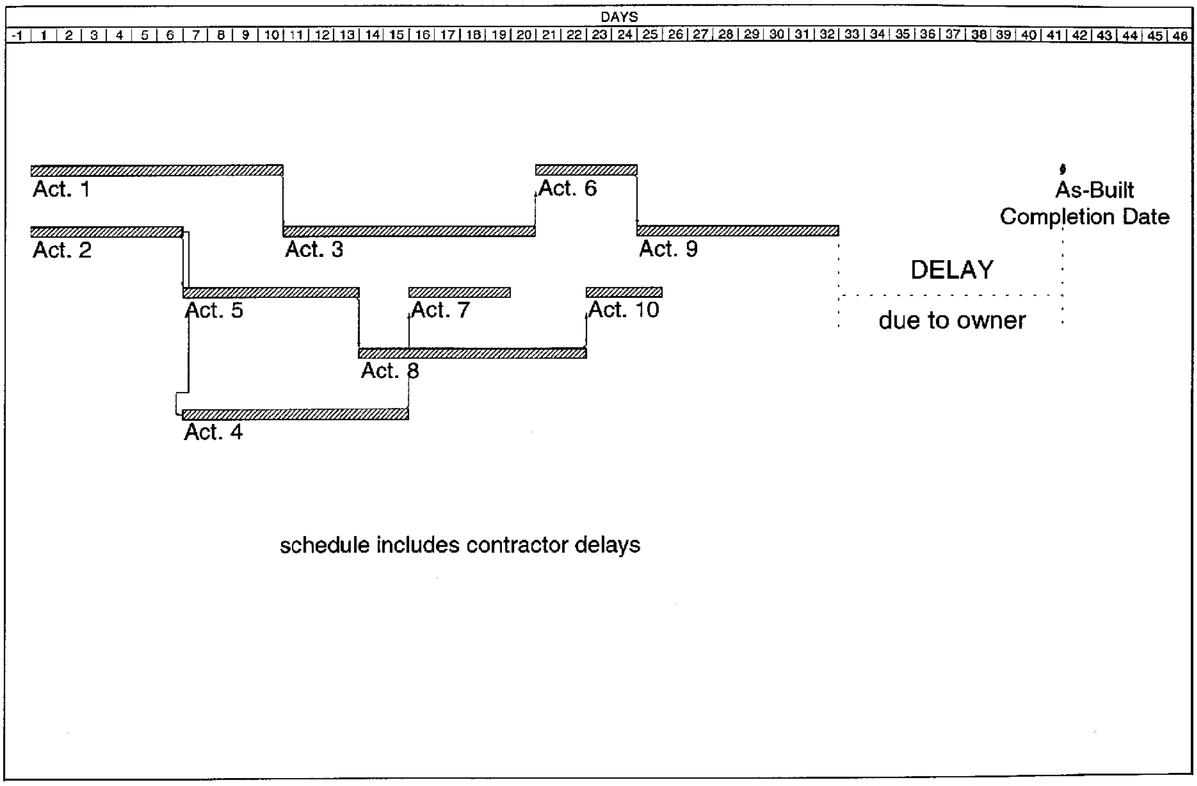

Figure 7 'But for' or collapsing owner's delays technique

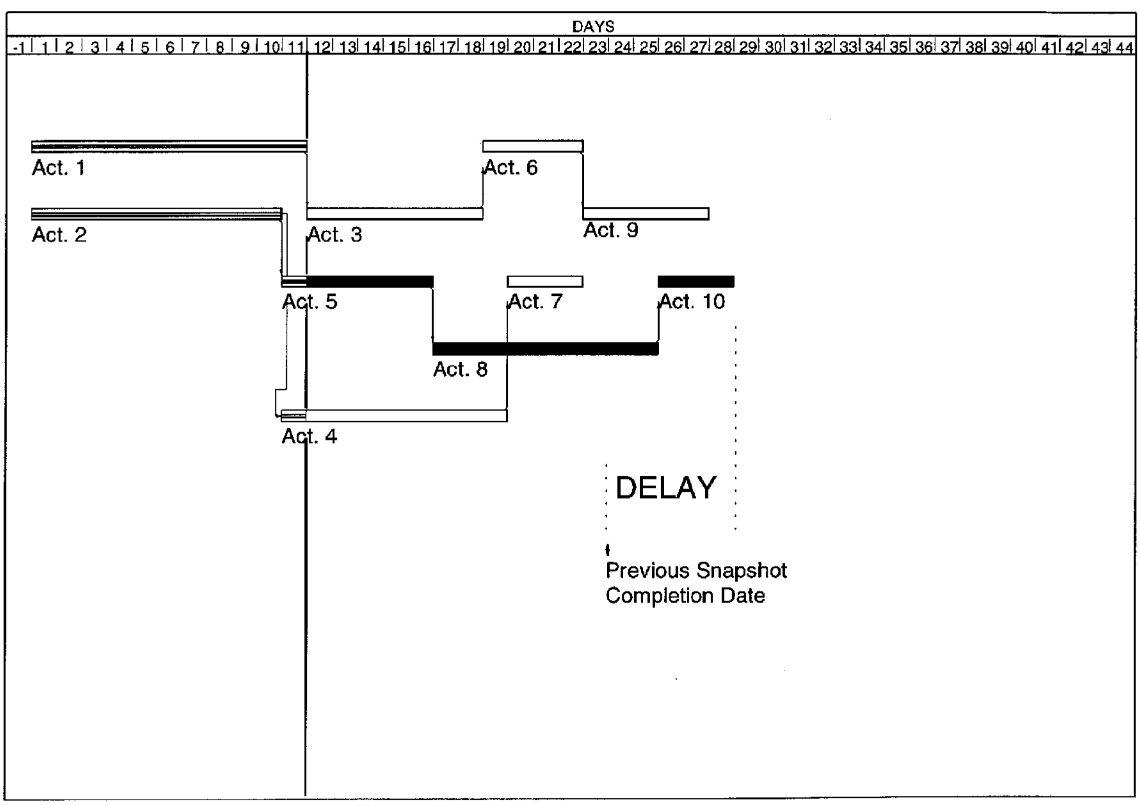

Figure 8 First snapshot technique

and duration of the as-planned schedule for the remaining activities after the snapshot period. The project completion date of the thus extended schedule is compared with the established, as-planned completion date of the project prior to this procedure. The difference between the completion dates is the amount of delay that occurred to the project as a result of delaying events during that snapshot period. Once the amount of delay is determined, the causes of delay are assessed.

While performing the delay analysis using this technique, several snapshot periods were used. They were: from starting day to the 11th day, from the 12th to the 25th day and from the 26th to the 41st day. Starting with the as-planned schedule, the as-built duration and logic of activities associated with the first snapshot period were incorporated and thus the schedule was extended. The remaining activities, after the snapshot period, were scheduled as denoted by the as-planned schedule. The project's completion date was recalculated and compared to the as-planned completion date of the project. The difference between the completion dates is the amount of delay to the project as a result of delaying events that occurred during that snapshot period. Figure 8 illustrates the first snapshot analysis for the period ending at the 11th day. Due to delays occurring between the first and the 11th day, the project completion date was extended from 23 to 28 days. This new schedule, the extended duration schedule, now becomes the baseline schedule for the next snapshot. In all snapshot analyses, any alterations to the CPM logic should be incorporated into the extended duration schedule before progressing to the next snapshot. In this test case, however, there were no alterations to the CPM logic, therefore this step was not needed in the analyses.

Although many snapshots could be used, this analysis was limited to three. For the second snapshot, the schedule from the first snapshot was used. Incorporating the as-built logic for the activities occurring between the 11th and the 25th day, a new extended duration schedule was determined. Figure 9 illustrates the second snapshot for the period ending at the 25th day. The completion date was extended by another nine days, finishing on the 37th instead of the 28th day.

For the third and final snapshot, the schedule from the second snapshot was used. Incorporating the as-built logic for the activities occurring between the 25th and 41st day, a new extended duration schedule was determined. Figure 10 illustrates the third snapshot for the period ending on the 41st day. The completion date was extended by another four days, finishing on the 41st instead of the 37th day.

Summing up all the differences in completion dates that occurred from the three snapshot analyses, a total of 18 days (5 + 9 + 4) of delay to the as-planned project completion date was accumulated. The amount of total delay represents the total extended duration, which should then be analysed for responsibility apportionment between the owner and contractor. Also, this amount is not necessarily the sole basis from which to quantify damage; the extent of acceleration costs would also have to be considered if the test case had been accelerated.

The snapshot analysis technique offers a systematic and objective method of quantifying the amount of delay incurred in a project on a progressive basis. The accuracy of this technique is a function of the number of snapshots used. It takes into account concurrent delays and considers the effect of delays in the context of time and CPM schedule. However, this method does not scrutinize delay types prior to the analysis, therefore the results obtained need further analysis to apportion the entitlement.

Time impact technique analysis

The time impact technique, similarly to the snapshot technique, examines the effects of delays or delaying events at different times in the project. The difference is that the time impact technique concentrates on a specific delay or delaying event, not a time period containing delays or delaying events. The idea is to obtain a 'stop-action' picture of the project before and/or after a major delaying event has occurred.

The as-planned schedule is first verified to reflect the contractor's actual plan, and then it is updated at certain critical periods in the construction process: thereafter, the actual project duration is recalculated and a new completion date is established. The difference between the different completion dates is the effect that the particular delay had on the project as a result of the delay being inserted into the schedule.

To perform the delay analysis using the time impact technique, delayed activities of the test case were identified. Of the ten activities in the test case, nine of them had experienced delays, therefore each delayed activity was analysed. Starting with the as-planned schedule and activity 1, the actual duration of activity 1 was inserted into the schedule. The project completion date was recalculated and compared against the previous (as-planned) schedule's completion date. The difference between the completion dates was the amount of delay to the project as a result of delays experienced by activity 1. The project completion date was extended from 23 to 27 days. Figure 11 illustrates the first time impact analysis.

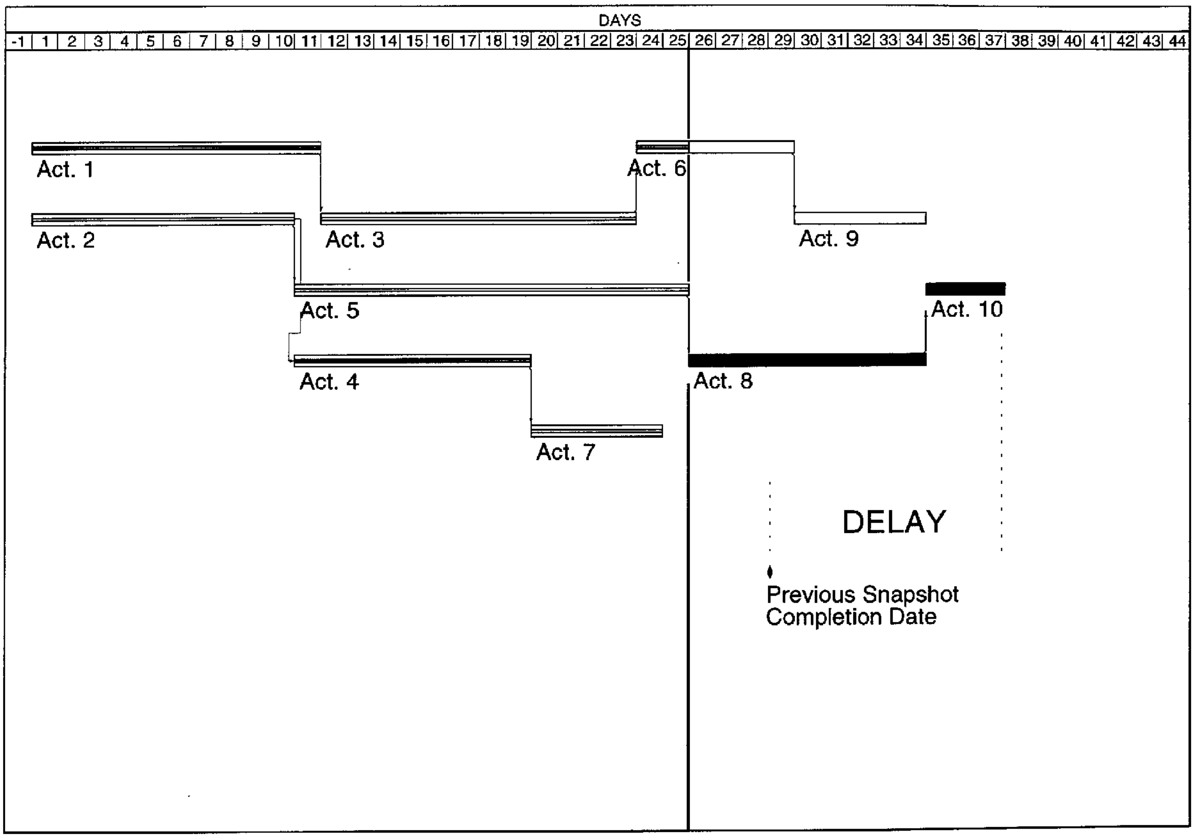

Figure 9 Second snapshot technique

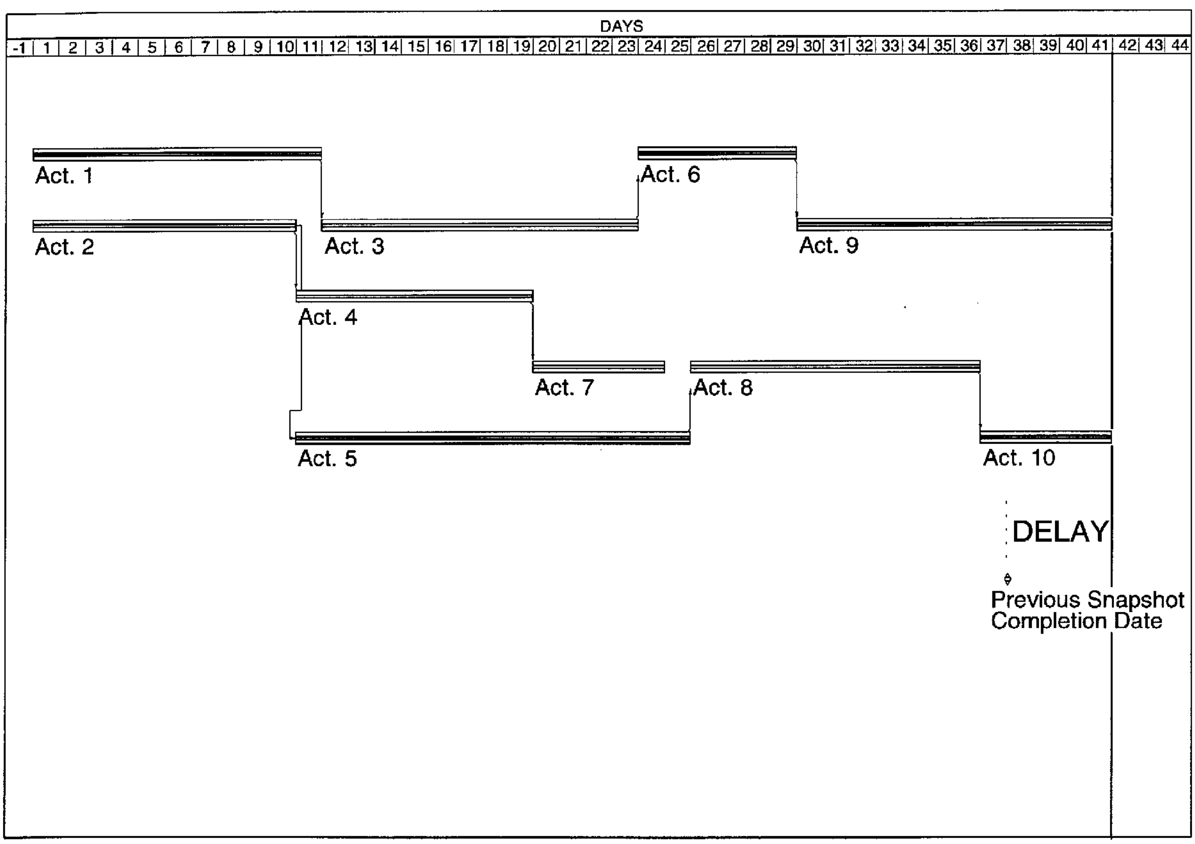

Figure 10 Third snapshot technique

The next delayed activity was activity 2. The actual duration of activity 2 was inserted into the as-planned schedule. After recalculation, the project completion date was extended from 23 to 28 days, a difference of five days. Figure 12 illustrates the second time impact analysis.

Activity 3 was the next delayed activity analysed. Before inserting the actual duration of activity 3, the as-planned schedule was revised to reflect the actual schedule prior to the start of activity 3. Once this was done, the revised schedule was recalculated to determine the project's completion date. The actual duration of activity 3 was then inserted into the revised schedule. After recalculation of the schedule, the project completion date was extended from 28 to 32 days, a difference of four days. Figure 13 illustrates the third time impact analysis.

The next delayed activity was activity 5. Revising the schedule prior to activity 5, and then inserting the actual duration of activity 5, caused the project's completion date to be extended from 28 to 37 days, a difference of nine days.

This procedure was executed for the remaining delayed activities 6, 7, 8, 9 and 10. Summing up all the differences in completion dates that were determined in the nine analyses, a total of 30 days (4 + 5 + 4 + 9 + 0 + 0 + 2 + 4 + 2) of delay to the as-planned project completion date was accumulated. The amount of total delay represents the total extended duration, which should then be analysed for responsibility apportionment between the owner and contractor.

The time impact technique provides a systematic and objective method of quantifying the effect of delays on a project, since it considers the effect of the delays in the context of time and CPM schedule. However, there are a few downfalls. This method does not scrutinize delay types prior to the analysis, therefore further analysis to apportion entitlement is required. Also, since each delayed activity is analysed individually, the effects of concurrent delays in the project are not immediately addressed making the approach unrealistic. Further analysis is also required to address this issue. The accuracy of this technique is a function of the number of analyses performed, however it may become too cumbersome if there are an overwhelming amount of delay-causing events.

Findings from the delay analysis techniques assessment

A test case was used to apply the various delay analysis techniques which are presently used by the construction industry. The amount of time deemed eligible for compensation, as per the test case results, were as follows:

1. global impact: 38 days;
2. net impact: 18 days;
3. adjusted as-built CPM: 18 days;
4. 'but for' or collapsing contractor's delays (owner's point of view): 2 days;
5. 'but for' or collapsing owner's delays (contractor's point of view): 9 days;
6. snapshot: 18 days (to be apportioned between owner and contractor); and
7. time impact: 30 days (to be apportioned between owner and contractor).

There are three main concerns in ensuring the accuracy of a delay analysis. They are: proper classification of delay types (excusable compensable, excusable noncompensable, and nonexcusable), concurrent delays and real time analysis. It is important to properly assess who is responsible for the delay. This ensures that wrongful entitlement does not occur. Concurrent delays also have an effect on the amount of compensation. If two or more delays occur at the same time, only the net effect of the delays should be accounted for, not the total sum of the delays. Real time analysis ensures that when delays are incorporated in the delay analysis, the CPM that was in effect at the time of delay is used. This can have a great impact on the results since critical paths may change as the schedule changes. Delays which are deemed critical on the as-planned CPM schedule might not have been critical when the delay actually occurred.

The previously described techniques can be grouped into two levels of sophistication. The first level is simplistic, and includes the global impact, net impact and adjusted as-built CPM techniques. The second is detailed, which includes the 'but for' or collapsing, time impact and snapshot techniques.

The main problem with the simplistic approach of the global impact, net impact and adjusted as-built CPM techniques is that they do not scrutinize delay types. As a result, delays which should not be included in the delay analysis are included, giving over-exaggerated results. In addition, these techniques are only applied once, to the as-planned schedule, which assumes the critical path(s) were constant throughout the project. This leads to delays potentially being deemed as critical, when in fact they were not. The global impact technique, unlike the net impact and adjusted as-built CPM, has one more criticism against it in that it does not even consider concurrency in delays.

The detailed approach of the 'but for' or collapsing, time impact and snapshot techniques provides sound

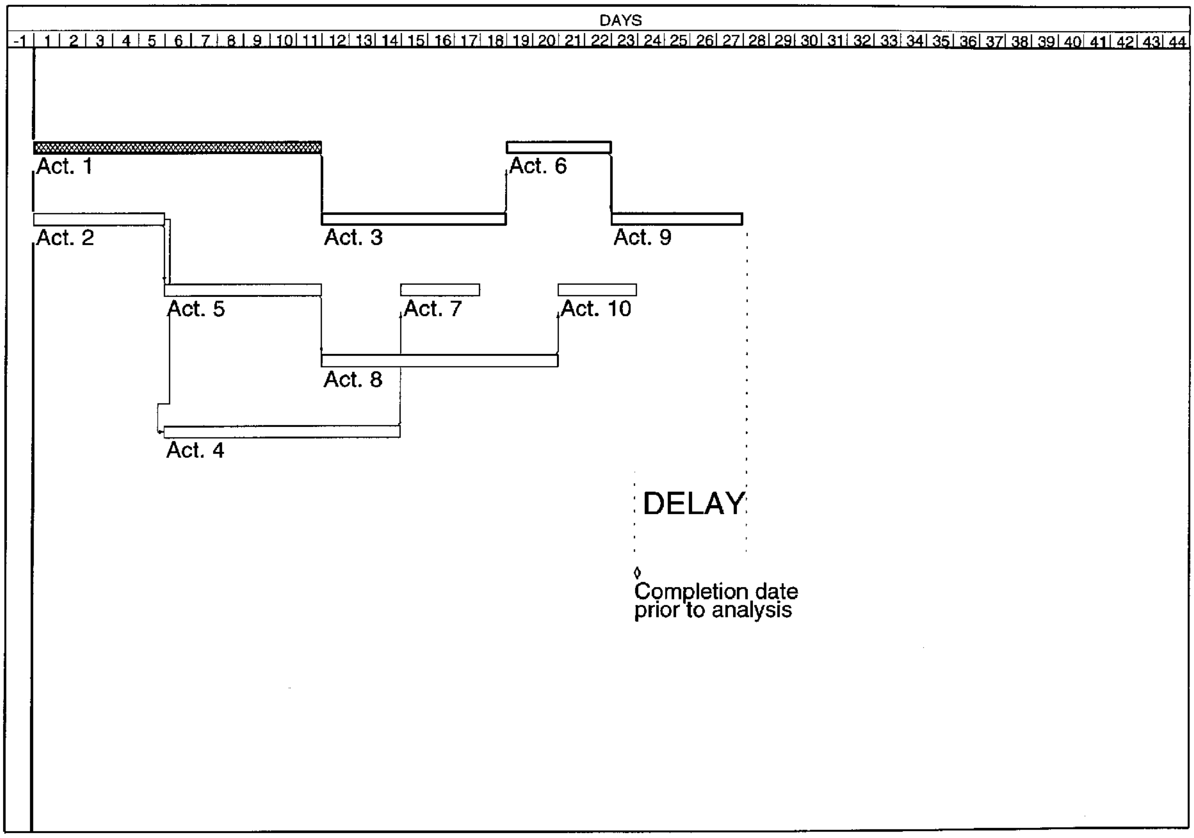

Figure 11 Time impact technique – activity 1

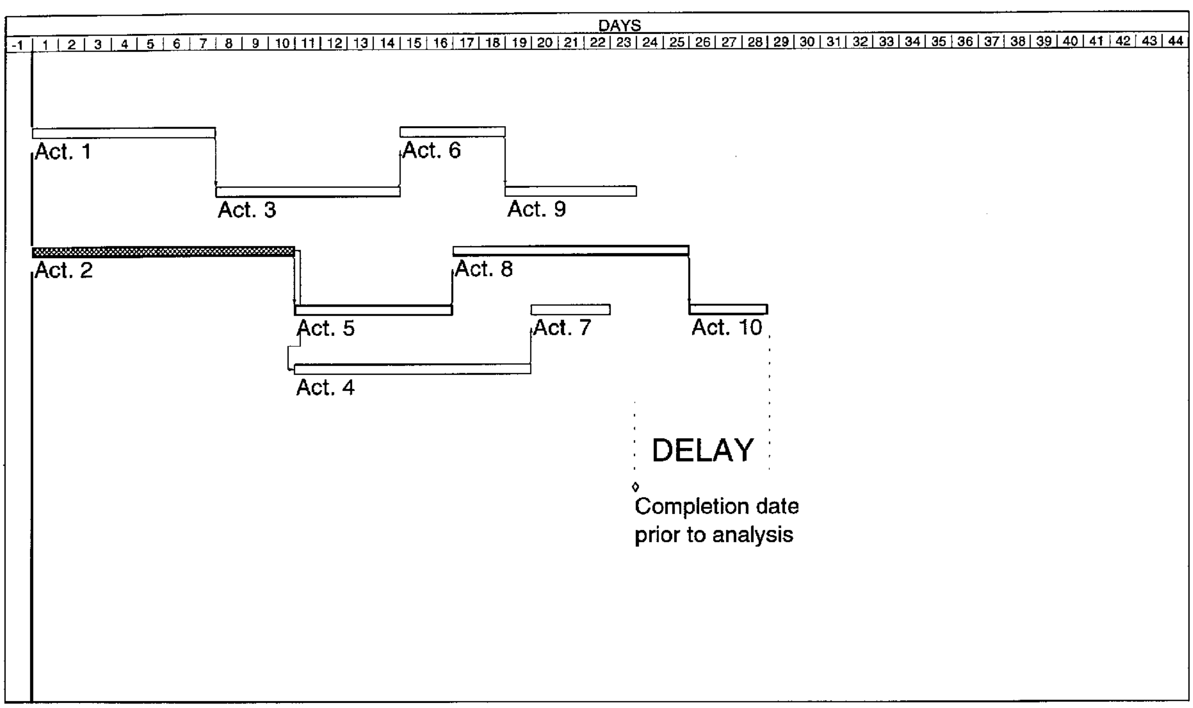

Figure 12 Time impact technique – activity 2

methods for performing a delay analysis. The 'but for' technique scrutinizes delay types and addresses concurrent delays, however the main problem lies in the fact that the technique is only applied once to the as-planned schedule. It does not account for any changes in the critical path(s) during the project. Of all the methods, the time impact and snapshot techniques both provide the most systematic and objective methods of quantifying the effect of delays on a project since they both consider the effect of delays in their context of time and CPM schedule. The main problem with both of them is that they do not scrutinize delay type during the analysis. Further analysis is required to apportion entitlement between the owner and the contractor. The time impact has another downfall since delayed activities are analysed discretely; the effect of concurrent delays in the analysis is not immediately addressed. Also, it may become too cumbersome if there is an overwhelming number of delay-causing events. The accuracy of both the time impact and snapshot techniques is a function of the number of analyses performed.

Which technique to use depends on the reason for preparing the delay analysis. A contractor who presents documentation to the owner for a time extension, but does not have the time for an extensive delay analysis, will lean towards the simplistic global impact, net impact or adjusted as-built CPM techniques. These techniques grossly overstate delays, but the contractor hopes for some amount of compensation. Going to the other extreme, there are documents which are prepared for litigation. The court system has seen many claims cases, hence, the level of sophistication almost excludes the simplistic techniques. The more detailed 'but for' or collapse, time impact and snapshot techniques are more reliable and are the preferred methods for preparing delay analyses.

Proposed delay analysis technique (IDT)

As mentioned before, the main concerns for ensuring the accuracy of a delay analysis are: proper classification of delay types, concurrent delays and real time CPM analysis. None of the existing delay analysis techniques consider all three issues at the same time. To overcome these deficiencies, an alternate method called the 'isolated delay type' (IDT) technique has been introduced. Table 1 shows a comparison of the attributes of the delay analysis techniques.

Table 1 Comparison of delay analysis technique attributes

Delay analysis technique	Scrutinizes delay types	Concurrent delays	Real time CPM
global impact	–	–	–
net impact	–	✔	–
adjusted as-built CPM	–	✔	–
'but for' or collapse	✔	✔	–
snapshot	–	✔	✔
time impact	–	–	✔
isolated delay type	✔	✔	✔

The proposed isolated delay type technique attempts to address all three issues by using the systematic and objective approach of the time impact and snapshot techniques, while applying the scrutinizing approach of the 'but for' technique. Time periods are determined, based on either major delaying events or after a series of delays have occurred. The IDT technique respects the different delay types within the delaying events and applies only the relevant portion of the delays in that time period. Comparing the project's completion date before and after inserting the delaying events into the schedule may reveal a change in the project's completion date. This discrepancy is attributed to the delays that were incorporated into the schedule.

Assessing the isolated delay type (IDT) technique

The IDT technique was tested against the same test case that was used to assess the other delay analysis techniques. In doing so, three time periods were used, similar to those in the snapshot technique analysis. The time periods were: from the starting day to the 11th day, from the 12th to the 25th day, and from the 26th to the 41st day. The IDT analysis was performed twice, first from the owner's point of view, and second from the contractor's point of view. In both cases, the as-planned schedule was used as the starting point. The results of the IDT technique analyses quantifies the amount of time the respective owner/contractor was justifiably delayed on the project.

IDT – owner's point of view

To perform the first IDT analysis, delayed activities falling within the first time period were identified. Of the activities identified, only the delaying events which contained nonexcusable (NE) delays were used. These delays were then incorporated into the as-planned schedule. The project's completion date was recalculated and compared to the as-planned completion date. The difference between the as-planned and the first IDT schedule completion dates is the amount of delay

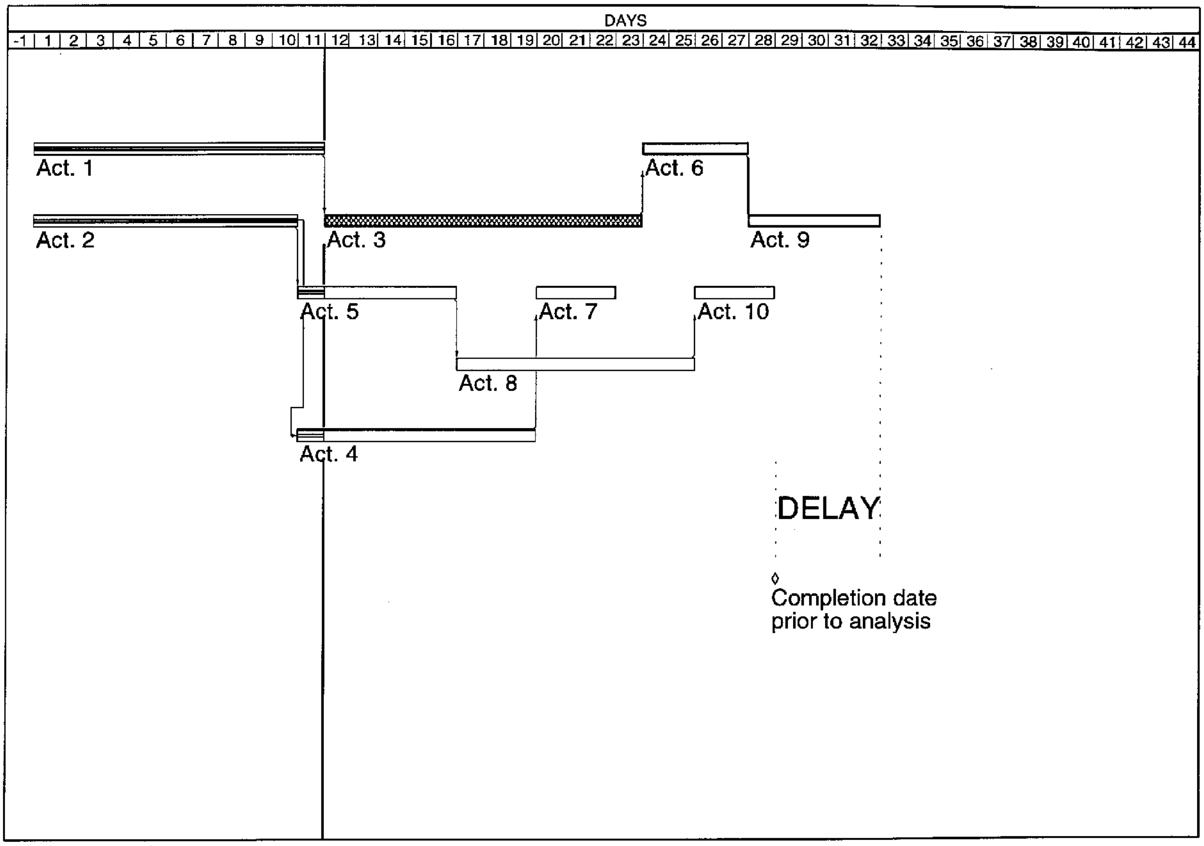

Figure 13 Time impact technique – activity 3

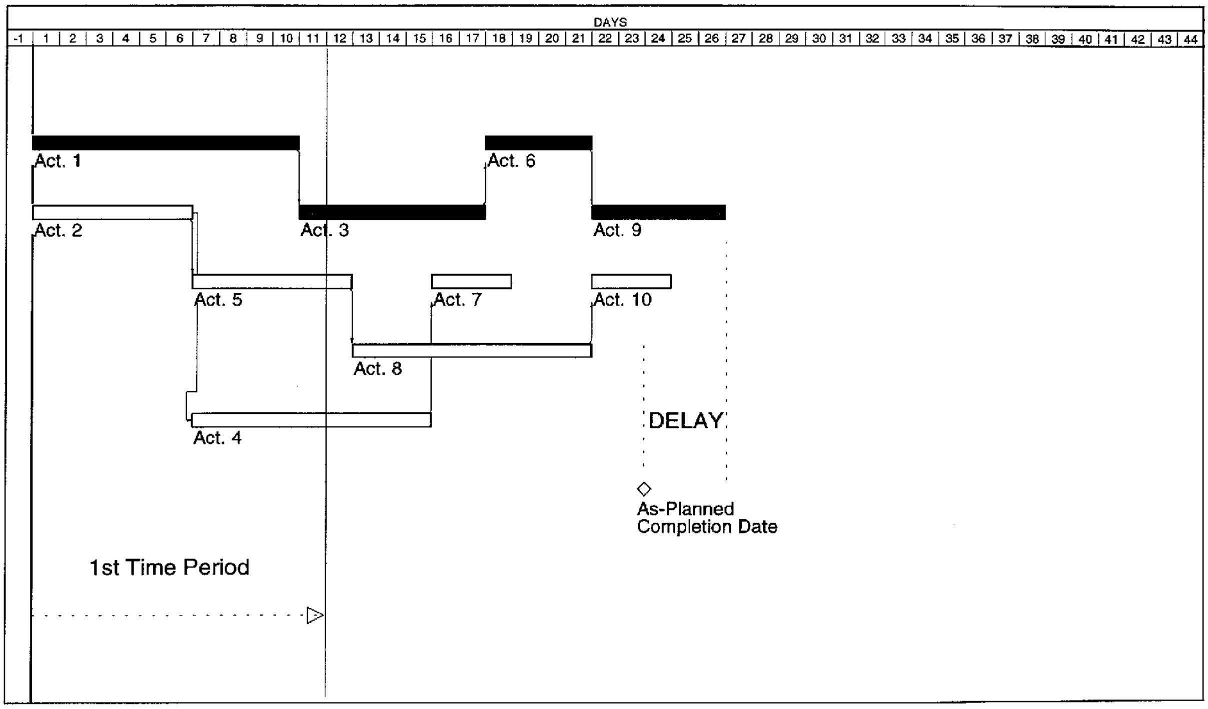

Figure 14 First IDT analysis (from the owner's point of view)

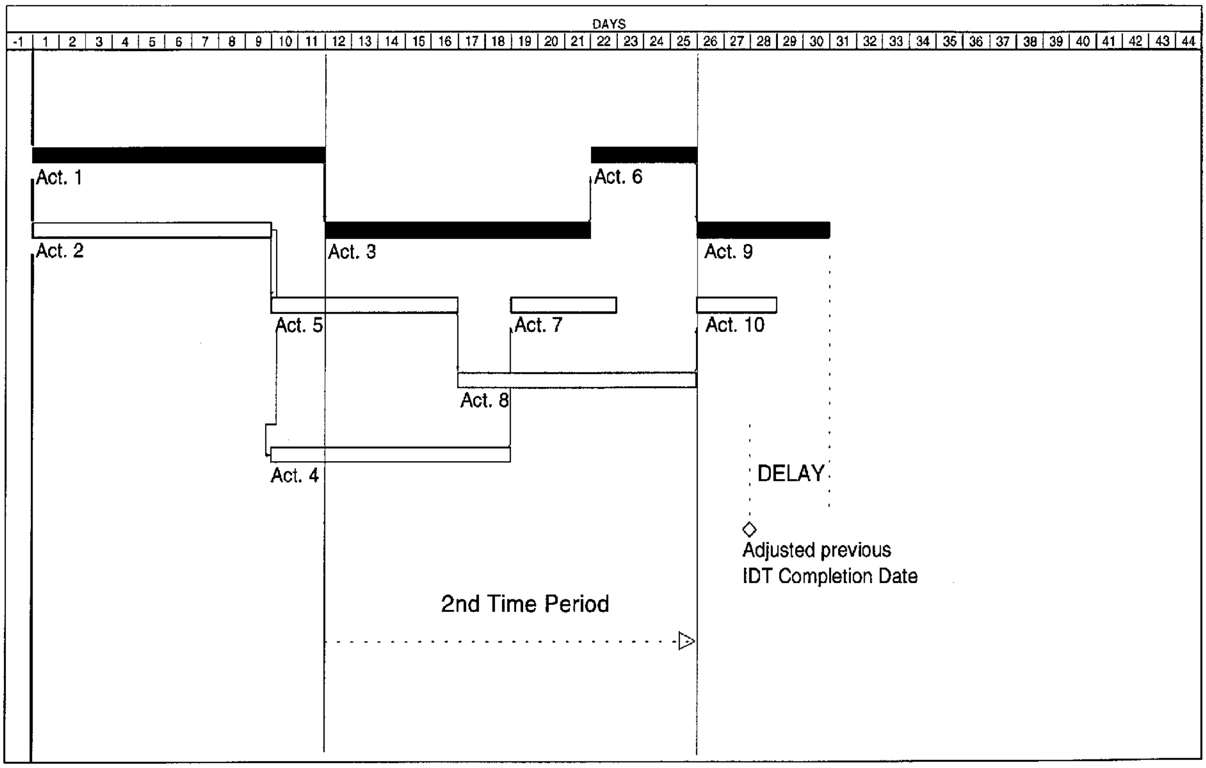

Figure 15 Second IDT analysis (from the owner's point of view)

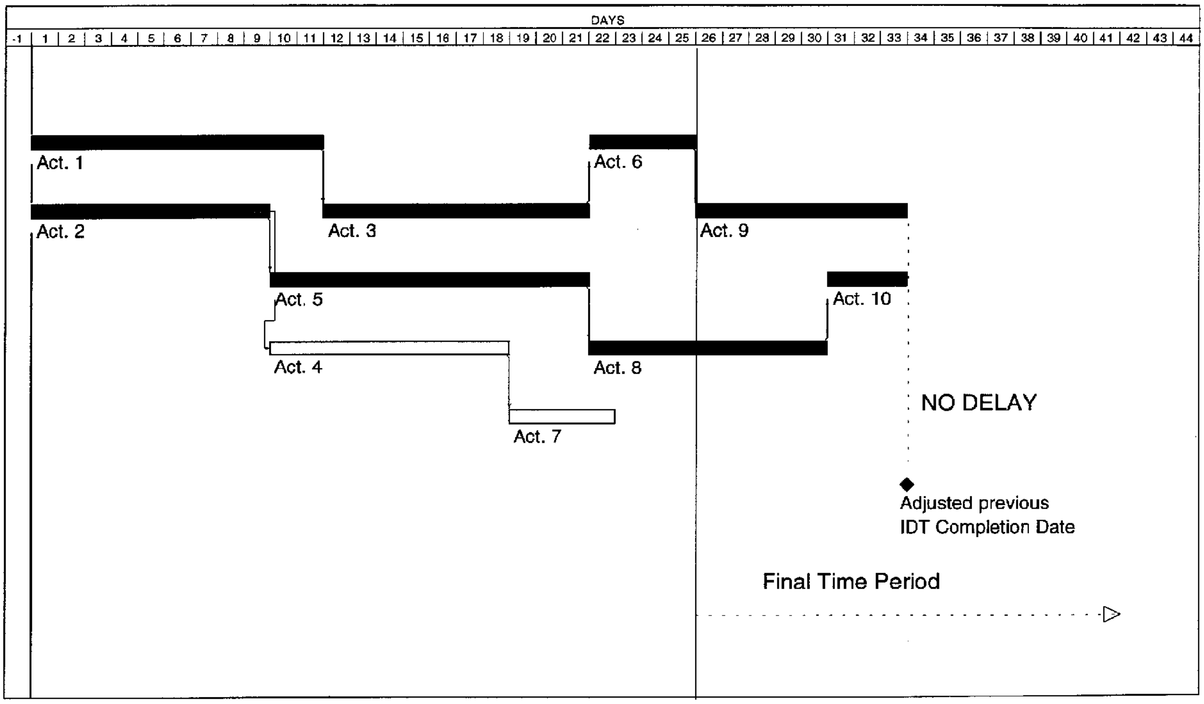

Figure 16 Third IDT analysis (from the owner's point of view)

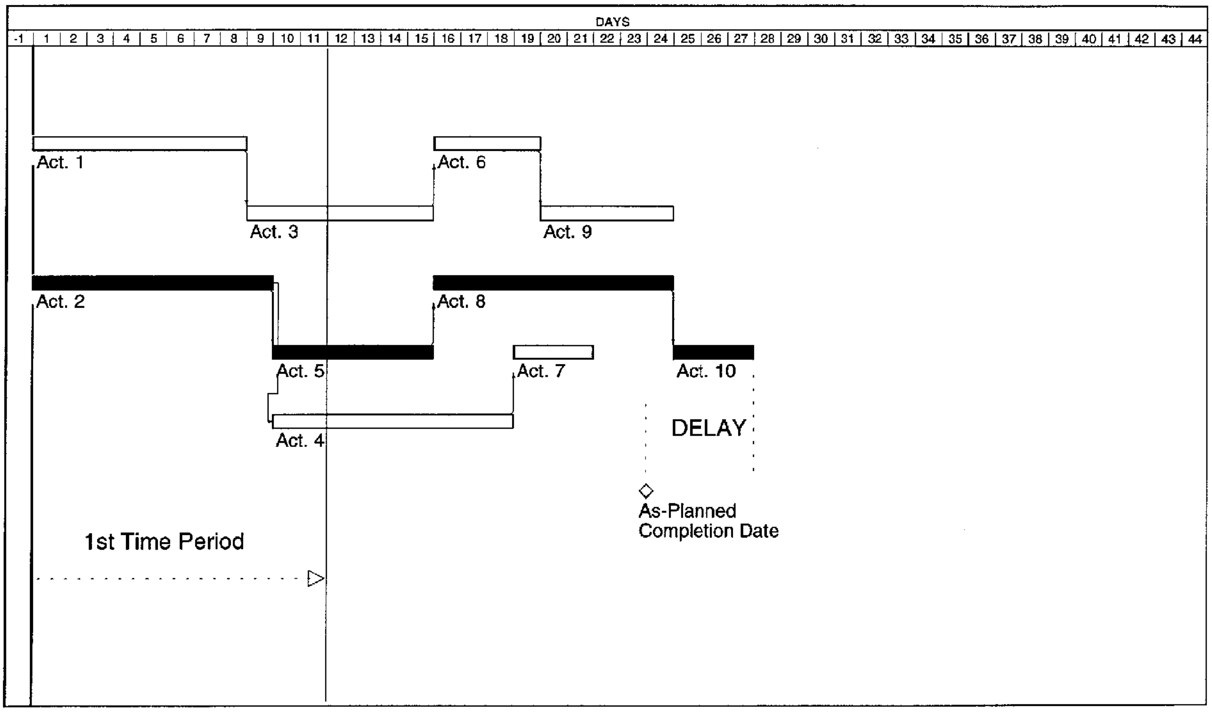

Figure 17 First IDT analysis (from the contractor's point of view)

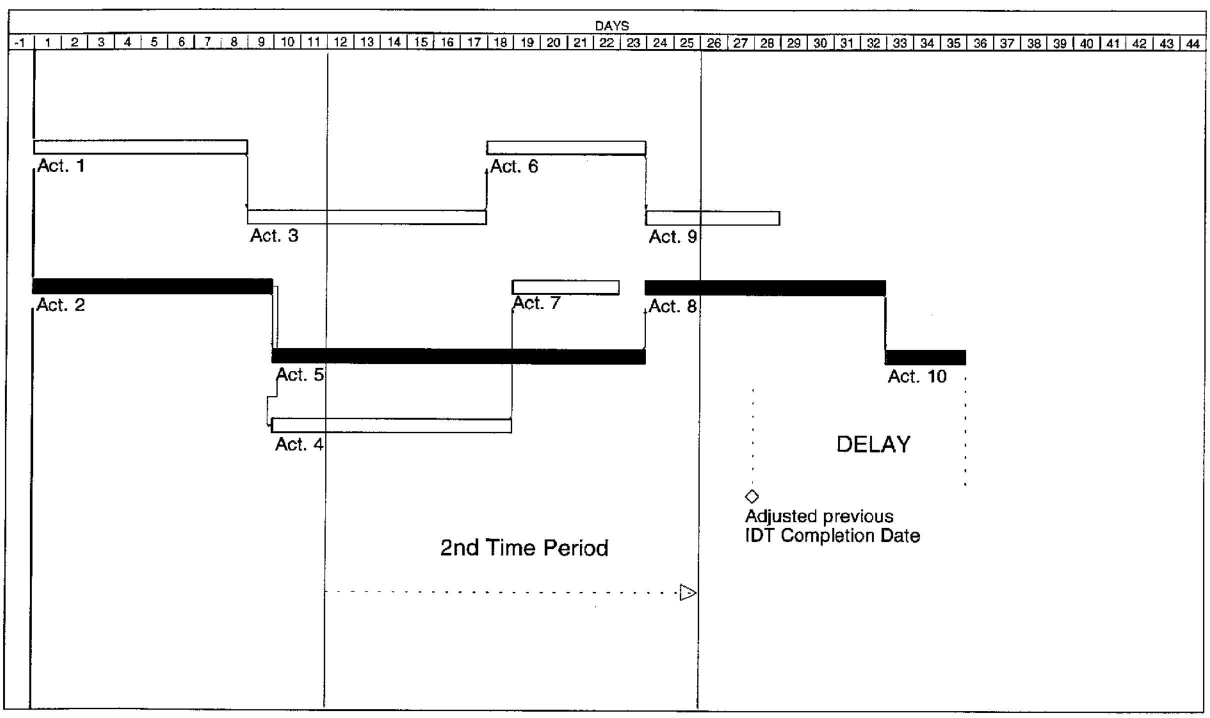

Figure 18 Second IDT analysis (from the contractor's point of view)

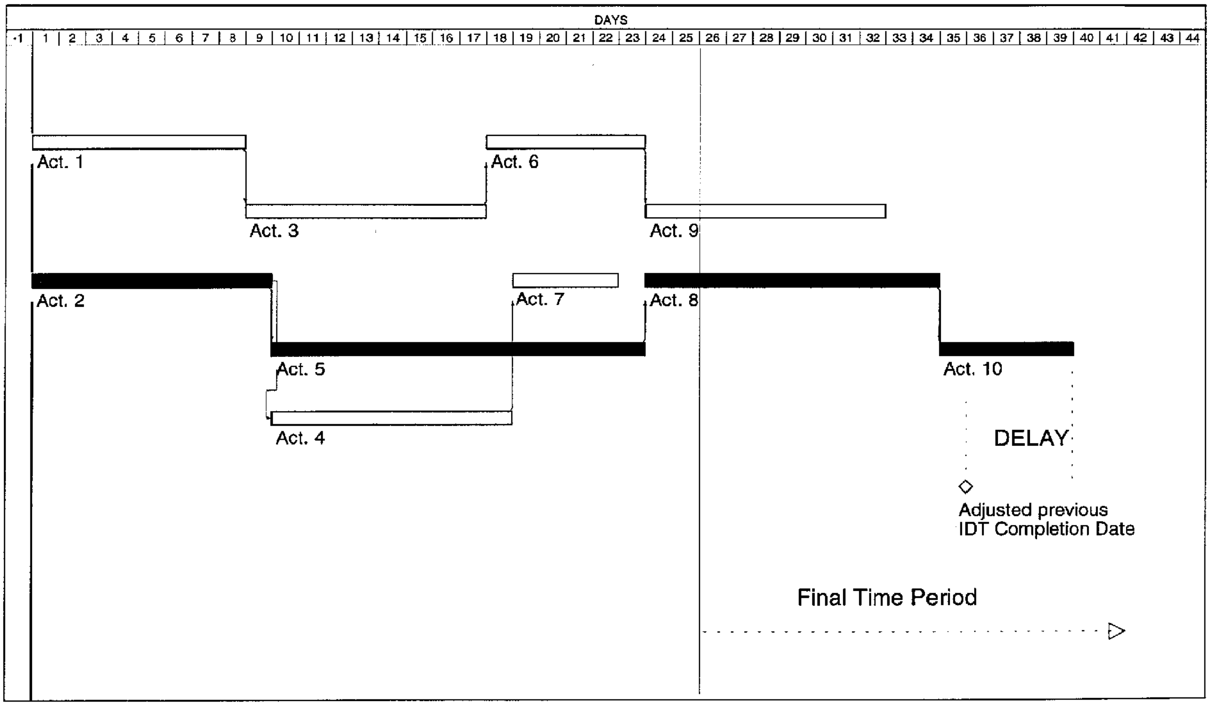

Figure 19 Third and final IDT analysis (from the contractor's point of view)

to the project as a result of NE delaying events within the first time period. Figure 14 illustrates the first IDT analysis from the owner's point of view. Due to NE delays occurring in the first time period, the project completion date was delayed three days.

The second IDT analysis builds upon the first. However, before the delaying events of the second time period are applied, any changes to the as-planned schedule logic or activity duration that actually occurred beyond the first time period, must be incorporated. Also, since this analysis applies only NE delays, any EN delays experienced within the first time period should be incorporated into the schedule at this point. Since EN delays are acceptable to either party, they should be reflected in the comparing schedule. These two steps ensure that proper critical paths are reflected in the second IDT analysis. Upon recalculation, an adjusted completion date is then established.

Once the first IDT schedule has been adjusted and a new completion date calculated, any NE delays encountered within the second time period are incorporated into the schedule. Figure 15 illustrates the second IDT analysis from the owner's point of view. As a result of NE delays occurring within the second time period, the completion date was extended by another three days.

The third and final IDT analysis is performed in a similar way to the second IDT analysis. The logic and activity duration beyond the second time period are modified, if applicable. Also, any EN delays encountered within the second time period are incorporated. Once this is done, an adjusted schedule is created and can be used for the third IDT analysis. Figure 16 illustrates the third IDT analysis from the owner's point of view.

Incorporating the NE delays experienced within the third time period and recalculating the schedule shows no change to the completion date. This indicates that NE delays encountered within the third time period had no direct effect on delaying the project, since the critical path was not affected.

Summing up the results from the three IDT analyses, a total of six days (3 + 3 + 0) of delay as a result of NE delays had occurred. This amount represents the number of days that the owner was delayed by the contractor's failure.

IDT – contractor's point of view

To perform the IDT analysis from the contractor's point of view, delaying events falling within the first time period which have excusable noncompensable (EN) and excusable compensable (EC) delays are selected. These delays are then incorporated into the as-planned schedule. Figure 17 illustrates the first IDT analysis from the contractor's point of view. Due to

EC and EN delays, the completion date has been extended by four days.

Before moving on to the second analysis, any logic or activity duration changes beyond the first time period should be reflected in the schedule. Since EN delays were already part of the contractor's analyses, no adjustment for EN delays was required. Upon recalculation, an adjusted completion date is established.

By identifying the EN and EC delaying activities that fall within the second time period, and incorporating them into the previously adjusted IDT schedule, a revised completion date is calculated again. Figure 18 illustrates the second IDT analysis from the contractor's point of view. Due to EC and EN delays, the completion date was extended by another eight days.

The third and final analysis is performed similarly to that of the second IDT analysis. The logic and duration of activities beyond the second time period are adjusted if applicable, and an adjusted completion date is calculated. By applying the EC and EN delays that are encountered in the final time period to this adjusted schedule, a revised completion date is then calculated. Figure 19 illustrates the third and final IDT analysis which shows that EC and EN delays have caused the project to slip an additional four days.

Summing up all the differences in completion dates from the three IDT time periods, a total of 16 days (4 + 8 + 4) of delay as a result of EC and EN delays had occurred. Thus, the contractor was delayed by 16 days as a result of the owner's actions.

During the analysis the following factors were taken into consideration (Mazerolle, 1993; McCullough, 1989):

1. overall delay of all impacts;
2. start date of the impact;
3. end date of the impact;
4. delay for each responsible party;
5. timing of delays;
6. concurrent delays;
7. revised activity duration;
8. improper constraints or logic;
9. revised constraints or logic; and
10. Contract language.

The source of this information is normally project documentation, such as: contract language, letters, minutes of meetings, notes, material receipts, supervision and inspection reports, resource data and costs, daily reports, extra work orders, occurrence reports and cost reports of a project, and so on. Unfortunately, the varied and often ad-hoc sources for this information present the claims analyst with a difficult task in preparing an accurate entitlement schedule. This task alone can take several months, and can end up costing the client large sums of money in consulting fees. For this reason, the use of a database to store information about each delay when it occurs would be very useful; information such as: delay type, description of the delay, who is responsible, delay code number, date of occurrence, letters and notes sent and received including dates, resources used and their costs, and so on (Alkass *et al.*, 1991, 1993). The advantages of keeping track of this information when the delays occur become evident when delay information is required and easily retrieved.

Advantages of the IDT technique

1. The analysis is done within time periods (snapshots) in a systematic and dynamic analysis, using the delays in their real context better to reflect the effect of delays.
2. Concurrent delays are analysed and adjusted to overcome the problem of overstatement of the time extension.
3. Delays are scrutinized according to their type (EN, EC, NE) during the analysis, hence saving substantial time and preventing future mistakes and repetition of the analysis.
4. The analysis can be performed using any time period at any stage of the schedule, making it a valuable tool to be used during the construction phase of a project.
5. Float is used by both parties.
6. The analysis is objective since it can be used for both parties at the same time.
7. The technique can be accommodated within an integrated computer system that utilizes existing management software such as scheduling, spreadsheets, database and expert system.

Conclusions

Delays on a construction site are inevitable and, as a result, many projects end up in litigation making it a costly process. Present methods of analysing delays and preparing claims are inaccurate, time consuming and costly. A large portion of effort in preparing these claims arises from the meticulous digging through piles of project documentation to sort and ascertain pertinent delays encountered during the project.

Different delay analysis techniques were assessed using a test case; their advantages and shortcomings were identified and a new delay analysis technique (IDT) was introduced, described and tested. The new technique proved to have numerous advantages in comparison to the other techniques. It allows for the delays to be scrutinized during the analysis process, reducing substantially the time required for the delay analysis and hence reducing the analysis cost. This will be more effective when the IDT technique is used within an integrated computer system that utilizes a database management system of stored and organized project information.

Although this technique deals with concurrent delays in different activities, the assessment of such concurrent delays would still have to be addressed manually, prior to the delay analysis. This is an area where an expert system can aid practitioners in the assessment of delays.

The time and expense incurred to prepare a claim document in itself is substantial. There is room for improvement in present practices for keeping track of delays. Thus, an integrated system to aid in the analysis of claims arising from construction delays can be valuable.

Acknowledgements

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