Project Mngt - Processes, methodology & Economics
— Avraham Shtub, Jonathan Bard, Shlomo Globerson.

Resource Management

1 EFFECT OF RESOURCES ON PROJECT PLANNING

In project scheduling, we have thus far assumed that the precedence relations among activities are the sole constraints. Based on this assumption, each activity could start as soon as all of its predecessors were completed (assuming finish-to-start precedence relations). This type of analysis is based on the implicit assumption that there are enough resources available to permit any number of activities to be scheduled simultaneously. As we will see, this is rarely the case.

Resource planning is the process by which the project manager decides which resources to obtain, from which sources, when to obtain them, how to use them, and when and how to release them. Therefore, project resource planning is mainly concerned with the tradeoff analysis between (1) the cost of alternative schedules designed to accommodate resources shortages and (2) the cost of using alternative resources; for example, overtime to meet a schedule or subcontracting to accommodate a schedule change. This analysis may be subject to constraints on resource availability, budget allocations, and task deadlines.

An important function of the project manager is to monitor and control resource use and performance during project execution. If technical personnel are scarce or if materials and equipment are in short supply, then rescheduling becomes a top management priority. Shortages and uncertainty can wreak havoc on the best of plans; however, the efficient use of resources goes a long way in reducing both the cost and the duration of a project at each stage of its life cycle.

Project resources are aggregated through the budget and expended over time. Money is used to acquire the resources needed for the project, but in some financial organizations such as banks and insurance companies, money itself is a resource used for operations. Information is also an important resource in projects. This can be confusing, so to plan for and track resource use, some type of classification system is needed. This is taken up next.

2 CLASSIFICATION OF RESOURCES USED IN PROJECTS

Project resources can be classified in several ways. One approach is based on accounting principles, which distinguish between labor costs (human resources), material costs, and other "production" costs, such as subcontracting and borrowing. This classification scheme is very useful for budgeting and accounting. Its major drawbacks are that it does not specifically include the cost of the less tangible resources such as information (blueprints, databases), and it does not capture the main aspect of project resource management (i.e., the availability of resources).

A second approach is based on resource availability. Some resources are available at the same level in every time period (e.g., a fixed workforce). These are *renewable* resources. A second class consists of resources that come in a lump sum at the beginning of the project and are used up over time. These are *depletable* resources, such as material or computer time. A third class of resources is available in limited quantities each period. However, their total availability throughout the project is also circumscribed. These are called *doubly constrained* resources. The cash available for a project is a typical example of a doubly constrained resource. Based on this classification, one objective in using renewable resources is to minimize idle time or to maximize utilization. An objective in using depletable resources is to maximize "effectiveness"—the ratio between output and input.

A third classification scheme is similarly based on resource availability. The first class includes all "nonconstrained" resources—those that are available in unlimited quantities for a cost. A typical example is untrained labor or general-purpose equipment. The second class includes resources that are very expensive or impossible to obtain within the time span of the project. Special facilities, such as the use of a supercomputer, and technical experts who work on many projects are two such examples. This class also includes resources of which a given quantity is available for the entire project, such as a rare type of material that has a long lead time. The quantity ordered at the beginning of the project must last throughout, because of its limited supply.

This scheme is characteristic of an ABC inventory management system. Resources of the first class (C category) are available in unlimited quantities and so do not require continuous monitoring. Nevertheless, they still might be expensive, so their efficient use will help keep project costs down. Resources in the second class (A category) have high priority and should be monitored closely because shortages might significantly affect the project schedule and success. In general, depletable resources and those limited by periodic availability should be considered individually during the planning process. This means that project schedules should be designed to ensure optimal use of constrained resources and that tight controls should be placed on the consumption of nonconstrained resources.

In addition to availability considerations, the cost of resources should be weighed when developing project schedules. This is critical whenever activities can be performed by various resources. The combination of resources (often called the "mode") assigned to an activity affects both the duration and the cost of the activity and may affect the schedule and the cost of the entire project.

Often, it is not possible to allocate resources to activities accurately at the early stages of a project. This is because of the underlying uncertainty that initially shrouds resource requirements. Therefore, resource planning monitoring and control is a continuous process that takes place throughout the life cycle of the project.

In a multiproject environment, the specific resource alternative selected also affects other ongoing projects. It is common sense to start the planning process by assuming that each activity is performed by the minimum cost resource alternative. This mode of operation is known as the "normal" mode, and it is associated with the "normal" time and "normal" cost of the activity. To identify this alternative, the following points should be considered:

- The selection of resources should be designed for maximum flexibility so that resources that are not essential for one project can be used simultaneously on other projects. This flexibility can be achieved by buying general-purpose equipment and by broadly training employees.
- Up to a certain point, the more of a particular resource used, the less expensive it is per unit of time (as a result of savings in setup cost, greater learning, and economies of scale).
- The marginal contribution of a resource decreases with usage. Frequently, when increasing the quantity of a resource type assigned to an activity, a point at which additional resources do not shorten the activity's duration is reached. That is, inefficiencies and diminishing returns set in.
- Some resources are discrete. When this is the case, decreasing resource levels, necessarily in integer quantities, could result in a sharp decline in productivity and efficiency.
- Resources are organizational assets. Resource planning should take into consideration not only what is best for an individual project but also what is best for the organization as a whole.
- The organization has better control over its own resources. When the choice of acquiring or subcontracting for a resource exists, the degree of availability and control should be weighed against cost considerations.

The output of each resource is measured by its capacity, which is commonly defined in two ways:

1. *Nominal capacity*: maximum output achieved under ideal conditions. The nominal capacity of equipment is usually contained in its technical manual. Nominal capacity of labor can be estimated with standard work measurement techniques commonly used by industrial engineers.
2. *Effective capacity*: maximum output taking into account the mixture of activities assigned, scheduling and sequencing constraints, maintenance aspects, the operating environment, and other resources used in combination.

Resource planning is relatively easy when a single resource is used in a single project. When the coordinate use of multiple resources in multiple projects is called for, planning and scheduling become more complicated, especially when dependencies exist among several projects. In some cases, it is justified to use excessive levels of inexpensive readily available resources (type C in the ABC classification) to maximize the utilization of resources that are expensive or in limited supply (type A in the ABC classification).

The life cycle of a project affects its resource requirements. In the early stages, the focus is on design. Thus, highly trained personnel such as system analysts, design engineers, and financial planners are needed. In subsequent stages, execution becomes dominant, and machines and material requirements increase. A graph of resource requirements as a function of time is called a *resource profile*. An example of labor and material profiles as a function of a project's life-cycle stages is presented in Fig. 1. Curve (a) depicts the requirements for engineers as a function of time. As can be seen, demand peaks during the advanced development phase of the project. Curve (b) displays the requirements for technicians. In this case, the maximum is reached during the detailed design and production phases. This is also true for material requirements, as shown in curve (c).

The general shape of the profiles depicted in Fig. 1 can be modified somewhat by careful planning and control. Slack management is one way to reshape resource requirements. Because it is always possible to start an activity within the range defined by its early- and late-start schedules, it may be possible to achieve higher resource utilization and lower costs by exploring different assignment patterns. In some projects, limited resource availability forces the delay of activities beyond their late start. When this happens, project delays are inevitable unless corrective action can be taken immediately.

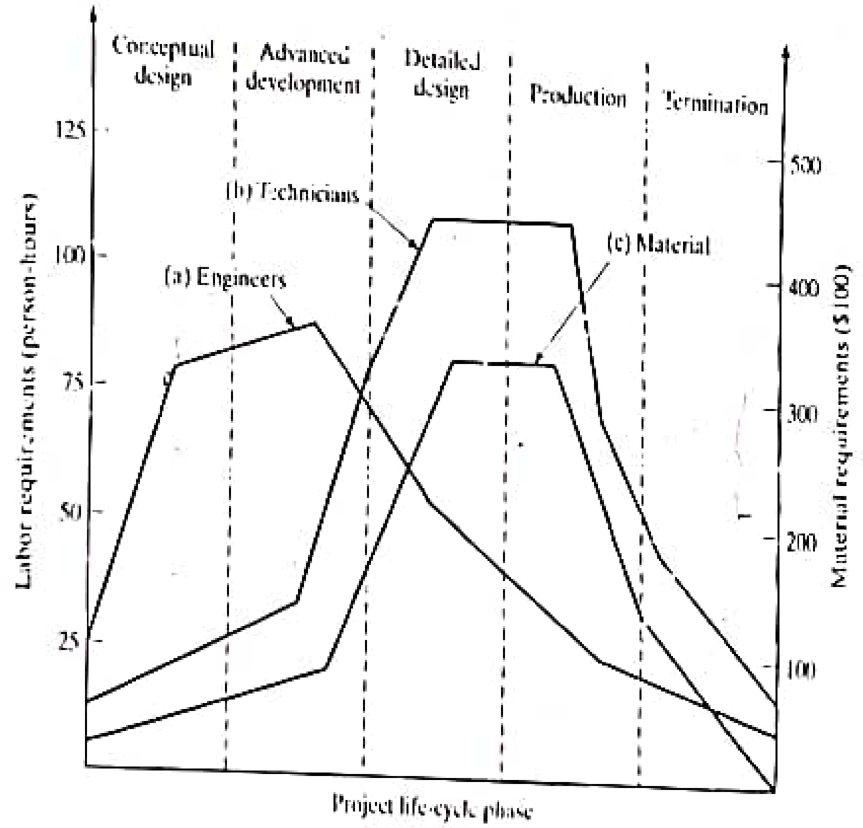


Figure 1 Typical resource requirement profiles.

3 RESOURCE LEVELING SUBJECT TO PROJECT DUE-DATE CONSTRAINTS

To discuss the relationship between resource requirements and the scheduling of activities, consider the example project that was introduced in Table 9.2. Assuming that only a single resource is used (unskilled labor) in the project, Table 1 lists the resource requirements for each of the seven activities.

The data in Table 1 are based on the assumption that performing an activity requires that the resource be used at a constant rate. Thus, activity A requires 8 unskilled labor-days in each of its 5 weeks. When the usage rate is not constant, resource requirements should be specified for each time period (a week in our example).

The Gantt chart for the early-start schedule is shown in Fig. 2a; the corresponding resource requirement profile is depicted in Fig. 2b. As can be seen, the early-start schedule produces a high level of resource use at the early stages of the project. During the first 3 weeks, there is a need for 17 labor-days each week. Assuming 5 working days per week, the requirement during the first 3 weeks is 17/5 = 3.4 unskilled workers per day. The fractional component of demand can be met with overtime, second-shift, or part-time workers. The lowest resource requirements occur in week 15, when only 3 labor-days are needed. Thus, the early-start schedule generates a widely varying profile, with a high of 17 labor-days per week and a low of 3 labor-days per week; the range is 17 − 3 = 14.

The Gantt chart and resource requirement profile associated with the late-start schedule are illustrated in Fig. 3. Because of the effect that scheduling decisions have on resource requirements, there is a difference between the profiles associated with the late-start and early-start schedules. In the example, the late-start schedule moves the maximum resource usage from weeks 1 through 3 to weeks 3 through 5. Furthermore, maximum usage is reduced from 17 labor-days per week to 12 labor-days per week, giving a range of 12 − 3 = 9. It is important to note that the reduction in range while moving from the early-start to the late-start schedule is not necessarily uniform over the intermediate cases.

Resource leveling can be defined as the reallocation of total or free slack in activities to minimize fluctuations in the resource requirement profile. It is assumed that a more steady usage rate leads to lower resource costs. For labor, this assumption is based on the proposition that costs increase with the need to hire, fire, and train personnel. For materials, it is assumed that fluctuating consumption rates mean an increase in storage

labour days/week

TABLE 1 Resource Requirements for the Example Project

Activity	Duration (weeks)	Required labor (days per week)	Total labor (days required)
A	5	8	40
B	3	4	12
C	8	3	24
D	7	2	14
E	7	5	35
F	4	9	36
G	5	7	35

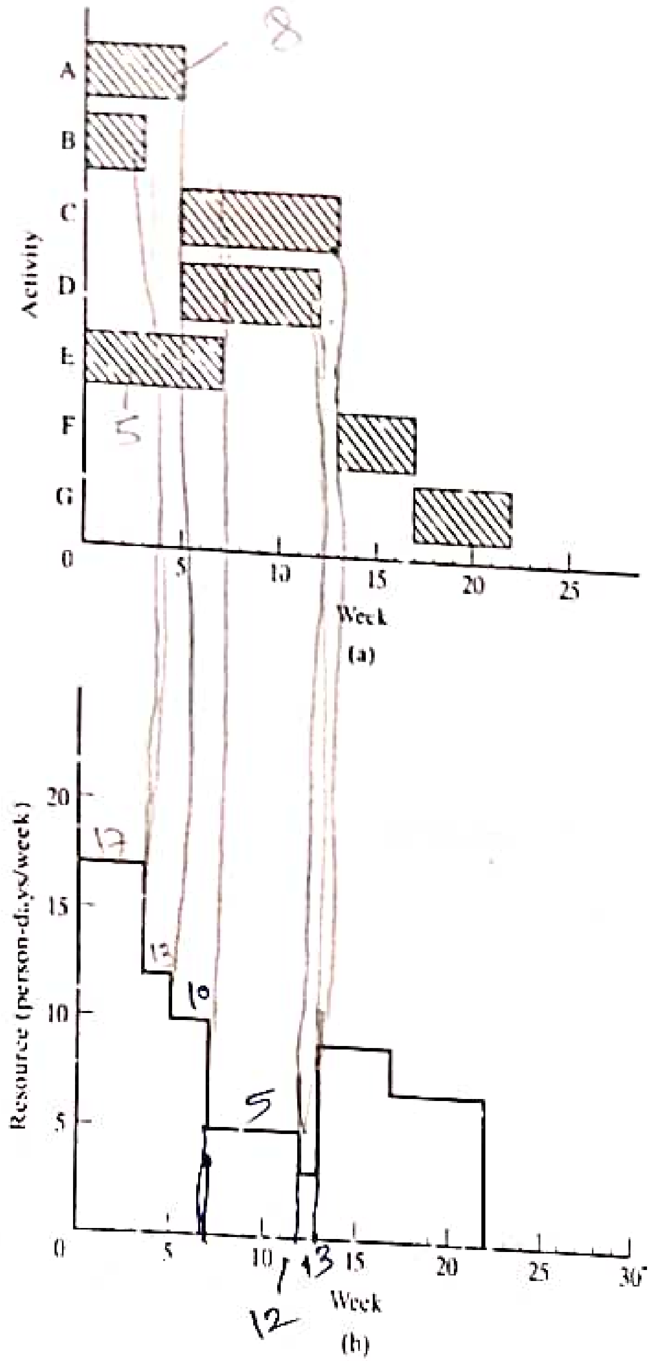
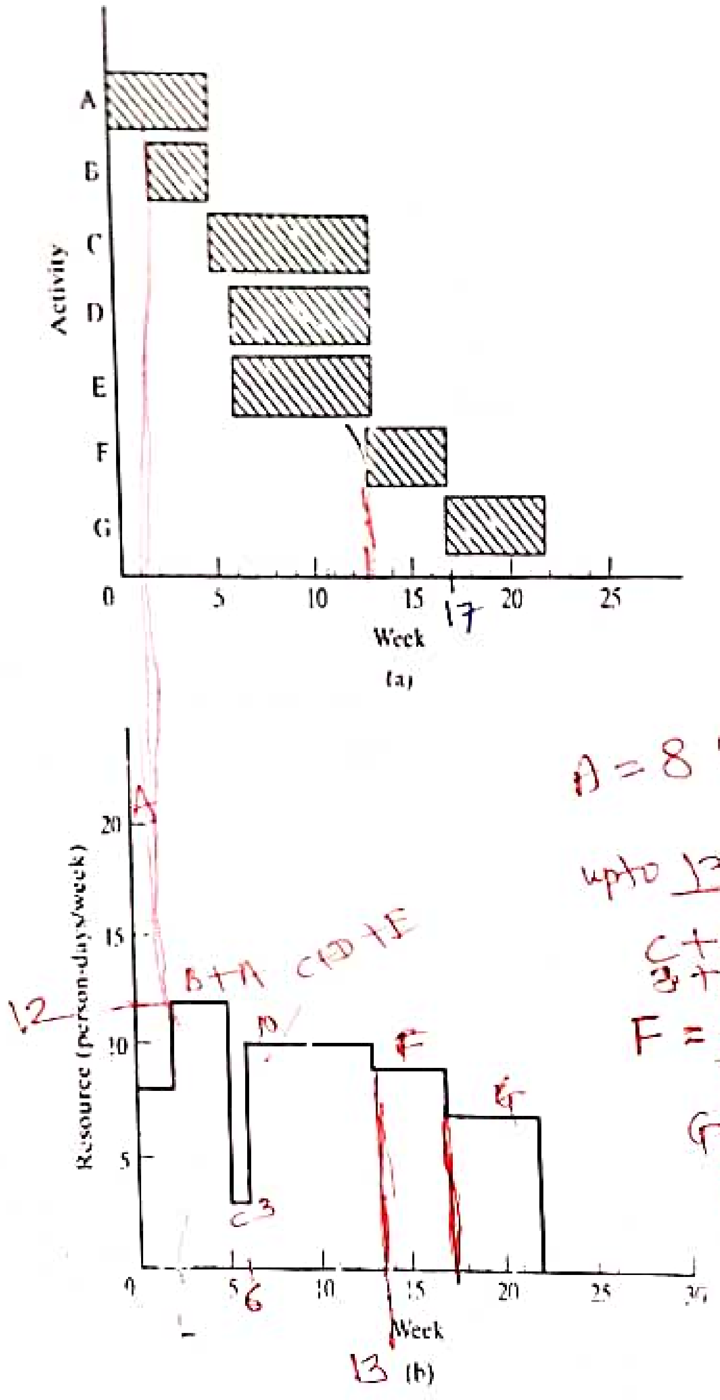


Figure 2 (a) Gantt chart and (b) resource profile for the early-start schedule.



A = 8 (0–2)

upto 13 (6–13)

C+D+E
3+2+5 = 10

F = 9

G = 7
17 to 22

Figure 3 (a) Gantt chart and (b) resource profile for the late-start schedule.

requirement (perhaps to accommodate the maximum expected inventory) and more effort invested in material planning and control.

Resource leveling can be performed in a variety of ways, some of which are described in the references listed at the end of the chapter. A generic resource-leveling procedure is illustrated next and used to solve the example project.

1. Calculate the *average* number of resource-days per period (e.g., week). In the example, a total of 196 resource-days or labor-days are required. Because the project duration is 22 weeks, 196/22 = 8.9 or approximately 9 labor-days per week are required on the average.
2. With reference to the early-start schedule and noncritical activities, gradually delay activities one at a time, starting with those activities that have the largest free slack. Check the emerging resource requirement profile after each delay. Select the schedule that minimizes resource fluctuations by generating daily resource requirements close to the calculated average.

Continuing with the example, we see from earlier that activity E has the largest free slack (6 weeks). The first step is to delay the start of E by 3 weeks until the end of activity B. This reduces resource requirements in weeks 1 through 3 by 5 units. The emerging resource profile is

If A & B is considered in wk1

Week	1	2	3	4	5	6	7	8	9	10	11
Load	12	12	12	13	13	10	10	10	10	10	5
Week	12	13	14	15	16	17	18	19	20	21	22
Load	5	3	9	9	9	9	7	7	7	7	7

This profile has a maximum of 13 and a minimum of 3 labor-days per week. Because the maximum occurs in weeks 4 and 5 and activity E can be delayed further, consider a schedule in which E starts after A is finished (after week 5). The resource requirements profile in this case is

Week	1	2	3	4	5	6	7	8	9	10	11
Load	12	12	12	8	8	10	10	10	10	10	10
Week	12	13	14	15	16	17	18	19	20	21	22
Load	10	3	9	9	9	9	7	7	7	7	7

The maximum resource requirement is now 12 and occurs in weeks 1 through 3. The minimum is still 3, giving a range of 12 − 3 = 9. The next candidate for adjustment is activity B with a free slack of 2 weeks. However, delaying B by 1 or 2 weeks will only increase the load in weeks 4 and 5 from 8 to 12, yielding a net gain of zero. Therefore, we turn to the last activity with a positive free slack—activity D, which is scheduled to start at week 5. Delaying D by 1 week results in the following resource requirement profile:

Week	1	2	3	4	5	6	7	8	9	10	11
Load	12	12	12	8	8	8	10	10	10	10	10

Week	12	13	14	15	16	17	18	19	20	21	22
Load	10	5	9	9	9	9	7	7	7	7	7

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The corresponding graph and Gantt chart are depicted in Fig. 4. Note that this profile has a range of $12 - 5 = 7$, which is smaller than that associated with any of the other candidates, including the early-start and late-start schedules. This is as far as we can go in minimizing fluctuations without causing a delay in the entire project.

For small projects, the foregoing procedure works well but cannot always be relied on to find the optimal profile. To improve the results, a similar procedure can be executed by starting with the late-start schedule and checking the effect of moving activities with slack toward the start of the project. In some projects, the objective may be to keep the maximum resource utilization below a certain ceiling rather than merely leveling the resources. If this objective cannot be met by rescheduling the critical activities, then one or more of them would have to be expanded to reduce the daily resource requirements.

The analysis is more complicated when several types of resources are used, the number of activities is large, and several projects share the same resources. Sophisticated heuristic procedures have been developed for these cases, some of which are listed in the references. Most project management software packages use such procedures for resource leveling.

4 RESOURCE ALLOCATION SUBJECT TO RESOURCE AVAILABILITY CONSTRAINTS

Most projects are subject to resource availability constraints. This is common when resources are limited and suitable substitutes cannot be found. As a consequence, any delay or disruption in an activity may render the original project schedule infeasible. Cash flow difficulties may limit the availability of all resource types: renewable, depletable, and nonconstrained. Some resources may be available in unlimited quantities, but as a result of cash flow problems, their use may have to be cut back in a specific project or over a specific period of time.

Under resource availability constraints, the project completion date calculated in the critical path analysis may not be achieved. This is the case when the resources required exceed the available resources in one or more time periods and the slack of noncritical activities is not sufficient to solve the problem.

Of course, resource availability constraints are not always binding on the schedule. This can be illustrated with the example project. If 17 or more labor-days are available every week, then either an early-start or a late-start schedule can be used to complete the project within 22 weeks. The leveled resource profile derived above requires at most 12 labor-days per week. Therefore, as long as this number is avail[illegible] no delays will be

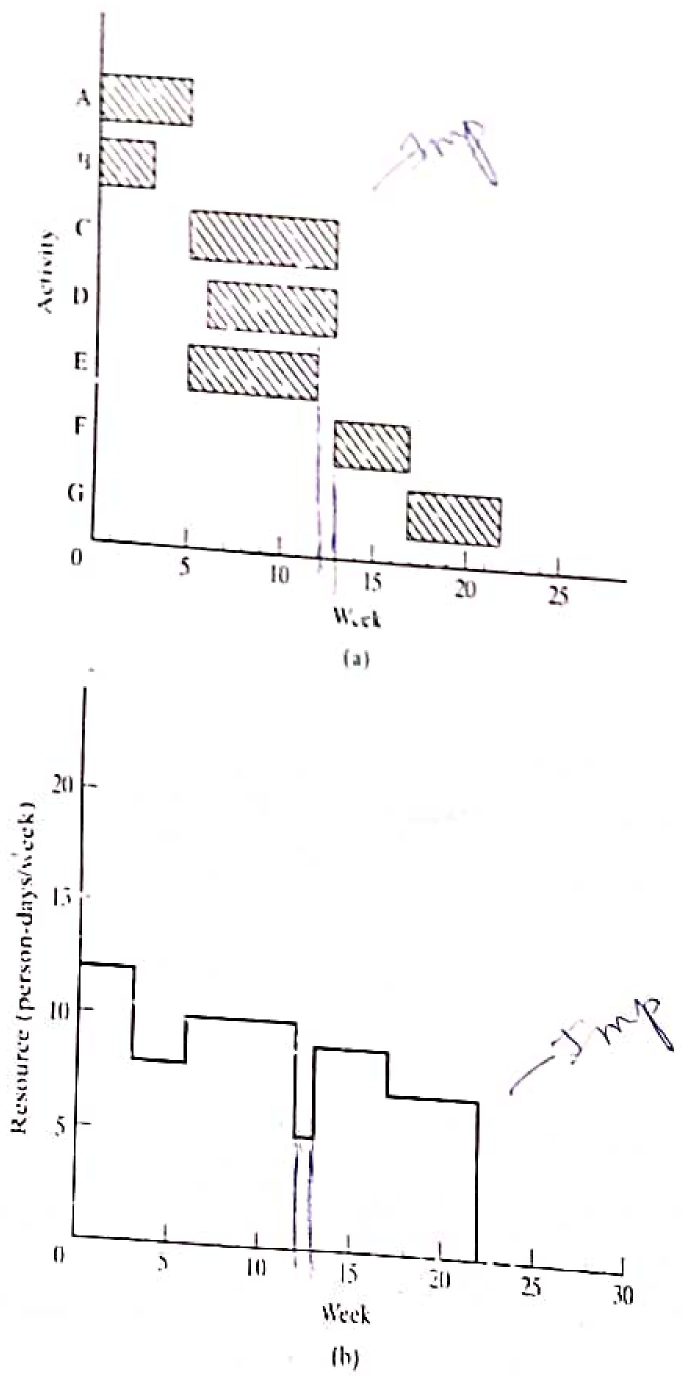

Figure 4 (a) Gantt chart and (b) leveled resource profile for the example project.

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experienced. If fewer resources are available in some weeks, however, then the project may have to be extended beyond its earliest completion date. Activities A and B require a total of 12 labor-days per week when performed in parallel. Despite low resource availability, the project manager can try using one or more of the following strategies to avoid an extension:

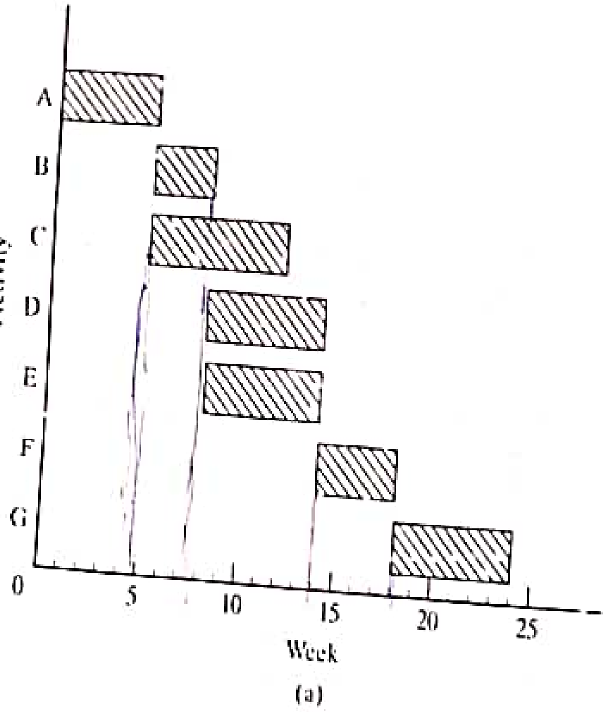
1. *Performing activities at a lower rate using available resource levels.* This technique is effective only when the duration of an activity can be extended by performing it with fewer resources. Consider activity B in the example. Assuming that only 11 labor-days are available each week and activity A (which is critical) is scheduled to be performed using 8 of those days, only 3 days a week are left for activity B. Because B requires a total of (3 weeks) × (4 labor-days per week) = 12 labor-days of the resource, it may be possible to schedule B for 3 days per week for 4 weeks. If this is not satisfactory, then extending B to 5 weeks at 3 days per week may provide the solution.

   B is taken for 4 weeks.

   This technique may not be applicable if a minimum level of resources are required each period (week) in which the activity is performed. Such a requirement might result from technological or safety considerations.
2. *Activity splitting.* It might be possible to split some activities into subactivities without significantly altering the original precedence relations. For example, consider splitting activity A into two subactivities: A_1, which is performed during weeks 1 and 2, and A_2, which is performed after a break of 4 weeks. It is possible then to complete the project within 22 weeks, using only 11 labor-days each week. This technique is attractive whenever an activity can be split, the setup time after the break is relatively short, and the activities that succeed the first subactivity can be performed in accordance with the original plan; that is, the second subactivity has no effect on the original precedence relations.
3. *Modifying the network.* Whenever the network is based solely on end-to-start precedence relations, the introduction of other types of precedence relations might help manage the constrained resources. For example, if an end-to-start connection on the critical path is replaced by a start-to-start connection, then the delay caused by lack of resources may be eliminated. By considering the real precedence constraints among activities and modeling these constraints using all types of precedence relations, some conflicts can be resolved.
4. *Use of alternative resources.* This option is available for some resources. Subcontractors or personnel agencies, for example, are possible sources of additional labor. However, the corresponding costs may be relatively high, so a cost overrun versus a schedule overrun tradeoff analysis may be appropriate.

If these strategies cannot solve the problem, then one or more activities will have to be delayed beyond their total slack, causing a delay in the completion of the project. To illustrate, consider the example project under a resource constraint of 11 labor-days per week. Because activity A requires 8 of these 11 days, activity B can start only when A finishes. The precedence relations force a delay of activity D—the successor of B, as well as F and G. The new schedule and resource profile are depicted in Fig. 5.

After A finishes, B is started



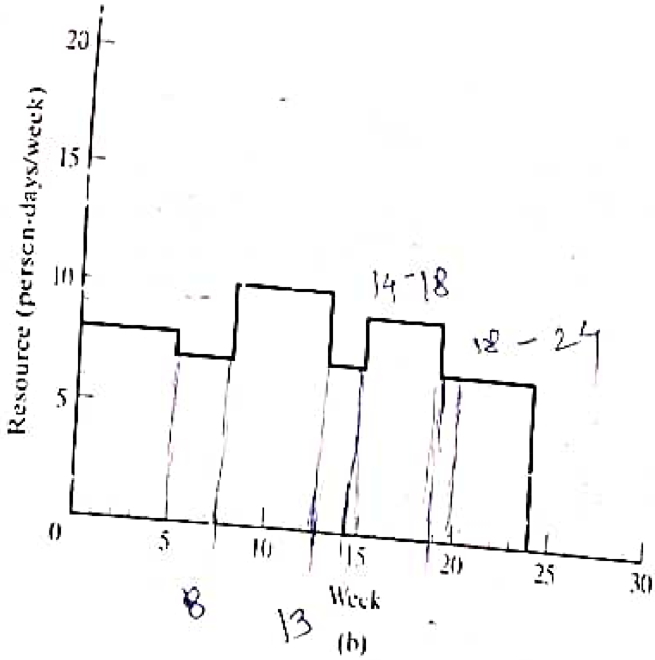


Figure 5 Scheduling under the 11 resource days/week constraint: (a) Gantt chart; (b) resource profile.

It is interesting to note that the maximum level of resources used in the new schedule is 10 labor-days. Thus, in the example project, a reduction of the available resource level from 11 to 10 labor-days per week does not result in a change in the schedule. A further reduction to 9 labor-days each week will cause a further delay of the project because the concurrent scheduling of activities C, D, and E requires a total of 10 resource-days. A feasible schedule in this case and the accompanying resource profile are shown in Fig. 6.

It is impossible to reduce the resource level below 9 labor-days per week because activity F must be performed at that level. Table 2 summarizes the relationship between the resource level available and the project duration.

TABLE 2 Implications of Resource Availability

Resource availability (work-days/week)	Project duration (weeks)	Resource utilization
12	22	0.74
11	24	0.74
10	24	0.82
9	29	0.75

In his book *Critical Chain*, Goldratt (1997) called the resource that is responsible for a project delay the *critical resource* or *bottleneck*. The activities that are performed by this resource are part of a sequence of activities that connect the start of the project to its end and constitute the "critical chain."

Resource utilization is defined as the proportion of time that a renewable resource is used. For example, if 12 labor-days are available each week and the project duration is 22 weeks, a total of 12 × 22 = 254 resource days are available. Because only 196 days are used to perform all of the project's activities, the utilization of this resource is 196/254 = 0.74. Resource utilization is an important performance measure, particularly for renewable resources in a multiproject environment. Resource leveling and resource allocation techniques can be used to achieve high levels of utilization over all projects and resources. Matrix organizational structures help organizations achieve high utilization by taking advantage of pooled resources.

The analysis of multiple projects in which several types of resources are used in each is a complicated scheduling problem. In most real-life applications, the problem is solved with heuristics using priority rules to make the allocations among activities. Some of these rules are discussed in the following section.

5 PRIORITY RULES FOR RESOURCE ALLOCATION

A common approach to resource allocation is to begin with a simple critical path analysis assuming unlimited resources. Next, a check is made to determine whether the resultant schedule is infeasible. This would be the case whenever a resource requirement exceeds its availability. Infeasibilities are addressed one at a time starting with the first activity in the precedence graph and making a forward pass toward the last. A priority

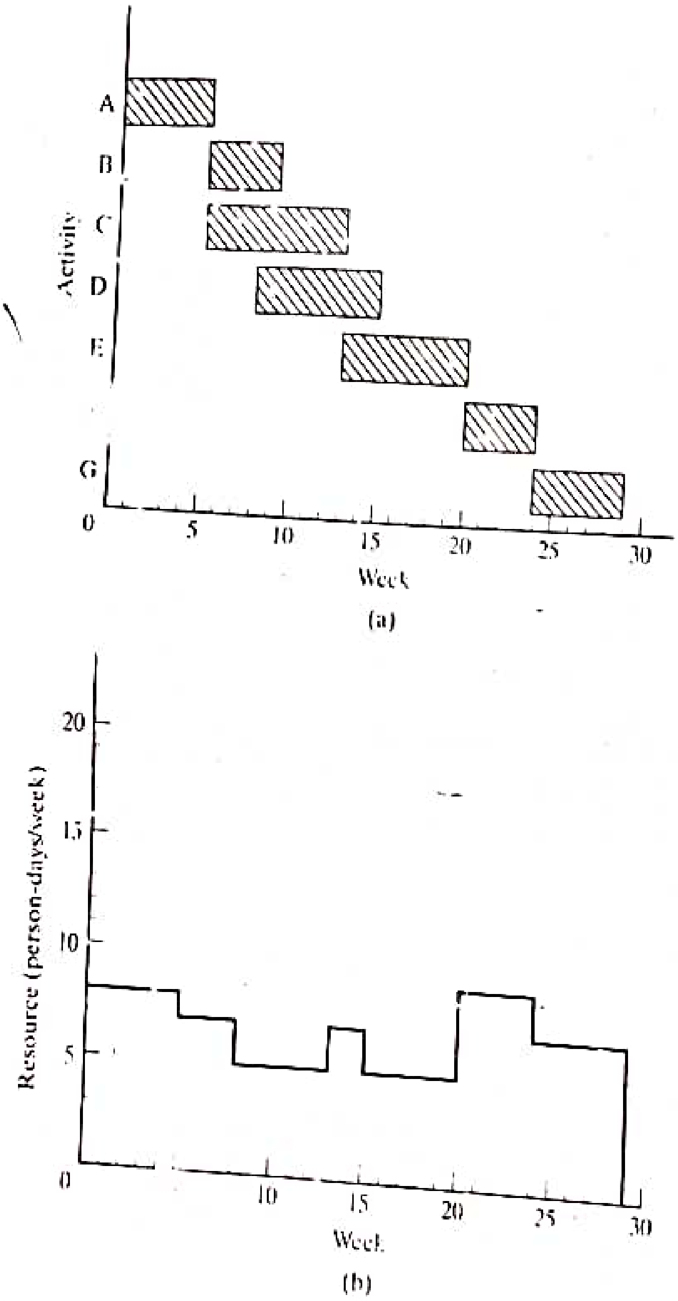


Figure 6 Scheduling under the 9 resource-days/week constraint: (a) Gantt chart; (b) resource profile.

measure is calculated for each activity competing for a scarce resource. The activity with the lowest priority is delayed until sufficient resources are available. This procedure is used to resolve each infeasibility.

Examples of common priority rules are as follows:

- Activity with the smallest slack
- Activity with minimum late finish time (as determined by critical path analysis)
- Activity that requires the greatest number of resource units (or the smallest number of resource units)
- Shorter activities (or longer activities)

A priority rule based on the late start of the activity and the project duration calculated by a critical path analysis is also possible. For example, define

$$\begin{aligned} \text{CPT} &= \text{earliest completion time of the project (based on critical path analysis)} \\ \text{LS}(i) &= \text{late start of activity } i \text{ (based on critical path analysis)} \\ \text{PT}(i) &= \text{priority of activity } i\text{, where } \text{PT}(i) = \text{CPT} - \text{LS}(i) \end{aligned}$$

This rule gives high priority to activities that should start early in the project life cycle. In the case of multiple-project scheduling, the value of CPT is calculated for each project.

Next, we look at a priority rule that is based on each activity's resource requirements. Let

$$\begin{aligned} \text{AT}(i) &= \text{duration of activity } i \\ \text{R}(i, k) &= \text{level of resource } k \text{ required per unit of time for activity } i \\ \text{PR}(i, k) &= \text{priority of activity } i \text{ with respect to resource type } k, \\ &\quad \text{where } \text{PR}(i, k) = \text{AT}(i) \times \text{R}(i, k) \end{aligned}$$

In this rule, high priority is given to the activity that requires the maximum use of resource k.

A rule that is based on aggregated resources is used when some activities require more than a single resource. Define

$$\begin{aligned} \text{PSUMR}(i) &= \text{priority of activity } i \text{ based on all of its required resources} \\ &= \text{AT}(i) \times \textstyle\sum_k \text{R}(i, k) \end{aligned}$$

To operationalize this rule, it is necessary to define a common resource unit such as a resource-day.

A weighted time-resource requirement priority rule can be fashioned from two of the previous rules; for example, let

$$\begin{aligned} \omega &= \text{weight between 0 and 1} \\ \text{PTR}(i) &= \text{the weighted priority of activity } i, \\ &\quad \text{where } \text{PTR}(i) = \omega\, \text{PT}(i) + (1 - \omega)\, \text{PSUMR}(i) \end{aligned}$$

By controlling the value of ω, emphasis can be shifted from the time dimension, PT(*i*), to the resource dimension, PSUMR(*i*).

Many of the priority rules above can be modified to take into account a variety of additional factors, including

- Slack of the activity (total slack, free slack)
- Early start, late start, early finish, and late finish of the activity
- Duration of the activity
- Number of succeeding/preceding activities
- Length of the longest sequence of activities that contain the activity
- Maximum resource requirement sequence of activities that contain the activity

6 CRITICAL CHAIN: PROJECT MANAGEMENT BY CONSTRAINT

Goldratt (1997) extended the notion of bottlenecks used in job-shop and flow-shop scheduling to project resource management. Critical resources or bottlenecks delay activities on the critical chain as a result of their limited availability. In a multiresource project, bottlenecks whose capacity is relatively inexpensive to increase may cause low utilization of expensive or scarce resources. For example, a leased crane is an expensive resource that might be idle if an operator is not available because both resources are required simultaneously to perform an activity. From an economic point of view, it is preferable to maximize the utilization of the expensive resource at the risk of underutilizing the inexpensive one. Therefore, if the leased crane is available and needed 14 hours each day but an operator can work only between 8 and 10 hours a day, then it would be advisable to hire two operators for a total of 16 hours a day, allowing for 2 hours of operator idle time.

Of course, idle resources signal inefficiencies that should be brought to the attention of management to determine whether they can be put to alternative use. Resource utilization is a key factor, sharing center stage with cost and on-time performance during project evaluation. Each of these factors figures prominently in the planning and review process.

Because the critical chain is the longest sequence of activities that connect the start of the project to its end under resource constraints and because any delay in the critical chain will cause a delay of the entire project, Goldratt suggested using buffers to hedge against uncertainty. In particular, a time buffer can be used to protect the critical resource and the critical chain.

7 MATHEMATICAL MODELS FOR RESOURCE ALLOCATION

Project scheduling under resource availability constraints has been the subject of much research (e.g., see Demeulemeester and Herroelen 1997, Herroelen et al. 1999, Tavares 1990). Most of the related studies assume that the scheduling objective is to complete the project as early as possible (the scheduling approach) or to maximize the net present value (NPV) (minimize the net present cost) of the project (the budgeting approach). An early model proposed by Patterson et al. (1989, 1990) can handle both objectives.

Risk management

Risk management Approaches -

1. Reactive
2. Proactive

Reactive - adverse / unfavourable events occur with the risk & take steps to prevent future occurrences of the same risk.

Consider a project in which the server hosting the project data crashes. Once this event has occurred, the team members may put ~~best~~ efforts to recover the data & also initiate the practice of taking regular backups.

Risk assessment -

risk exposure = (potential damage) x (probability of occurrence).

Say a project depended on a data centre vulnerable to fire. It might be estimated that if a fire occurred, a new computer configⁿ could be established for $500,000. It might also be estimated that where the computer is located, there is a 1 in 1000 chance of a fire actually happening, that is probability of 0.001.

∴ Risk exposure = $500,000 x 0.001 = $500.

Qualitative descriptions of the possible impact and likelihood of each risk.

Prob. level	Range
High	Greater than 50% chance of happening
Significant	30 - 50% chance of happening
Moderate	10 - 29% —"—
low	less than 10% —"—

Qualitative descriptors of impact on cost & associated range values

Impact level	Range
High	More than 30% above budgeted expenditure.
significant	20 - 29% —"—
moderate	10 - 19% —"—
low	within 10% of budgeted expenditure.

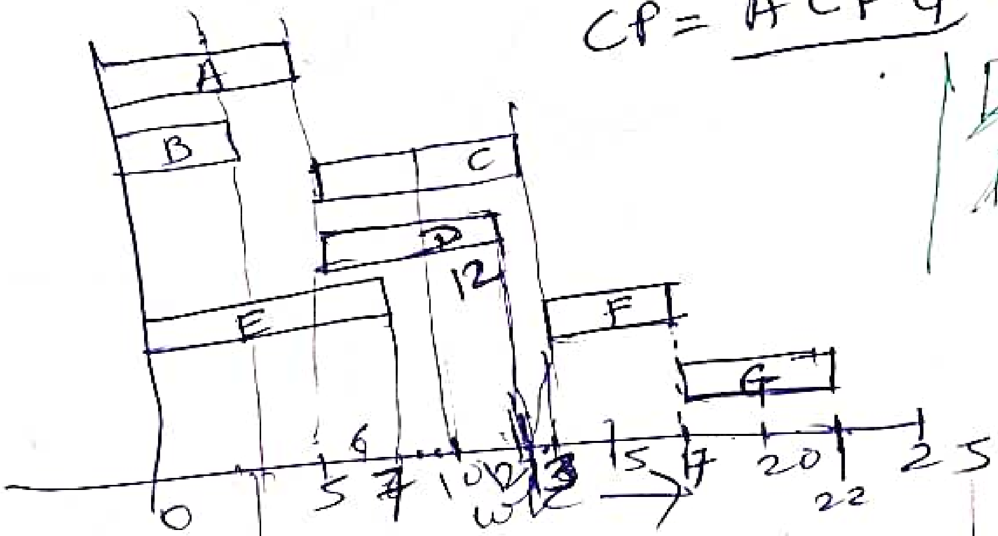
Probability impact matrix

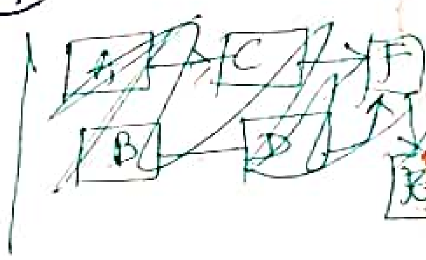
Tolerance line

Impact ↑	low	moderate	significant	High
High		R6		R1
signifi		R2, R3, R5		R4
Moderate				
low				

Activity	wks	Req labour (days/wk)	Total labor (days reqd)	Predecessor
A	5	8	40	—
B	3	4	12	—
C	8	3	24	A, B
D	7	2	14	B
E	7	5	35	
F	4	9	36	C
G	5	7	35	F

CP = ACFG





Resource profile for early start schedule.