Schedule Analysis under the Effect of Resource Allocation

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Abstract: The construction industry has employed various schedule analysis techniques to support delay claims. Paradoxically, resource-related issues are frequently ignored even though they can affect project completion time, too. The research presented here shows that delay analysis without resource allocation practice substantially affects results of schedule analysis. Some delay can cause unrealistic resource allocation in downstream work, which in turn may further delay the project. The effect of resource allocation can either add to or reduce the severity of some delaying event. Apportionment of delay responsibility may be inaccurate unless resource allocation practice is considered in the analysis. Practical and necessary steps are proposed to enhance the existing window analysis technique. A case study is presented to compare the enhanced window analysis with the existing window analysis. This research enables practitioners to make delay analyses and claims more practical and reliable. Further studies are needed to improve the usability, credibility, and acceptability of schedule analysis considering resource allocation.

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Introduction

Project schedules are invariably dynamic and uncertain. Various controllable and uncontrollable factors can adversely affect the project schedule and cause delays. As a result, the identification and analysis of delays become essential (Finke 1999). They are however, onerous tasks. Contractors are prone to view most delays as the responsibility of the owner while owners frequently attempt to tag delays as contractor caused, third party caused, or concurrent (Zack 2001). Consequently, delays may lead to some form of dispute resolution alternatives, from negotiation to litigation, which may be expensive and a crapshoot. Responding to such challenge, the industry has created and employed many schedule analysis techniques. The level of acceptability of each technique depends on its credibility and the court or board ruling the corresponding delay claims. However, resource-related issues such as constraints, availability, or in broader term resource allocation can cause delays yet their effects are typically neglected in those techniques. It should be noted that although a number of studies have focused on scheduling with resource allocation (e.g., Wiest 1967; Davis 1974; Willis 1985; Fondahl 1991; Bowers 1995; Hegazy 1999; Kim and de la Garza 2003, 2005; Chua and Shen 2005), none of them addressed resource allocation in “after-the-fact” schedule delay analysis.

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The objectives of this research are threefold: (1) prove that effects of resource allocation should not be neglected in schedule analysis via a motivating case; (2) propose practical and necessary steps for dealing with resource allocation and embed them in the most acceptable technique—window analysis; and (3) compare the enhanced window analysis with the existing window analysis for a simple case study. The benefit of this research is that project parties will make schedule analysis more credible and practical. This research also raises issues that need further studies to improve credibility of schedule analysis.

Delays

Delays are acts or events that extend the time necessary to finish activities under a contract (Stumpf 2000). They are classified in several ways. The classification can be based on origin, compensability, and timing of these delays (Kartam 1999). In terms of responsibility, delays can be owner-, contractor-, or third party-caused delays. As their names suggest, an owner-caused (contractor-caused) delay is within the control of, is the fault of, or is due to the negligence of the owner (contractor) (Sweet and Schneier 2004). The third party caused delay is attributable to neither the owner nor contractor (Kraiem and Diekmann 1987).

Liability for a certain delay is normally stipulated by contractual terms. Identification of which delays are the responsibility of the owner relies significantly upon the language of the contract itself (Hughes and Ulwelling 1992). In general, compensable, inexcusable, and excusable delays correspond to owner-, contractor-, and third party-caused delays, respectively. However, there are some exceptions that are imposed by contract clauses, for example “no-damage-for-delay” clauses. This leads to the fact that several excusable delays may be caused by the owner (Bartholomew 1989). Also, some inexcusable delays may not be attributable to the contractor. Bartholomew (1989) claimed that the event may have been unforeseen, or due to no fault or negligence of the contractor, yet not necessarily qualify as an excusable delay. Apportionment of delays will be more complicated when

concurrent delays exist. Discussion of concurrent delays is beyond the scope of this paper. Discussion of “no-damage-for-delay” clauses can be found elsewhere (e.g., Lesser and Wallach 2003; Thomas and Messner 2003).

Schedule Analysis

Process of Schedule Analysis

Schedule analysis is a formidable challenge. It is the analytical process through which a professional employs the critical path method (CPM), together with a forensic review of project documentation and other pertinent data, to evaluate and apportion the effects of delays and other impacts on the project schedule (Holloway 2002). There are some typical steps for schedule analysis. Al-Saggaf (1998) describes a formal schedule analysis procedure with the following five steps: (1) data gathering; (2) data analysis; (3) identification of the root cause; (4) classification of the type of delay; and (5) assigning responsibility. Additionally, selecting an expert witness can be another earlier step (Pinnell 1992). Kartam (1999) proposes a generic methodology for analyzing delay claims. The window analysis or contemporaneous period analysis technique is the only delay analysis method recommended in that methodology since the data are assumed or perceived sufficient.

In general, CPM schedules play a critical role in success or failure of schedule analysis. Use of CPM schedules to prove construction claims became the standard (Wickwire and Smith 1974). A CPM analysis is one of the best ways to fulfill courts and mediators who want to hear in the simplest possible terms what really occurred day to day on the project (Frost 2002). Though its success is varied, CPM has been widely used for supporting delay and disruption claims in the early 1970s such as in Chaney & James Construction Co. v. United States, 190 Ct. Cl. 699, 421 F.2d 728 (1970) and Continental Consolidated Corp. v. United States, 17 CCF ¶81,137 (1972).

Schedule Analysis Techniques

Major schedule analysis techniques include: (1) total time or as-planned versus as-built; (2) what-if or impacted as-planned; (3) but-for or collapsed as-built; (4) window, snapshot, or contemporaneous period analysis; and (5) time impact analysis. Each technique may have several variants. Different techniques may yield different results for a same circumstance (Alkass et al. 1996; Stumpf 2000). Also, the same technique may provide inconsistent results (Hegazy and Zhang 2005). Detailed descriptions, advantages, and disadvantages of these techniques are available in previous studies (e.g., Alkass et al. 1996; Finke 1999; Wickwire and Ockman 1999; Stumpf 2000; Niesse 2004; Lovejoy 2004; Kim et al. 2005).

Inspired by the sometimes inexact and inconsistent results yielded by these techniques, both researchers and practitioners have attempted to either improve the existing techniques or propose new methods for schedule analysis. Alkass et al. (1996) proposed a new method called “isolated delay type” which utilizes advantageous attributes of the three techniques; namely but-for, window analysis, and time impact analysis. Unfortunately, there is no successful case using that method reported during the last 10 years. Shi et al. (2001) proposed a computation method using as-planned schedules as a basis of analysis and not based on the criticality of activities. Those premises in concert with other limitations can hamper its acceptability in the real world. Hegazy and Zhang (2005) developed a spreadsheet to facilitate daily window analysis for small and medium-size projects. From a practical viewpoint, however, daily window analysis tends to be too much work.

Lee et al. (2005) present a delay analysis method considering lost productivity. Unclear differentiation between delay and disruption as well as between their claims may really challenge its applicability. Discussion of delay versus disruption can be found elsewhere (e.g., Finke 2000). Kim et al. (2005) proposed a method using delay section, which addresses the two limitations of available methods, namely ambiguity in the analysis of concurrent delays and inadequate consideration of time-shortened activities. As the authors point out the method requires much effort and time in project records, updates, and analyses. Mbabazi et al. (2005) interestingly employ a Venn diagram to eliminate such drawbacks of the but-for method as its narrow focus on the viewpoint of a single party and its inability to accurately consider concurrent delays. However, the other drawbacks of the but-for method still exist. For instance, the context of when delays arose is not addressed when modifying the but-for method. This is especially important when effects of resource allocation are taken into account during delay analysis.

Motivating Case

Fig. 1 illustrates the as-planned, as-built, and collapsed as-built schedules of the motivating case. The as-planned duration is 7 weeks. The contractor will only be able to allocate two backhoes on this site. Numbers denoted in each activity bar indicate the number of backhoes needed for that activity. During the course of work there are two 2-week delays by the owner and the contractor on two activities, namely “excavation trench 1” and “excavation trench 2,” respectively [Fig. 1(b)]. The project is therefore de-
layed 1 week. Similar to Hegazy and Zhang (2005), the "o" (or "c") denoted in the bar indicates the owner-caused (or contractor-caused) delay in that activity.

The but-for method is used to analyze the delays. Fig. 1(c) shows the collapsed as-built schedule, which results from removing the owner delay in the as-built schedule. The difference in time between the completion date on the as-built and collapsed as-built schedules is the amount of owner-caused delays (Schumacher 1995). Thus, the owner solely caused the 1-week delay. Note that a window analysis with day-by-day window sizes also yields the same result.

The effect of resource allocation actually reverses the above result. The collapsed as-built schedule indicates that the contractor would have completed the project in 7 weeks but for the owner-caused delay. However, this is not true and practical. At the fourth week, the work would have required three backhoes for simultaneously performing the three excavation activities [Fig. 1(c)]. This contradicts the fact that the contractor could have been able to allocate only two backhoes on this site. That is, the contractor would still have delayed (paced) the project 1 week even if the owner had not caused the delay. The 1-week compensable delay yielded from available schedule analyses is therefore misleading. In other words, the owner has to be responsible for what he or she does if the effect of resource allocation is not taken into consideration in this circumstance. This example case demonstrates that resource allocation practices may substantially affect the credibility of schedule analysis and therefore should not be neglected.

Window Analysis under Effect of Resource Allocation

The need for reflecting and capturing the practice of resource allocation in schedule analysis is apparent and imperative. Many existing and new techniques pay little or no attention to this crucial issue. This paper adopts window analysis as a current technique for improvement. The reasons are twofold. First, courts and boards as well as practitioners and researchers generally agree that window analysis is the best available option (Finke 1999; Kartam 1999; Stumpf 2000; Hegazy and Zhang 2005). Second, a mechanism that incorporates resource allocation is more feasible, practical, and ready to use.

Enhanced window analysis considering resource allocation includes additional steps compared to the current window analysis. Seven steps of current window analysis are adopted from Stumpf (2000). Basically, Steps 2, 3, 5, and 6 between current and enhanced window analyses are similar. The enhanced window analysis introduces Step 0 which emphasizes that technical and resource constraints, and resource availability and allocation practice should be documented, disseminated, and obtained a consensus between the contractor and owner. This ensures that schedule analysis considering the effect of resource allocation is legally enforceable thereafter. For instance, the contractor must inform the owner at the beginning that he or she will only be able to allocate two backhoes on the site in the case described above. Resource allocation practices can change and/or be changed over time when more information from the project or the project parties is available. This reflects in Step 7, which includes updating Step 0 and repeats the procedure from Steps 2 to 6 for each window period to the end of the project.

Step 1 is to prepare and periodically update the as-planned CPM schedule under technical and resource constraints, and resource availability and allocation practices from Step 0. Step 4 of the current window analysis is subdivided into Steps 4a and 4b. Step 4b is the same between the two analyses. By including Step 4a, the enhanced analysis stresses rescheduling and rescheduling the not-yet-completed and not-yet-started activities, which reflects technical and resource constraints, and resource availability and allocation practice. Delays not only change critical path(s) but also disorganize planned resource allocation practices. This appears to be disregarded in current window analysis.

Finally, existing CPM scheduling with resource constraints, resource-constrained scheduling, and resource leveling in commercial scheduling software packages can facilitate Steps 1 and 4a. The answer to which one is chosen depends upon various factors such as contractual stipulations, availability of those scheduling techniques and/or software packages, and reliability of their underlying algorithms. Discussion of this issue is also beyond the scope of this paper.

Although several steps in the enhanced and current window analyses are similar, the enhanced method will result in more reliable delay analysis. As the motivating case suggests, resource allocation practice can significantly affect delay analysis. Unfortunately, the current method barely weighs resource allocation. The enhanced window analysis presented herein fundamentally solves this problem. It ensures how resource allocation practice should be embedded during delay analysis so that its effects in apportionment of delay responsibility can be captured in an equitable manner. As such, an answer to the question “who really caused delays” is more reasonable and potentially less disputable.

Case Study

Case Overview

Fig. 2 presents the as-planned schedule of the case study adopted from a resource-constrained CPM schedule (Kim and de la Garza 2003). The original planned contract duration was 13 days. The maximum available resource limits were two and one unit(s) per day for resource Types A and B, respectively (Fig. 2). Both the as-planned and as-built schedules met the resource limits. The actual contract duration was 16 days as shown on the hypothesized as-built schedule (Fig. 3). The project was thus delayed 3 days. There were four delays during the course of contract work. Like Mbabazi et al. (2005), these delays are directly inserted in the corresponding delayed activities (Fig. 3). Responsibility of this 3-day delay needs analyzing and apportioning.

Analysis of Delays

This section presents a window analysis for the case study. For comparison purposes, both current and enhanced window analyses described above are presented simultaneously. Microsoft (MS) Project is used for the analyses. As previously discussed, enhanced window analysis can employ existing CPM scheduling with resource constraints, resource-constrained scheduling, or resource leveling in commercial scheduling software packages for Steps 1 and 4a. In this case study, we use CPM scheduling and resource leveling in MS Project for the analyses.

Step 0: Dissemination and Consensus of Resource Allocation Practice

Resource allocation practice was simply to meet the resource limits for both resource Types A and B. This practice and other tech-
nical constraints (e.g., precedence relationships) remained unchanged during the course of work. The parties agreed on these issues.

Step 1: Development of As-Planned CPM Schedule Considering Resource Allocation Practice

The as-planned resource-constrained CPM schedule was developed based on Kim and de la Garza (2003) (Fig. 2). The contract duration was 13 days.

Step 2: Selection of Meaningful Window Sizes

Both existing window analysis and enhanced window analysis use similar window periods. Based on the as-built schedule (Fig. 3), the project is divided into four windows. Windows 1, 2, 3, and 4 are Days 1–5, Day 6, Day 7, and Days 8–16, respectively. Guidelines for defining reasonable windows can be found in Finke (1999).

Steps 3–7: Apportionment of Delays

The windows method is a repetitive process. To avoid unnecessary redundancy in presentation, we describe the analyses from Steps 3 to 7 in the same section. Schedule analysis of Windows 1 and 2 has graphical illustrations for representative purposes. Also, only resource allocation graphs that do not satisfy resource allocation practices will be presented and embedded in the corresponding schedule windows. Since the enhanced window analysis
ensures proper resource allocation for the remaining work after a window period, resource allocation graphs are not encompassed in that window.

Figs. 4 and 5 display results of the first window by traditional and enhanced window analyses, respectively. Traditional window analysis shows a 1-day compensable delay in this window period (Days 1–5). However, the resource Type A would be overallocated at Days 7 and 8. This implies that compensable delays in this period not only delayed the project 1 day but also made the initial resource allocation for remaining work impractical. Enhanced window analysis shows a 2-day compensable delay in the same period. Compared to the traditional window analysis, the actual compensable delay is 1 more day (2 versus 1).

The analysis is similar for the other windows. Figs. 6 and 7 depict the traditional and enhanced window analyses for the second window, respectively. There is a 1-day concurrent delay (compensable and inexcusable) in this period under traditional analysis. Again, the resource Type A would be overallocated at Days 7–9. In contrast, the enhanced window analysis shows that the project did not suffer any delay due to the delays in this window. The excusable and inexcusable delays on Activities C and D, respectively, in the third window actually did not cause project delay by both traditional and enhanced window analyses. However, the traditional analysis results in resource overallocation on Days 8–10. Both the traditional and enhanced analyses for the fourth and last window yield the same results, which show a 1-day inexcusable delay.

Table 1 summarizes results of the two schedule analyses. Compensable, concurrent (compensable and inexcusable), and inexcusable delays are 1, 1, and 1 days, respectively, under traditional window analysis. Enhanced window analysis results in 2 days and 1 day for compensable and inexcusable delays, respectively. Comparing the traditional analysis to the enhanced analysis, we see that there is a 1-day delay shift from the concurrent delay category to the compensable delay category. It should be noted that contractors are normally entitled to time extensions for concurrent delays. Consequently, the contractor would be penalized if resource allocations were neglected in this case study.

Discussion

This paper proves that practice of resource allocation significantly affects results of schedule delay analysis and apportionment of delay responsibility. This raises several interesting issues for practitioners and researchers as follows.
Possible Extended Effect of Delays

Traditional schedule analysis evaluates whether an event, several, or all events prolong the critical path(s) of the project. This paper shows that some delay can make unrealistic resource allocation in downstream work, which in turn may further delay the project. Available schedule analysis methods do not readily capture this possible extended effect of the delay. In other words, a schedule delay analysis that considers resource allocation is able to evaluate the “forward” effects of some delay. This results in a more trustworthy apportionment of delay responsibilities. Delay analysis aims at measuring the time difference between the actual project completion date and when the project would have ended but-for the owner-caused delays (Zack 2000). Unfortunately, the answer to “when the project would have ended but-for the owner-caused delays” will be unreasonable unless the effect of resource allocation is addressed in that delay analysis. Future research may develop systematic algorithms that can readily identify whether a certain delaying event causes an extended effect and effectively quantify it, if any.

Table 1. Schedule Analysis Summary

<table>
<thead>
<tr>
<th>Window number</th>
<th>Window period (date)</th>
<th>Completion duration (days)</th>
<th>Compensable</th>
<th>Excusable</th>
<th>Inexcusable</th>
<th>Concurrent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1–5</td>
<td>15 (14)*</td>
<td>2 (1)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>15 (15)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0 (1)</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>15 (15)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>8–16</td>
<td>16 (16)</td>
<td>—</td>
<td>—</td>
<td>1 (1)</td>
<td>—</td>
</tr>
</tbody>
</table>

*Results of enhanced window analysis (existing window analysis).
Positive/Negative Effect of Resource Allocation on Delay Responsibility

The effect of adding resource allocation considerations to a traditional schedule analysis can either add or reduce the impact of a delaying event. That is, either owners (i.e., in the motivating case) or contractors (i.e., in the case study) may face disadvantages in apportionment of delays under existing schedule analysis. The key question is “under what delay circumstances will contractors or owners face such disadvantages?” We are continuing to research this issue.

Legal Acceptability

Available schedule analysis techniques have frequently not incorporated the effects of resource allocation. Nevertheless, courts and review boards have supported delay claims based upon rigorous analysis techniques, especially the schedule window analysis method. We believe the methodology presented herein is logical and rigorous and will, over time, be acceptable to such bodies.

Implications of Applying Enhanced Window Analysis

Undoubtedly, the enhanced method potentially yields more reliable results. It however requires much more information from the project under dispute. Data collection for traditional window analyses is already an arduous task. Together with project records regarding delays (i.e., weather, change orders, etc.) as in the traditional method, the enhanced method further requires project records regarding practices of resource allocation. Although initial agreed resource allocation is important for the analysis, actual resource allocation also needs recording and using in the enhanced method. The reason is that some planned resource allocation practices have to be changed to accommodate uncertainties (including delay occurrences) that manifest during project execution. The other allocation practices may rarely change over time such as spatial resource constraints for a given activity.

Work methods can lead to change resource allocation. For example, a shift from a labor-intensive method to an equipment-intensive one and vice versa may result in radical changes in both resource allocation practices and project completion time. This raises an interesting issue that unrealistic resource allocation in downstream work in certain circumstance can be caused by either current delays as previously discussed or by current changes in work methods. Thus, the status of work methods, especially when differing from original approved plans, has to be recorded and addressed during delay analysis. The analysis also needs to separate changes in resource allocation due to delays from those due to work method changes. This further emphasizes the importance of collecting pertinent project records under the contexts of delays.

Recording project data for the enhanced window analysis can be less burdensome if resource allocation practices are selectively collected. Only critical resources which likely affect the project schedule need tracking and gathering their allocation practices. They include, but are not limited to, manpower, scarce and long-lead materials, and major equipment and plants. Their status consists of availability, delivery issues, technical and market constraints, planned versus actual allocations, and so forth. A computer-aided tool such as a spreadsheet program may facilitate tracking these resource allocation practices.

Conclusions

Resource allocation substantially influences project time performance. Impractical allocation may account for the project delay. Unfortunately, current schedule analysis often does not consider a project’s resource allocation. This paper illustrates that resource allocation can affect the results of a delay analysis. Performing a schedule analysis without considering resource allocations may increase the owner’s or contractor’s risk of assuming delay responsibility which is not his or her fault.

This paper has proposed steps to ensure that delay analysis considers impacts of resource allocation. They are embedded in the window analysis, which is currently the most acceptable schedule analysis technique, to enhance its credibility. A case study was used to compare the analyses and results of the traditional and enhanced schedule window analysis methods.

A delay analysis that includes the resource allocation used on the project is more trustworthy. As such, this research is useful to both industry professionals and researchers. The research enables more reliable schedule analysis. Future research may focus on issues to increase the usability, credibility, and acceptability of delay analysis considering resource allocation by project stakeholders.

References

Continental Consolidated Corp. v. United States, 17 CCF ¶81,137. (1972).


