Chapter 6: Resources Management

6.1 Introduction

As we have seen in network scheduling, the basic inputs to critical-path analysis are the individual project activities, their durations, and their dependency relationships. Accordingly, the forward-path and backward-path calculations determine the start and finish times of the activities. The CPM algorithm, therefore, is duration-driven. Activities' durations here are function of the resources that are required (rather than available) to complete each activity. The CPM formulation, therefore, assumes that all the resources needed for the schedule are available. This assumption, however, is not always true for construction projects. Under resource constraints, the schedule becomes impractical, cost and time are not accurate, and resources may not be available when needed. In order to deal with such issue, a proper management of available resources is required to adjust the schedule accordingly.

When a project plan is first devised it is likely that the plan will identify peaks of resource requirements. However, given the finite nature of resource availability, it may be impractical to meet such peak resource needs. Ideally, there should be an even demand for resources over the entire project duration, with a smooth increase at the beginning of a project and a smooth decrease at the end. Given the limited nature of resources, consideration should be given to the project resource requirements; the project plan should be refined when necessary so that it is practical.

6.2 Resource Definition

The first step in resource management is to decide exactly what resources are considered important enough to be managed. While the most resource used is people or workers (such as welders or carpenters), it may also include other resources such as machines (such as an excavator or loader), space on a project where space is restricted and where this restriction limits the amount of other resources which can be deployed at any one time, financial resources (money) that are needed to perform the required work, or materials needed to accomplish different activities. Generally, a resource can be defined as any thing (labor, equipment, material, money, etc.) that is needed to have the work done.

Often resources are specified in terms of the number of units of resource required, e.g., 5 welders or 3 computer programmers. Alternatively, resources may be specified in terms of the hours or days that a specific resource is required, e.g., 40 welder-hours or 24 man-days.

Resources may be considered as consumable, such as materials that may be used once and once only, or non-consumable, such as people, which may be used again and again. The way in which consumable resources are used is not critical as long as they are used efficiently. However, the way in which non-consumable resources are used can have a significant impact on the project. Resource management is therefore mainly concerned with non-consumable resources.

Also, resources may be classified according to their importance to key resources, secondary resources and general resources. Key resources are the most important, expensive and non-available resources in the project such as skilled labors, or equipment. These types of resources will have a great attention in the resource scheduling process. Secondary resources are those resources which have no constraints on their availability, such as normal labor. General resources are defined as those resources that are used by all or most of the activities on the project such as site overheads. General resources will not be included in the resource management described later.

6.3 Resource Management

The most important resources that project managers have to plan and manage on day-to-day basis are people, machines, materials, and money. Obviously, if these resources are available in abundance then the project could be accelerated to achieve shorter project duration. On the other hand, if these resources are severely limited, then the result more likely will be a delay in the project completion time. In general, from a scheduling perspective, projects can be classified as either time constrained or resource constrained.

Resource leveling (smoothing)

A project is classified as time constrained in situations where the project completion time can not be delayed even if additional resources are required. However, the additional resource usage should be no more than what is absolutely necessary. Accordingly, the primary focus, for purposes of scheduling, in time constrained projects is to improve resource utilization. This process is called resource leveling or smoothing. It applies when it is desired to reduce the hiring and firing of resources and to smooth the fluctuation in the daily demand of a resource, as shown in Figure 6.1. In this case, resources are not limited and project duration is not allowed to be delayed. The objective in this case is to shift non-critical activities of the original schedule, within their float times so that a better resource profile is achieved.

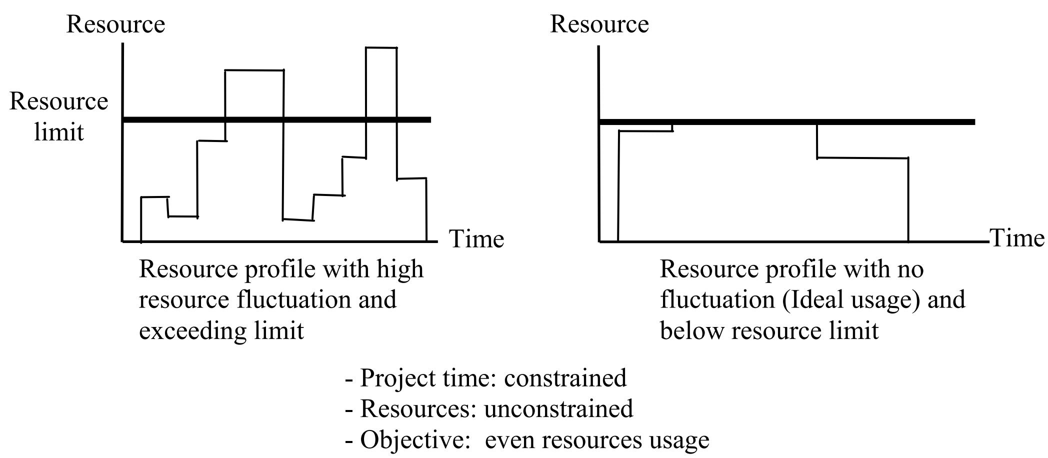


Figure 6.1: Resource leveling (smoothing)

Resource scheduling

On the other hand, a project is resource constrained if the level of resource availability cannot be exceeded. In those situations where resources are inadequate, project delay is acceptable, but the delay should be minimal. The focus of scheduling in these situations is to prioritize and allocate resources in such a manner that there is minimal project delay. However, it is also important to ensure that the resource limit is not exceeded and the technical relationships in the project network are respected.

6.4 Resource Allocation

Resource allocation, also called resource loading, is concerned with assigning the required number of resources identified for each activity in the plan. More than one type of resource may be assigned to a specific activity. For example, fixing steel plates on a bridge deck may require different types of resources such as: welders, laborers and a certain type of welding machine. From a practical view, resource allocation does not have to follow a constant pattern; some activities may initially require fewer resources but may require more of the same resources during the later stages of the project.

6.5 Resource Aggregation (Loading)

After each activity has been assigned its resources, the next step is to aggregate the resources used by all activities. Resource aggregation is simply the summation, on a period-by-period basis, of the resources required to complete all activities based on the resource allocation carried out previously. The results are usually shown graphically as a histogram. Such aggregation may be done on an hourly, daily, or weekly basis, depending on the time unit used to allocate resources. When a bar chart is used, the resource aggregation is fairly simple and straightforward. For a given bar chart, a resource aggregation chart can be drawn underneath the bar chart. However, a separate graph will be required for each resource type.

An example is shown in Figure 6.2, where, for a particular resource, the required resource units for each time period are written on the bar chart. The total number of resource units for each time period can then be summed and a resource aggregation or load chart can be produced as presented underneath the bar chart. Thus, having a project scheduling is necessary to facilitate the bar chart drawing.

The non critical activities, activities which are not on the critical path, do not have fixed starting and finishing times but are constrained by the earliest and latest starting and finishing times. This situation offers the planner chance for adjusting the demand for resources. Figure 6.3 illustrates such situation, which shows the resource aggregation when the activities scheduled on their early times and late times. It can be seen that the resource requirements that arise when both earliest and latest start times are considered are different. The shaded area represents the resources required by the critical activities, as these activities have a fixed position because their early times equal their late time. Figure 6.3 shows, also, the accumulation of resources at the beginning of the project when the activities scheduled on their early time. On the other hand, the resources accumulate at the end of the project when the activities scheduled on their late times.

Activity \ Week	1	2	3	4	5	6	7	8	9
A	10	10							
B		8	8	6					
C				2	6				
D				2	6	10	10	8	
E								6	6
Total resource units requirement	10	18	8	10	12	10	10	14	6

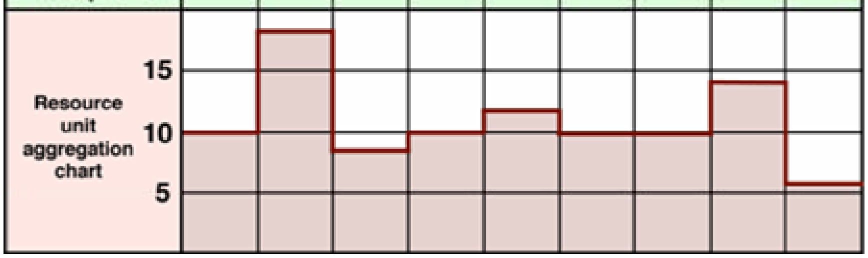


Figure 6.2: Resource aggregation

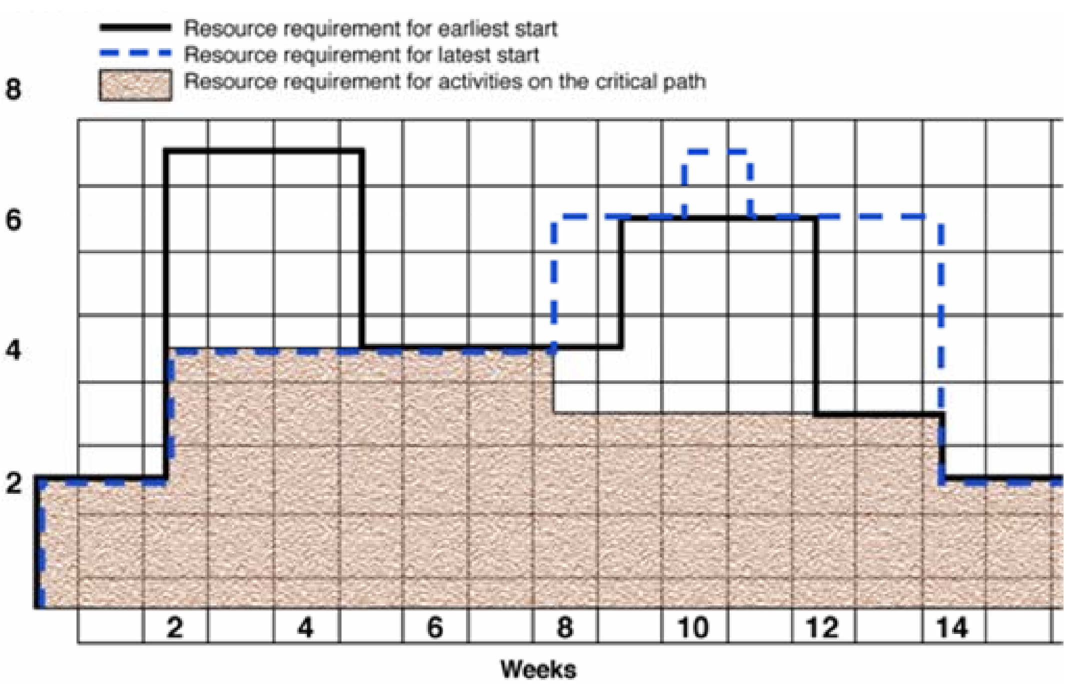


Figure 6.3: Resource aggregation chart showing resource requirements associated with earliest and latest times along with highlighted resource requirements for critical activities

6.6 Resource Leveling (Smoothing)

As shown in Figure 6.3, the problem of resource fluctuation appears after the initial scheduling of the project without considering the resources. The peaks and valleys in the resource profile indicate high day-to-day variation in the resource demand. Resource smoothing is the process that attempts to determine a resource requirement that is "smooth" and where peaks and valleys are eliminated. For example, even if 7 units of a given resource are available at any one time, utilizing 5 of these units each week is preferable than using 4 units for the first week, 7 the next, 2 the next and so on. Even if there is no limit to the amount of any one resource available, it is still desirable that resource usage is as smooth as possible. Given that the resource requirements of those activities on the critical path are fixed, some order or priority needs to be established for selecting which activity and which particular resource associated with this activity should be given priority in the smoothing process.

Resource leveling heuristics shift non-critical activities within their float times so as to move resources from the peak periods (high usage) to the valley periods (low usage), without delaying the project (i.e., area underneath the resource profile remains constant). Usually, project managers may prefer having a desired resource profile in which the resource usage starts with low values and then the resources are build up till its maximum values and starts to decrease as the project approaches its end as shown in Figure 6.4.

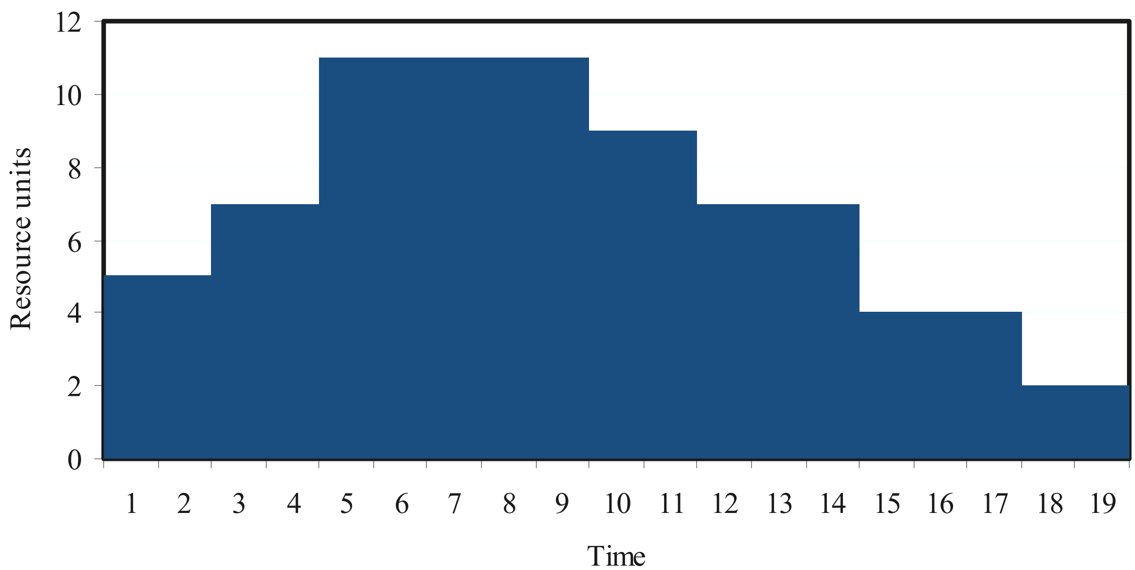


Figure 6.4: Preferred resource usage

6.6.1 Method of Moments for Resource Smoothing

The method of minimum moment is well known heuristic algorithm for smoothing resource profiles. The Minimum Moment Algorithm has been used as a heuristic approach to calculate a measure of the fluctuations in daily resource demands. This is represented in Figure 6.5, where Histogram 1 and Histogram 2 are two alternative resource histograms, both having a total area of 40 resource days (i.e., equal total resource demands). Histogram 1 is an ideal one with a constant daily demand of 4 resource units, no day-to-day resource fluctuations, and the resource will be released after day 10. Histogram 2, on the other hand, exhibits high resource fluctuation with daily demand in the range of 2 to 6 resource units, and the resource will not be released until the end of day 12. The moment (Mx) of both histograms around the horizontal axis (days) are 160 and 166, respectively, representing a better resource leveling of Histogram 1.

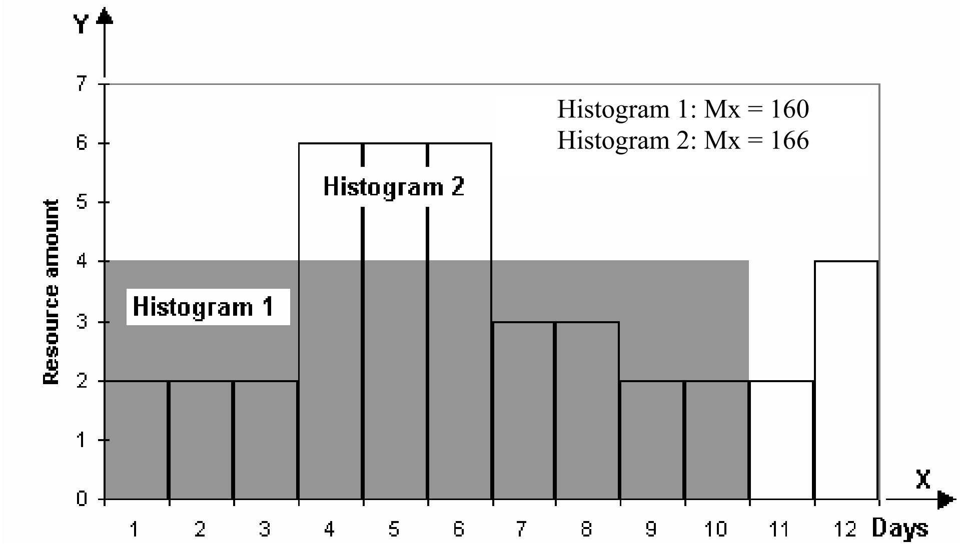


Figure 6.5: Moment calculations of resource histogram

The moment Mx is calculated by summing the daily moments, as follows:

$$M_x = \sum_{j=1}^{n} \left[(1 \, x \, \text{Resource Demand}_j) \, x \, \frac{1}{2} \text{Resource Demand}_j \right] \qquad (6.1)$$

Where, n is the working-day number of the project's finish date. Or, for comparison reasons, equation (1) becomes:

$$M_x = \sum_{j=1}^{n} (\text{Resource Demand}_j)^2 \qquad (6.2)$$

Having the moment calculations defined, a project manager may use them as to minimize the Mx to reduce daily resource fluctuations.

6.6.2 Heuristic Procedure for Resource Smoothing

This section describes another way to smooth resource profile using some heuristic rules. This method can be summarized in the following steps:

- Prepare a complete activity schedule.
- Draw a bar chart of the project under study based on ES timing of the activities.
- Critical activities to be drawn first (as these activities will not be moved).
- Write the resource usage above each bar of the related activity.
- Draw the FF as dashed line beside the upper side of the bar and the TF beside the lower side.
- Aggregate (determine the resource sum) the resources in each time period.
- Calculate the total usage of resources = ∑ unit period usage.
- Calculate the average resource usage = ∑ usage / utilization period.
- Shift non-critical activities within their FF first, then their TF to decrease the peaks and raise the valleys.
- Revise activities floats.
- Aggregate resources in each time period after shifting any activity.
- When shifting activities, it is preferred to start with the activities that have no successors, as shifting these activities will not affect other activities. Also, by shifting these activities, a float will be created for its predecessors.
- Shift activities only that will enhance the resource profile.

Example 6.1

The activities involved in the construction of a certain project are given in Table 6.1. One resource type will be used during the contract. Determine minimum level of the resource required to complete the project.

Table 6.1: Data for Example 6.1

Activity	Duration (Weeks)	Predecessors	Resource (units/week)
A	0	-	0
B	2	1	0
C	5	1	2
D	3	1	2
E	2	2	1
F	6	2	2
G	6	3	3
H	6	4	1
I	4	4	0
J	2	5, 6	4
K	7	6, 7	2
L	3	2, 8	2
M	2	2, 8, 9	4
N	2	10, 11, 12, 13	0

Solution

The project network is shown in Figure 6.6 with the activity timings and project completion time of 20 weeks. Table 6.2 shows the activities timings and floats.

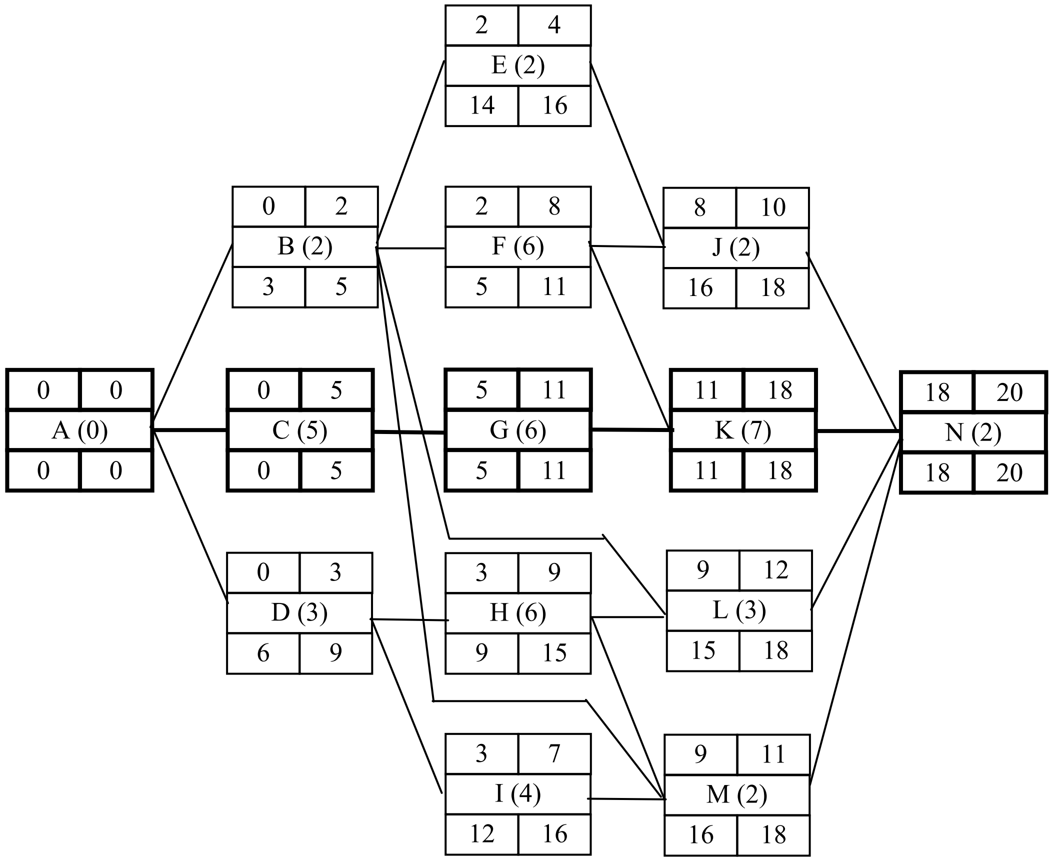


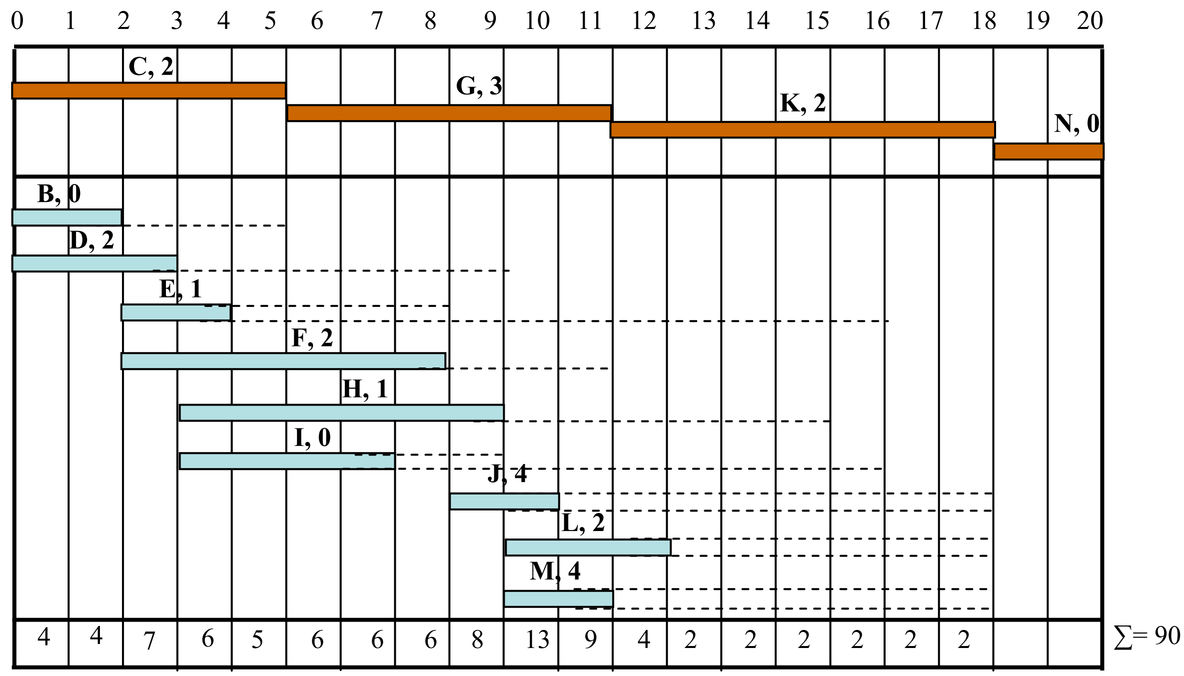
Figure 6.6: Precedence network of Example 6.1

Table 6.2: Activities times and floats of Example 6.1

Activity	ES	EF	FF	TF
A	0	0	0	0
B	0	2	0	3
C	0	5	0	0
D	0	3	0	6
E	2	4	4	12
F	2	8	0	3
G	5	11	0	0
H	3	9	0	6
I	3	7	2	9
J	8	10	8	8
K	11	18	0	0
L	9	12	6	6
M	9	11	7	7
N	18	20	0	0

Figure 6.7 shows the bar chart and the resource histogram of the project and the weekly usage of the resources and the total usage of 90 resource units. As shown in the resource histogram, the

peak resource usage is 13 units and the minimum usage is 2 units. The total resource usage equals 90 units with utilization period of 18 weeks. Then, the average resource usage equals 5 units (=90/18=5).



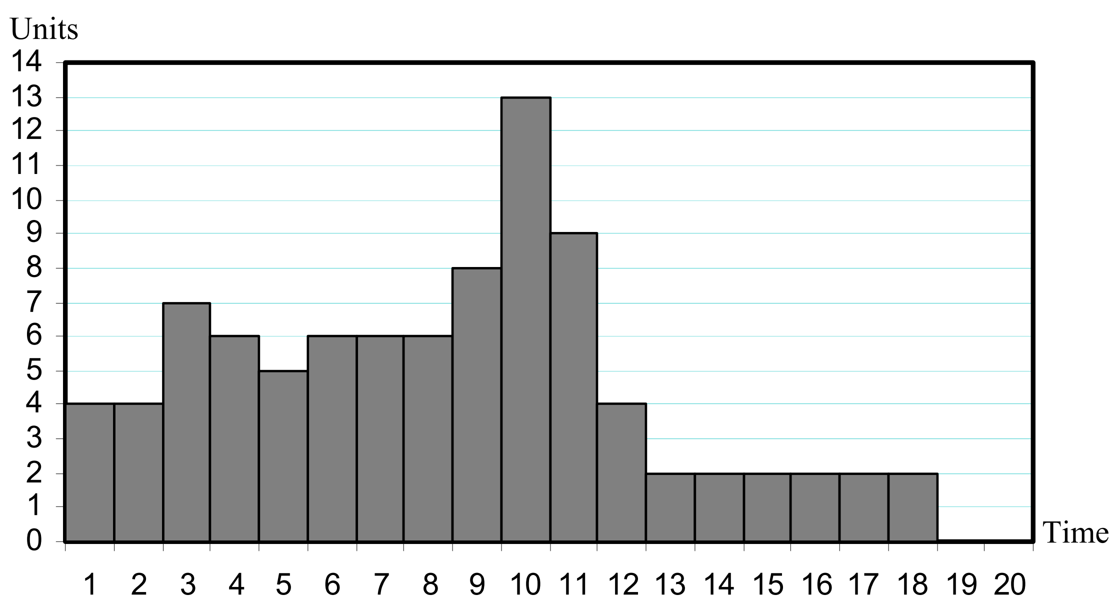
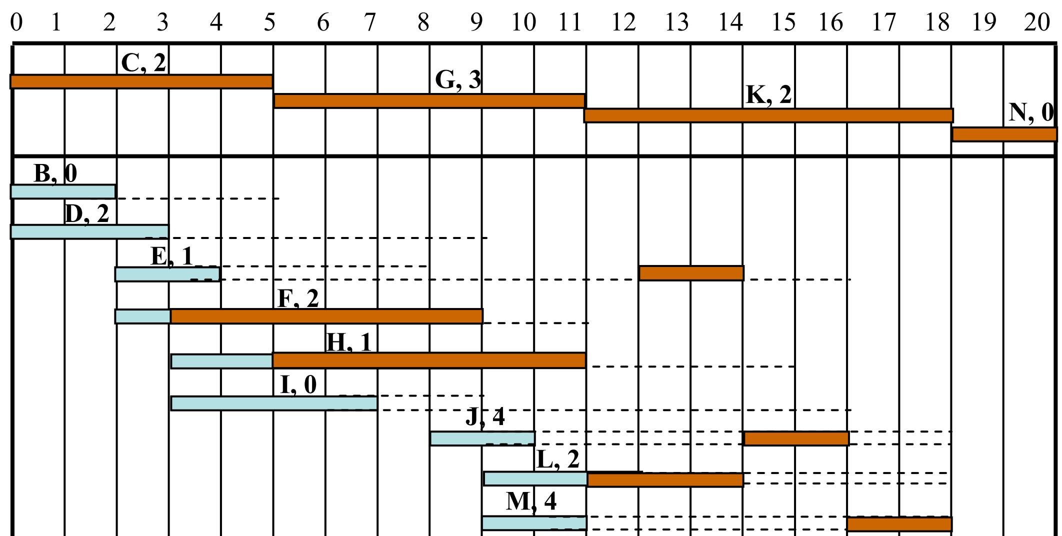


Figure 6.7: Bar chart and resource histogram before leveling of Example 6.1

The resource demand on weeks 9, 10, and 11 is high, while it is low in weeks 13 through 18. Accordingly, the solution process will try to sift the resources from that peak period to the period of low usage. The following activities will be shifted:

- Activity M has a free float of 7 weeks. Shifting activity M by 7 weeks will reduce the peak usage of the resource on weeks 10 and 11 and increase the usage on weeks 17 and 18. Also, shifting activity M will give chance for preceding activities to be shifted.
- Activity J can be shifted by 6, however it has 8 weeks free float. By shifting activity J, the free float of both activities E and F are changed.
- Shift activity L by 2 weeks to optimize the resource usage. The free float of activity will be changed to 2 weeks.
- Next, shift activity E by 10 weeks to improve the resource usage.
- Shift activity H by 2 weeks.
- Finally, shift activity F by 1 week.

The heuristic procedure for leveling project resource is shown in Figure 6.8. In each step, the resources are aggregated to ensure that shifting an activity improves the resource utilization. The resource histogram for the leveled project is shown in Figure 6.9.



	4	4	7	6	5	6	6	6	8	1 3	9	4	2	2	2	2	2	2			∑= 90
M (7 weeks)	4	4	7	6	5	6	6	6	8	-4 9	-4 5	4	2	2	2	2	+4 6	+4 6			
J (6 weeks)	4	4	7	6	5	6	6	6	-4 4	-4 5	5	4	2	2	+4 6	+4 6	6	6			
L (2 weeks)	4	4	7	6	5	6	6	6	4	-2 3	-2 3	4	+2 4	+2 4	6	6	6	6			
E (10 weeks)	4	4	-1 6	-1 5	5	6	6	6	4	3	3	4	+1 5	+1 5	6	6	6	6			
H (2 weeks)	4	4	6	-1 4	-1 4	6	6	6	4	+1 4	+1 4	4	5	5	6	6	6	6			
F (1 week)	4	4	-2 4	4	4	6	6	6	+2 6	4	4	4	5	5	6	6	6	6			

Figure 6.8: Applying heuristic procedure for resource leveling

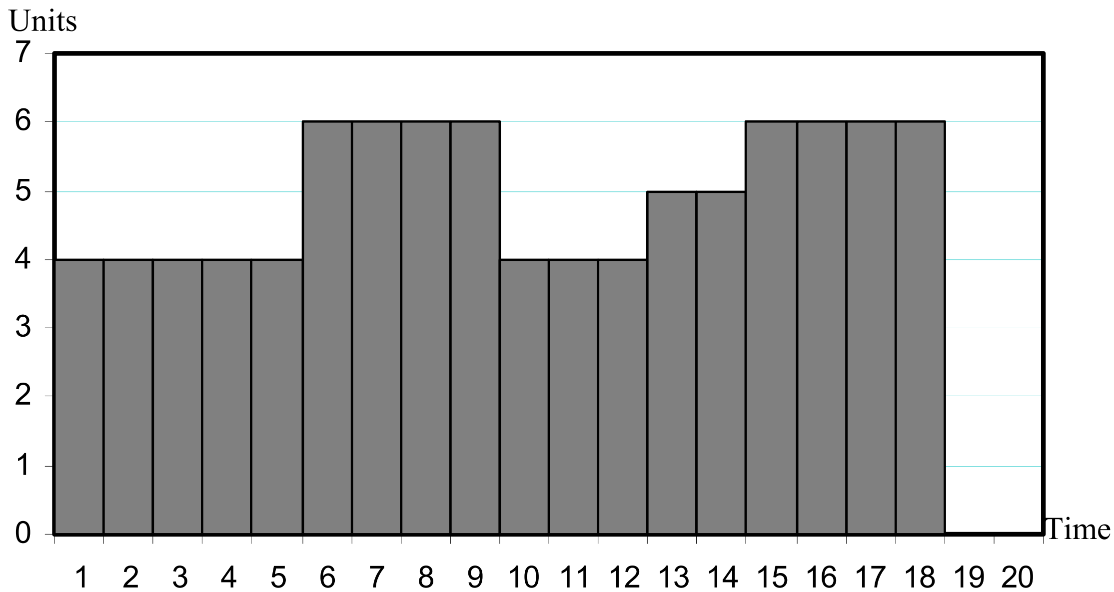


Figure 6.9: Resource histogram for Example 6.1 after leveling

Example 6.2

The activities involved in the construction of a small project are given in Table 6.3. The resource usage for each activity is shown in Table 6.32. Smooth the resource so that a preferred resource usage is obtained.

Table 6.3: Data for Example 6.2

Activity	Duration (Weeks)	Predecessors	Labors (units/week)
A	3	-	9
B	5	-	6
C	1	-	4
D	1	A	10
E	7	B	16
F	6	B	9
G	4	C	5
H	3	C	8
I	6	D, E	2
J	4	F, G	3
K	3	H	7

Solution

The precedence network of the project is shown in Figure 6.10 with the activity timings and project completion time of 18 weeks.

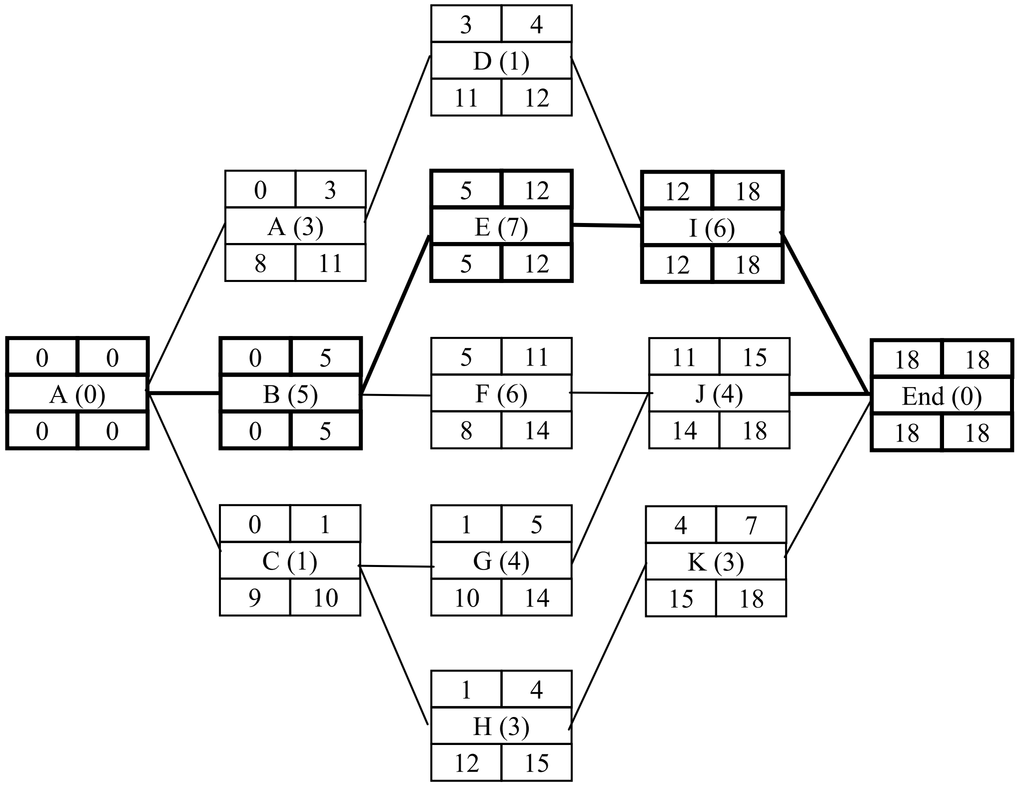


Figure 6.10: Precedence network of Example 6.2

Figure 6.11 shows the bar chart and the resource histogram of the project and the weekly usage of the resources.

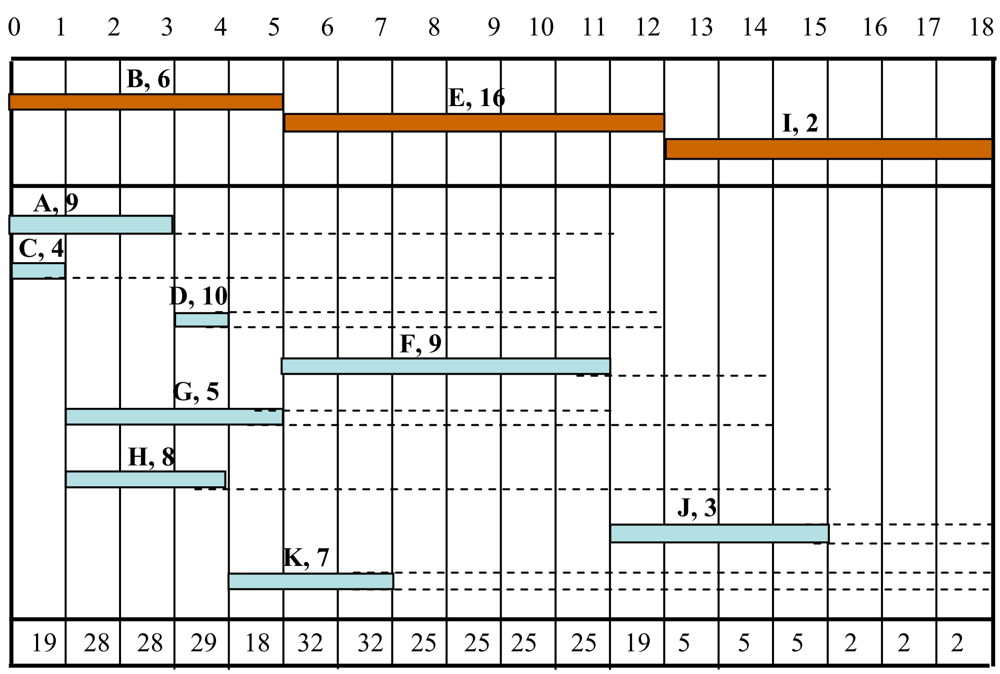
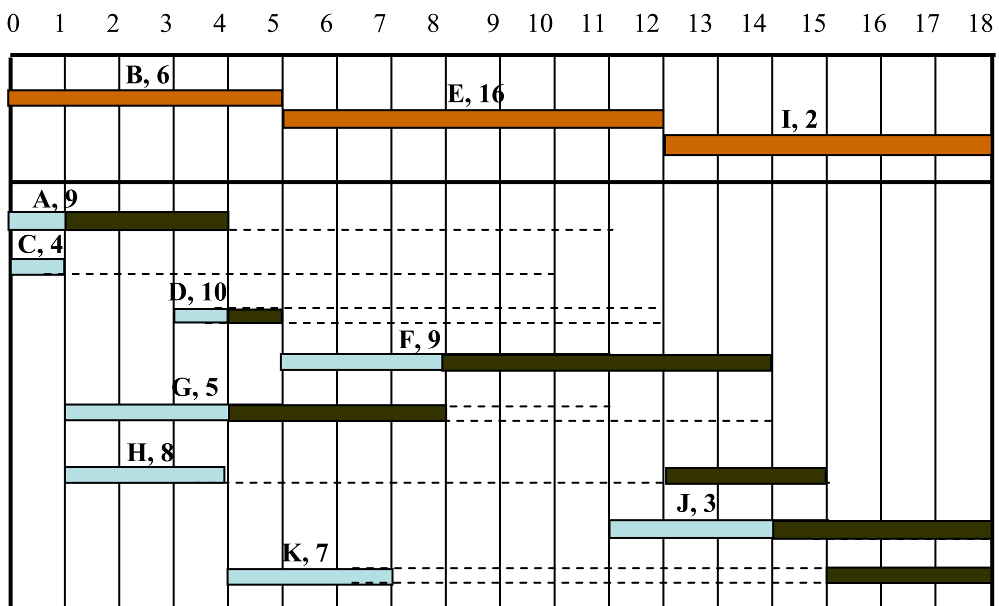


Figure 6.11: Bar chart and resource aggregation of Example 6.2

To achieve a resource profile with less resource load at the beginning and build up towards the middle of the project and decreases towards the end, the following activities will be shifted:

- Shift activity K by 11 weeks, this activity has a free float 11 weeks.
- Shift activity H by 11 weeks (it has 11 weeks free float).
- Activity A will be shifted by one week, accordingly, activity D will e shifted by one week. This is because activity A has no free float.
- Shift activity F by 3 weeks and accordingly, activity J will be shifted 3 weeks because activity F has no free float.
- Finally, shift activity G by 3 weeks.

The heuristic procedure for leveling project resource is shown in Figure 6.12. In each step, the resources are aggregated to ensure that shifting an activity improves the resource utilization. The resource histogram for the leveled project is shown in Figure 6.13.



	19	28	28	29	18	32	32	25	25	25	25	19	5	5	5	2	2	2
K (11 weeks)	19	28	28	29	-7 11	-7 25	-7 25	25	25	25	25	19	5	5	5	+7 9	+7 9	+7 9
H (11 weeks)	19	-8 20	-8 20	-8 21	11	25	25	25	25	25	25	19	+8 13	+8 13	+8 13	9	9	9
A (1 week) D (1 week)	-9 10	20	20	+9 -10 20	+10 21	25	25	25	25	25	25	19	13	13	13	9	9	9
F (3 weeks) J (3 weeks)	10	20	20	20	21	-9 16	-9 16	-9 16	25	25	25	+9 -3 25	+9 -3 19	+9 -3 19	13	+3 12	+3 12	+3 12
G (3 weeks)	10	-5 15	-5 15	-5 15	21	+5 21	+5 21	+5 21	25	25	25	25	19	19	13	12	12	12

Figure 6.11: Solution of Example 6.2

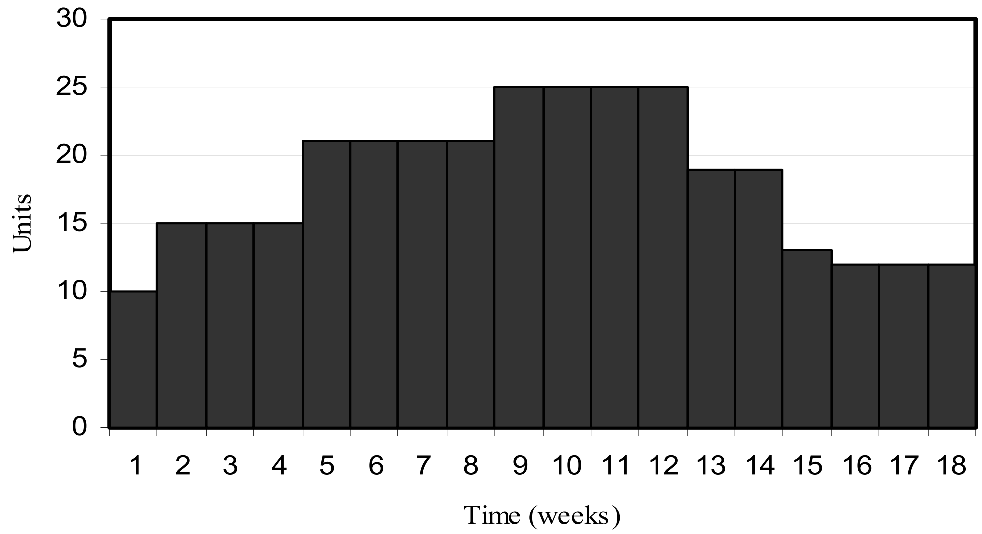


Figure 6.12: Resource histogram after leveling of Example 6.2

6.7 Scheduling Limited Resource

Shortage of resources is a major challenge for construction projects. Often, the number of skilled labor is limited, a related equipment has to be returned as soon as possible, and / or a limited require our special consideration. Scheduling under these resource constraints becomes a complex problem, particularly when more than one resource is limited.

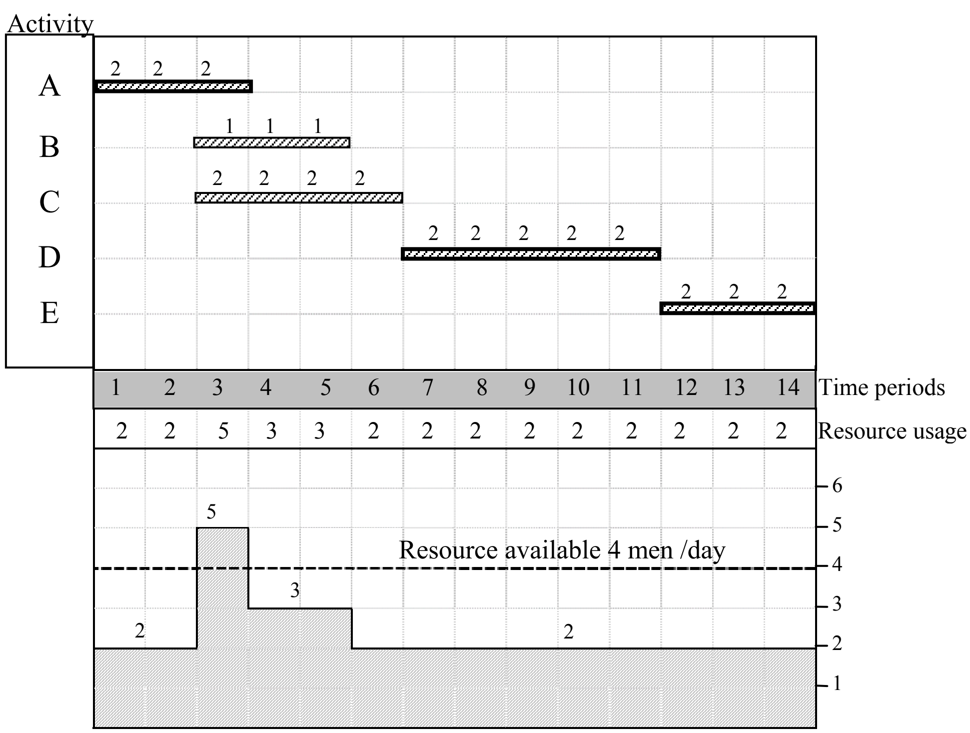


Figure 6.13: Resource needed exceed resource limit

The technique that deals with limited resources has been referred to as "resource-scheduling" and "resource-constrained scheduling".

The problem of resource-constrained scheduling appears after the initial netwrok analysis is conducted and a bar chart is drawn. A resource conflict occurs when at any point in the schedule several activities are in parallel and the total amount of required resource(s) exceeds the availability limit, for any of the resources required in these parallel activities. The situation is illustrated in Figure 6.13 with activities A, B, and C that, at time period 3, require 5, while 4 are only available per day.

The simple solution to that situation is that we can prioritizing the parallel activities, given the resource to higher priority activities and delay the others until the earliest time the resource become available again. Notice that if we delay an activity at time period 3, to solve the situation, we may end up with another resource conflict later in time. Continuing with identifying next conflict points and resolving them, determines the new schedule and the new project duration. Accordingly, the objective in such situation is to delay some activities so that the resource conflict is resolved and the project delay is minimized.

Various models were developed in an attempt to answer this question, and thus optimize resource-scheduling decisions. Early efforts used mathematical optimization, dynamic programming, and linear programming. These models, however, were applicable only to very small size problems. On the other hand, heuristic solutions for this problem have been developed. Heuristic solutions, in general, use simple rules of thumb to provide approximate but good solutions that are usable for large scale problems. An example of these rules of thumb is that the resource can be assigned to activity (ies) having smaller total float values than others (indicating a desire not to delay the critical and close-to-critical activities). Figure 6.14 show an example where priority was assigned to the activities having least total float when conflict arises.

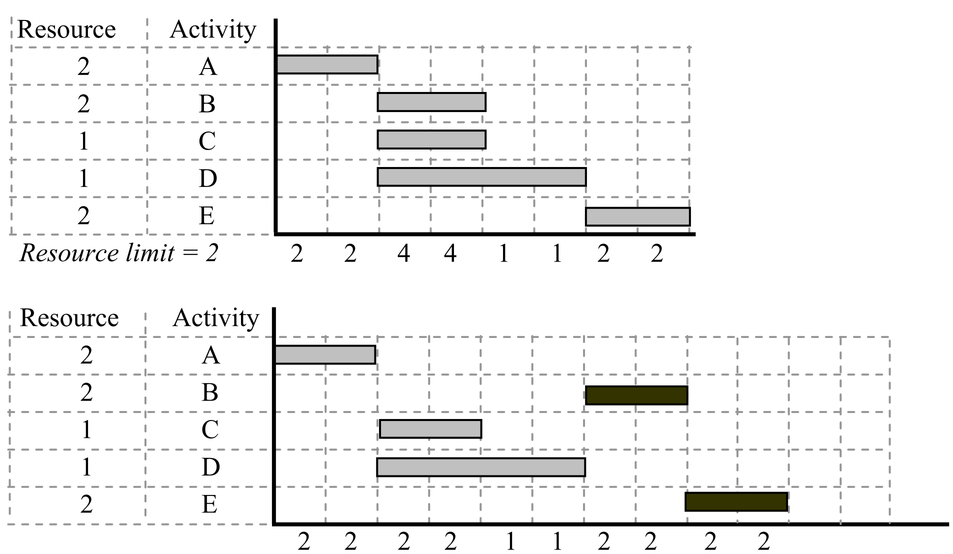


Figure 6.14: Resource scheduling using least TF rule

These heuristic rules are based mainly on activity characteristics. The two most effective and commonly used heuristic rules are the least total-float (LTF) and the earliest late-start (ELS). These two rules have been proven to provide identical results, with the ELS rule being advantageous compared to the LTF rule. This is because the value of the late-start derived from the original CPM calculations, unlike the total-float, need not to be changed every time an activity is rescheduled due to insufficient resource availability. As such, the ELS rule can be applied with much less computational effort than the LTF rule, and accordingly has been used as a basis for the resource scheduling.

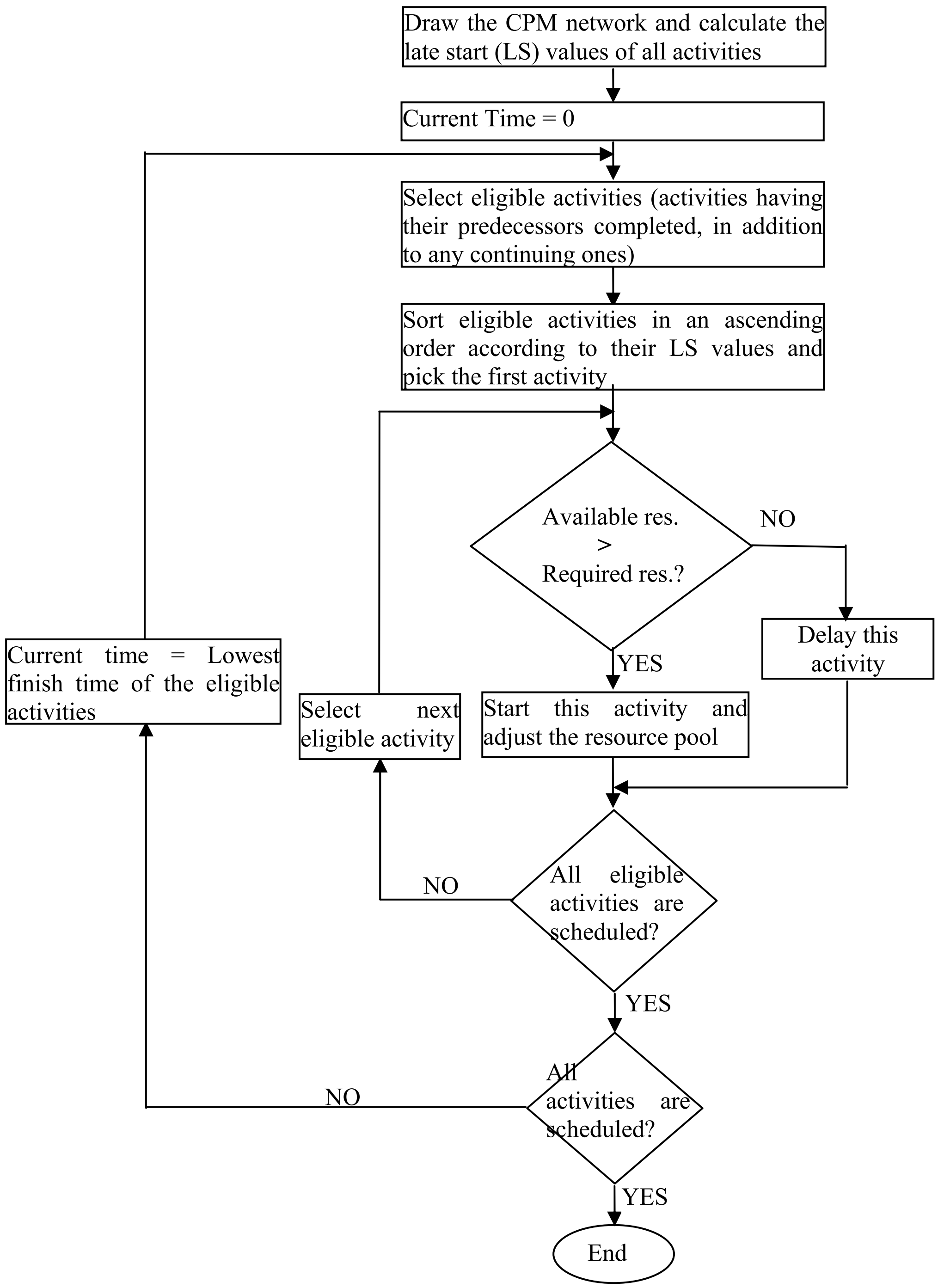


Figure 6.15: Resource scheduling procedure using the ELS rule

The resource scheduling procedure using the ELS is outlined in Figure 6.15. It starts from the project start time and goes through cycles of identifying eligible activities according to the network logic.

6.8 Case Study

The procedure described earlier will be demonstrated on a case study project having 20 activities and each activity uses 6 resources with their limits given in Table 6.4. It is required to schedule the project so that the daily resource requirements do not exceed the resource limits.

Table 6.4: Case study data

Activity	**Duration (days)**	**Predecessors**	**Daily Resource Requirements**					
			R1	**R2**	**R3**	**R4**	**R5**	**R6**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
A	6	----	5	2	2	2	7	4
B	3	----	3	5	2	3	9	6
C	4	A	2	4	4	2	3	1
D	6	----	5	4	3	5	5	4
E	7	A, B	3	5	2	3	8	0
F	5	C	4	1	4	9	2	5
G	2	D	4	1	4	3	9	8
H	2	A, B	5	5	4	0	9	1
I	2	G, H	3	2	4	3	4	2
J	6	F	1	5	4	6	7	3
K	1	C, E	3	3	2	4	5	1
L	2	E, G, H	3	2	2	8	3	4
M	4	I, K	2	2	2	2	4	8
N	2	F, L	1	4	4	3	4	1
O	3	L	5	5	4	6	2	3
P	5	J, M, N	3	2	3	4	7	8
Q	8	O	4	5	4	2	3	4
R	2	D, O	5	3	3	3	7	8
S	6	P, R	2	4	6	2	3	4
T	2	Q	1	6	2	7	5	2
Daily Resource Limits			**7**	**10**	**10**	**16**	**18**	**13**

The CPM network of the case study is shown in Figure 6.16, indicating project duration of 32 days, without considering the resource limits (constraints). Applying the heuristic procedure to consider resource constraints resulted in the manual solution given in Table 6.5, with 49 days project duration. In Table 6.5, the first 10 columns represent the activities' data, while the last 2 columns are the scheduling decisions made at each cycle.

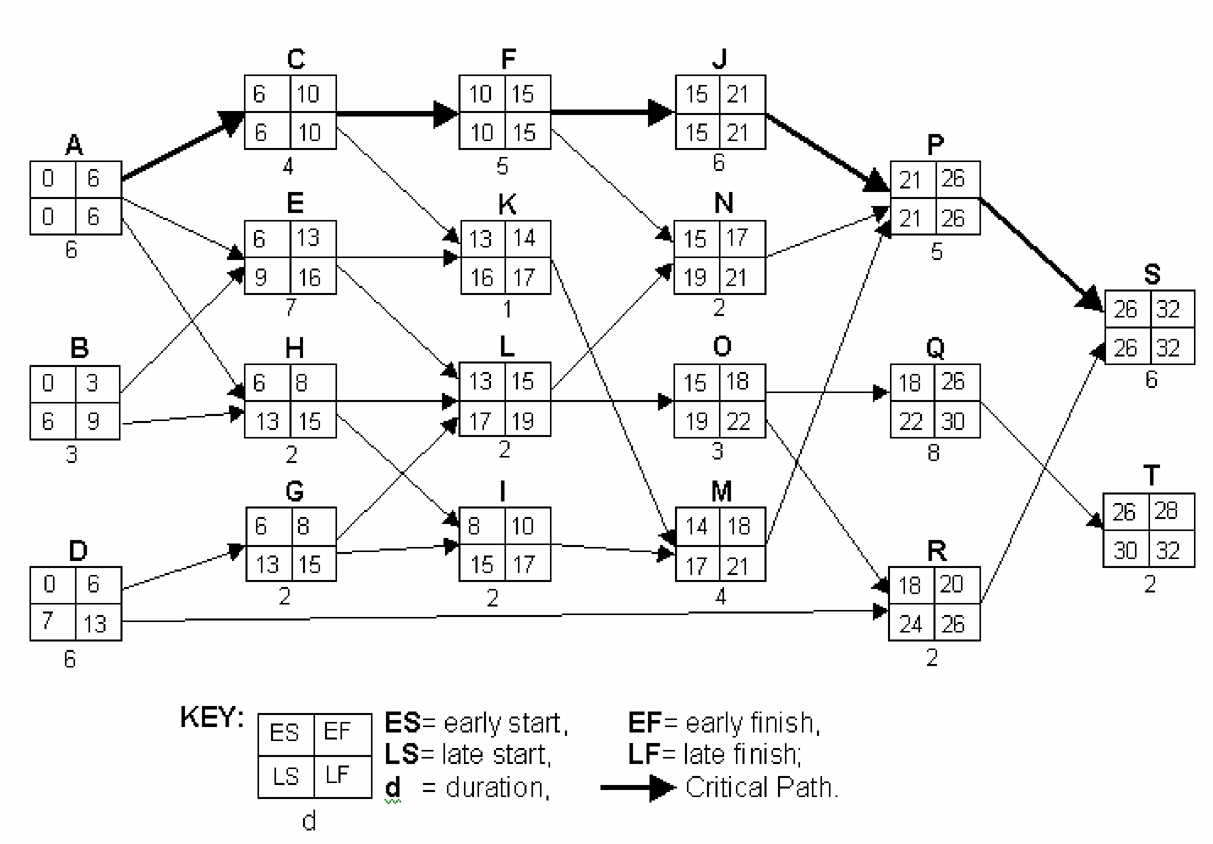


Figure 6.16: Precedence network of the case study project

According to the project network of Figure 6.16, activities A, B, and D are at the start of the project and thus they become eligible for scheduling at current time = 0 (beginning of the project), as shown in the first cycle of Table 6.5. The eligible activities were sorted by their late-start values (the criteria used for assigning resources, as shown in column 9). Considering these three activities in their priority order, available resources were enough to start activity A, but the remaining amounts of resources were not enough for either B or D. As such, activity A was scheduled to start at time 0 and to end at time 6 (duration = 6 days), while activities B and D were delayed till the earliest time more resources became available (day 6).

At day 6, activity A was finished, and as such, all its immediate successors become eligible for scheduling (unless they have other unfinished predecessors), in addition to B and D which were delayed in the previous cycle. After sorting and considering these activities one-by-one, B and C could start, while D was delayed. The process, therefore, was continued at day 9 which is the finish time of activity B (C was scheduled to finish at day 10). The third cycle at day 9, as such, included 4 eligible activities: activity C (continuing till day 10); activity D (delayed from previous cycle); and two more activities (E and H, which immediately follow B).

Decisions for these activities were made as shown in Table 6.5 and the process was continued through all the cycles until all activities were scheduled (project duration = 49 days; a 17-day extension beyond the original CPM duration of 32 days). Notice that at any cycle, the total amount of resources used by the starting and continuing activities is less than or equal to the resource availability limit.

Table 6.5: Solution of the case study project

Time	Eligible Activities	Resources						Late Start	Duration	Decision	Finish Time
		R1=7	R2=10	R3=10	R4=16	R5=18	R6=13				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0	A	5	2	2	2	7	4	0	6	Start	6
	B	3	5	2	3	9	6	6	3	**Delay**	-
	D	5	4	3	5	5	4	7	6	Delay	-
6	B	3	5	2	3	9	6	6	3	Start	9
	C	2	4	4	2	3	1	6	4	Start	10
	D	5	4	3	5	5	4	7	6	Delay	-
9	C	2	4	4	2	3	1	6	4	Continue	10
	D	5	4	3	5	5	4	7	6	Start	15
	E	3	5	2	3	8	0	9	7	Delay	-
	H	5	5	4	0	9	1	13	2	Delay	-
10	D	5	4	3	5	5	4	7	6	Continue	15
	E	3	5	2	3	8	0	9	7	Delay	-
	F	4	1	4	9	2	5	10	5	Delay	-
	H	5	5	4	0	9	1	13	2	Delay	-
15	E	3	5	2	3	8	0	9	7	Start	22
	F	4	1	4	9	2	5	10	5	Start	20
	G	4	1	4	3	9	8	13	2	Delay	-
	H	5	5	4	0	9	1	13	2	Delay	-
20	E	3	5	2	3	8	0	9	7	Continue	22
	G	4	1	4	3	9	8	13	2	Start	22
	H	5	5	4	0	9	1	13	2	Delay	-
	J	1	5	4	6	7	3	15	6	Delay	-
22	H	5	5	4	0	9	1	13	2	Start	24
	J	1	5	4	6	7	3	15	6	Start	28
	K	3	3	2	4	5	1	16	1	Delay	-
24	J	1	5	4	6	7	3	15	6	Continue	28
	I	3	2	4	3	4	2	15	2	Start	26
	K	3	3	2	4	5	1	16	1	Start	25
	L	3	2	2	8	3	4	17	2	Delay	-
25	I	3	2	4	3	4	2	15	2	Continue	26
	J	1	5	4	6	7	3	15	6	Continue	28
	L	3	2	2	8	3	4	17	2	Delay	-
26	J	1	5	4	6	7	3	15	6	Continue	28
	L	3	2	2	8	3	4	17	2	Start	28
	M	2	2	2	2	4	8	17	4	Delay	-
28	M	2	2	2	2	4	8	17	4	Start	32
	N	1	4	4	3	4	1	19	2	Start	30
	O	5	5	4	6	2	3	19	3	Delay	-
30	M	2	2	2	2	4	8	17	4	Continue	32
	O	5	5	4	6	2	3	19	3	Start	33
32	O	5	5	4	6	2	3	19	3	Continue	33
	P	3	2	3	4	7	8	21	5	Delay	-
33	P	3	2	3	4	7	8	21	5	Start	38
	Q	4	5	4	2	3	4	22	8	Start	41
	R	5	3	3	3	2	8	24	2	Delay	-
38	Q	4	5	4	2	3	4	22	8	Continue	41
	R	5	3	3	3	2	8	24	2	Delay	-
41	R	5	3	3	3	7	8	24	2	Start	43
	T	1	6	2	7	5	2	30	2	Start	43
43	S	2	4	6	2	3	4	26	6	Start	49

Example 6.3

The activities of a project along with their durations, predecessors and resource used are given in Table 6.6. If resource 1 is limited to 8 units and resource is limited to one unit, determine the activities schedule start and finish times so that the weekly resource usage does not exceed the resource limits.

Table 6.6: Data of Example 6.3

Activity	Duration (Weeks)	Predecessors	Resource (units/week)	
			R1≤8	R2 ≤1
A	4	-	3	0
B	6	-	6	1
C	2	-	4	0
D	8	A	0	1
E	4	D	4	1
F	10	B	0	1
G	16	B	4	0
H	8	F	2	0
I	6	E, H	4	1
J	6	C	5	1
K	10	G, J	2	0

Solution

The project network is drawn and the activities timings are calculated giving a project completion time of 32 weeks without considering the resource limits.

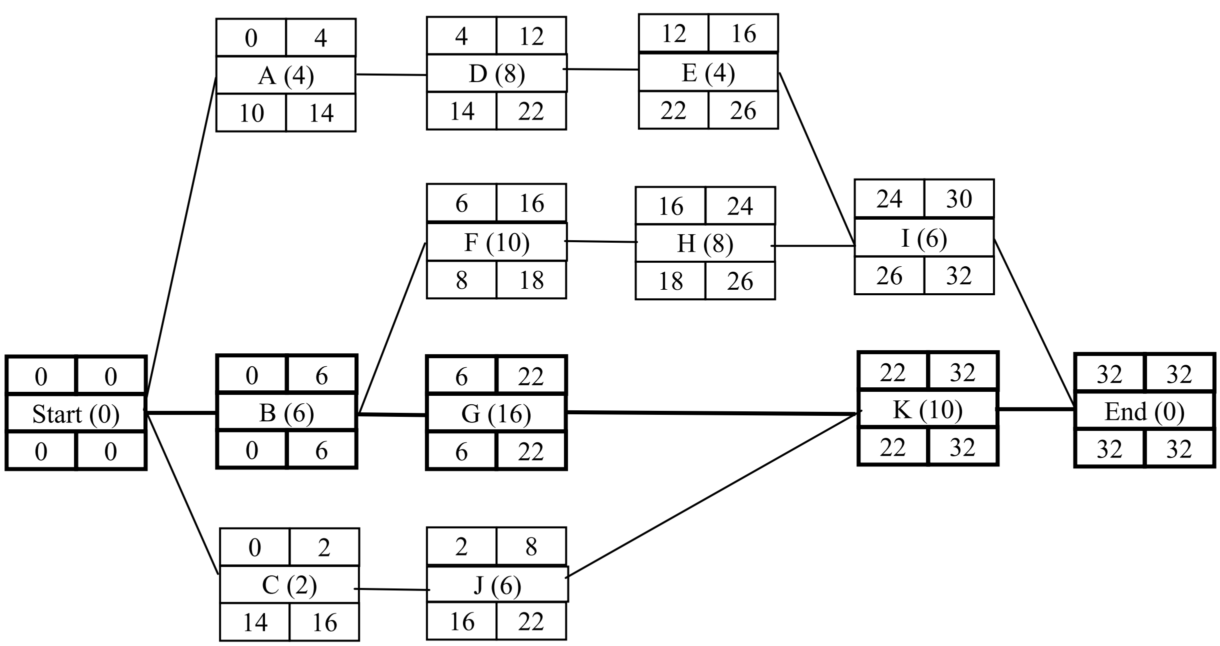


Figure 6.17: Precedence diagram of Example 6.3

The solution will be arranged in the Table below (Table 6.7).

Table 6.7: Solution of example 6.3

Current time	Eligible activities	Resources		Duration	ELS	Decision	Finish time
		R1 ≤8	R2 ≤1				
0	B A C	6 3 4	1 0 0	6 4 2	0 10 14	Start Delay Delay	6 - -
6	G F A C	4 0 3 4	0 1 0 0	16 10 4 2	6 8 10 14	Start Start Start Delay	22 16 10 -
10	G F C D	4 0 4 0	0 1 0 1	16 10 2 8	- - 14 14	Continue Continue Start Delay	22 16 12 -
12	G F D J	4 0 0 5	0 1 1 0	16 10 8 6	- - 14 16	Continue Continue Delay Delay	22 16 - -
16	G D J H	4 0 5 2	0 1 1 0	16 8 6 8	- 14 16 18	Continue Start Delay Start	22 24 - 24
22	D H J	0 2 5	1 0 1	8 8 6	- - 16	Continue Continue Delay	24 24 -
24	J E	5 4	1 1	6 4	14 22	Start Delay	30 -
30	E K	4 2	1 0	4 10	22 22	Start Start	34 40
34	K I	2 2	0 0	10 6	- 26	Continue Start	40 40

Then, the project completion time is 40 weeks with activities timing as given below:

Activity	Schedule start	Schedule finish	Activity	Schedule start	Schedule finish
A	6	10	G	6	22
B	0	6	H	16	24
C	10	12	I	34	40
D	16	24	J	24	30
E	30	34	K	30	40
F	6	16			