Review of Delay Analysis Methods: A Process-Based Comparison

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Abstract: Schedule delays frequently occur in construction projects. Many methods have been developed and used to analyze and measure the schedule delay of construction projects. Selecting a suitable analysis methodology is a major task for resolving the schedule delay claims encountered. This study reviews 18 delay analysis methods, and compares in detail three process-based dynamic analysis methods, namely, the snapshot analysis method, the windows analysis method and the isolated delay type method. A dynamic method is ideal for resolving a delay claim, since it provides accurate analysis. The differences among the dynamic methods in terms of the capabilities, required documents, timing and analysis process are discussed to help delay analysts to select an appropriate method. Finally, this study attempts to propose six suggestions on developing an ideal analysis method.

Keywords: Delay analysis, process comparison, dynamic analysis method, claim management.

1. INTRODUCTION

Schedule delays frequently occur in construction projects. Many recent studies have focused on analyzing delay values accurately and systematically from the as-planned and as-built schedules, since the obtained information are the basis for resolving delay disputes and claims. Various methods have been developed and used for analyzing and measuring construction schedule delays. However, these methods have different analytical approaches and require different information. For a complicated delay case, different method may provide different results, and require different input data. That is, no single method is universally accepted by all project participants, suitable for all situations. Therefore, there is a need to provide complete information of available delay methods for a delay analyst while he/she wants to select a suitable method to resolve his/her delay problems. This study tries to provide this useful information.

Arditi and Pattanakitchamroon [1] discussed selecting a suitable delay analysis method and concluded that the most appropriate analysis method depends on information available, time of analysis and capabilities of the method, as well as time, funds and effort allocated to the analysis. They discussed four delay analysis methods, namely, the as-planned vs. as-built method, the impact as-planned method, the collapsed as-build method and the time impact method. All the methodologies discussed by Arditi and Pattanakitchamroon, except the time impact method, are static methodologies, which provide less promising information for delay claim management than dynamic methodologies, which analyze delay events systematically and objectively to both contract parties. Furthermore, the comparisons provided by Arditi and Pattanakitchamroon still do not fulfill the requirement to select a suitable analysis method based on a deeper investigation on process variations that influence the accuracy of delay analysis.

This study comprehensively reviews 18 delay analysis methods, categorized as mathematical, computer-based and process-based models, to identify their characteristics in analysis processes. This study compares three process-based dynamic delay analysis methods, namely the snapshot analysis method, the window analysis method and the isolated delay type method, that are adopted to analyze delay events contemporaneously. The capabilities, timing and documents required in these methodologies are compared. The analytical processes of each methodology are then described by flow charts for comparison. The research results should allow potential users to select an appropriate method easily based on their available information. Moreover, this study attempts to propose some suggestions on developing an ideal analysis method based on the discussion about dynamic delay analysis method.

2. RELATED STUDIES

Bubshait and Cunningham [2] proposed an approach for selecting one suitable method among the as-planned method, the as-built method, and the modified as-built method. Their approach consists of four scenarios, each comprising various approved schedules (network or bar chart) with different evidence and progress reports. They concluded that method selection depends on the time and resources available, and on the accessibility of project control documentation. To make an appropriate selection among the as-planned vs. as-built method, the impact as-planned method, the collapsed as-build method and the time impact method, Arditi and Pattanakitchamroon [1] prepared a tabular checklist with schedule type (as planned, as-built, updated, adjusted and fragnets) and information type (progress report, bar chart, approved network and updated approved network) documents to act as a selection aid. The study results of Arditi and Pattanakitchamroon and of Bubshait and Cunningham reveal that dif-

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ferent delay analysis methods require different documents and consume different levels of resources.

It is interested that previous literature discussing the selection of proper delay analysis methodology has concentrated mainly on available schedule-related documents. Although available schedule-related documents dominate the selection of schedule delay analysis methods, the execution processes with required documents can provide constructive information for selection of methodologies. The purpose of this study is to depict the analysis processes to help schedule analysts to understand the complexity of discussed methodologies, thus enabling them to select the most appropriate methodology. Similar to the scope of this study, Mohan and Al-Gahtani [3] discussed ten delay analysis techniques in analysis flow and compared them in resolving the issues of real time delay, concurrent delay and pacing delay. Based on study results, Mohan and Al-Gahtani proposed a desirable delay analysis system consisting of eleven requirements, such as the requirement for the project schedule to be updated every day, taking account of all delays and changes in total floats. Comprehensive schedule data about real world cases involving construction schedule delays are clearly hard to gather. The objective of this study is to differentiate among available delay analysis techniques with general schedule-related documents and distinct analysis processes, thus providing an attainable target for most delay analysts in their real-world analyses.

3. GENERAL DOCUMENTS FOR DELAY ANALYSIS

The schedule information of construction projects for tracing delay events after project completion is generally varied. Elnagar and Yates [4] conducted a survey of project control personnel from contractors, owner and the US Army Corps of Engineers, and concluded that schedule network, daily construction report, quality control report, correspondence, progress curves, productivity measurement and change-order log are the essential delay indicators. At least four types of schedule network, namely, as-planned, as-built, adjusted and entitlement schedules are used in various delay analysis methods.

An as-planned schedule is an initial approved schedule submitted by the contractor to the owner for a project. The as-planned schedule is regarded as a baseline schedule or a target schedule for managing a project. An as-built schedule is the final schedule for a project and is usually prepared when the project is completed and contains all the actual start and finish dates, and the disruptions (for example, delays) that have occurred in the project [5]. An adjusted schedule is obtained by modifying the as-planned or as-built schedule according to the method dictated by the chosen delay analysis technique [5]. 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. The final entitlement schedule reflects the original, adjusted and actual completion dates used to establish the total time that the contractor or the owner is entitled to for compensation [6]. These four schedule types are found in different delay methodologies, as discussed below.

4. DELAY ANALYSIS METHOD

4.1. Available Delay Analysis Method

Many delay analysis methods have been present in the literature [1, 3, 7-11]. They can be categorized as process-based, mathematical and computer-based models (Fig. **1**).

The famous process-based methods include the global impact, net impact, adjusted as-built CPM, as-planned expanded, but-for, snapshot, time impact, windows and isolated delay type techniques [12, 13]. Mathematical models are developed to help delay analysts to calculate accurately the delay impact of a single activity on a project. Computer-based model are designed to help delay analyst to collect and record required data (or information) and running definite delay analyses. Mathematical methods include an equation-activity-based calculation method proposed by Shi *et al*. [14]; a fuzzy logic approach for estimating delay duration to improve delay analysis, proposed by Oliveros and Fayek [15]; and a method proposed by Lee *et al*. [16] that considers lost productivity for analyzing schedule delay.

With regard to computer-based methods, Yates [17] developed a construction decision support system for delay analysis with the capability of determining possible causes for project delays. The system used some information technology (IT) to process data for delay analysis. Aoude [18] developed a computer program to help identify and quantify delays encountered in construction projects. The system used general project appraisal information to analyze project and activity level delays. Abudayyeh developed a multimedia system for construction delay management, in order to demonstrate the roles of pictorial and audio data and information in management of delays and potential claims [19]. This investigation only focuses on the process-based methods.

4.2. Reviews on Delay Analysis Methods

Table **1** summarizes 18 methods found in periodical journals. Each methodology is briefly introduced. Additionally, similar methods from other studies are presented. Further descriptions about discussed delay methods may be found in the references provided. Notably, methods that appeared in reports or proceedings are not discussed in this investigation, due to their low accessibility. The excluded methods are the Entropy [23, 32] and Scatter Diagram [23] methods.

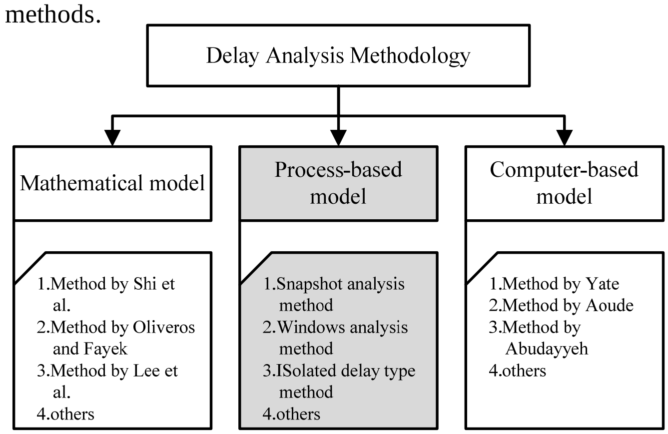

Fig. (1). Rationale classification of delay analysis method.

Table 1 Delay Analysis Method and its Isomorphism and Similar Method

Method	Introduction	Isomorphism/ Similar Method	Category
Reams' systematic approach [20]	This method systematically isolates the impact in time of each alleged delay, impact or acceleration directive occurred, then determines the type of the alleged delay by comparing the impacts of previous delays.	None	concept method
Global impact technique [7]	This method represents all the delays and disruptions on a bar chart, and then calculates the total delay by summarizing all delaying events.	None	concept method
Net impact technique [7]	This method is similar to the global impact technique, but only the net effect of all the delays. The method determines total delay by calculating the difference between the as-planned and the as-built completion dates.	Adjusted as-built CPM technique [6, 7]	concept method
Snapshot technique [7]	This method divides the as-built schedule into a number of consecutive snapshot (time period) and updates the as-planned schedule by imposing all delays that occur in each snapshot and in succession. The method records the delay caused by each update, and then summarizes all the recorded delays.	None	dynamic method
Isolated delay type [7]	This method is similar to the snapshot technique, except that it classifies delay types as excusable compensable delays, excusable non-compensable delays and non-excusable delays, instead of considering all the delays together. The method imposes the delay to update the as-planned schedule and summarizes all apportioned delay values that have been recorded.	None	dynamic method
After-the-fact and modified CPM schedule [21]	Similar to the impacted as-planned method, this method uses a created new baseline or modified as-planned schedule, instead of the original as-planned schedule.	None	forward path method
Dollar-to-time relationship [21]	This method supports the direct relationship between the project cost and time. However, delay value is hard to calculate from the extra cost.	None	concept method
Bar chart analysis [10, 22]	This method compares the as-planned bar chart with an as-built bar chart prepared by recording delays on extended or added bars. This method systematically ignores the lack of underlying logic between the activities.	As-built bar chart [23]	concept method
CPM update review [10, 22]	This method examines each schedule update submitted on the project, and explains the cause of the delay on each update, without performing any further analysis.	None	concept method
As-planned versus as-built analysis [10, 22]	Similar to the bar chart analysis method, this method simply compares the baseline or as-planned schedule with the final or as-built schedule. The time owed is calculated by subtracting the time planned from the actual time expended to determine.	None	concept method
Linear schedule analysis [10, 22]	This method is only used for linear type projects. The method compares the as-planned schedule with actual linear progress.	None	concept method
B&B's delay analysis method [23]	This method uses critical path techniques to simulate the impact of events that have been identified as likely to cause delays to the project. This method is a clear, straightforward step-by-step approach with a dynamic model considered by both experts and practitioners.	None	forward path method
Impacted as-planned method [10, 22]	This method starts with the as-planned schedule and adds delay one by one (generally caused by other party) to an activity to demonstrate why the project was completed later than planned.	As-planned plus delay analysis [10, 22, 25]; impacted baseline schedule [21]; what-if, [24, 25]; affected baseline schedule [26]; as-planned method [27]	forward path method

Table 1. Contd….

Method	Introduction	Isomorphism/ Similar Method	Category
But-for [24]	This method concentrates on a specific delay or delaying event, not a time period containing delays or delaying events. This method starts with the as-planned schedule, and imposes delayed activity one by one caused solely by the other party to calculate its liability.	Time impact technique [2, 10, 22, 27]; modified as-built [2, 10]; baseline adding impacts method [23]; forensic scheduling [27]	forward path method
	This method starts with the as-built schedule, and removes one party's delays from the schedule to collapse it, leaving those delays caused solely by the other party.	Traditional method [2]; but-for schedules [10]; as-built subtracting impacts method [23]; as-built method [27]; as-built less delay analysis, [10, 22]; collapsed as-built [8, 10, 22, 26]; impacted as-built CPM, [8]; collapsing technique [5, 6]	backward path method
Modified but-for [24]	This method designed to produce repeatable and accurate results by reconciling all parties' points of view. This method uses the Venn diagram representation for three-party critical delays and the selected set of compensation rules [28].	None	dynamic method
Apportionment delay method [5]	This method is a compromise between the net impact and but-for techniques. It apportions the actual delay amount according to the ratios of the compensable-delay, non-excusable-delay and excusable -delay to the total delays.	None	dynamic method
Windows analysis [24]	This method breaks the project into discrete time increments (windows) and examines the effects of the delays attributable to each project participant as the delays occur. This method adopts the as-planned schedule as its baseline; determines the delay values in each window, and then summarizes all recorded values.	Contemporaneous period analysis [10, 24, 29]; modified windows analysis [8]; daily windows delay analysis [9]; delay section [30]	dynamic method
Total float management [31]	This method starts with the as-planned schedule to run a day-by-day analysis of changes in order of operation, namely delayed or accelerated events on total float consumption.	None	forward path method

4.3. Classification of Process-Based Delay Analysis Method

Process-based methods can be further categorized as (1) concept method, (2) forward path method, (3) backward path method and (4) dynamic method (Fig. **2**) [14]. The final column in Table **1** shows the classified results. The concept method simply calculates delay value by examining final schedule evidence; the forward path method systematically calculates the delay value from an as-planned schedule to an as-built schedule; the backward path method systematically calculates the delay value from an as-built schedule to an as-planned schedule; and the dynamic method systematically calculates the delay value in specific time frames forward or backward from as-planned and as-built schedules.

Owing to the method categorized into the 'dynamic method' category providing the ability of comprehensive analysis to differentiate the liability between contract parties accurately, this study analyzed three famous delay analysis methods in the category to present their differences in analysis processes. The discussed methods include the snapshot analysis method, the windows analysis method and the isolated delay type method.

The dynamic methods enable comprehensive analysis to differentiate accurately the liabilities of different parties to a contract. Therefore, this investigation analyzed three well-known dynamic delay analysis methodologies, namely, snapshot windows and isolated delay type.

5. PRE- AND POST-ANALYSIS PROCESS

To help delay analysts or claim managers to collect required information, several researchers have proposed various guided processes for delay analysis [20, 21, 23]. Although various researchers have proposed different approaches to cover different issues or scopes. Processes related to claim management can be split into the following five phases (Fig. **3**).

1) Preparation phase: all required documents including as-planned schedule, bid documents, construction daily reports and as-built schedules, are gathered.
2) Diagnosis phase: impacted delay events are identified for further analysis. Delay events are classified as excusable and non-excusable delays. The excusable delays are further classified into excusable compensable and excusable non-compensable delays.
3) Analysis phase: to adopt the available and reliable delay analysis methodology to calculate the delay impact value of identified delay events.

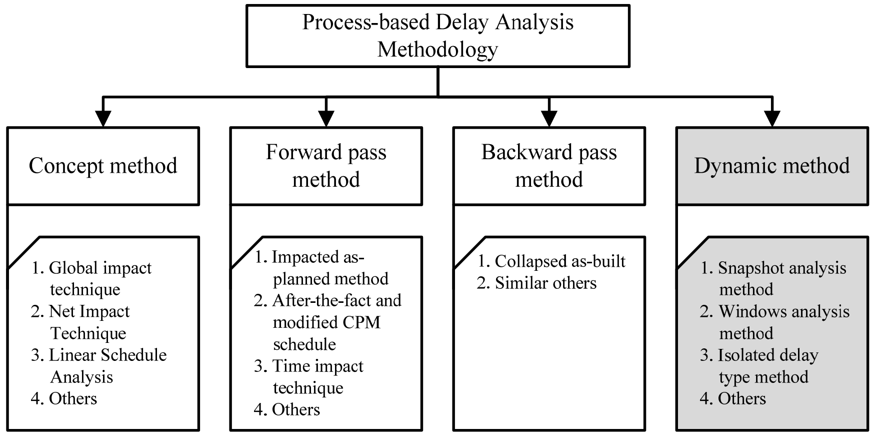

Fig. (2). Classification of process-based delay analysis method.

4) Interpretation phase: to clarify the schedule impact on the critical path or total duration. In this phase, concurrent delay should be carefully considered in order to differentiate its liability to contract parties.

5) Summation phase: all analysis results are summarized to generate a comprehensive analysis report.

The steps or processes in Phases 1 and 2 are the pre-analysis processes, which concentrate mainly on collecting required information for formal delay analysis. In contrast, the steps or processes in Phases 4 and 5 are the post-analysis processes, concentrating on summarizing the analysis results that are beneficial to the analyst. To differentiate among three discussed dynamic analysis methodologies, the next section illustrates the analysis processes of three discussed methodologies, and then discusses the similarities and dissimilarities among them. The analytical processes in the following section only focus on Phase 3, which is the analysis phase in Fig. (**3**).

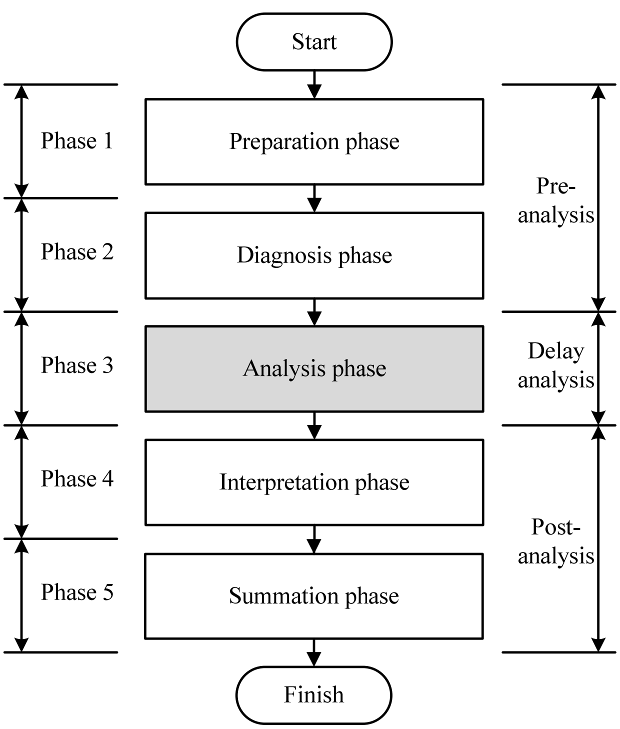

Fig. (3). General delay analysis processes.

6. PROCESS-BASED ANALYSIS AND COMPARISON

6.1. Snapshot Analysis Method

The snapshot analysis (SA) method is based on the as-planned, as-built and any revised schedules that have been implemented during the execution of a project. The total project duration is divided into a number of time periods, called snapshots. The dates of these snapshots usually coincide with major project milestones, significant changes in planning or times 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 [6]. Fig. (**4**) shows the analysis process of the SA method. The SA method calculates the delay value based on each snapshot from the as-planned schedule and then summarizes project delay values from all analyzed snapshots for each contract party.

6.2. Windows Analysis Method

The windows analysis (WA) method, also called the contemporaneous period analysis method, analyzes delay event(s) on a predefined time period (termed as a window). This section focuses on the traditional windows analysis method, although variants such as the daily windows and delay section methods have been proposed. The analyst identifies several analysis windows from the as-planned schedule, and then puts delays in their proper windows within the overall context of the project to calculate the delay value in one window. Fig. (**5**) shows the analysis process of the WA method. Like the SA method, the WA method also computes the delay value according to each window from the as-planned schedule, and then summarizes project delay values from all analyzed windows for each contract party. However, the main differences between the SA and WA methods are the algorithms to determine the analysis timeframe and to

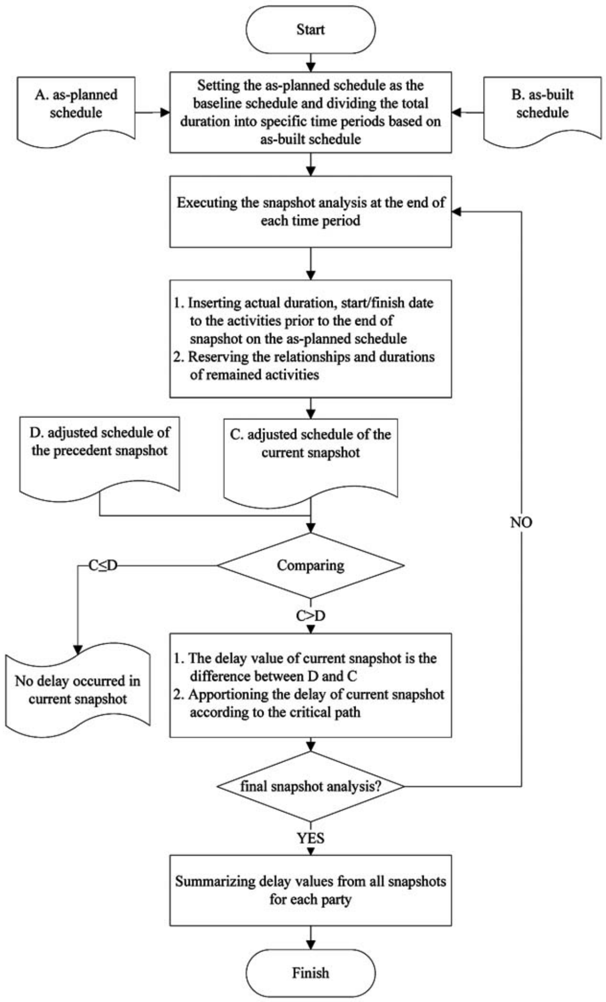

Fig. (4). Delay analysis processes of SA method.

settle the relationships and duration of activities within the timeframe.

6.3. Isolated Delay Type Method

The isolated delay type (IDT) method uses the approach of SA method to overcome the drawbacks of previous methods in dealing with proper classification of delay types, concurrent delays and real-time CPM analysis [6]. Therefore, the IDT method can be regarded as a modified SA method. The IDT method is based on the as-planned schedule, but performs delay analysis based on the extracted analysis section schedule, and explicitly considers the liabilities of contract parties. Fig. (**6**) shows the analysis process of the IDT method. This method summarizes project delay liability for each contract party from all analyzed periods, based on the same processes as the above two methodologies.

6.4. Comparison

The required, start-up and comparison documentations of three dynamic delay analysis methodologies were compared. Table **2** shows the documentations used by all discussed methods. Clear, all methods start delay analysis from the as-planned schedule, and require the as-planned schedule and identified liability documents along with adjusted schedules to be generated from the as-planned schedule or as-built

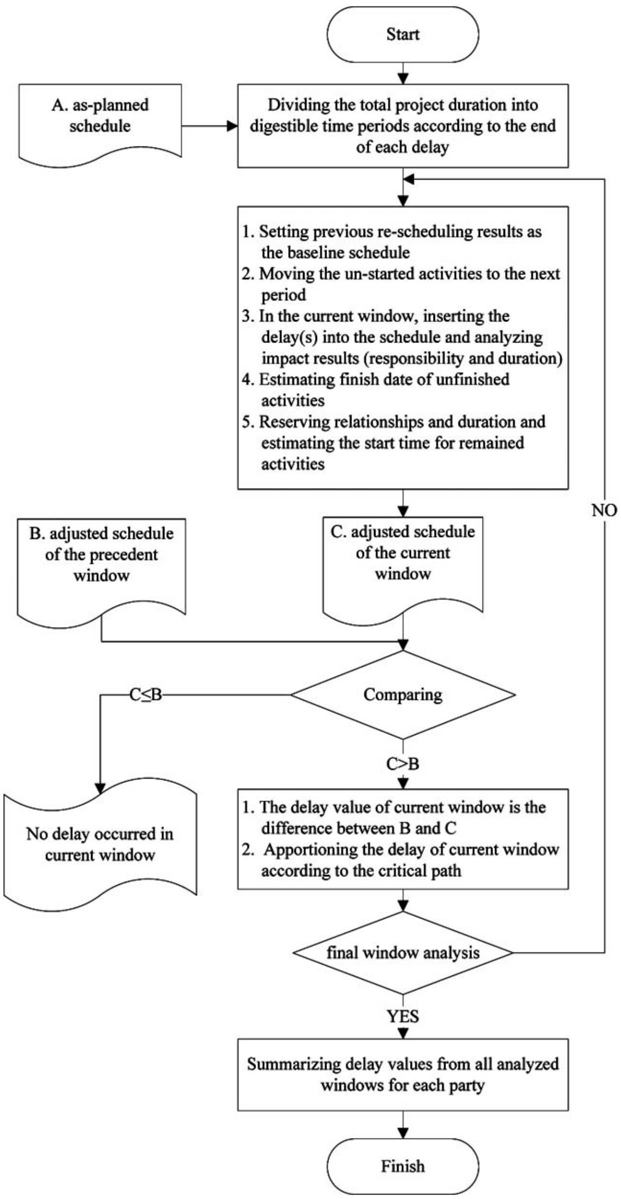

Fig. (5). Delay analysis processes of WA method.

schedule. This implies that the three dynamic methods are homologous in analysis documents.

Figs. (**4, 5**) and (**6**) present the analysis processes of SA, WA and IDT, respectively. All three methods start to decide the analysis time point, and then proceed to run complete delay analyses. SA, WA and IDT determine the analysis time point from an arbitrary basis (usually considering milestone, significant changes or a delay event on the as-built schedule), the end of each delay event and major delaying events (or after a series of delays), respectively. The determined analysis time points based on the above three methods are analogous. Although it is hard to evaluate which method is the best in selecting analysis time point, to run delay analysis at the beginning and end of a delay event provides a holistic check to compare those two points. None of three method run delay analyses on both antecedent time points.

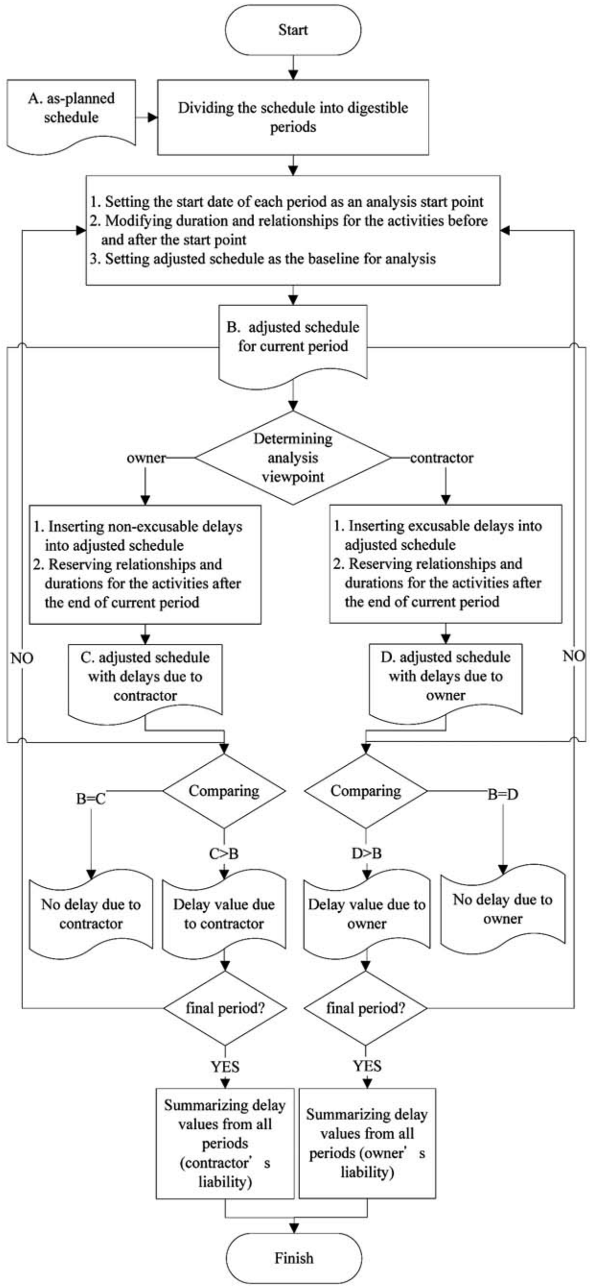

Fig. (6). Delay analysis processes of IDT method.

A comparison of the processes in Figs. (**4, 5**) and (**6**) reveals that SA and WA do not address analysis viewpoints (the owner or the contractor) prior to the delay impact analysis, and therefore generate results that require further processing to apportion the entitlement. A complicated delay event is usually combined with various excusable non-compensable, excusable-compensable and non-excusable delays. The impact of various delay types during delay analysis need to be clearly interpreted for delay analysis. The IDT method interprets the delay entitlement more clearly than the others.

Table **3** shows a functionality and limitation comparison of all three methods. Since the IDT method was developed to overcome the drawbacks of previous methods, it has most advantages, namely, dealing with various delay types, concurrent delay and serial delay, and operating real-time critical path analysis. However, the IDT method still has some limitations including having logic defect and disability in finding missing activity, time-consuming in execution and high cost. The above comparisons reveal that no method is perfect. A mechanism needs to be developed to help delay analysts to select an appropriate methodology. Accordingly, an ideal delay analysis methodology can be developed to resolve the delay problem.

7. IDEAL DELAY ANALYSIS METHOD

An ideal delay analysis method should contribute to a fair and accurate delay analysis result that can be accepted by contract participants and professional schedule analysts. A new methodology should fix several defects suffered by available delay analysis methods. Although previous studies have proposed several improvements or suggestions on available methods, they still have some pitfalls that should be fixed. Based on above reviews and discussions, this study proposes six suggestions on developing an ideal delay analysis method. The suggestions are explained as follows.

1. Concerning of as-planned and as-built schedules. These two types of schedules are regarded as fundamental legal documents in claim debate, and are usually used for liability diagnosis. Making best use of these two schedules or even entitlement schedules mitigates extra disputes in claim debate. If a delay analysis method can perform its analysis based on these schedules, the outcomes will be convinced that all evidences are from as-planned or as-built schedules.
2. Dealing with various delay types. A delay event is usually accompanied with another delay event. Complicated delays even combine with various delay types, i.e., concurrent and pacing delays, or excusable non-compensable, excusable-compensable and non-excusable

Table 2. Documents for Three Dynamic Delay Analysis Methods

Feature	SA	WA	IDT
Required docs.	As-planned schedule, as-built schedule and identified liability documentations	As-planned schedule, as-built schedule and identified liability documentations	As-planned schedule, as-built schedule and identified liability documentations
Start-up docs.	As-planned schedule	As-planned schedule	As-planned schedule
Comparison docs.	As-planned schedule and adjusted schedules from as-built schedule	As-planned schedule and adjusted schedules from as-planned schedule	As-planned schedule and adjusted schedules from as-planned schedule

Table 3. Comparison of Functionçality and Limitation

Feature	SA	WA	IDT
Considering the actuality in the as-planned and as-built schedules	Yes	Yes	Yes
Debate in responsibility distribution	Partially	Partially	Fully
Scrutinizing delay types	None	None	Yes
Disability in finding missing activity	Yes	Yes	None
Dealing with concurrent delay	None	None	Yes
Analytical process	Not clearly	Clearly	Clearly
Determining time frame	Depends	Clearly	Depends
Logic defect for revising next analysis schedule	Yes	Yes	Yes
Employing timing	Depends	After-the-fact	Depends
Analysis effort	Huge	Huge	Huge

delays. These types of delay should be manipulated by additional process compared to the discussed delay analysis process previously. The ability of dealing with diverse delay types makes analyst satisfied with the results. A delay analysis method can solve more delay types; it can provide more analysis results for a delay analyst for final judgment. This judgment will be fair for both of dispute parties.

3. Providing clear liability distribution. Discussed dynamic delay analysis methods simply provide guided analysis processes, but lack accurate liability distribution mechanism. A good delay analysis report should provide clear liability distribution for argument delay events. To provide calculation rules and formulae for distinguishing delay liability makes analysis result more convincing than traditional results. The liability distribution information will be useful for further damage calculation.

4. Considering multiple critical paths and critical path(s) change. Delaying an activity on a critical path usually means taking the responsibility for delay. However, the original critical path(s) on the as-planned schedule may be not the actual critical path(s) that delayed the project target date. The effect of multiple critical paths on delay analysis, and the changes in critical path(s) following delay analysis, should be addressed. The delay information on critical path(s) can provide evidences for liability distribution.

5. Defining total float in a clear position. Delay analysis traditionally considers the total float as an index to calculate the effect of a delay event on the total project duration. However, the value of total float should be shared with other activities in a non-critical chain. Calculating an activity's impact value from its total float on the as-planned schedule produces incorrect results, and leads to further dispute. To appraise the delay impact, a mathematical algorithm needs to be developed for clearly calculating the effect of a single delayed activity on the total project duration, considering the accurate total float consumption.

6. Incorporating the developed methods into popular commercial scheduling software. Currently, most construction projects perform planning and controlling schedules by available commercial scheduling software. However, no popular commercial scheduling software exists to provide satisfactory delay analysis functionality. Basic schedule variance analysis and delay analysis is available in some commercial scheduling software, but it is far from professional [11]. If a developed delay analysis method can be embedded in or based on commercial scheduling software; it will increase convenience for analysts or end-users.

CONCLUSIONS

Schedule delays occur frequently in construction projects. How to develop a comprehensive method to help delay analysts to calculate the liability of contract participants has received much attention. Although many methods have been developed and adopted to analyze and measure construction schedule delays, no-one is accepted for all project participants and suitable for all delay situations. This investigation compared three dynamic delay analysis methodologies, namely snapshot analysis, windows analysis and isolated delay type, to disclose their advantages and disadvantages. This investigation not only compared the features of capabilities and required documents, but also discussed the analysis process and timing of all discussed methods. Results of this study will help delay analysts to choose an appropriate method. However, complete delay information should be kept regardless of the delay resolution method adopted.

Since available delay analysis methods have some limitations in resolving delay problem, this study attempts to propose six suggestions on developing an ideal delay analysis method, consisting of concerning of as-planned and as-built schedules, dealing with various delay types, providing clear liability distribution, considering multiple critical paths and critical path(s) change, defining total float in a clear position, and incorporating the system into popular commercial scheduling software. Although above issues are hard to be considered fully in a new method, these information provides some directions for following.

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