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Selecting a delay analysis method in resolving construction claims

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Abstract

Delays occur commonly in construction projects. Assessing the impact of delay is sometimes a contentious issue. Several delay analysis methods are available but no one method can be universally used over another in all situations. The selection of the proper analysis method depends upon a variety of factors including information available, time of analysis, capabilities of the methodology, and time, funds and effort allocated to the analysis. The paper reviews 20 research studies that discuss various aspects of delay analysis methods and summarizes the advantages and disadvantages of widely used delay analysis methods, including the as-planned vs. as-built, impact as-planned, collapsed as-built, and time impact analysis methods. The paper also discusses the most important issues in delay analysis that affect the results of the analysis. The selection of a suitable analysis method depends heavily on the availability of scheduling data, the familiarity of the analyst with the capabilities of the software used in the project, clear specifications in the contract concerning the treatment of concurrent delays and the ownership of float.

Keywords: Claims management; Delay analysis; CPM; Bar charts

1. Introduction

Delays in construction can cause a number of changes in a project such as late completion, lost productivity, acceleration, increased costs, and contract termination. The party experiencing damages from delay needs to be able to recognize the delays and the parties responsible for them in order to recover time and cost. However, in general, delay situations are complex in nature. A delay in an activity may not result in the same amount of project delay. A delay caused by a party may or may not affect the project completion date and may or may not cause damage to another party. A delay can be caused by more than one party; however, it can also be caused by none of the parties (such as unusually severe weather conditions). A delay may occur concurrently with other delays and all of them may impact the project completion date. A delay may sometimes contribute to the formation of other delays.

In construction contracts, schedule delay analysis is commonly conducted to demonstrate cause and effect relationships of time-related disputes. Schedule delay analysis makes use of the as-planned schedule, the as-built schedule, and schedule updates. Sometimes, subnetworks or "fragnets" are used to present details about delay events. The schedules may be in the form of bar charts or network diagrams. The network diagram is more effective than the bar chart as it shows the logical sequences between activities. CPM schedules add another dimension to schedule analysis as they provide schedule analysts with a critical path, float consumption, and the opportunity of utilizing what-if methodology. CPM has long been accepted by courts as an effective tool to evaluate the impact of delays [1].

There are many delay analysis methods that have been used by researchers and practitioners including the *Global Impact Technique* which simply plots delays on a bar chart and determines the global impact of delay by summing up the total duration of all delays. The global impact

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technique is an easy way to assess delay when detailed calculations cannot be performed. However, courts and arbitration panels resist the use of the global impact technique because it wrongly assumes that every delay has an equal impact on the project duration. The results of delay analysis may be influenced by the method selected and therefore the selection of the most appropriate method is of importance to all parties concerned.

The objective of the study presented in this paper was to establish selection guidelines for delay analysts by comparing the characteristics of the most commonly used delay analysis methods, and considering their advantages and disadvantages under different circumstances. The paper starts out with a brief description of the universally accepted delay analysis methods, and discusses the issues involved in delay analysis. The criteria that need to be considered when a party tries to select the most suitable methods are presented after the views expressed by various researchers/practitioners in papers/textbooks published between the years 1987 and 2004 are reviewed.

2. Delay analysis methods

There are four methods often mentioned in the construction literature that are professionally acceptable. They include (1) the as-planned vs. as-built schedule analysis method, (2) the impact as-planned schedule analysis method, (3) the collapsed as-built schedule analysis method, and (4) the time impact analysis method. They are sometimes referred to by different names in the literature.

The *as-planned vs. as-built method* is the observation of the difference between an as-planned schedule and an as-built schedule. The method identifies the as-built critical activities, compares these activities with the activities on the as-planned schedule, assesses the impact of delays on the project, identifies the sequences which actually define the duration of the project, and determines the causation and responsibility of delays that impact project completion [2].

The *impact as-planned* method uses only an as-planned or baseline schedule for delay analysis. It is based on the theory that the earliest date by which a project is completed can be determined by adding the delays into the as-planned schedule. New activities that represent delays, disruptions, and suspensions are added to the as-planned schedule and are used to demonstrate the reason why the project was completed later than planned. Contractors who submit claims that involve a time extension, add only owner-caused delays to the as-planned schedule in the appropriate sequence to document the total project delay caused by the owner [3].

The *collapsed as-built method* is also referred to as the "but-for" schedule method. This analysis is popular in claim presentations because it is easily understood by triers of fact [4]. SCL defines it as a method where the effects of delays are "subtracted" from an as-built schedule to determine what would have occurred but for those events [5]. This approach is a method of choice when a contractor lacks an acceptable schedule during the project, or when no as-planned schedule was required in the contract [2].

The *time impact method* relies on the assumption that delay impacts to a project can be assessed by running a series of analyses on schedule updates. Time impact analysis is a procedure that uses CPM principles. It assesses delays' effects on the project schedule by analyzing the schedule periodically, generally on a day-by-day basis [3]. *Window analysis*, a variation of time impact analysis, uses weekly or monthly updates to perform the analysis. Delay events are inserted into the schedule and delay impacts are accumulated every time the schedule is recalculated.

3. Issues in delay analysis

A number of factors may influence the result of delay analysis regardless of which delay analysis method is used. These factors are most of the time specified in contract clauses and include concurrent delays, float ownership, theories of critical path, and scheduling software options. Sometimes, the way these factors are presented in the contract favor the owner's interests and contractors are reluctant to follow them. Fair solutions for both parties have been discussed in the literature.

3.1. Concurrent delays

The basic concept of concurrency was defined by Rubin et al. [6] as the situation in which two or more delays occur at the same time, either of which had it occurred alone, would have affected the ultimate completion date. The events are considered to result in concurrent delay when it is clear that one of the events caused a delay in the schedule, but even if that event had not occurred, the schedule would have been delayed anyhow by the other event. Some argue whether the two delays are required to occur at the same time to be considered as concurrent delays. Some delay events may not start and end exactly at the same time but their effects may happen at the same time. SCL [5] suggests using the term "concurrent effect" for sequential delay events to avoid confusion and treat them differently from a concurrent delay.

Any type of delay, i.e., excusable non-compensable (a contractor is entitled to an extension of time only), excusable-compensable (a contractor is entitled to an extension of time and damages), and non-excusable delays (a contractor is responsible for the delay) can occur concurrently. The possible combinations of concurrent delays are described by Kraiem and Diekmann [7]. Arditi and Robinson [8] identified the possible variations of concurrent delays by taking into account the timing of the start of each activity, the chronological sequence in which delay types occur in the constituent activities that are concurrently delayed, and the criticality of the activities where concurrent delays occur.

The contentious point of discussion is which remedy to which party should be assessed from any concurrent delay event [9]. Such delay that affects the overall project duration is the responsibility of either the contractor or the owner. Even if one party is able to prove the causation of the project delay, the assessment of the damage to the delay raises further questions of how extended time and compensation would be assessed in case of the owner's fault, and how liquidated damages would be issued to the contractor in case of delay caused by the contractor. In theory, the possible results of delay concurrency can be summarized in Table 1. The question marks in this table indicate that the solution is not clearly defined more often than not. When concurrent delays exist, the assessment of delay damages and/or time extensions is difficult and often results in serious disagreements. Research is necessary to develop agreeable methods that will allow the parties to reach consensus by examining the root causes of the individual concurrent delay events.

3.2. Float ownership

In a construction project, float is valuable for both contractors and owners. Float provides flexibility to the contractor's time and budget management. On the other hand, the owner also needs float to accommodate the impact of change orders on the project. Float ownership is usually specified in the conditions of contract. Contracts typically state that float belongs to the project or on a "first-come first-served basis". In other words, when an owner-caused delay occurs first and uses up the total float, a contractor becomes responsible for contractor-caused delays that put off the project completion date, and that could have been accumulated if the project float had not been exhausted by the owner. Similarly, when a contractor uses up all the float at the beginning of the project, the owner becomes responsible for all delays caused by change orders, a situation that could have been averted had the contractor not exhausted the total float.

There are a number of suggestions seeking a fair resolution for the float ownership problem. The UK Delay and Disruption Protocol's position on float ownership is that if the clause stating the entitlement of float is not specified in the contract, float should belong to a project [5]. In other words, the first-come first-served principle should govern the use of float. On the other hand, Scott et al.'s survey [10] of 46 UK professionals employed by owners, contractors, and claims consultants shows that the majority of respondents believed that the contractor should have exclusive control of float while only few owners supported the position that float should be allocated on a first-come first-served basis. de la Garza et al. [11] agree with the British professionals that float is exclusively for the benefit of the contractor and add that float should be traded as a commodity. According to de la Garza et al. [11], the contractor is entitled to sell the float in case the owner needs to consume such float. The method to convert the value of the total float into selling price is provided in their article.

Householder and Rutland [12] suggest that the use of float should be reserved for the party who loses or gains as a result of fluctuation in the project cost. In other words, in fixed-price contracts, wherein the contractor has ultimate risk or benefit from project cost, the contractor should exclusively control float usage. Conversely, wherein the owner has the ultimate risk or benefit from project cost in a cost-plus contract, the owner should be entitled to own float to minimize cost to the owner. Ponce de Leon [13] suggests a compromise position regardless of the type of contract: allocating float in a shared way. Activities would be allocated a percentage of the float available to the path based on the individual activity's duration. If an activity is delayed beyond its allocated float, then time extension may be justified to preserve the allocated float of other activities in the approved schedule. Another compromise solution is offered by Pasiphol and Popescu [14] who propose a qualitative method to distribute total float into each activity prior to executing a project. The qualitative factors proposed by the authors are subjectively assessed and therefore may be subject to the preparer's manipulation.

The varied positions concerning who owns float can influence the result of delay analysis. The sample design/build project presented in Fig. 1 is composed of three activities, two of which involve contractor provided design and construction, and one is owner's approval of design. The design needs to be approved by the owner before construction can start. The contract duration is 12 days while the contractor has planned to execute the project in only 10 days, which yields two days of total float. Two alternative scenarios of actual activities are also shown in Fig. 1. In the first scenario, the contractor's design activity experiences a 2-day delay, followed by an owner-caused delay of 2 days.

Table 1
Possible remedies for concurrent delays

Delay concurrency				Possible remedies							
Excusable non-compensable	Non-excusable	–	→	EOT?							
Excusable non-compensable	Excusable compensable	–	→	EOT	and	COMP?					
Non-excusable	Excusable compensable	–	→	EOT?	and	COMP?	or	LD?	or	Nil?
Excusable non-compensable	Non-excusable	Excusable compensable	→	EOT?	and	COMP?	or	LD?	or	Nil?

EOT, extension of time to the contractor; Comp, compensation to the contractor; LD, liquidated damages assessed by the owner; NIL, neither contractor, nor owner recover damages.

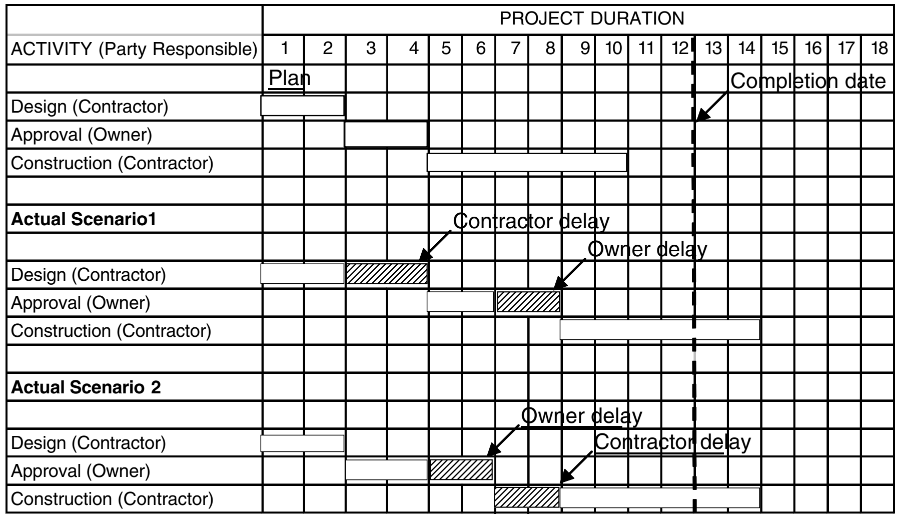

Fig. 1. Effect of ownership of float.

In the second scenario, the contractor-caused delay of 2 days occurs after the 2-day delay caused by the owner. The different position of float ownership would influence the results of delay analysis significantly as presented in Table 2. It is therefore imperative that float ownership be clearly defined in the contract in order to avoid disagreements in delay-related claims. If the party that owns float is identified in the contract, both the owner and the contractor can anticipate the outcome of potential actions and can adjust their activities accordingly.

3.3. Scheduling options

Scheduling issues also influence the result of the analysis because network-based delay analysis substantially relies on CPM principles. For example, the critical path can be defined by the longest path(s) in the network diagram, and by the amount of total float in the different paths. These two methods become contentious when considered in delay analysis because only critical delay should be considered when awarding time extensions [15]. The example shown in Fig. 2 presents concurrent contractor and owner delays in a situation where the contract time has expired. Under the longest path theory, the owner is responsible for 2 days of delay that extended project completion because only the delay caused by the owner is on the critical path. However, under the float theory, a concurrent delay is justified on day 14 because the contractor's activity is also critical since it has one day of negative float caused by the contractor's delay. The resolution of the issue of

Table 2
Results of delay analyses

Float ownership	Scenario 1		Scenario 2	
	Extension of time granted to contractor in days	Liquidated damages assessed to contractor in days	Extension of time granted to contractor in days	Liquidated damages assessed to contractor in days
Contractor exclusively owns float	2	0	2	0
Owner exclusively owns float	0	2	0	2
Project owns float (first-come, first-served basis)	2	0	0	2
Distribute float to both parties proportionally (duration)	1.6	0.4	1.6	0.4
Ignore float	2	2	2	2

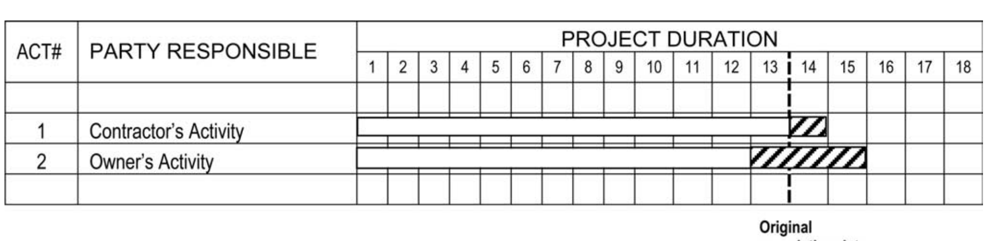

Fig. 2. Longest path vs. float.

negative float has a significant impact on the entitlement to time extensions, compensation for the extended performance period, and the assessment of liquidated damages.

CPM software packages offer various functions that provide flexibility for scheduling tasks, but some of these functions sometimes cause problems when incorporated into delay analysis. For example, some CPM software packages such as Primavera Project Planner allow users to select between *retained logic* and *progress override*. The progress override mode calculates an updated schedule regardless of the logic relationships of the activities that have started in order to avoid creating unrealistically long paths caused by the out-of-sequence activities that would happen in retained logic mode.

The delay analysis shown in Fig. 3 is conducted during the performance of the activity ''Approval'' while ''Construction'' has started out of sequence. The *retained logic* mode maintains the logic relationship between ''Approval'' and ''Construction''. The computed start date of the remaining portion of ''Construction'' is still imposed by the finish date of ''Approval'' even though ''Construction'' has actually started out of sequence. As a result, the retained logic mode computes the new completion date as day 11 and ''Approval'' is on the critical path. On the other hand, the *progress override* mode ignores network logic that has been out of sequence and allows ''Construction'' being driven without the predetermined logic. As a result, the progress override mode displays day 10 as the new completion date and ''Approval'' is not on the critical path. When delay analysis is conducted, disputes may arise if the contract does not specify which logic mode is to be used. While the retained logic mode is preferred by some for updating schedules, others claim that it makes it impossible to get an accurate update schedule [16].

Some software packages allow different calendars to be assigned to each activity and resource. Although this function reflects realistic uses of specific resources governed by different working schedules, it makes activities in the same path contain different amounts of float based on their individual calendar. A path may contain critical and non-critical activities, and as a result, may make the critical path less definable. It should also be noted that some of the well established software packages generate inconsistent and sometimes incorrect results under certain multiple calendar conditions discussed in detail by Kim and de la Garza [17].

In addition to duration and logic errors contained in analyzed data, different uses of scheduling software bring about a number of intricate problems in delay analysis. The most mentioned include the use of constraint/mandatory functions that force activities to start or finish by specific dates, the use of unconventional logic such as start-to-finish relationships, and the use of long or negative lag times [16]. These software functions often yield anomalous results in delay analysis and should be considered with caution by analysts.

4. Comments on delay analysis methods

The views of some researchers and practitioners who published about standard delay analysis methods in the years 1987–2004 are presented in Table 3. Twenty sets of comments were obtained from various sources, including 19 papers and 3 textbooks about construction claims. These articles and book chapters discuss how the methods work based on theoretical and practical considerations. They may not constitute the entirety of the body of work published in this field but they represent a good cross-section of what is available. The responses to the methods are varied. Some authors recommend using some methods, while others discourage using them, and some others have a neutral position. Substantial comments are made on advantages and disadvantages. Table 3 contains the preferences of

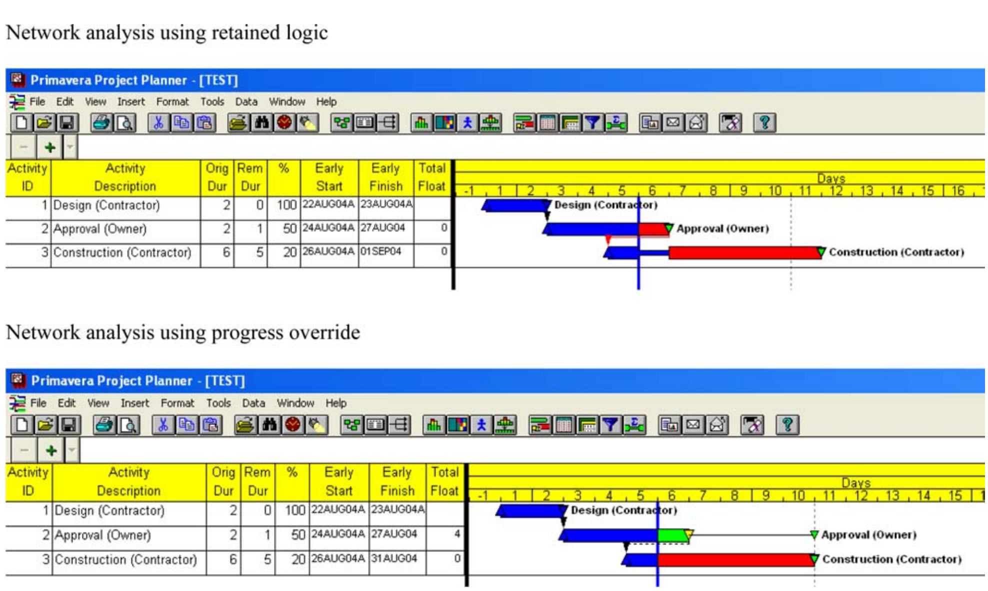

Fig. 3. Retained logic vs. progress override.

Table 3
Comments compiled from the literature (1987–2004)

References	Delay analysis methods			
	As-planned vs. as-built method	Impact as-planned method	Collapsed as-build method	Time impact method
Sandlin et al. [28]	N/A	Spurious results	Erroneous evaluation	Overcomes some disadvantages of others
Lovejoy [25]	Fair	Good	Excellent	Very good
Sgarlata and Brasco [19]	Worthy method	N/A	Most acceptable by courts	Useful for prospective analyses, but minimal utility supporting claims
Gothand [23]	Major drawbacks	Major drawbacks	Major drawbacks	Reliable
SCL [5]	Simple, limited	Simple, limited	Suitable for some situations, subjective	Most reliable when available
Harris and Scott [24]	Least popular	N/A	Fair, most accepted	Make some use by claims consultants
Zack [4]	Critical flaws	Critical flaws	Unreliable, easy to manipulate	Accurate but expensive
Stumpf [22]	Can be challenged	Easy to prepare, fundamental flaws	Easy to prepare, fundamental flaws	Reliable, but time consuming
Fruchtman [2]	Reliable	Simple, limited	No baseline needed, limited	Contemporaneous basis, but no future changes considered
Finke [26,27]	N/A	Less reflective of actual events	Less reflective of actual events	Most reasonable and accurate
Zack [21]	Unreliable	Many flaws, widely discarded	Suitable	Suitable
McCullough [20]	Not acceptable	Not acceptable	Useful in some situations but easy to manipulate	Dependent on baseline schedule, accurate
Bubshait and Cunningham [30,31]	Acceptable, dependent on availability of data	Acceptable, dependent on availability of data	Acceptable, dependent on availability of data	Acceptable, dependent on availability of data
Levin [1]	N/A	Simple, consistently rejected by courts	Dependent on quality of as-built schedule	Dependent on how the method is applied
Alkass et al. [32]	N/A	Some major problems	Sound, but ignores changes of critical paths	Some drawbacks/propose modified method
Zafar [18]	Reliable	Fault analysis	Fault analysis	N/A
Schumacher [33]	N/A	Potential shortcoming, one-sided analysis	Overcome some shortcomings	Effective method
Baram [29]	Dependent on	Dependent on	Most practical in some circumstances	Most desirable approach
Wickwire et al. [3]	N/A	“Great lie”	Alive and well	Recommended
Bramble and Callahan [34]	Acceptable, dependent on availability of data	Acceptable, dependent on availability of data	Acceptable, dependent on availability of data	N/A

the researchers relative to each method, ordered by date of publication. Some of the researchers do not specifically prefer one method over the others. They suggest that the selection of a suitable method should depend on a number of criteria and circumstances including those discussed in the preceding section.

4.1. As-planned vs. as-built method

There seems to be consensus that the as-planned vs. as-built method is the simplest form of analysis among the four methods. But the majority of the researchers listed in Table 3 have negative opinions of the reliability of this method for the very reason that this method is only a simple comparison of as-planned and as-built schedules and that there is no advanced technique being applied. SCL [5] suggests that the as-planned vs. as-built method is useful as a starting point in relation to other complex methods of analysis.

McCullough [20], Zack [21], Stumpf [22], and Gothand [23] do not recommend using the as-planned vs. as-built method because this method simply determines a net impact of all delay events as a whole rather than scrutinizing each individual delay event separately. The as-planned vs. as-built method assumes the as-planned and as-built schedules are correct in both activity durations and logic relationships even though there are no intermediate updates available. In addition, the method requires that additional activities be treated separately to make sure that the comparison is valid [24]. It is also difficult to make a detailed comparison when an as-built schedule has been modified compared to an as-planned schedule.

On the other hand, Zafar [18] and Fruchtman [2] encourage the use of this method because it takes into account both as-planned and as-built schedules to evaluate delay impacts and because it identifies and quantifies both owner and contractor delays. Sgarlata and Brasco [19] report that courts and boards have found this a worthy method of analysis. The as-planned vs. as-built analysis method is thought to be capable of addressing concurrency and compensability.

A significant advantage of this method is that the analysis requires only existing materials associated with general administrative procedures, i.e., as-planned and as-built schedules. In a project with less restricted general requirements where CPM schedules may not be available, only a bar chart diagram with an as-built schedule or updated records are sufficient to conduct the analysis. The as-planned vs. as-built method does not require generating an adjusted or a newly created network such as in additive or subtractive methods. This prevents analysts from incorporating a biased position into the analysis [18].

In conclusion, the as-planned vs. as-built analysis relies on common sense, a comparison of before-and-after delay events. The analysis incorporates both as-planned and as-built schedules, and both contractor and owner delay events, which supports the ability for recognizing concurrent delays and acceleration. It also offers ease of use and flexibility in delay analysis. However, it lacks a systematic procedure to evaluate the impact of delay events individually. Insufficient methodological support in the literature results in the as-planned vs. as-built method being least mentioned in the articles.

4.2. Impact as-planned method

The impact as-planned method is the least favored method among the four methods discussed the articles/books listed in Table 3 due to its theoretical flaws. The articles/books listed in Table 3 consistently criticize the impact as-planned method, and not one of them recommends the use of the impact as-planned method to prove delay impact. Many courts have not accepted this method since the 1990s. One of the reasons is because the method relies only on an as-planned schedule to determine the impact of delay. Indeed, this method does not measure the effect of actual work performed, but relies heavily on the validity of a baseline schedule. An analysis based on an unrealistic baseline schedule will not only suffer from faulty logics, but also from overestimated project durations.

Another reason that undermines the reliability of the impact as-planned method is that the contractor, (i.e., the party that files the claim) inserts only owner-caused delays into the as-planned schedule to prove the case. Wickwire et al. [3] consider this method to be a "great lie" because the analysis fails to incorporate the delay events caused by all parties to the contract.

4.3. Collapsed as-built method

The collapsed as-built method is based on the concept of what-if methodology similar to the impact as-planned analysis, but it has evolved to overcome some of the drawbacks of the impact as-planned analysis. The as-built schedule depicts the factual information concerning the work that has been undertaken. Courts and boards in the US consider the collapsed as-built method to be useful because the activities in this method are consistent with actual occurrences on the project [19]. Likewise, most UK professionals approve of this method [24]. In case an as-planned schedule does not exist or is not updated, an as-built schedule can be initiated from records such as monthly progress reports. The collapsed as-built method is often selected when reliable schedules cannot be readily obtained from project records or the project does not have scheduling information. The other advantage of this method is that it incurs less time and cost than time impact analysis. According to Lovejoy [25], the collapsed as-built analysis is the most practical approach since it offers a good combination of benefits.

On the other hand, Zafar [18], Finke [26,27], Fruchtman [2], Stumpf [22], Zack [4], Gothand [23], and Sandlin et al. [28] criticize the premise of the collapsed as-built analysis.

First, when a contractor conducts a collapsed as-built analysis, the analyst considers only the delays caused by the owner to prove the effects of owner-caused delays on the project completion. The analyst does not include contractor-caused delays in the analysis. Therefore, concurrent delays cannot be recognized using this delay analysis and this constitutes a drawback. This flaw is similar to the shortcoming observed in the impact as-planned method as the contractor's analyst chooses which delays to analyze. Second, the collapsed as-built method does not consider the dynamic nature of the critical path method. Indeed, it assumes that the as-built schedule makes use of the contractor's original as-planned intentions to execute the project, using the same sequence of activities and the same productivities [4]. Consequently, the events that cause delay along the course of the project may not be detected. Third, the collapsed as-built analysis is highly subjective and subject to manipulation. The analyst is required to recreate logic relationships into an as-built schedule from project records in order to perform the CPM analysis. Indeed, an as-built schedule no longer depends on the logic of the original network but on actual dates of activity progress. This process is subjective because the records, including logical sequences, lag times, etc., can be subjectively interpreted. Both parties are expected to examine the records and agree with the interpretation of a recreated as-built network before performing the analysis.

To conclude, the collapsed as-built schedule can determine delay impact in case of limited time and resources available for analysis. This method will be useful when both the contractor and the owner have access to the detail of as-built records and reasonably concur in interpreting the information used to construct the as-built network.

4.4. Time impact analysis method

Time impact analysis is the most credible delay analysis method among the four methods discussed in this paper. The majority of the viewpoints cited in Table 3 agree that the method yields the most reliable results. Time impact analysis does not display the shortcomings of the other methods discussed. This approach uses fragnets to analyze individual delay events. The durations of the delays and the relationships of delays to project activities are reviewed in detail with contemporaneous information. The delay is then inserted into the project. This process provides both parties an opportunity to scrutinize the delay and reduce disputes.

Baram [29], Finke [27], Zack [4], and Stumpf [22] address the importance of the dynamic nature of project critical paths. Time impact analysis performs a series of analyses throughout a project period, in contrast to the major disadvantage of the previously mentioned methods that observe a schedule at a single point in time. The analysis is able to trace the causes and effects of delay events systematically. The impact of a delay event is individually evaluated in detail. Using the CPM algorithm, the time impact analysis method follows up on the project day-by-day from beginning to completion date, including consumption of float, concurrent delays, recovery time and acceleration or resequencing accurately. According to SCL [5], this technique is therefore the preferred technique to resolve complex disputes related to delay and its compensation.

Time impact analysis is distinguished from the impact as-planned and collapsed as-built analyses in the fact that it incorporates both party delays into the analysis. The excusable compensable, excusable non-compensable, and non-excusable delays can be separately identified. In addition to this advantage, Wickwire et al. [3] describe indirect benefits generated by the use of time impact analysis in that it also provides a disciplined basis for the contractual parties to keep a project schedule up-to-date and properly adjusted.

Some limitations that exist in some actual construction projects may weaken the power of this method. First of all, time impact analysis requires a large amount of information in order to perform the analysis. An as-planned schedule in CPM format is necessary; additionally, the schedule needs to be periodically updated. The projects that lack strict administrative procedures and/or updated schedules are not good candidates for this method. Baram [29] suggests that the use of time impact analysis is the most desirable approach to handle a delay claim, but only when data and source documents are available in the required format and in the required time frame.

Second, the analysis may not be appropriate when resources or time allowed are limited. As to the detail involved in the methodology, time impact analysis consumes much more time compared to the other methods. Examining periodic updates is burdensome as actual data associated with many activities may need to be verified and compared for every updated period. Added or deleted activities have to be documented. In situations where time and budget are limited, time impact analysis may not be the method of preference.

Third, the result of the analysis may be influenced by a variety of factors because time impact analysis is intricate as it determines accumulative results from a number of contemporaneous data. For example, when a window period is treated separately from a delay event, the analysis may require approximation if the delay is divided between two window periods [26]. Also the different outcomes between the *retained logic* and *progress override* methodologies can influence the result of the analysis whenever on-going schedules in time impact analysis are analyzed in each window update.

In conclusion, time impact analysis is a refined method that determines delay impact in construction projects. It incorporates contemporaneous data to simulate actual circumstances at the time the delay occurs and accumulates impacts of delay events by using a series of windows. However, it requires significant time and effort.

5. Recommendations for selecting a delay analysis method

The delay analysis methods discussed in this paper may or may not be well suited in different situations and their selection depends on four criteria including data requirements, time of analysis, capability of methodology, and time and effort required (see Table 4).

5.1. Availability of information

Delay analysis methods determine the impact of delay by using different types of schedules. As-planned and as-built schedules and updates are commonly required as part of administrative procedures, while adjusted schedules and fragnets will be created specifically for delay analysis purposes. The selection of the most appropriate method partly depends on the type of schedule that was used throughout the project. For example, the impact as-planned analysis can be used with projects that have only an as-planned schedule and no updates. On the other hand, the collapsed as-built method is applicable in situations where little scheduling information is available since it is always possible to create an as-built schedule at the end of the project by making use of commonly available project records.

Some small projects may be managed by simple bar charts whereas larger projects may make use of network schedules. While some of these network schedules are approved by the owner and often updated by the contractor, some are seldom or never updated. The varied degree of availability of different types of schedules may constrain the selection of the most appropriate delay analysis method. While the as-planned vs. as-built method can be conducted by making use of simple bar charts, the remaining three methods require that a CPM schedule be available. While CPM-based analyses are more detailed and therefore more reliable, a bar chart-based analysis has the advantage of being simple, practical, and easily understandable by the parties.

The time impact method is more complex than the remaining three methods because it requires multiple runs that examine the situation one delay at a time or from update to update. The availability of update information greatly affects the use of this method whereas the remaining three methods rely on only one run using the delay information at hand.

5.2. Time of analysis

Delay analysis can be performed at different points in time relative to a delay. Foresight analysis is conducted to present the effects of potential delays caused by proposed events such as future change orders. For delays that have occurred, the best time to evaluate them is when they actually arise [20]. Hindsight analysis is a common practice in construction due to the hesitation of project parties to take

Table 4
Comparison of delay analysis methods

	As-planned vs. as-built analysis	Impact as-planned analysis	Collapsed as-built analysis	Time-impact analysis
Availability of information				
Type of schedule				
As-planned schedule	✓	✓		✓
As-built schedule	✓		✓	✓
Updated schedules				✓
Adjusted schedules		✓	✓	✓
Fragnets		Depends	Depends	✓
Type of information				
No CPM (bar chart)	✓			
No CPM but progress record			✓	
CPM approved/not updated	✓	✓		
CPM approved/updated	✓	✓	✓	✓
Time of analysis				
Foresight		✓		
Real time		✓		✓
Hindsight, during performance period	✓	✓	✓	✓
Hindsight, after project completion	✓	✓	✓	✓
Capabilities				
Float consumption/critical path	✓/depends	✓	✓	✓
Time extension	✓	✓	✓	✓
Compensation	Depends	Depends	Depends	✓
Concurrent delay	✓			✓
Resequencing	Depends		✓	✓
Dynamic nature of CPM				✓
Acceleration	✓			✓
Time-cost-effort				
Type of analysis	Observative	Additive	Subtractive	Additive
Level of effort	Low	Low	Moderate	High

action at the time the delay began. Because of their methodological characteristics, some delay analysis methods cannot be used to perform foresight or hindsight analyses at wish. For instance, the collapsed as-built method cannot be used to assess the delay impact caused by a potential change order because the method relies on as-built information which does not exist at that time. Impact as-planned or time impact analyses may be used in these circumstances.

5.3. Capabilities of the methodology

The outcome of delay analysis is expected to be reliable in that it should represent the actual events that took place throughout the project. But in situations where a project schedule is composed of a complex network and contains numerous delays, different delay analysis methods may yield different results. Stumpf [22], Bubshait and Cunningham [30], and Alkass et al. [32] have tested delay analysis methods and found that owner-caused delays had a higher impact on project completion when they were analyzed using the time impact method. But this finding cannot be generalized because it appears that the outcome of the methods depend on the individual effect of each type of delay, the effect of concurrent delays, scheduling changes during construction, and the effects of delays at different points in time during performance.

Some analysis methods may sometimes be misleading. For example, activities that have a great deal of float in the early portion of a project may end up on the critical path during the course of the project and then be returned to a non-critical status with float time at the end of the project [4]. As a result, some experts challenge the reliability of the single-run schedule analysis methods, including the as-planned vs. as-built, impact as-planned, and collapsed as-built methods since they fail to consider the critical paths at different times during the project. Some researchers criticize the method that uses only one schedule at a single point in time [22,23,27]. A mere as-planned schedule may not actually reflect contractor intent to execute the schedule. The contractor may thereafter have performed more or less productively than planned, and sequences of work may have been readjusted due to unforeseen changes. An analyst should therefore avoid a delay analysis method that uses only an as-planned schedule when the schedule experienced drastic changes and resequencing because such a method does not faithfully represent the impact of the delay events in such circumstances. Conversely, a mere as-built schedule assumes that there was a single unchanging critical path throughout the life of a project, which is unlikely to happen in construction projects.

A preliminary observation of delay situations may help an analyst to select the proper analysis method. In a schedule where numerous concurrent delays exist, the analysis method that incorporates both owner and contractor delays (such as as-planned vs. as-built) should be able to better show a clear picture of the concurrencies. In a schedule where critical paths have shifted back and forth over the course of the project, using a series of analyses (such as in time impact analysis) can demonstrate the collective cause and effect of delays and provide an accurate result. On the other hand, an analyst should avoid using delay analysis methods that consider delays caused by only one party (e.g., impact as planned analysis conducted by contractor to prove the impact of only owner-caused delays) if concurrent delays are numerous throughout the project.

When a contractor seeks compensation for constructive acceleration, the contractor is not only required to prove that the excusable delay exists, but also that the contractor actually improved its performance relative to the plan and incurred additional cost. The delay analysis method selected has to recognize schedule acceleration. A contractor would benefit from using time impact analysis to examine the impact of acceleration claims because this method allows the analyst to assess the relationship between delays and corresponding accelerations. The delay analysis method that uses only the as-planned or only the as-built schedule may not represent acceleration properly.

In some cases, schedule disruption does not obviously interrupt the schedule but may cause a decline in working resources' efficiency. For example, if a disruption forces an activity to stop and start over and over, workers may experience lost productivity caused by a slowdown in the "learning effect". This kind of delay is unlikely to be detected and evaluated by schedule analysis. It is necessary for an analyst to incorporate productivity observation in the analysis in order to prove cause and effect of delay.

5.4. Time and funds available for analysis

The as-planned vs. as-built method is the simplest of the methods because it uses an "observative" approach that simply compares the as-planned against the as-built schedule, whereas the remaining three methods have a basic methodology that is either "additive" or "subtractive" depending on whether delays are added to an as-planned schedule or subtracted from an as-built schedule. These last three methods are based on a "what-if" concept that allows assessing the impact of each individual delay on the final project duration and may involve greater or lesser effort depending on the method used.

The most sophisticated delay analysis method (i.e., time impact analysis) may consume much time and may incur high cost compared to simpler methods such as the as-planned vs. as-built, impact as-planned, and collapsed as-built methods. It also requires specialized expertise to perform the analysis. The selection of the analysis method depends on the degree of detail and accuracy that the analyst compromises given the time constraints and budget limitations. Any delay analysis method should produce the same result when evaluating a simple non-concurrent delay event. In this sort of situation, it is not necessary for an analyst to spend unnecessary time, money, and effort on an elaborate time impact analysis.

6. Conclusion

A fair and effective evaluation of delay impact is possible if the most appropriate delay analysis method is selected that provides a reliable solution with the information available and within the time and cost allocated for this purpose. Time impact analysis is clearly accepted by the literature cited in Table 3 as the most reliable delay analysis method among the four standard methods discussed in this paper. However, the transient nature of construction projects not often allowing scheduling data being well documented as well as time and budget limitations lead a number of researchers to suggest that the choice of a simpler method may be sensible. The as-planned vs. as-built and collapsed as-built methods are efficient in some situations. The impact as-planned method falls behind these three as it has so many critical flaws.

The reliability of delay analysis depends on the selection of a suitable analysis method and on the availability of scheduling data. An analyst should meticulously review the data obtained from the project records because none of the methods yields reliable results if the information used is invalid. It is necessary to be very familiar with the capabilities of the software used in project scheduling and progress control in order to be able to generate legitimate schedules for the analysis. The other controversial issues such as the treatment of concurrent delays and the ownership of float should be clearly specified in the contract. Project participants should settle these issues early in the project so as to maintain proper scheduling administration.

The best practice is to be prepared for delay management throughout the project by adopting these recommendations as a routine procedure. Since time impact analysis is by far the most effective method in proving time-based claims for the reasons discussed in this paper, ideally speaking, all project managers should engage in practices that will generate adequate information to allow the use of time-impact analysis in case a time-based claim needs to be proven. However, given the different circumstances in different projects, it is not always possible to generate such information. In such cases, the recommendations made in this paper should allow a claims analyst to pick the most effective delay analysis method that is compatible with the information at hand at the time of analysis.

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