CHAPTER 6

CONSTRUCTION PROGRESS CONTROL

No project planned by the CPM can be completed satisfactorily if only the planning and scheduling phases are performed. Control needs to be carried out to satisfy the dynamic nature of the construction process. Essential control demands a continuing application of the CPM concepts to guide project execution.

This chapter is devoted to study construction progress control. Three areas will be covered to demonstrate control of the construction phase of a project. These are:

1. Updating construction schedules.
2. Cost control.
3. Evaluation of work changes and delays.

6.1 Updating Construction Schedules

As construction proceeds it is common that the actual activity durations will not be exactly as estimated. Furthermore, there may be additions or deletions to the scope of a contract that will affect the times at which the activities can be started and completed. Updating is a procedure for introducing into the schedule the latest progress information.

The degree of uncertainty, the troubles encountered and the time to completion are the factors influencing the frequency of periodic schedule updating. Update time is the time at the end of which data have been submitted for updating the schedule. A completely new estimate of the amount of work remaining to be done should be made for each activity at the time of updating. In the same time the probable output of various resources should be assessed. This gives new durations for various activities.

If the job is found to be behind schedule, future activities may be crashed to restore the position. Other remedial courses to maintain the desired completion date are redistribution of resources and/or introducing new construction methods. These alternative remedies should be compared to obtain the cheapest overall solution.

Procedure for updating construction schedules

1. Change the duration of all completed activities to zeros.

2. Identify all activities on which work is currently proceeding as live activities.

3. Put early start time of live activities equals the update time and their durations equal the remaining duration given by the update report.

4. Change durations of future activities as given in the update report.

5. Carry out network analysis in the normal way and prepare a new activity schedule.

Example 6.1

Consider Example 2.14. Figure 2.19 shows the initial schedule of this small construction contract. The position of the activities at the end of the fifth week is as follows:

- Activities B, C, D and E have been completed.
- Activity F is ready to start at beginning of week 6.
- Remaining duration of activity H is 4 weeks.
- Remaining duration of activity I is 3 weeks.
- Activity G will not start until end of week 7.
- Volume of work in activity L has been increased by 33% approximately.
- Activity J has been omitted.
- It is decided to shorten activity K by 2 weeks.

Construct the updated schedule indicating the critical path and showing new activities times.

Solution

The solution is given in Figure 6.1. Live activities are F, H and I. Unless activity K has been shortened by 2 weeks, the completion time will be delayed. Critical activities are G, K, and N.

6.2 Cost Control

Objective and Scope

The key to a profitable construction contract is to keep construction costs within the budget and to know when and where job costs are deviating. The budget determines the amount of cash that will be required over the various periods of a contract. Construction cost reports should be prepared to determine those activities where expenses are excessive. The detection of those costs after the work is finished leaves the contractor with no possibility of taking corrective action. The objectives of a cost control system are:

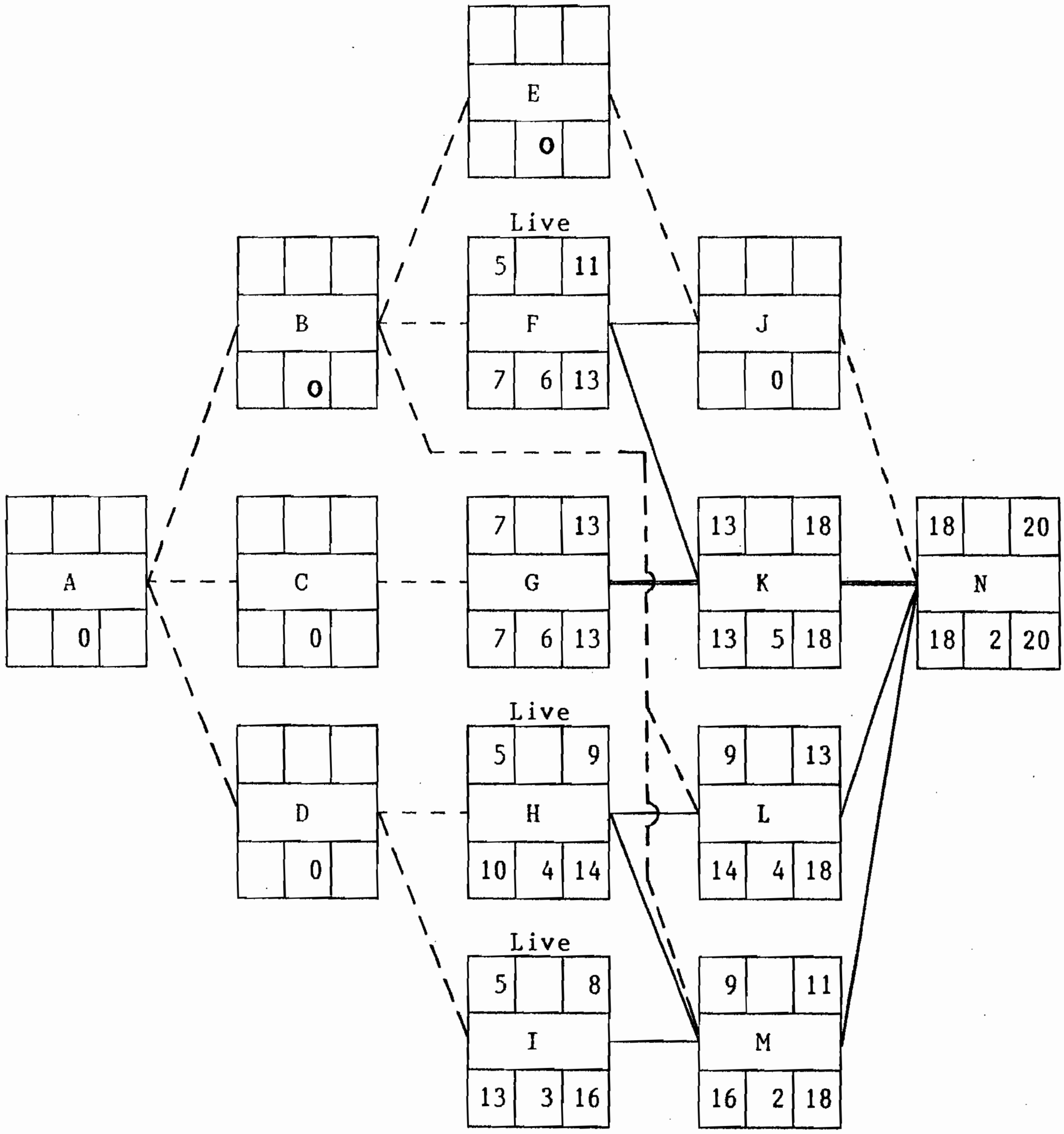


Figure 6.1 Updating Construction Schedule of the Contract of Example 2.14

1. to draw immediate attention to any contract activity which is proving to be uneconomic to the contractor in order that corrective actions can be taken to keep cost within acceptable bounds.

2. to develop actual production rates of labour and equipment and actual percentages of material wastage to feedback estimating of future works.

The cost estimate prepared for a contract should be the basis for the cost control of that contract. Therefore the figures prepared by the estimator before submitting the tender should be in a form suitable for use in cost control.

Cost control for a construction contract is limited to the cost of labour, plant, materials and site overheads. An effective correspondence between activities used for scheduling and the codes used for cost accumulation should be established. Costs associated with subcontractors are affected mainly by analysing the subcontractor's quotations; so these costs will not be included in the cost control system. Head office expenses need not also arise in the cost control system; site has no control on the spending of these items and they are dealt with at a higher level of management.

Control of cost and time should be linked together. This is because if the information on cost is used without reference to the programme, the progress of work can be very misleading.

Collection of Site Cost Data

The foreman who is in direct charge of a small group of men is responsible to allocate costs on a daily basis, in respect of the labour under his supervision and the plant which is working in association with him. Cost of the amount used of each individual material is also recorded. Summary sheets have to be prepared at intervals to accord with the detail of the cost control system.

The Contract Time-Cost Envelope

One of the most frequently prepared graphical displays used for contract control is the time-cost envelope. Curves are produced by plotting the cumulative cost of the works throughout the period of the contract. They will have the appearance of a letter S that has been somewhat flattened. A typical S - curve is shown in Figure 4.5. The S - curve derived from the early start schedule may be considered as one boundary of a field of S - curves. The curve derived from the late start schedule serves as the other boundary of the field. The two boundaries form a closed envelope which is called the contract time-cost envelope, see Figure 6.2.

The physical relationship between the earliest cost and latest cost curve will depend upon the relative amount of float each activity in the network has. If there is a great deal of float on the activities of the network, this will tend to widen the horizontal distance between the curves. Therefore, the shape of the envelope provides an indication of the nature of the control which will be required for the contract.

All other schedules will produce S - curves that lie within the contract time-cost envelope. A target curve is generated with all activities at their scheduled times. It will be called Budgeted Cost of Work Scheduled (BCWS) curve.

Frequently, activity performance differs from the plan for a combination of two reasons. First, the spending rate differs because insufficient work was accomplished during the preceding period. Second, the cost per unit of work was different than anticipated, although the scheduled quantity was achieved. Two other curves can then be derived.

The actual cost information which the contractor collects from the site during the progress of work can be used to draw a cost-to-date curve. It will be called Actual Cost of Work Performed (ACWP) curve. All the time that this curve remains within the envelope, the contractor can be happy that progress is being made in accordance with the overall plan.

The other curve shows the valuation of the work carried out in accordance with the contractor's original tendered estimate, using the rates appearing in the bill of quantities. It is called budgeted cost-to-date curve or Budgeted Cost of Work Performed (BCWP) curve. This curve should always lie somewhere within the contract time-cost envelope.

The Earned Value Concept

The earned value concept is used for cost performance measurement. The technique relies on the existence of a baseline plan against which performance may be assessed. Performance is then measured using earned value, which is essentially a computation of the value of work satisfactorily completed.

The earned value technique recognizes that cost measurement is relatively easy for completed activities but difficult for those activities underway at the data date. The manager should determine the percent complete for each activity using Equation 6.1. Then the earned value of an activity is its percent complete times its current budget.

$$\text{percent complete} = \frac{\text{projected duration} - \text{remaining duration}}{\text{projected duration}} \times 100 \qquad (6.1)$$

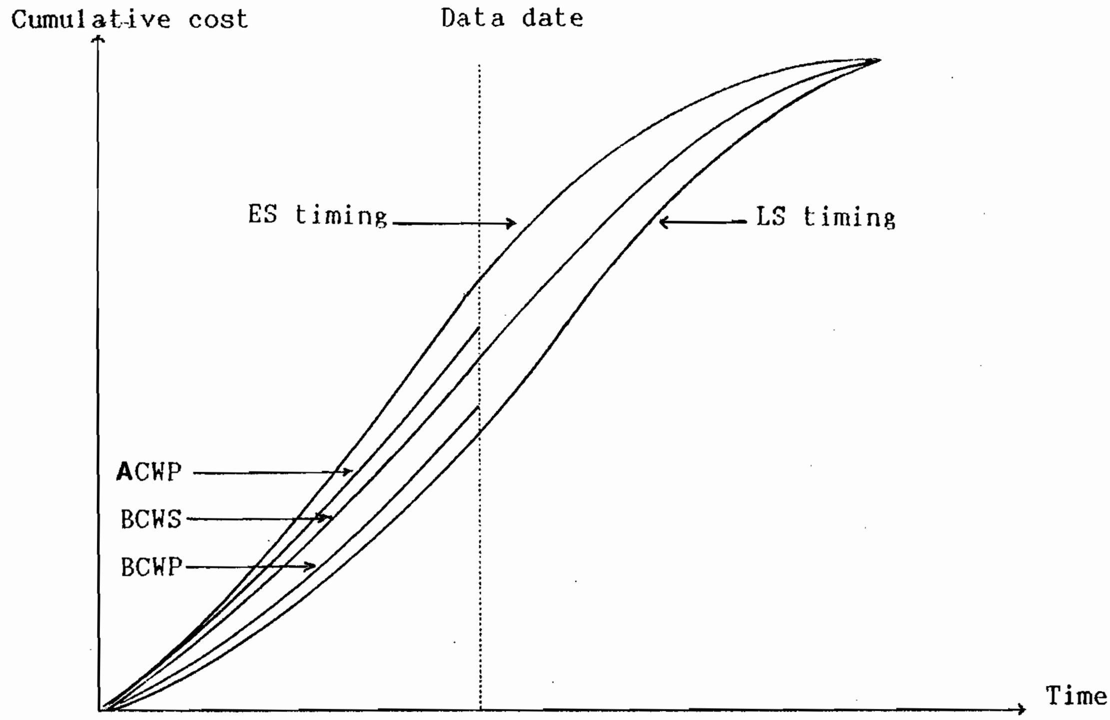


Figure 6.2 The Contract Time-Cost Envelope

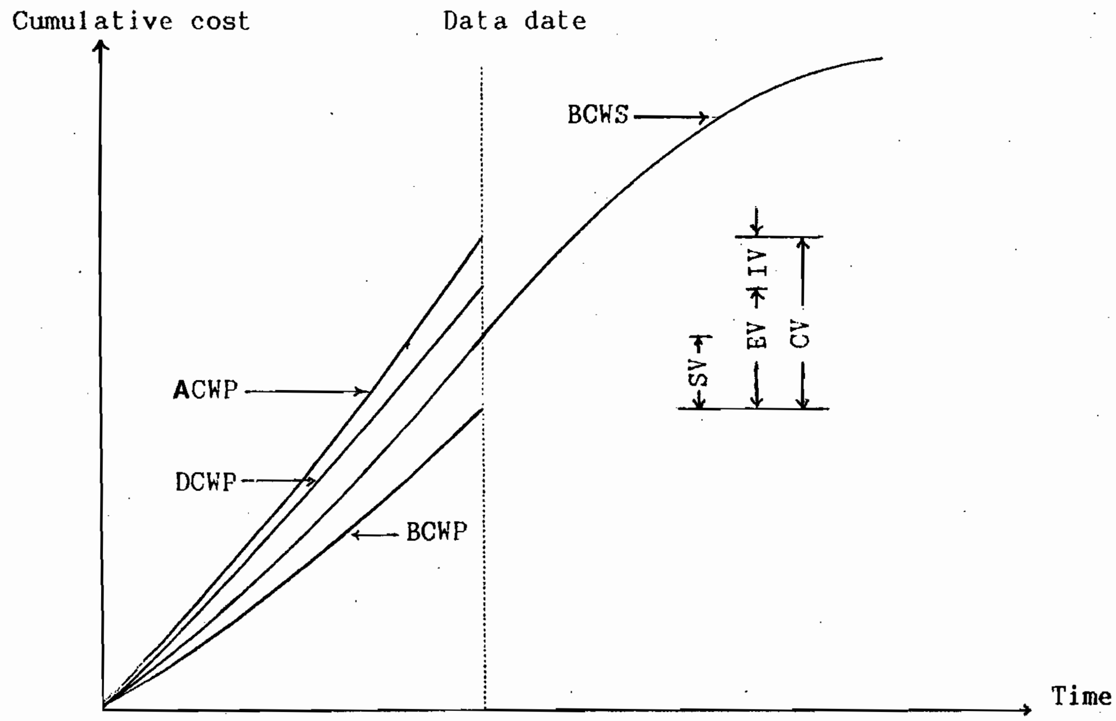


Figure 6.3 Indicators for Performance Measurement

There are three key indicators in performance measurement: budgeted cost for work scheduled (BCWS), budgeted cost for work performed (BCWP) and actual cost for work performed (ACWP), see Figure 6.3.

BCWS measures the planned budget for the work which should take place, provided that the contract is performed exactly in accordance with the baseline plan.

BCWP measures the value of work that has been accomplished to date. The value is based on the expected cost for achieving the work element and the degree to which it has been accomplished. It is independent of the actual cost of the work effort.

ACWP measures the expenditures to perform the work effort. The cost of the work is independent of the value of what has been done and independent of the plan for accomplishing work.

The above three indicators are used now to measure the contract cost performance, see Figure 6.3.

Cost Variance (CV)

The difference between the actual cost (ACWP) and the earned value (BCWP) is known as cost variance. If the work effort has cost less than the value of the work accomplished, there is a favourable cost variance.

$$CV = BCWP - ACWP \qquad (6.2)$$

where negative CV means over cost,
zero CV means on cost, and
positive CV means under cost.

Schedule Variance (SV)

The difference between the planned effort (BCWS) and the earned value (BCWP) is known as schedule variance. If the work accomplished has surpassed the effort planned to be achieved by the data date, there is a favourable schedule variance - the contract is ahead of schedule as measured in units of cost, rather than time units.

$$SV = BCWP - BCWS \qquad (6.3)$$

where negative SV means behind schedule,
zero SV means on schedule, and
positive SV means ahead of schedule.

<u>Cost Performance Ratio (CPR)</u>

The ratio of BCWP to ACWP is known as cost performance ratio. If the work effort has cost less than the value of the work completed, there is a favourable cost performance ratio.

$$CPR = \frac{BCWP}{ACWP} \tag{6.4}$$

where CPR > 1 means under cost,
= 1 means on cost, and
< 1 means over cost.

<u>Schedule Performance Ratio (SPR)</u>

The ratio of BCWP to BCWS is known as schedule performance ratio. If the work completed has exceeded the effort planned to be achieved by the data date, there is a favourable schedule performance ratio - the contract is ahead of schedule as measured in equivalent monetary units.

$$SPR = \frac{BCWP}{BCWS} \tag{6.5}$$

where SPR > 1 means ahead of schedule,
= 1 means on schedule, and
< 1 means behind schedule.

<u>Effect of Inflation</u>

The BCWS and BCWP are in constant (real) value money while ACWP must be in current monetary values (MOD) by definition. A deflated (real) cost of work performed (DCWP) curve should be derived by using the inflation indices, see Figure 6.3.

<u>Inflation Variance (IV)</u>

The difference between the actual cost (ACWP) and the deflated cost (DCWP) is known as inflation variance. It represents effect of changes in wages and prices. The contractor is not responsible for this part of CV.

$$IV = DCWP - ACWP \tag{6.6}$$

where negative IV means deflation over cost,
zero IV means no inflation, and
positive IV means inflation over cost.

Expenditure Variance (EV)

The difference between the deflated cost (DCWP) and the earned value (BCWP) is known as expenditure variance. It represents the part of CV which the contractor is responsible for.

$$EV = BCWP - DCWP \tag{6.7}$$

where negative EV means over cost,
zero EV means no increase, and
positive EV means under cost.

Example 6.2

The contractor of the small contract given in Example 2.14 introduces the following cost control system to check progress of his work.

code 10	plant type A
code 20	plant type B
code 30	labour gang A
code 40	labour gang B
code 50	labour gang C
code 60	materials
code 70	site overheads

The contract programme is given in Table 2.18. The budget for the work is given in Table 6.1. At the end of week 5, the current progress is recorded as shown in Table 6.2. Actual costs to the end of week 5 have been recorded and are listed in Tables 6.3 and 6.4.

a) Draw the contract BCWS curve and the BCWP and ACWP curves to the end of week 5. Comment on the progress of the contract.
b) Draw up a table of variances for the various codes and give recommendations to the site manager for future action.

Solution

a) Figure 6.4a shows the contract programme in bar chart form. The planned total expenditure on each activity is assumed to be uniform with time. The weekly budgeted totals are plotted on a cumulative basis as the BCWS, shown in Figure 6.4c.

Figure 6.4b shows the contract bar chart updated to end of week 5. The percentages complete are determined using Equation 6.1. Once again it is assumed that expenditure is uniform with time. The weekly budgeted totals are plotted on a cumulative basis as the BCWP, shown in Figure 6.4c.

Table 6.1 Budget Values for the Contract Given in Example 6.2

Activity	Cost Codes							Total (LE'000)
	10	20	30	40	50	60	70	
B	-	10	10	-	-	-	4	24
C	11	15	15	20	-	60	24	145
D	10	-	-	-	20	40	14	84
E	5	20	20	10	-	50	21	126
F	10	25	25	-	20	60	28	168
G	15	10	10	30	-	40	21	126
H	5	-	-	-	10	50	13	78
I	-	25	23	-	-	20	12	80
J	20	25	25	40	-	70	36	216
K	10	-	-	-	20	30	10	70
L	10	40	40	20	-	80	38	228
M	20	15	15	-	40	10	20	120
N	-	-	-	30	-	-	6	36
Budget totals	116	185	183	150	110	510	247	1501

Table 6.2 Progress Report at End of Week 5

Activity	ES	Projected Completion
B	0	3
C	0	5
D	0	4
E	2	5
H	3	9
I	3	8

Table 6.3 Actual Costs to End of Week 5

Weeks	Costs (LE'000)
1	72
2	72
3	125
4	130
5	65
	Σ = 464

Table 6.4 Distribution of Actual Costs to End of Week 5

Cost Codes							Total (LE'000)
10	20	30	40	50	60	70	
29	60	58	31	21	186	79	464

The actual costs to end of week 5, given in Table 6.3 are used to draw ACWP curve shown in Figure 6.4c. From this figure, it is clear that SV = LE -92000, i.e., the contract is behind schedule and CV = LE -27000, i.e., the contract has been losing money.

b) The value of work done in each of the individual cost codes for each activity is computed on a similar basis and summarized in Table 6.5. From this table of variances, it is clear that all cost codes, except code 50 (labour gang c), have negative variances. Clearly, cost code 60 (materials), cost code 70 (site overheads) and cost code 20 (plant type B) have adverse variances and they need great attention.

Corrective actions to reduce materials variance include checking that: the storage space is adequate, mechanical equipment is used for handling materials, the storekeeper is well trained, and a materials engineer is employed to plan the flow of the right quantity of materials at the right time and to check that all invoices fulfill the original order.

Concerning site overheads, an attempt should be made to shorten the overrun to reduce losses. Actions to deal with adverse variance of a unit of equipment include changing or adding personnel, employing different equipment and switching to an alternate construction method. Corrective actions to reduce labour variance include changing personnel or supervision and changing labour incentive scheme.

Table 6.5 Value of Work Done up to End of Week 5

Act.	Percent Complete	Cost Codes							(LE'000)
		10	20	30	40	50	60	70	
B	100		10	10				4	24
C	100	11	15	15	20		60	24	145
D	100	10				20	40	14	84
E	100	5	20	20	10		50	21	126
H	33.33	1.7				3.33	16.67	4.33	26
I	40		10	9.2			8	4.8	32
BCWP		27.7	55	54.2	30	23.33	174.67	72.13	437
ACWP		29	60	58	31	21	186	79	464
CV		-1.3	-5	-3.8	-1	2.33	-11.33	-6.87	-27

(a)

Act.	Budget/wk
B	12
C	29
D	28
E	63
F	28
G	21
H	13
I	20
J	108
K	10
L	76
M	60
N	18

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Weekly	69	69	148	153	90	82	82	62	142	265	157	86	10	10	10	10	10	10	18	18
Cumulative	69	138	286	439	529	611	693	755	897	1162	1319	1405	1415	1425	1435	1445	1455	1465	1483	1501

(b)

Act.	Budget/wk	% Complete
B	8	100
C	29	100
D	21	100
E	42	100
H	13	33.33
I	16	40

Week	1	2	3	4	5
Weekly	58	58	100	121	100
Cumulative	58	116	216	337	437

(c)

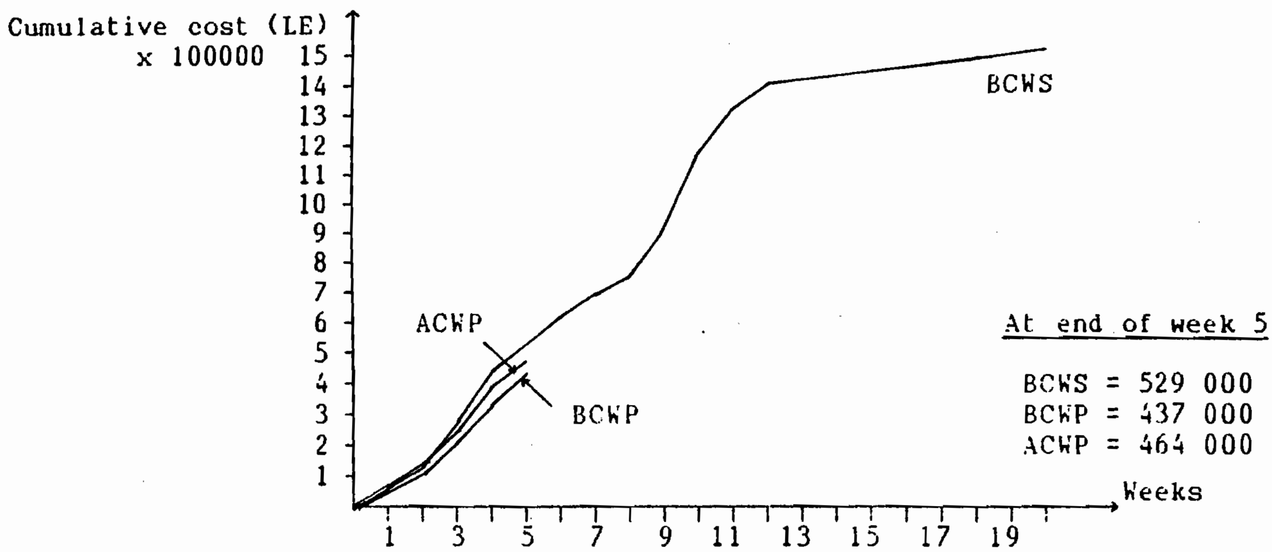


Figure 6.4 Solution of Example 6.2
(a) Bar Chart for Contract Schedule Showing Budgeted Expenditure
(b) Bar Chart Updated to End of Week 5 Showing Value of Work Done
(c) Budget Value and Cost Curves

6.3 Evaluation of Work Changes and Delays

Work changes mean changes in the volume and duration of work to be performed from that envisaged at the start of the contract. Variation in the form of addition and deduction result in more or less cost and time to execute the varied item. On the other hand, omissions mean less cost but not necessarily less time. It may result in wasting resources.

For instance, if the quantity of work in a critical activity is increased by x% then the duration of the activity will be extended by x%. The direct cost of the activity should be increased by the same ratio while the indirect cost of the contract might be increased for the extended period.

It is typical for construction contracts to be delayed. A delay that occurred on a noncritical activity does not participate to the delaying completion date of the contract. Therefore delays on noncritical paths are not considered.

Types of Delays

Delays can be divided into the following categories:

1. those over which the client has control; compensable delays
2. those over which the contractor has control; nonexcusable delays
3. those over which neither party has any control, excusable delays
4. concurrent delays

A brief description of each category is given below.

<u>Compensable Delays</u>

A delay is deemed compensable to the contractor when its cause is within the control of, is the fault of, or is due to the negligence of the client. Examples include:

- late possession of site
- faulty design
- incomplete drawings and specification
- changes in scope
- suspension of work
- differing site conditions
- late delivery of client-supplied materials
- client's failure to disclose information vital to the contractors

For this type of delays, the conditions of contract should allow the contractor to be entitled to a time extension and to monetary recompense for extra costs associated with the delay.

Nonexcusable Delays

In this category the contractor's own actions or inactions have caused the delay. The contractor is not entitled neither time extensions nor monetary recompense from the client. He may pay liquidated damages according to the contract.

Excusable Delays

These are occurrences over which neither the client nor the contractor has any control. Examples include:

- unforeseen future events which the contractor has not been aware.
- impracticable things which the contractor can only do at an excessive cost.
- events in which the contractor is blameless such as material shortages beyond what was expected at the time of bidding.

The contract should declare the excusable delays. The sole relief for these delays is a time extension.

Concurrent Delays

Concurrent delays are two or more delays that occur at the same time, either of which, if it occurred alone, would have affected contract completion date. They can be classified as follows:

a. Excusable delays and nonexcusable delays.
b. Excusable delays and compensable delays.
c. Excusable delays and compensable delays and nonexcusable delays.
d. Compensable delays and nonexcusable delays.

Concurrent delays with an excusable delay will generally be considered as excusable delays. For these delays the contractor is entitled to time extension if the delays are on the critical path. This protects him from any resulting liquidated damages. For concurrent compensable and nonexcusable delays, the contractor is allowed a time extension for completion with each party suffering its own losses. The terms of the contract should declare the method of evaluation of such claims.

The As-Built Schedule

The as-planned schedule of a contract is its initial schedule. The as-built schedule will show the time status of the contract and the causes of all the time changes that happen. Both schedules will be drawn as time-scaled diagrams.

The as-built schedule provides a complete record of the work as-built. It shows all delays encountered and the actual starting and finishing dates of every activity. When compared with the initial schedule, it gives the data for the evaluation of all time delays encountered during construction. The following legend will be used to draw the as-built schedule: "o" to represent compensable delays; "c" to represent nonexcusable delays and "n" to represent excusable delays.

This schedule will now become the basis for analysis of the effect of different types of delays on the contract's progress.

Analysis of the As-Built Schedule

If the as-built schedule contains more than one equally delayed critical path, each of them will be examined in turn to determine its net working duration. This is the actual time in which all the activities along a path could have been completed if there had been no work changes or delays affecting the path. This can be found as follows:

A path net working duration = its total duration - all delay times lying on it (6.8)

The net working duration may be less than the estimated contract duration given by the as-planned schedule. This means that the contractor has performed the contract within the estimated time. On the other hand, it may exceed the contract duration. Then the contractor's original estimates were incorrect.

Having examined all apparent critical paths, the scheduler can determine the primary path(s) as that(those) with the longest net working duration. The work could not have been completed in less time than this, even if the delays had not occurred. Other parallel apparent critical paths may be classified as secondary as they do not control the contract duration. They have float with respect to the primary path.

If the as-built schedule contains one primary critical path, then the overall effects of all eventualities on the contract will be the difference between the path actual duration and its net working duration. The responsibility of each party for the contract delayed completion is then determined by inspection.

If the schedule contains more than one primary critical path with the same net working duration, then it may have concurrent delays. A brief discussion of these delays is provided next.

Analysis of Concurrent Delays

The difference between the as-planned schedule duration and the as-built primary critical paths duration represents the total delay duration. This total delay duration can be portioned out as follows:

1. The number of days in which the contractor's and the client's delays were concurrent are those days where the two types of delays occurred; one delay affected a primary critical path and the other affected the other primary critical path on the same day(s).

2. The number of days of concurrent delays with an excusable delay are those days where an excusable delay occurred on any primary critical path and a contractor's delay, a client's delay, or both delays occurred on other primary critical path(s) on the same day(s).

3. Excluding delays number 1 and 2 above, the number of days a contractor should be assessed for liquidated damages is the smallest number of days of inexcusable delays on all primary critical paths.

4. Excluding delays number 1 and 2 above, the number of days a contractor should be reimbursed for additional overhead expense plus a time extension is the smallest number of days of compensable delays on all primary critical paths.

5. Finally the number of days a contractor should be given a time extension is the difference between the total delay duration and the summation of the above four delays duration.

Example 6.3

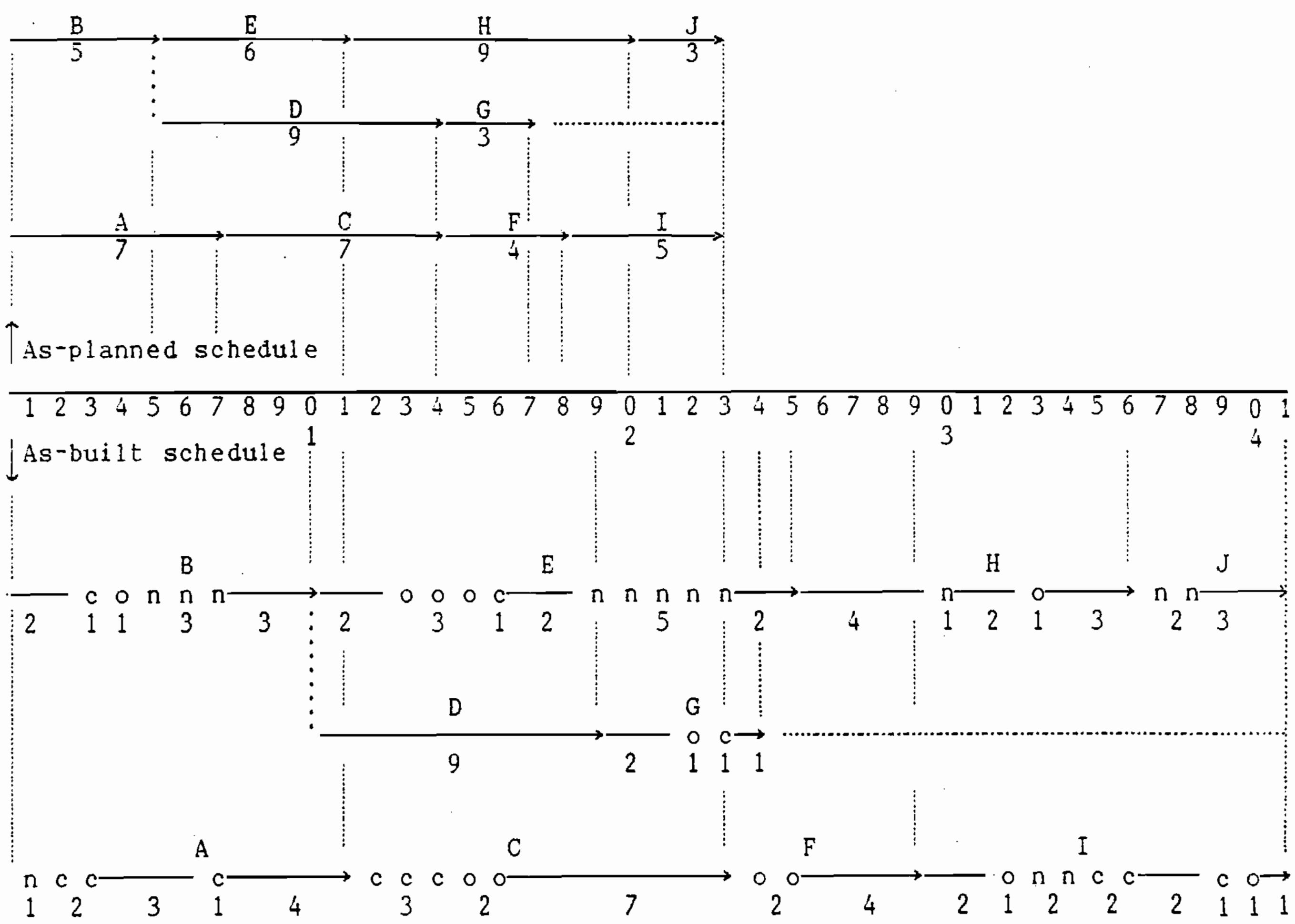
Consider the contract given in Table 6.6. The delay report given in Table 6.7 was recorded for this contract. Determine how each party is responsible for the contract delayed completion.

Table 6.6 Contract Data for Example 6.3

Activity	Predecessor	Duration (days)
A	-	7
B	-	5
C	A	7
D	B	9
E	B	6
F	C	4
G	D	3
H	E	9
I	F	5
J	H	3

Table 6.7 Recorded Delays for Example 6.3

Delay no.	Category	Activity affected	Effective dates	Delay time
1	Neither	A	1	1
2	Contractor	A	2-3	2
3	Contractor	A	7	1
4	Contractor	B	3	1
5	Owner	B	4	1
6	Neither	B	5-7	3
7	Contractor	C	12-14	3
8	Owner	C	15-16	2
9	Owner	E	13-15	3
10	Contractor	E	16	1
11	Neither	E	19-23	5
12	Owner	F	24-25	2
13	Owner	G	22	1
14	Contractor	G	23	1
15	Neither	H	30	1
16	Owner	H	33	1
17	Owner	I	32	1
18	Neither	I	33-34	2
19	Contractor	I	35-36	2
20	Contractor	I	39	1
21	Owner	I	40	1
22	Neither	J	37-38	2



Legend :
c = Contractor
o = Owner
n = Neither

Figure 6.5 Analysis of Delays for Example 6.3

Solution

The as-planned and as-built schedules are drawn in Figure 6.5. Apparent critical paths are B E H J and A C F I. Each of them has a net working duration = 41 - 18 = 23 days. So, the two apparent critical paths are primary critical paths. The total delay of 18 days can then be divided as follows:

a) Concurrent compensable & nonexcusable = 3 days
b) Concurrent with excusable = 2 days
c) Inexcusable = 1 day
d) Compensable = 2 days
e) Excusable = 18 - (3 + 2 + 1 + 2) = 10 days

Accordingly, the contractor should be given a time extension of 17 days. He will pay liquidated damages for 4 days and will be reimbursed for overheads of 5 days.