COMPARISON OF DELAY ANALYSIS METHODOLOGIES

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ABSTRACT: During a construction project, delays may result from many circumstances. Delays may be caused by the owner, the contractor, by acts of God, or a third party. They may occur early or late in the job, alone or with other delays. Negotiating a fair and timely damage settlement is beneficial to all parties. Network-based scheduling is an excellent vehicle for negotiating settlement of changes, disputes, and delays throughout the project. In the construction industry, however, there is no single, standard, and "accepted" procedure to determine the impact of schedule delays due to change orders or other unplanned developments. In this paper three delay measurement processes were studied. These procedures were employed to measure delay impact, utilizing computerized critical path method (CPM) analyses, performed on genuine construction schedules. Results indicate that outcomes of delay analyses are not predictable, nor can one method be used universally. However, in given circumstances, one procedure can be more beneficial than another. Guidelines for the utilization of each method have been presented.

INTRODUCTION

The time that is allowed for construction performance is usually an important consideration for both the project owner and the project contractor. Yet, it is typical for construction projects to be delayed. Because of the many sources and causes of construction delays, it is often difficult to analyze the ultimate liability in delay claims (Kraiem and Diekmann 1987). There is more than one circumstance where delay may be encountered. It may occur early or late in the job, alone, or concurrent with other delays. How does an arbitrator settle a complex claim when both parties are at fault? The value of critical path method (CPM) network scheduling as a management tool is well known. In recent years, the use of network scheduling techniques in evaluating the validity of requests for time extensions has proven beneficial. Network-based scheduling has developed into an excellent vehicle for negotiating timely settlement of changes, disputes, and delays throughout the life of a project.

There are various methods offered in construction literature that are considered professionally acceptable for determining the schedule impact resulting from project delays and interruptions (most often, change orders), but which one should be used? Which technique might benefit the owner, which might prove most desirable from the standpoint of the contractor, which is most "fair" to all? It is interesting to note that there is no single, standard procedure to determine the impact of schedule delays due to change orders and other unplanned developments. Being cognizant of more than one procedure could be perplexing to the scheduling engineer. Different procedures could certainly lead to varying results in the amount of time a party has been impacted. This is due to the unique calculations required by each method.

The objective of this study is to analyze the impact of schedule delay on construction schedules, whose progress has been disrupted as a result of various types of project disturbances. This assessment of delay (in days) is valuable to project managers because it becomes a basis for financial calculations to determine penalties or other damages. The results produced by the analyses of the CPM networks will indicate the advantages and/or disadvantages that each method offers the owner and the contractor.

METHODS OF SCHEDULE IMPACT ANALYSIS

Three accepted methods were considered in this study. These are (1) As-Planned Method (U.S. Veterans Administration); (2) As-Built Method (Traditional Method); and (3) Modified As-Built Method (U.S. Corps of Engineers). There are two additional methods reported in the literature that are not considered in this study. There are the Float Allocation Method (U.S. Board of Contract Appeals) and the Concurrent Delay Method. The first method was dropped due to lack of literature that supported the use of it. In the second method's case, this study does not assign delay responsibility; therefore, the Concurrent Delay Method would be the same as the Modified As-Built Method, with the same results.

As-Planned Schedule Delay Analysis

The As-Planned Method measures the contractor's planned or intended performance. It does not measure the effect on the actual performance (Bramble and Callahan 1992). For a contractor to use the As-Planned Schedule, as a means of quantifying damages in a delay claim, whether it is a bar chart or a CPM diagram, it is required to show the following:

1. The As-Planned Schedule was in fact the basis of his bid estimate; that is, that the As-Planned Schedule was prepared before the bid and not as an afterthought.
2. The logic of the schedule is correct and could be performed.
3. The set-out durations are correct. That is, that the set-out durations "tie" to the estimate and can be derived by a calculation that recognizes the quantity of work to be performed, a reasonable estimate of productivity, and an assignment of a crew size (the size that was actually used) (Adrian 1988).

Under the As-Planned Method the scope of the changed work is reviewed to determine where and how the revisions should be incorporated into the schedule. The various delays are then formulated as events (activities), with time duration. The As-Planned Method requires all information concerning all delays to be analyzed at one time rather than making separate calculations for each delay. The analysis should wait until all the contractor's requests for changes are submitted. The schedule is then recalculated. The effect of the changes on the schedule is determined by comparison of the schedules before and after the changes were incorporated into the schedule.

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As-Built Schedule Delay Analysis

The As-Built Schedule is a widely accepted method of determining the impact of project delays. This consists basically of comparing what was planned to what actually occurred at the job site. This procedure, sometimes referred to as the "Traditional Method" is the most frequently used and easily recognized, but the most misunderstood and misused is the Delay Analysis Method (Bramble and Callahan 1992).

As-Built Scheduling Analyses presented in support of claims can be severely undermined if the dates used in the analysis conflict with those contained in project documentation, such as daily reports or monthly schedule updates. The scheduling expert's task and effectiveness can be substantially enhanced and such problems avoided through the proper maintenance of project documentation. Ideally, project documentation should be prepared as the project evolves, serving a purpose analogous to the "As-Built" drawings. That is, they should document how things happen when they happen (Barrie and Paulson 1978).

An important procedure is to verify the As-Planned Schedule prepared and submitted by the contractor. This schedule is often time-scaled, which reflects the contractor's intended progress, and which has been prepared prior to, or shortly after, the commencement of the work.

Developing the As-Built Schedule: After the As-Planned Schedule has been verified the next step is to develop a detailed As-Built Schedule from the project records. The As-Built Schedule should correspond to the activities included on an As-Planned Schedule. Compare the planned duration to the actual progress on the job site. By comparing the As-Planned to the As-Built Schedules, instances of suspected delay may become apparent.

In the absence of a viable CPM representing what actually happened, or if these facts weren't accurately monitored, the owner may direct that a CPM be prepared to evaluate the real causes of delay. The daily, weekly, and monthly reports, as well as personal observation by the owner's field team and the CPM consultant, are utilized to develop a comprehensive CPM. Next, the delay data are divided by cause. The causes are either: contractor; owner; combined; or no fault. When the delays involve any combination of excusable and nonexcusable events, time but not money for the delays may be awarded. When combination delays involve two nonexcusable delays, one by each party, then time but not money is awarded, as both parties are penalized for contributing to the overall delay. In other words, the contractor receives a time extension, but not delay damages, and the owner does not receive liquidated damages (Callahan and Quackenbush 1992).

Comparing the As-Planned and As-Built Schedules: After the As-Planned and As-Built Schedules have been developed and refined, a comparison of the two is conducted. The comparison will show how different the actual progress was from the original plan. Similarities between the schedules may also be important, perhaps reflecting the lack of merit in a delay claim, or the acceleration required to overcome delays. If the activity was actually performed in its original duration, it will be evident that it was neither delayed nor accelerated.

From the As-Planned Schedules, the available float for the affected activity prior to the delay is determined. From the As-Built Schedule, the float available for the affected activity after the delay period is determined. By comparing the originally approved plan to the As-Built Schedule, periods of delay become apparent. By recording the original float of an affected activity to the float remaining after the delay duration has been quantified, the impact on the project completion date can be assessed.

Most construction contracts contain language that give ownership of the means, methods, technique, and sequence of construction to the contractor. In the absence of contract language in lump-sum contracts regarding the ownership of float, the owner is at risk if he appropriates float time. On projects with contracts stipulating that the owner owns the float, the owner must be prepared to pay extra for this luxury as contractors learn that these projects are most costly (Householder and Rutland 1990).

If there is available float after the delay, then there is no penalty. If the activity has been forced into a negative position, then the offending party will be assessed a penalty equal to the number of days that the impacted activity's float is negative. If the owner caused the delay, the penalty will be an extension to the project completion date. If the contractor caused the delay, he may be liable for a liquidated damage penalty, if this time is not made up by the end of the project.

Similarities between the schedules may also be important, perhaps reflecting the lack of merit in a delay claim or the acceleration required to overcome delays. If the activity was actually performed in its original duration it will be evident that it was neither delayed nor accelerated.

Modified As-Built Schedule Delay Analysis

This procedure is sometimes referred to as "Time Impact Analysis." It was reported that the As-Built Method is an unreliable procedure to accurately measure the impact of a project delay on affected activities. The work in the field does not often match the theoretical activity breakdowns of a planned network schedule (Harris 1978; Brample et al. 1990; Callahan et al. 1992).

The operation can be summarized first by showing that the current baseline must be established. This is accomplished by determining the true status of the affected activity, at the update period immediately prior to each impact. It is necessary for the contractor to keep his network dynamic and useful by marking off completed activities on the network. Next, current impact must be established. When each impact has been entered into the schedule as an activity, the schedule is then recalculated. The change to the project completion date is the delay attributable to the impact being evaluated. Each impact to the schedule will affect specific activities; these need to be identified and the current status reported. If the impact comes between updates (which is most often the case), some experts suggest a special update be performed. However, it is the opinion of the writers that when the As-Built Schedule has to be recreated from (sketchy) project records this special update is impossible to make. Only by interpolation can midmonth float calculations be made. Any attempt to interpolate involves more effort, and the result cannot be proven to be more accurate. Jobsite productivity of any construction activity can vary from day to day, or week to week. To assume after the fact that productivity was linear, for example, during the entire month in question, could not be substantiated. Therefore, in this study if the impact comes between updates, the position of the activity at the update prior to and immediately following the impact were compared.

CASE STUDY

Project Description

The project is a commercial facility, considered to be fairly straightforward in design and construction. A general description of the facilities is: two large multistory administration/office buildings "C" and "P" (see Fig. 1); and two warehouses "F" and "S" of considerable size, with multistory administration areas. There was an immense amount of paving, both concrete and asphalt, in the surrounding areas. Other support facility structures include guard houses, electrical power and air conditioning buildings, etc. The value of the facility is about $35,000,000.

Hundreds of purchase orders for material and equipment were placed. Products were obtained from manufacturers both in and outside of the Kingdom of Saudi Arabia. Many orders were placed through local vendors. Not all items were readily available, many items were backordered, which presented the occasion for delays. Those purchase orders that required out-of-Kingdom placement incurred the usual difficulties; these were centered around the vendor drawings and vendor information meeting the design criteria. Although not all that unusual, some of the material required special (and expensive) expediting. All available float had been consumed.

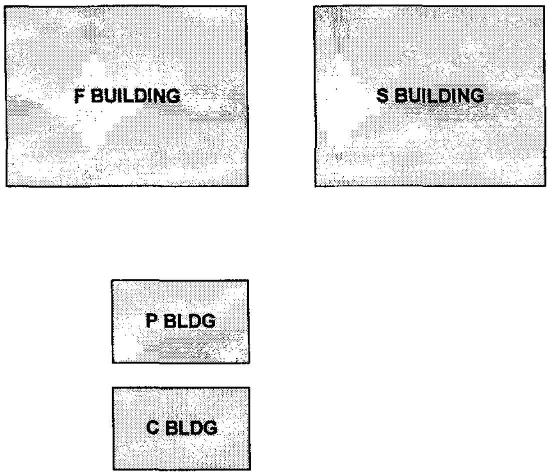


FIG. 1. Site Layout

The project schedule is a CPM diagram consisting of Revisions 00, 01 and 02, each made up of over 550 activities. These had been submitted to the owner for approval and to satisfy contractual obligations. Revision 00 was approved by the client on November 27, 1990. Shortly after the construction work, had started, the Gulf War began. A decision was made to cease the work effort because the length of the conflict was indeterminable. When the conflict had ended it was necessary to amend the contract, extending the completion date by two months. The scheduled project completion date had been December 17, 1992, but it was revised to February 28, 1993. This original schedule, issued for approval was hand drawn, and never computerized by the contractor. No progress updates were performed.

Within a few months after work was restarted it was apparent that the impact of the crisis on the project was greater than the two months by which the contract had been extended. The contractor requested, and received, an extension to the

PART A:						
	ACTIVITY		ORIGINAL	DELAY	INDIVIDUAL	REVISED COMPLETION
DELAY	NUMBER	DESCRIPTION	FLOAT	DURATION	IMPACT	DATE
ORIGINAL COMPLETION DATE = 23-Jun-93						
1	OCC17165	HVAC DUCTWORK 1st FL. C-BLDG.	164	121	0	6/23/93
2-A	0TM53222	DELIVER ELECTRIC DUCT HEATERS, C-BLDG. (2A)	169	127	0	6/23/93
2-B	0TM53321	DELIVER ELECTRIC DUCT HEATERS, P-BLDG. (2B)	71	127	-56	**8/18/93**
3	0CC09144	INTERIOR PARTITIONS, C-BLDG, 1st. FLOOR	65	16	0	8/18/93
4-A	0CC21166	ELECT. ROUGH-IN, C-BLDG. 1st. FLOOR	105	7	0	8/18/93
4-B	0CC21179	ELECT. ROUGH-IN, C-BLDG 2nd. FLOOR	11	7	0	8/18/93
5	0FC06158A	STRUCT. STEEL FRAME, F-BLDG, INSTALLATION	96	37	0	8/18/93
6-A	0FC10168	START PREFORM METAL ROOFING, F-BLDG.	96	98	0	8/18/93
6-B	0SC06007	STRUCTURAL FRAME, S-BUILDING	149	98	0	8/18/93
IMPACT OF EACH DELAY WHEN ENTERED AND CALCULATED INDIVIDUALLY			FLOAT/COMPL. DATE AFTER DELAYS		-56	**8/18/93**
PART B:						
IMPACT OF ALL DELAYS INCORPORATED INTO THE AS-PLANNED SCHEDULE, THEN CALCULATED.			FLOAT/COMPL. DATE AFTER DELAYS		-56	**8/18/93**

FIG. 2. As-Planned Analysis

project completion by four months (February 28, 1993 to June 13, 1993). The revised plan (Revision 01) was accepted by the client on June 8, 1991. This revision was also hand drawn, and never computerized. No progress updates were performed.

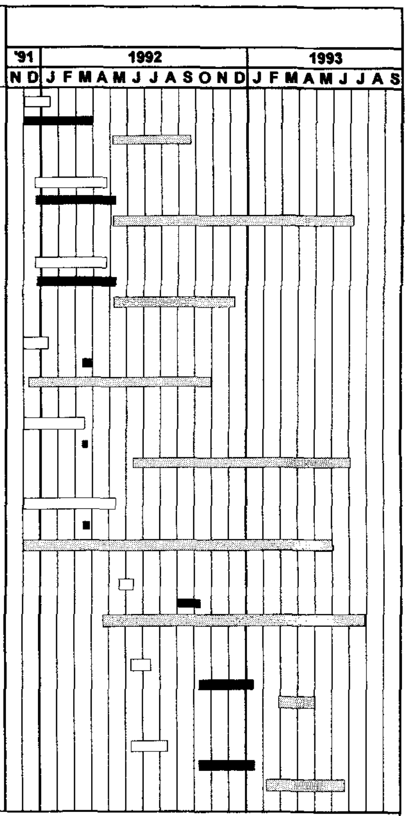
As the construction proceeded, a few delays had occurred —some caused by the owner and some by the contractor. It became clear that the project completion date was in jeopardy. The owner requested the contractor to update the schedule, reflecting the actual conditions of the project, and to display how they planned to complete the job on time. The contractor revised the plan, which was accepted by the owner as Revision 02, on August 8, 1992. This latest revision did not suggest another revision to the contract completion date (June 13, 1993). Once again, however, the contractor was not able to computerize his schedule or perform status updates. The project ultimately achieved completion, checkout and commissioning began in December 1993, 12 months after the original completion date.

Delay Description

Much time was spent in conferences and meetings between each available project engineer, as well as the contractor personnel. The results of this process was an accumulation of facts and figures that were summarized into six areas contributing the construction progress delay.

1. Demolition and reinstallation of HVAC ductwork: During the construction of building C and building P, it was discovered that the clearance in the hallway between the bottom of the A/C duct and the floor was insufficient. These main trunklines are very large, and when they had been installed as originally designed, there was not enough room for a person to walk underneath them. When this was discovered, the mechanical (air condition) design firm which was hired by the owner and is located in Europe, redesigned the system (resized the ductwork). Meanwhile, the construction contractor demolished what had already been installed. After design of the new heating, ventilation, and air-conditions (HVAC) system and approval of the plans by the client, the construction contractor was able to begin fabricating and installing the new ducts.
2. Late delivery of duct heaters: After resizing the ductwork the originally specified duct heaters were no longer acceptable. They needed to be redesigned and reordered. These electrical devices were not available in Saudi Arabia and, thus, needed to be ordered from the US. The long lead time associated with out-of-Kingdom procurement resulted in a delivery date that was well behind the originally scheduled installation date. This resulted in installation delays for buildings C and P.
3. Modification of interior partitions: As a direct result of the resizing of the air-conditioning ductwork, some of the interior concrete block walls required modification. The duct system was designed with the air-conditioning supply boxes entering the rooms through prepositioned "holes" in the walls. These holes, or blockouts were to be located high up the walls, above the location of where the suspended ceiling would be installed. The building contractor had to reposition most of the duct blockouts, where the walls had already been constructed, on the first floor of building C and P.
4. Rework of electrical wiring: As a result of the redesign of the duct heaters, the HVAC design firm also changed many of the locations of the duct heaters. By moving the duct heaters the electrical conduit that had already been installed needed to be changed. The building contractor

			PLANNED				ACTUAL				
DEL NO.	ACTIVITY ID	ACTIVITY DESCRIPTION	TARGET START	TARGET FINISH	ORIG DUR	ORIG FLT	ACTUAL START	ACTUAL FINISH	ACT DUR	DE-LAY DUR	BEG FLT MINU DELA
1	0CC17165	HVAC DUCTWORK 1st FL. C-BLDG.	12/1/91	1/12/92	43	164	5/3/92	9/26/92	146	121	+43
2A	0TM53222	DELIVER ELECTRIC DUCT HEATERS, C-BLDG.	12/21/91	4/28/92	130	169	5/7/92	7/3/93	422	127	+42
2B	0TM53321	DELIVER ELECTRIC DUCT HEATERS, P-BLDG.	12/21/91	4/28/92	130	71	5/7/92	12/5/92	212	127	<56>
3	0CC09144	INTERIOR PARTITIONS, C-BLDG, 1st. FLOOR	12/1/91	1/12/92	43	65	12/8/91	10/31/92	327	16	+49
4A	0CC21166	ELECT. ROUGH-IN, C-BLDG. 1st. FLOOR	12/1/91	3/14/92	105	67	6/14/92	6/30/93	381	7	+60
4B	0CC21179	ELECT. ROUGH-IN, C-BLDG. 2nd. FLOOR	12/1/91	5/9/92	161	11	12/1/91	5/31/93	547	7	+4
5	0FC06158A	STRUCT. STEEL FRAME, F-BLDG, INSTALLATION	5/20/92	6/9/92	21	96	4/26/92	7/31/93	461	37	+59
6A	0FC10168	START PREFORM METAL ROOFING, F-BLDG.	6/10/92	7/10/92	31	96	3/1/93	4/30/93	61	98	<2>
6B	0SC06007	STRUCT. FRAME, S-BLDG.	6/10/92	8/10/92	62	149	2/2/93	6/26/93	145	98	51



LEGEND:

▭ ORIGINAL SCHEDULE
▨ ACTUAL DURATION
■ PERIOD OF DELAY

FIG. 3. As-Planned versus As-Built Barchart

removed any conduit that was no longer usable. This removal was required on parts of all four floors of the C building.

5. Reinstallation of structural steel: The structural steel main trusses of the F building, which was provided by the owner's engineering consultant, had been installed according to the approved construction drawings. Due to the high winds experienced in the Eastern Province of Saudi Arabia, it is customary for large structures to undergo a 3D stress analysis. The result of the study indicated that the building design was undersized. The main girders were insufficient in size and strength. The analysis suggested that the steel members would not withstand the anticipated wind forces in the area. The solution was to weld steel plates, or "stiffeners" to the webs of the wide flange beams, in areas where the 3D analysis had shown possible weaknesses. Half of the dozen beams had already been lifted and fitted into place, the other six had been laid out on the floor. All welding teams were assigned to the work of strengthening the steel girders.
6. Rewelding of structural steel: During the assembly and installation of the structural steel components, random testing of the welds was conducted. Testing was conducted using X-ray procedures. The results indicated that some of the welds did not meet specifications. To ensure that the structure was joined soundly, all of the welds were individually inspected, and many of the joints required rewelding for additional strength. This delay further impacted construction progress in buildings F and S.

RESULTS

As-Planned Method

Two analyses were performed using the As-Planned Method, Part A and Part B. In Part A, after representing the

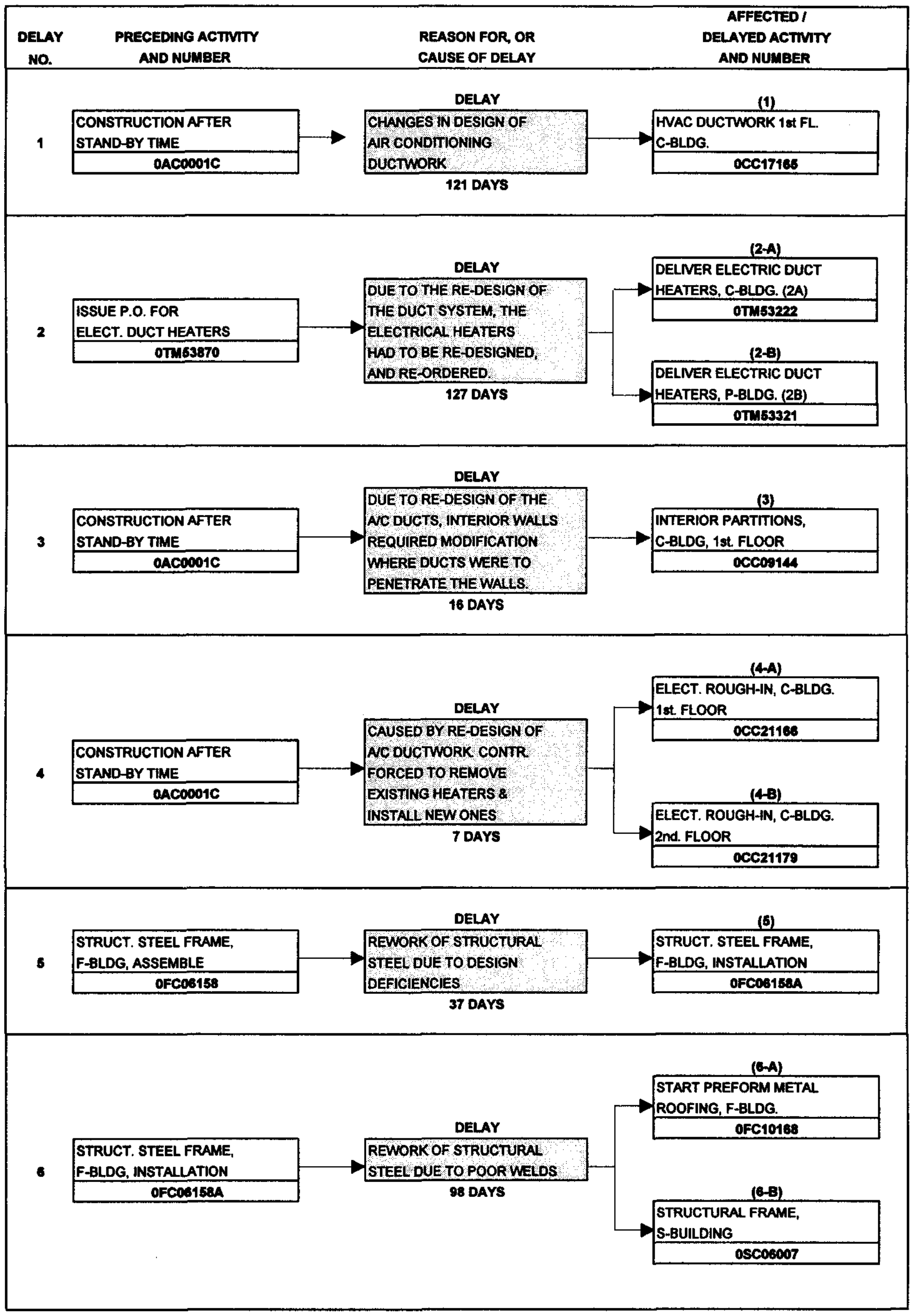


FIG. 4. CPM Network Fragments, As-Built Method

delay as activities, the delays were input one at a time and the schedule was calculated after each input. The resulting project completion date and total float available were recorded. In Part B, the six delays were input to the As-Planned Schedule, then the schedule was calculated. Utilizing these two approaches, there was no difference between them. In Fig. 2, Part A shows that the project completion date has been delayed by 56 days caused by delay No. "2-B," which is late delivery of electrical duct heaters. After the delay the total float was reduced to 56 days; therefore, delaying project completion by 56 days. Delay No. (6-A) caused 2 days delay to activities (0FC10168) and (0SC06007); however, these two days are included into the larger delay caused by delay No. (2-B).

As-Built Method

Fig. 3 shows the As-Planned Schedule overlay the As-Built Duration next to it. Hence, the relationship between the planned activity duration and when they were actually performed can be determined. Examination of job records provided substantiation of the start, finish, and duration of each delay. The effects of a change or disruption can be precisely determined with a CPM network. It can also be determined which succeeding activities have been impacted as a result. Fig. 4 is a graphical representation of each delay in the chain. The following summarize the findings.

- Delay No. 1 is 121 days. The delay does not impact the project completion date, as there are 43 days remaining after the delay. Therefore, this is a noncompensable delay.
- Delay No. 2 delayed two activities on the work plan by a total of 127 days. The first activity (delivery to the C-Bldg.) initially had 169 days positive float, and the second (delivery to the P-Bldg.) had 71 days positive float. After the delay, activity was reduced to −56 days total float, thus delaying project completion by that amount.
- Delay No. 3 impacted activity (0CC09144) by 16 days. This is a result of modification to the interior walls. The As-Planned Schedule indicated an original float of +65 days. Subsequent to the delay, there were +49 days remaining; therefore, no extension is warranted.
- Delay No. 4A impacts activities (0CC21166) and (0CC21179) by 7 days, as a result. The As-Planned Schedule indicates a float of +67 days for the first activity, and +11 for the second. Subsequent to the delay there are 60 and 4 days of positive float remaining, respectively; therefore, no extension is warranted.
- Delay No. 5, activity (0FC06158A) initially has 96 days of positive float. A delay of 37 days results in +59 days.
- Delay No. 6 causes delay to activities (0FC10168) and (0SC06007). The result is −2 days to the project completion date.

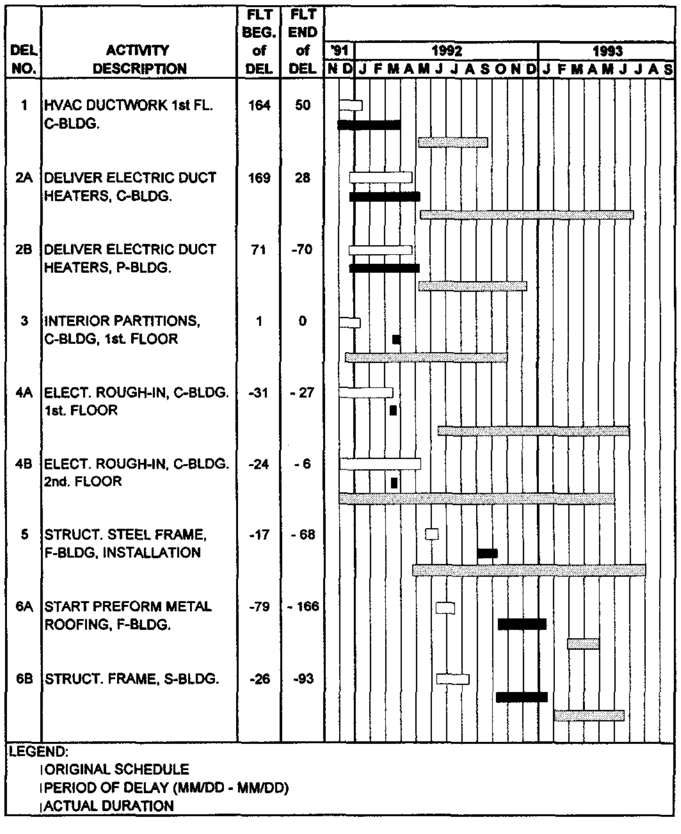
Therefore, the As-Built Method calculation shows that the project completion date has been delayed by 58 days.

Modified As-Built Method

When employing the Modified As-Built Method, the baseline from which to measure delay must first be established. The baseline schedule is the foundation for this delay analysis. Because the construction contractor failed to perform regular updating of the approved CPM schedule, "after-the-fact" contemporaneous status updating was done. This was performed by input of progress information (from monthly project reports) at intervals, simulating "real time" monthly statusing. Fig. 5 presents a bar chart that indicates the relationship between the float available per the original plan and that available at the time when the delay occurs. Impact of previous delay(s) is not taken into consideration or included in the calculation. Each calculation to determine the impact of a particular delay only considers the progress status at that period. This comparison (Fig. 6) presents how the total float of each activity has been affected by each delay. It should be noticed that an activity's float at the beginning of the period, minus the duration of the delay, is not necessarily equal to the remainder (mathematically). This is a result of the impact on the network paths as the project progresses. Activity on parallel paths can (and do) affect the float of the activities being considered in a specific delay analysis. In other words, total float is automatically recalculated at each reporting interval.

Utilizing the Modified As-Built Method, impacts are incorporated as they occur, the network recalculated, and the results immediately evaluated. The following summarize the findings.

- Delay 1: The impact is not a simple subtraction of original float minus delay duration, as in the As-Built Method. Although the activity is delayed by 121 days, the remaining float is determined by available float immediately following the disturbance. The delay did not impact the project completion date, there were 65 days remaining after the delay.
- Delay 2: After the delay period, there was no positive float available. Negative float was 70 days.
- Delay 3: The delay consumed all available float.
- Delay 4: Prior to the start of activities (0CC21166) and (0CC21179) float is −31 and −24 days, respectively. After the delay negative float was less; therefore, no compensation is required.
- Delay 5: The delay had an impact on the completion date by increasing negative float from −17 to −68 days. The delay is 51 days (68 − 17 = 51).
- Delay 6: Activity (0FC10168) realized increased negative float from −79 to −166 (87 days) as a result of the delay. Activity (0SC06007) increased negative float from −26 to −93 (67 days). Delay is 87 days.



DEL NO.	ACTIVITY DESCRIPTION	FLT BEG. of DEL	FLT END of DEL
1	HVAC DUCTWORK 1st FL. C-BLDG.	164	50
2A	DELIVER ELECTRIC DUCT HEATERS, C-BLDG.	169	28
2B	DELIVER ELECTRIC DUCT HEATERS, P-BLDG.	71	-70
3	INTERIOR PARTITIONS, C-BLDG, 1st. FLOOR	1	0
4A	ELECT. ROUGH-IN, C-BLDG. 1st. FLOOR	-31	- 27
4B	ELECT. ROUGH-IN, C-BLDG. 2nd. FLOOR	-24	- 6
5	STRUCT. STEEL FRAME, F-BLDG. INSTALLATION	-17	- 68
6A	START PREFORM METAL ROOFING, F-BLDG.	-79	- 166
6B	STRUCT. FRAME, S-BLDG.	-26	-93

LEGEND:
ORIGINAL SCHEDULE
PERIOD OF DELAY (MM/DD - MM/DD)
ACTUAL DURATION

FIG. 5. Original Float and Float after Delay

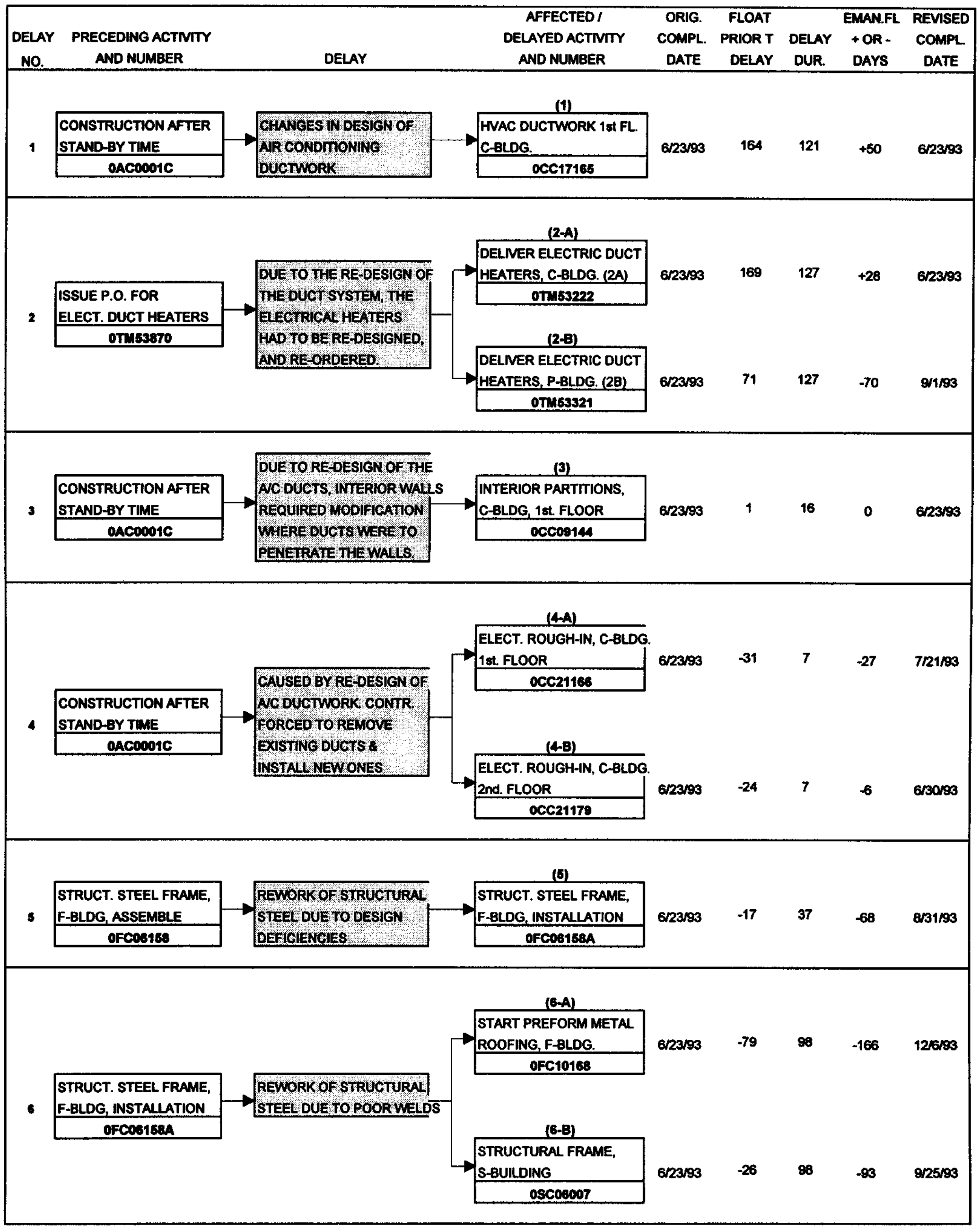


FIG. 6. CPM Network Fragments, Modified As-Built Method

TABLE 1. Summary of Results

Delay analysis procedure (1)	Delays (days) (2)
(1) As-Planned	56
(2) As-Built	58
(3) Modified As-Built	208

Therefore, the Modified As-Built Method calculation shows that delays are 70 days caused by delay No. 2, 51 days caused by delay No. 5, and 87 days caused by delay No. 6. The project completion date has been delayed by 87 days.

The summary matrix for the schedule analyses performed is presented as Table 1. This table compares the amount of delay when there is no responsibility. With no responsibility for delays assigned, the As-Planned Method accesses a penalty duration of 56 days. The As-Built Method penalizes the quilty part by 58 days. The difference between the penalty is in the applications of the methodologies. The As-Planned Method considers all delays at once, therefore, the completion date will be adjusted due to the largest delay, on the most critical path. The As-Built procedure compares original float to float available after the delay. Delay No. 2 forces the completion date negative by 56 days, and delay No. 6 by 2 additional days. Total delay is assessed as 58 days. The Modified As-Built Method results in delays of 70, 51, and 87 days, for delay Nos. 2, 5, and 6, respectively. The total is the sum of these, or 208 days. Each delay is calculated separately and at the time closest to when the delay actually occurred.

Table 2 presents guidelines for the utilization of each methodology. Depending upon the time and resources available, and the accessibility of project control documentation, one method may be more practical or cost effective. This matrix displays the three methodologies, and the suggested project documentation required to perform each. The As-Planned Method requires that only the original bar chart or CPM network be available. The As-Built Method requires the original bar chart or CPM network, together with some job-site records, schedule updates, etc. To conduct the Modified As-Built

TABLE 2. Suggested Use of Delay Analysis Methodologies

Project control data available for review and analysis (1)	Methodology		
	As-Planned (2)	As-Built (3)	Modified As-Built (4)
Original, approved construction schedule—CPM network or bar chart, with no progress status or updating having been performed	Yes	No	No
Original, approved construction schedule—CPM network or bar chart, with some progress status or updating having been performed	Yes	Yes	No
Original, approved construction schedule—CPM network, with regular progress status and updates having been performed	No	No	Yes
Original, approved construction schedule—CPM network, with regular progress status and updates having been performed. Evidence of concurrent and consecutive delay among contracting parties	No	No	Yes

delay analyses, the base schedule required is a CPM network, with sufficient job progress information to reconstruct a computerized As-Built Schedule.

CONCLUSIONS

This study analyzed the impact of schedule delay on construction schedules, whose progress has been disrupted as a result of various types of project disturbances. There are various methods offered in construction literature that are considered professionally acceptable for determining the schedule impact resulting from project delays and interruptions. Three methods were considered in this study. These are (1) As-Planned Method; (2) As-Built Method; and (3) Modified As-Built Method.

The results of the study indicate that the outcomes of delay analyses are often not predictable, that one method may not be used universally over another in all situations; or one method might prove to be the most desirable from the standpoint of the contractor or the owner. The study reveals that depending on the time and resources available, and the accessibility of project control documentation, one method may be more practical or cost-effective.

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