04. Planning Projects:

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4.1 Crashing project time: -

The Meaning Of Crashing

The process of shortening the time to complete a project is called crashing and is usually achieved by putting into service additional labour or machines to one activity or more activities. Crashing involves more costs. A project manager would like to speed up a project by spending as minimum extra cost as possible. Project crashing seeks to minimize the extra cost for completion of a project before the stipulated time.

Steps In Project Crashing

Assumption: It is assumed that there is a linear relationship between time and cost.

Let us consider project crashing by the critical path method. The following four-step procedure is adopted.

Step 1

Find the critical path with the normal times and normal costs for the activities and identify the critical activities.

Step 2

Find out the crash cost per unit time for each activity in the network.

This is calculated by means of the following formula.

$$\frac{Crash\ \text{cost}}{Time\ period} = \frac{Crash\ \text{cost} - Normal\ \text{cost}}{Normal\ time - Crash\ time}$$

Step 3

Select an activity for crashing. The criteria for the selection are as follows:

Select the activity on the critical path with the smallest crash cost per unit time. Crash this activity to the maximum units of time as may be permissible by the given data.

Crashing an activity requires extra amount to be spent. However, even if the company is prepared to spend extra money, the activity time cannot be reduced beyond a certain limit in view of several other factors.

In step 1, we have to note that reducing the time of on activity along the critical path alone will reduce the completion time of a project. Because of this reason, we select an activity along the critical path for crashing.

In step 3, we have to consider the following question:
If we want to reduce the project completion time by one unit, which critical activity will involve the least additional cost?
On the basis of the least additional cost, a critical activity is chosen for crashing. If there is a tie between two critical activities, the tie can be resolved arbitrarily.

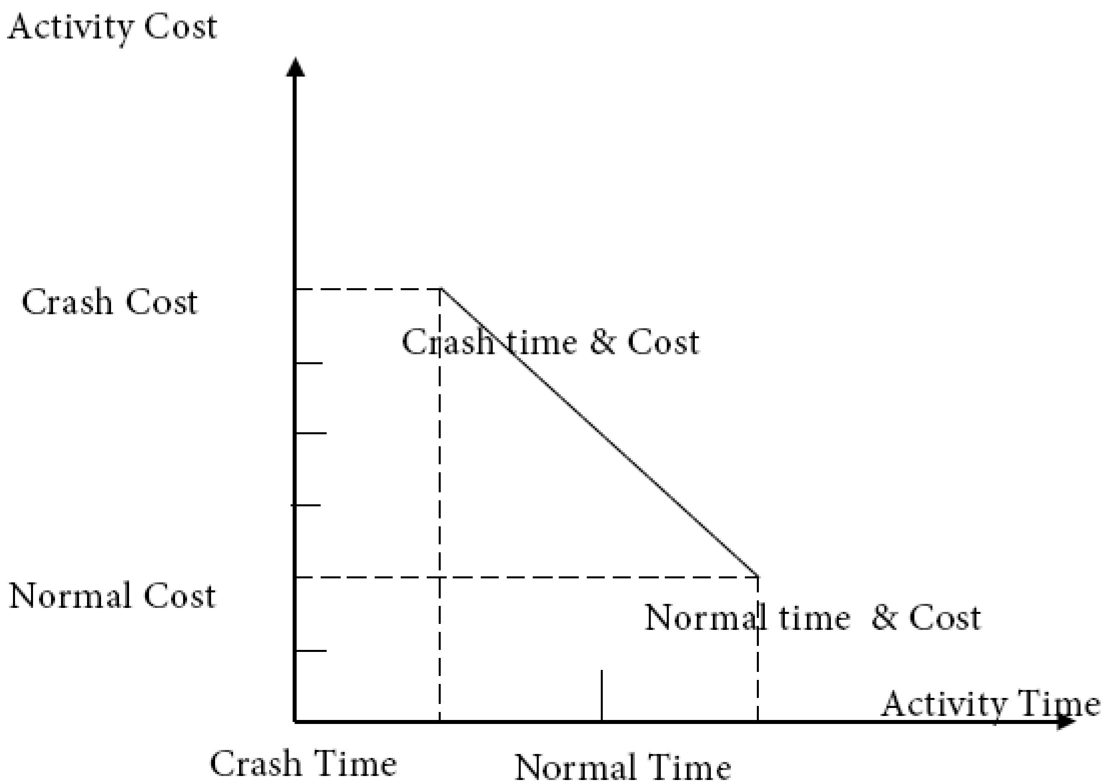


Fig. 4.1

Step 4
After crashing an activity, find out which is the critical path with the changed conditions? Sometimes, a reduction in the time of an activity in the critical path may cause a non-critical path to become critical. If the critical path with which we started is still the longest path, then go to Step 3. Otherwise, determine the new critical path and then go to Step 3.

Problem 1
A project has activities with the following normal and crash times and cost:

Activity	Predecessor Activity	Normal Time (Weeks)	Crash Time (Weeks)	Normal Cost (Rs.)	Crash Cost (Rs.)
A	-	*4*	*3*	*8,000*	*9,000*
B	*A*	*5*	*3*	*16,000*	*20,000*
C	*A*	*4*	*3*	*12,000*	*13,000*
D	*B*	*6*	*5*	*34,000*	*35,000*
E	*C*	*6*	*4*	*42,000*	*44,000*

F	*D*	*5*	*4*	*16,000*	*16,500*
G	*E*	*7*	*4*	*66,000*	*72,000*
H	*G*	*4*	*3*	*2,000*	*5,000*

Determine a crashing scheme for the above project so that the total project time is reduced by 3 weeks.

Solution

We have the following network diagram for the given project with normal costs:

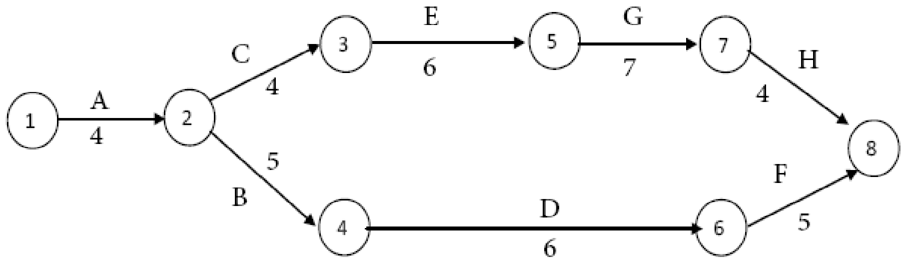
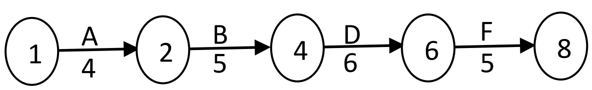


Fig. 4.2 Network Diagram of problem 1

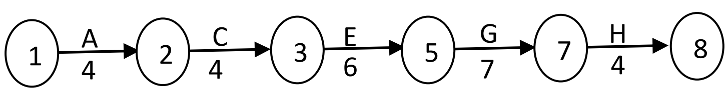
Beginning from the Start Node and terminating with the End Node, there are two paths for the network as detailed below:

Path I



The time for the path = 4 + 5 + 6 + 5 = 20 weeks.

Path II



The time for the path = 4 + 4 + 6 + 7 + 4 = 25 weeks.

Maximum of {20, 25} = 25.

Therefore, Path II is the critical path and the critical activities are A, C, E, G and H. The non-critical activities are B, D and F.

Given that the normal time of activity A is 4 weeks while its crash time is 3 weeks. Hence the time of this activity can be reduced by one week if the management is prepared to spend an additional amount. However, the time cannot be reduced by more than one week even if the management may be prepared to spend more money. The normal cost of this activity is Rs. 8,000 whereas the crash cost is Rs. 9,000. From this, we see that crashing of activity A by one week will cost the management an extra amount of Rs. 1,000. In a similar fashion, we can work out the crash cost per unit time for the other activities also. The results are provided in the following table.

Activity	Normal Time (Weeks)	Crash Time (Weeks)	Normal Cost (Rs.)	Crash Cost (Rs.)	Crash cost - Normal Cost	Normal Time - Crash Time	Crash Cost per unit time
A	*4*	*3*	*8,000*	*9,000*	*1,000*	*1*	*1,000*
B	*5*	*3*	*16,000*	*20,000*	*4,000*	*2*	*2,000*
C	*4*	*3*	*12,000*	*13,000*	*1,000*	*1*	*1,000*
D	*6*	*5*	*34,000*	*35,000*	*1,000*	*1*	*1,000*
E	*6*	*4*	*42,000*	*44,000*	*2,000*	*2*	*1,000*
F	*5*	*4*	*16,000*	*16,000*	*500*	*1*	*500*
G	*7*	*4*	*66,000*	*72,000*	*6,000*	*3*	*2,000*
H	*4*	*3*	*2,000*	*5,000*	*3,000*	*1*	*3,000*

A non-critical activity can be delayed without delaying the execution of the whole project. But, if a critical activity is delayed, it will delay the whole project. Because of this reason, we have to select a critical activity for crashing. Here we have to choose one of the activities A, C, E, G and H . The crash cost per unit time works out as follows:
Rs. 1,000 for A; Rs. 1,000 for C; Rs. 1,000 for E; Rs. 6,000 for G; Rs. 3,000 for H.
The maximum among them is Rs. 1,000. So we have to choose an activity with Rs.1,000 as the crash cost per unit time. However, there is a tie among A, C and E. The tie can be resolved arbitrarily. Let us select A for crashing. We reduce the time of A by one week by spending an extra amount of Rs. 1,000. After this step, we have the following network with the revised times for the activities:

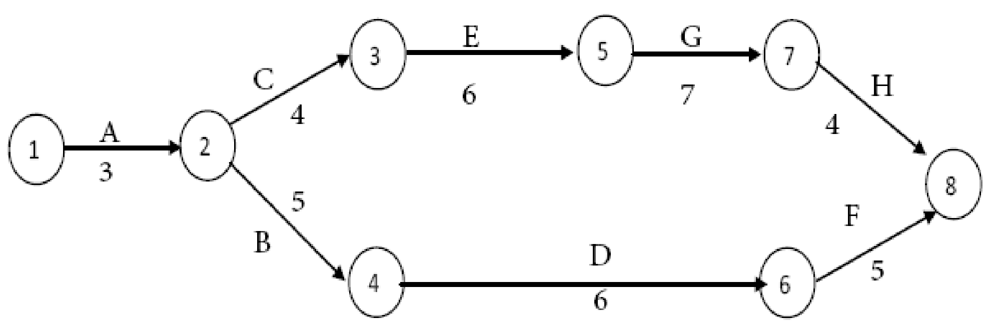


Fig. 4.2 Modified Network Diagram of problem 1 after crashing activity A

The revised time for Path I = 3 + 5 + 6 + 5 = 19 weeks.
The time for Path II = 3 + 4 + 6 + 7 + 4 = 24 weeks.
Maximum of {19, 24} = 24.
Therefore Path II is the critical path and the critical activities are A, C, E, G and H. However, the time for A cannot be reduced further. Therefore, we have to consider C, E, G and H for crashing. Among them, C and E have the least crash cost per unit time. The tie between C and E can be resolved arbitrarily. Suppose we reduce the time of C by one week with an extra cost of Rs. 1,000.
After this step, we have the following network with the revised times for the activities:

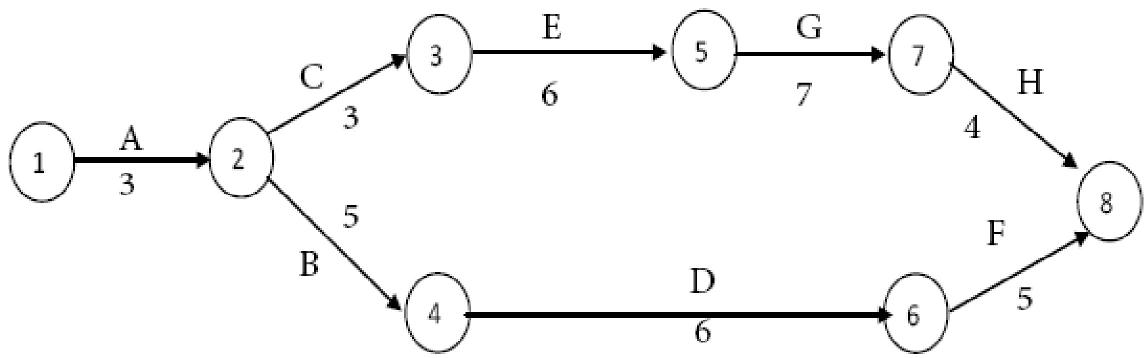


Fig. 4.2 Modified Network Diagram of problem 1 after crashing activity C

The time for Path I = 3 + 5 + 6 + 5 = 19 weeks.
The time for Path II = 3 + 3 + 6 + 7 + 4 = 23 weeks.
Maximum of {19, 23} = 23.
Therefore Path II is the critical path and the critical activities are A, C, E, G and H. Now the time for A or C cannot be reduced further.
Therefore, we have to consider E, G and H for crashing. Among them, E has the least crash cost per unit time. Hence we reduce the time of E by one week with an extra cost of Rs. 1,000.
By the given condition, we have to reduce the project time by 3 weeks. Since this has been accomplished, we stop with this step.
Result: We have arrived at the following crashing scheme for the given project:
Reduce the time of A, C and E by one week each.
Project time after crashing is 22 weeks.
Extra amount required = 1,000 + 1,000 + 1,000 = Rs. 3,000.

Network Diagram For the Constrained Resources

A network diagram is the graphical representation of a detailed project plan; it illustrates the job logic and basic activity sequencing. In general, a network diagram shows the 'big picture,' what is going to happen and in what order. In this way, it is an accurate, efficient, and reliable review method to prevent any bad logic from getting "lost" in the scheduling software. Thus, it is very important that interested parties understand how to read and evaluate these diagrams. The most popular, powerful, flexible, and effective diagramming method used in the construction industry is the Precedence Diagramming Method (PDM)—used by nearly every scheduling software—due to its ease of creation and use, and due to its incorporation of the four major activity relationships. A single node represents an activity and is logically connected to other activities by a line or arrow, as represented in Figure 4.3. Like other methods, PDM has rules and standards. Figure 4.4 shows the standard nomenclature for activities in a precedence network.

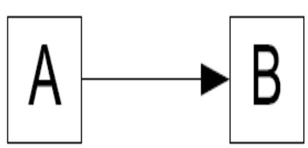


Fig. 4.3: Precedence Diagramming

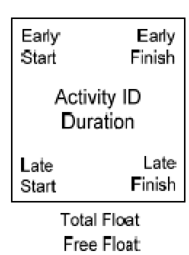


Fig. 4.4 : Standard Precedence Diagramming Nomenclature

The activities for successful project completion have been identified, their durations determined, and their sequence defined; all that remains is knowing exactly when they will occur, the specific time associated with their sequence. Essentially, the PDM puts the pieces of the plan together, preparing them for the scheduling process. Figure 4 shows an example precedence diagram where the basic job logic is applied in order to sequence the activities. The figure shows a very simple sub-network with very few activities, very straightforward logic, and no smart relationships. Nonetheless, a well-modeled network diagram for even the most complicated project is absolutely necessary. The scheduling of the model is only as effective as the model represents reality. Accordingly, in order that scheduling has any relevance, planning must define inputs that closely model the actual construction of the project.

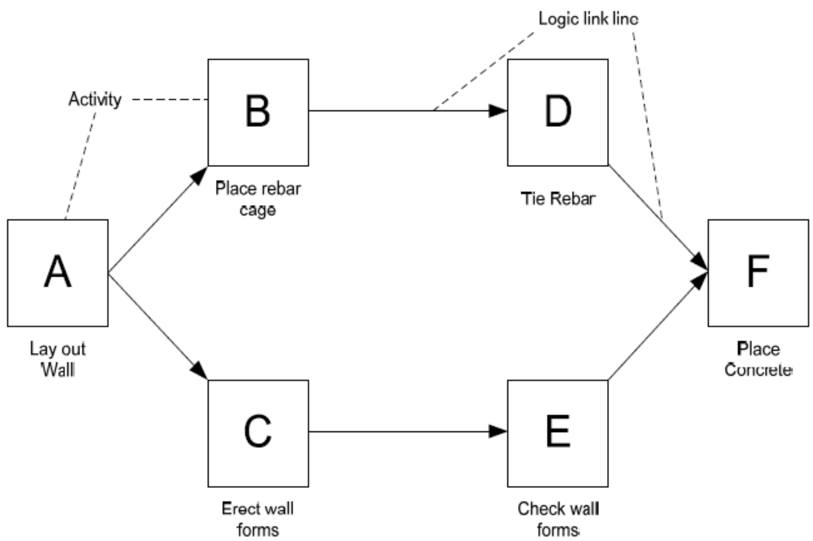


Fig. 4.5: Example Precedence Network

The Process

Once the project network is diagrammed and durations have been assigned to activities, the schedule is ready for calculation. CPM uses a forward and backward pass to calculate the following important scheduling information for each activity: early start (ES), early finish (EF), late start (LS), late finish (LF), and the float. (These topics will be thoroughly discussed in the Outputs section) The starts and finishes determined are in *ordinal* days—time not bound to a calendar or time period, but a unit of time. Thus, the sequential ordinal days are then converted to calendar days, from which a complete construction schedule is developed. Scheduling is not an easy process, but with the aid of computer-based software, the tedious and repetitive parts of scheduling are performed instantly. Modern calculations are performed by intelligent computer-based scheduling software. Inside the "black box," the software performs all the tedious calculations and iterations instantaneously. However, schedules produced by software are only as relevant as the inputs are reflective of the actual construction plan. And, the produced schedule is only as accurate as the software correctly applies the rules of CPM and resource leveling.

4.1 Forward Pass

The forward pass is the process of navigating through a network from start to finish and calculating the early dates for each activity and the completion date of the project [Mubarak 2005]. Specifically, the forward pass through an activity network yields the early start and early finish of each activity and the minimum total project duration. The process assumes that all activities in the network will start as soon as possible; each activity will start just as soon as the last of its predecessors finishes. Furthermore, the activities will finish as soon as possible; thereafter, succeeding activities will start immediately. The process starts with the first activity and time zero. The early finish (EF) is found by simply adding the duration of the activity to its earliest start. The early start (ES) for an activity is the earliest an activity can start; therefore, the early start is the same as the early finish of a preceding activity. However, if more than one activity precedes an activity, the early start comes from the latest finish of all preceding activities. Figure 5 illustrates the ease of the forward pass on a network without smart relationships.

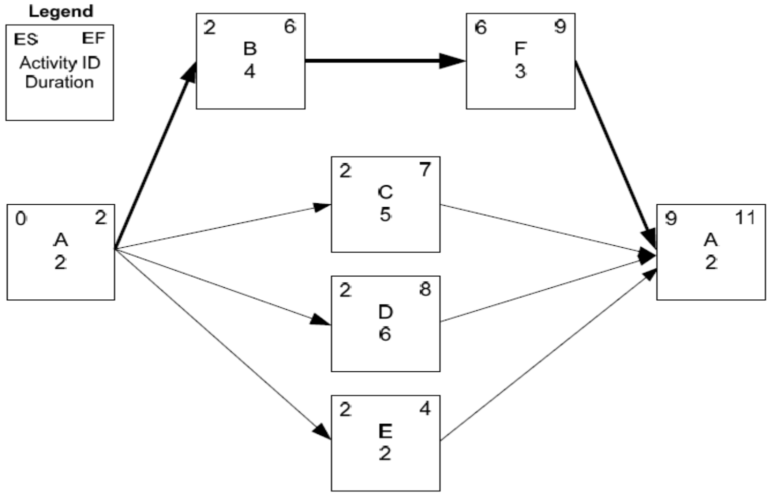


Fig. 4.6: Basic Forward Pass Example

Adding SS, FF, SF relationships and leads and lags significantly complicates the process. But, the definitions of early start and finish remain the same. When performing the forward pass with smart relationships and leads and lags, collect all the possible ES for each activity and choose the latest ES from the list. For FF and SF relationships, find the ES by first finding the EF and subtract the activity's duration. Figure 6 demonstrates how the forward pass becomes more complex when relationships and time are added to more realistically model a construction project.

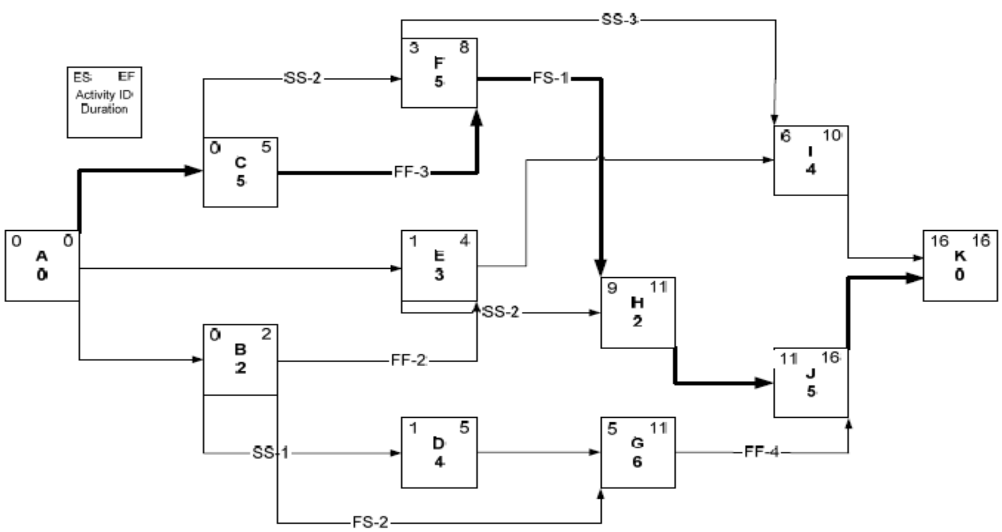


Fig. 4.76: Forward Pass with Smart Relationships

If multiple calendars are employed, forward pass calculations follow this rule: if the ES or EF of the successor calculated directly from the predecessor is a non-working day, the early time should be postponed to the next available working date in order to satisfy the minimum time interval. Clearly, multiple calendars add another layer of complexity, making even the simple forward pass time consuming and very complicated.

4.2 Backward Pass

The backward pass is *the process of navigating through a network from finish to start and calculating the late dates for all activities* [Mubarak 2005]. Specifically, the backward pass yields the late start and late finish of each activity and further helps identify the critical path and float times. The backward pass assumes that all activities in the network will start and finish as late as possible; each activity will finish as the earliest of its successors starts. Moreover, the process assumes that all preceding activities will also finish as late as possible. Working backward, from finish to start, the process starts with the final activity and assumes the zero-float convention, which uses the exact number of days calculated by the forward pass as its starting point. The late start (LS) is found by simply subtracting the duration from the LF if there is a single succeeding activity. In the event of multiple successors, the late finish is the earliest late start of all succeeding activities. Figure 7 illustrates the ease of the backward pass on a network without smart relationships.

Adding SS relationships and leads and lags significant complicates the process. But, the definitions of late start and finish remain the same. When performing the backward pass with smart relationships and leads and lags, collect all the possible LF for each activity and choose the earliest from the list. For SS relationships, find the LF by first finding the LS and adding the activity's duration. Figure 8 demonstrates how the backward pass becomes increasingly more complicated.

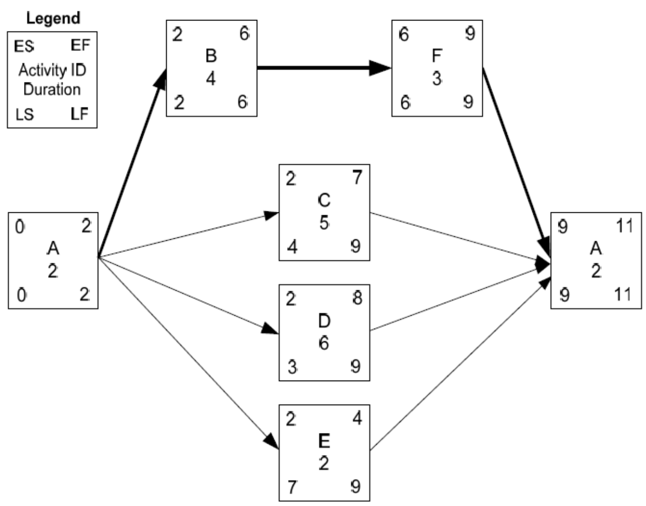


Fig. 4.8: Backward Pass Example

Again, if multiple calendars are involved, backward pass calculations follow this rule: if the LS or LF of the predecessor calculated directly from the successor is a non-working day, the late time should be advanced to the previous available working date in order to satisfy the minimum time interval. To reemphasize, multiple calendars add another layer of complexity to even the simplest of CPM calculations, making them very difficult and tedious.

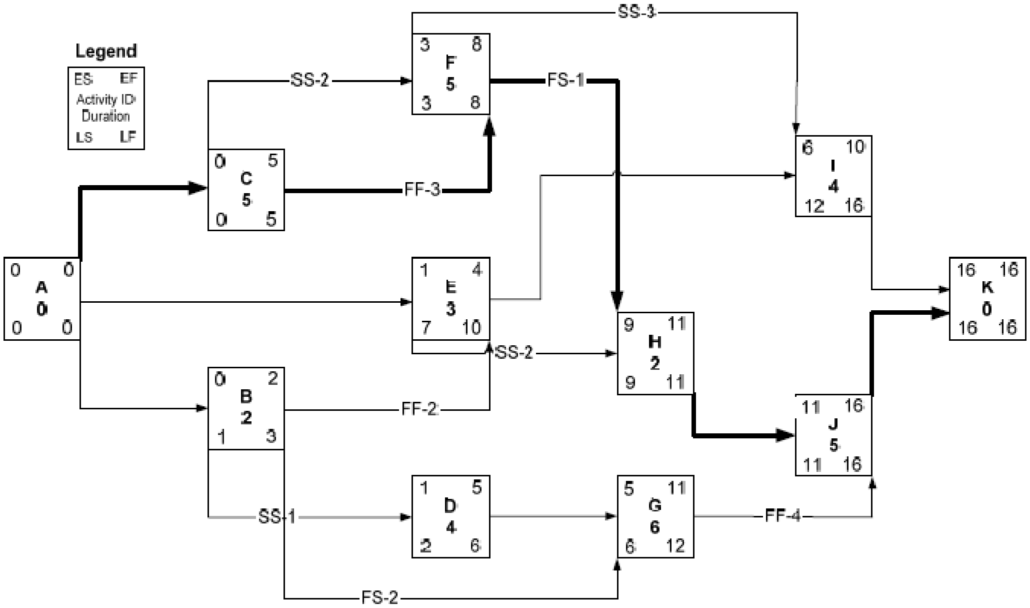


Fig. 4.9 : Backward Pass with Smart Relationships

4.2 Resource loading and leveling: -

Resource Loading

Resource loading describes the amounts of individual resources an existing schedule requires during specific time periods. Therefore, it is irrelevant whether we are considering a single work unit or several projects; the loads (requirements) of each resource type are simply listed as a function of time period. Resource loading gives a general understanding of the demands a project or set of projects will make on a firm's resources. It is an excellent guide for early, rough project planning. Obviously, it is also a first step in attempting to reduce excessive demands on certain resources, regardless of the specific technique used to reduce the demands. Again, we caution the PM to recognize that the use of resources on a project is often nonlinear. Much of the project management software does not recognize this fact. If resources of a project are increased by *X* percent, the output of the project usually does not increase by *X* percent, and the time required for the project does not decrease by *X* percent. The output and time may not change at all, or may change by an amount seemingly not related to *X*. An increase of 20 percent in the number of notes played does not necessarily improve the quality of the music. Any time the resource base of a project is altered from standard practice, the risk that the project may not be successful is changed, often increased. Given a WBS, deriving a resource-loading document is not difficult. The part of the WBS lists the personnel resources needed for each activity. Utilizing data in the WBS, MSP generated the resource usage profile or calendar. Each of the human resources used in the project is listed, followed by the name of the activities in which the resource is used. The total hours of work for each resource called for by the WBS are shown together with the amount planned for each activity. The schedule for resource loading is derived and the loading is then shown for each resource for each week (or day or month) of the project. It should be clear that if the information in this calendar were entered into an Excel® spreadsheet along with estimates of the variability of resource times, Crystal Ball® could be used to simulate the resource loading for any or all of these resources. Because the project WBS is the source of information on activity precedence, durations, and resources requirements, it is the primary input for both the project schedule and its budget. The WBS links the schedule directly to specific demands for resources. Thus, the AOA network technique can be modified to generate time-phased resource requirements. A Gantt chart could be adapted, but the AOA diagram, particularly if modified to slacks, will be helpful in the analysis used for resource leveling.

Let us illustrate with the AOA network is illustrated in Figure 4.10, and resource usage is illustrated for two hypothetical resources, A and B, on the arcs. The expected activity time is shown above the arc, and resource usage is shown in brackets just below the arc, with the use of A shown first and B second—for example, [5,3] would mean that five units of A and three units of B would be used on the activity represented by the arc. Figure 4.11 shows the "calendarized" AOA diagram, similar to the familiar Gantt chart.

Resource demands can now be summed by time period across all activities. The loading diagram for resource A is illustrated in Figure 4.12 and that for resource B in Figure 4.13. The loads are erratic and vary substantially over the duration of the project.

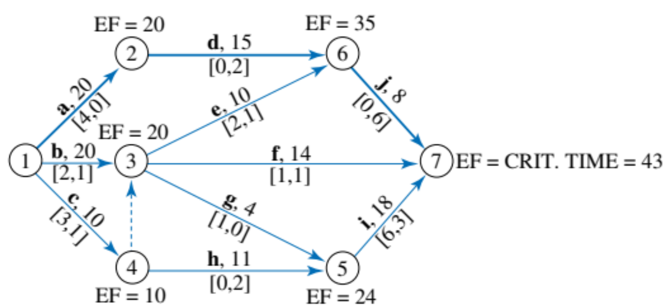


Fig. 4.10. AOA Network for illustration of Resource loading

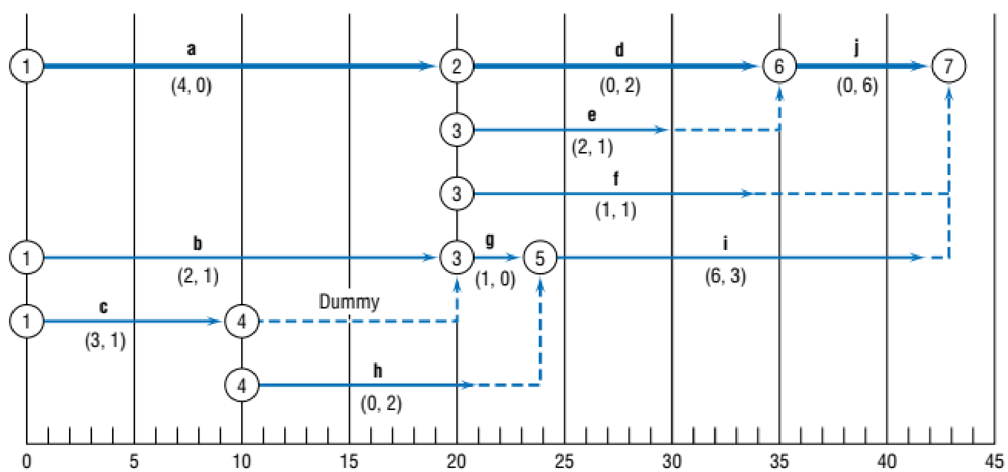


Fig. 4.11. Modified AOA diagram showing activity slack and resource usage (from Figure 4.10)

Resource A, used in tasks **a**, **b**, and **c**, has a high initial demand that drops through the middle of the project and then climbs again. Resource B, on the other hand, has low initial use but increases as the project develops. The PM must be aware of the ebbs and flows of usage for each input resource throughout the life of the project. It is the PM's responsibility to ensure that the required resources, in the required amounts, are available when and where they are needed. In the next three sections, we will discuss how to meet this responsibility.

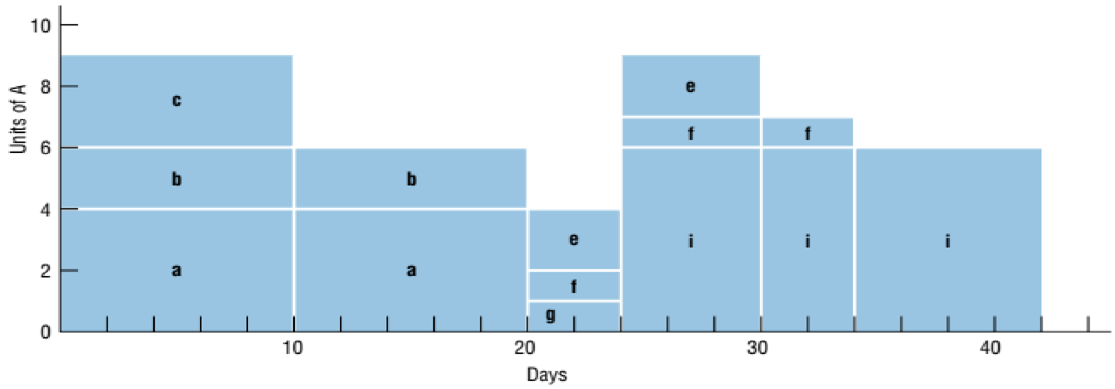


Fig. 4.12 Load diagram for resource A

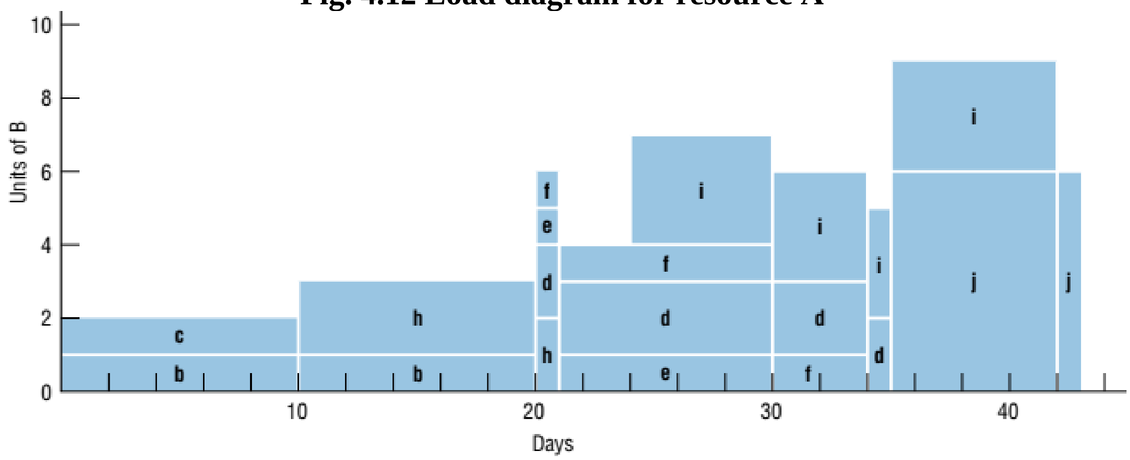


Fig. 4.13 Load diagram for resource B

Resource Leveling

Resource leveling, or smoothing, is a method for developing a schedule that attempts to minimize the fluctuations in requirements for resources. This method levels the resources so that they are applied as uniformly as possible without extending the project schedule beyond its required completion time. It is a trial-and-error method in which the start of noncritical activities (those with positive slack values) are delayed beyond their earliest start times (but not beyond their latest start times) to maintain a uniform level of required resources. Activities can be delayed only to the point where all their positive slack is used up, as any further delays would cause the project to extend beyond the project required completion time. Resource-leveling attempts to establish a schedule in which resource utilization is made as level as possible without extending the project beyond its required completion time. To reiterate, construction project success depends heavily on efficiently utilizing limited and costly resources—labor, materials, and equipment. A resource-loaded schedule demonstrates the interdependencies between activities and resources. Once resources are applied to an activity, the project resources should be leveled (or smoothed) to improve work efficiency and minimize costs. Formally, resource leveling minimizes the fluctuation in daily resource usage throughout the life of the project by shifting non-critical activities within their available float. To smooth resources realistically, the scheduler must employ resource constraints, because no contractor has unlimited resources. The constraints placed on resources should reflect the most likely amount of labor, equipment, and materials available to the contractor under normal conditions. The constraints supersede the original project duration; meaning, the project duration is extended if the constraints cannot be met by using the available total float. Hence, these resource limitations may drive the schedule, changing the critical path. Figures 4.14 and 4.15 illustrate how leveling resources may or may not extend the project duration.

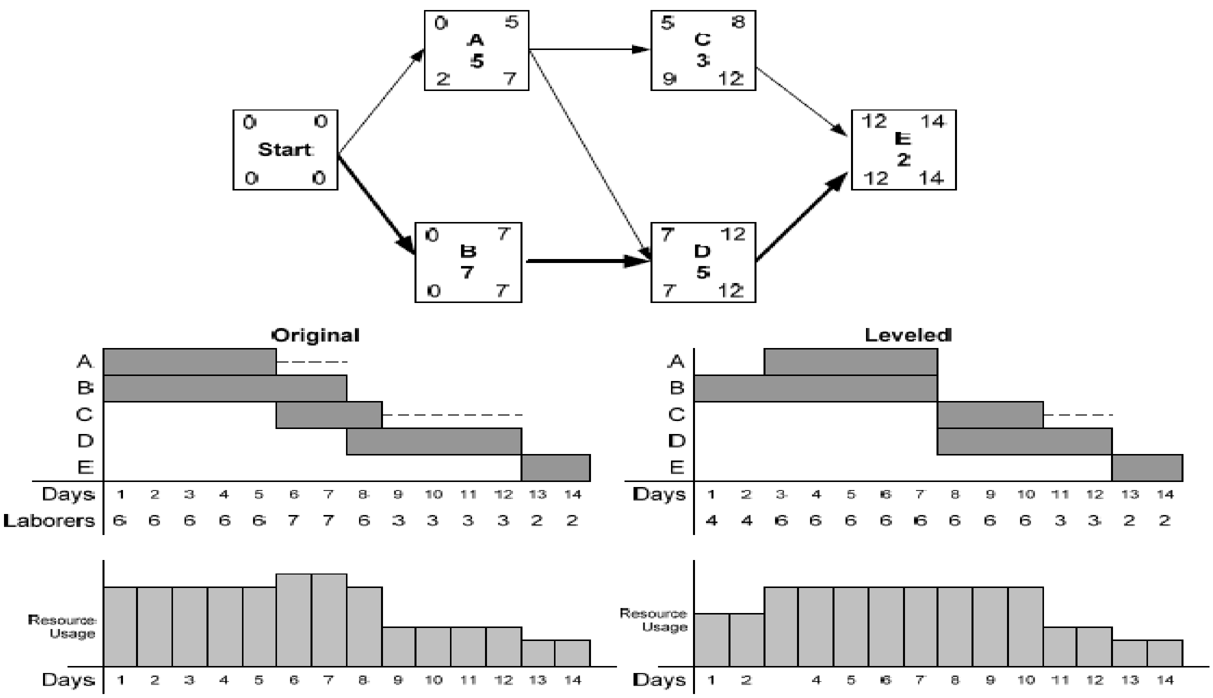


Fig. 4.14: Resource leveling without constraints (within original project duration)

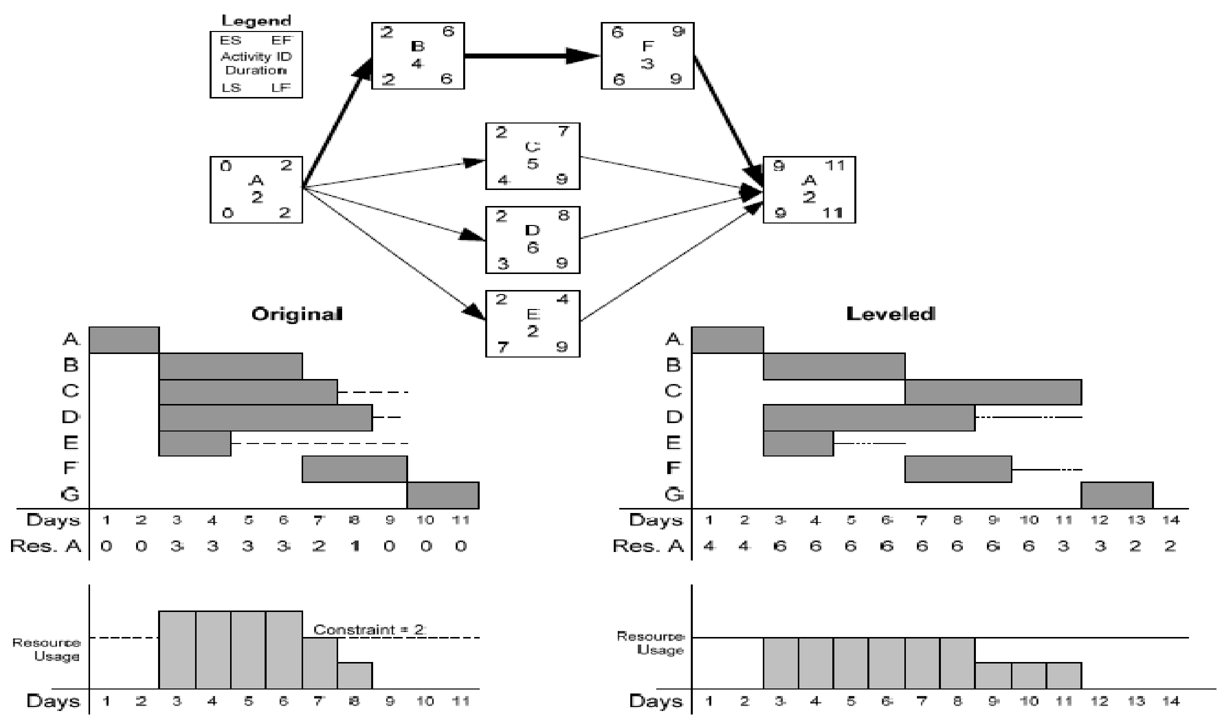


Fig. 4.15: Resource leveling with constraints (project duration extended 2 days)

Problem 2

Consider the following problem of project scheduling. Obtain a schedule which will minimize the peak manpower requirement and smooth out period to period variation of manpower requirement.

Activity	Duration in Weeks	Manpower requirements
1-2	6	8
1-3	10	4
1-4	6	9
2-3	10	7
2-4	4	6
3-5	6	17
4-5	6	6

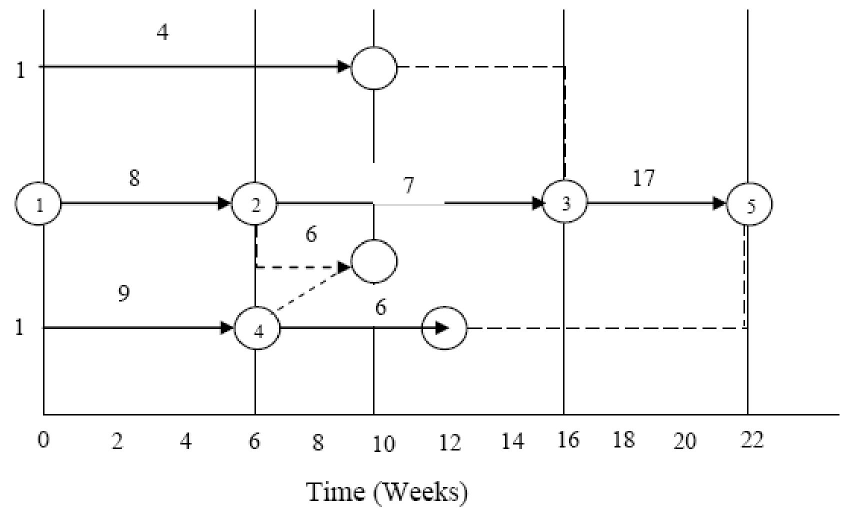


Fig. 4.16 Manpower Requirement for problem 2

The corresponding manpower requirement histogram is shown below.

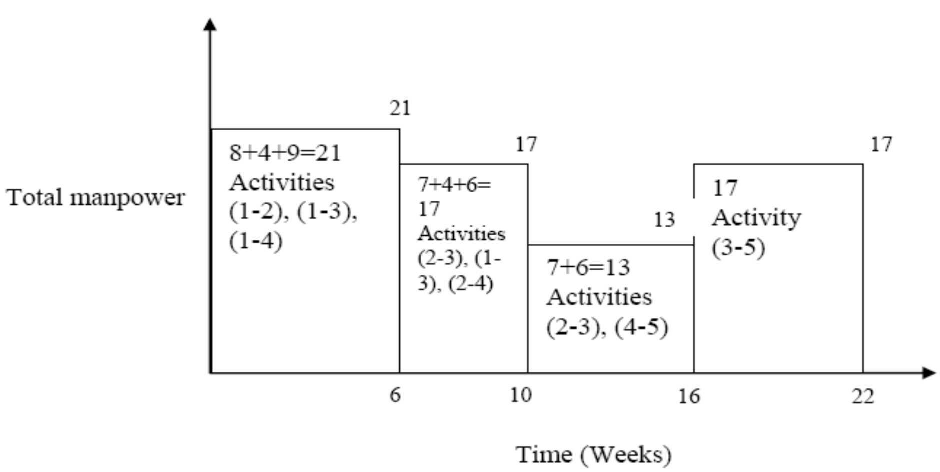


Fig. 4.17 Improvement in Manpower Requirement for problem 2

From this figure, it is observed that the peak manpower requirement is 21 and it occurs from 0 to 6 weeks. The activities which are scheduled during the period are: (1-2), (1-3) and (1-4). The activity 1-2 is critical activity. So it should not be disturbed. Between activities (1-3) and (1-4), the activity (1-3) has high slack value of 6 weeks (whereas its only 4 weeks for (1-4)). Hence, it can be started at the end of 6 weeks. The corresponding modification is shown by the following histogram.

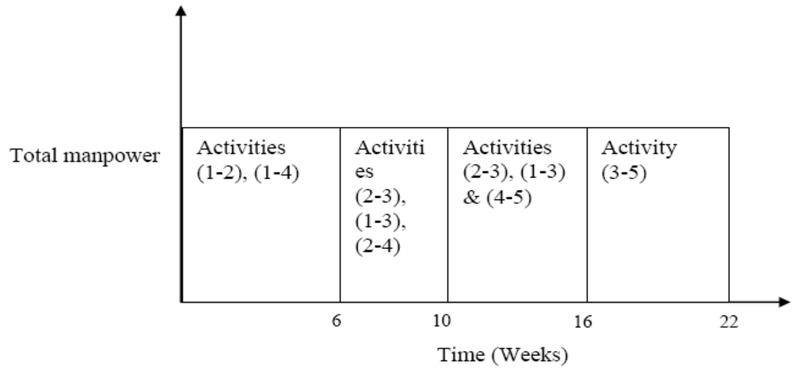


Fig. 4.18 Leveling of Manpower Requirement for problem 2

The manpower requirement is now smooth throughout the project duration.

Problem 3

Cables By Us is bringing a new product on line to be manufactured in their current facility in existing space. The owners have identified 11 activities and their precedence relationships. Develop an AON for the project, Plot on Gantt chart and calculate the slack.

Activity	Description	Immediate Predecessor	Optimistic (to)	Most Likely (tm)	Pessimistic (tp)
A	Develop product specifications	None	2	4	6
B	Design manufacturing process	A	3	7	10
C	Source & purchase materials	A	2	3	5
D	Source & purchase tooling & equipment	B	4	7	9
E	Receive & install tooling & equipment	C	12	16	20
F	Receive materials	D	2	5	8
G	Pilot production run	E & F	2	2	2
H	Evaluate product design	G	2	3	4
I	Evaluate process performance	G	2	3	5
J	Write documentation report	H & I	2	4	6
K	Transition to manufacturing	J	2	2	2

Solution

Step-1 Calculate Estimated Time (te)

Activity	Optimistic (to)	Most Likely (tm)	Pessimistic (tp)	Estimated Time (te)
A	2	4	6	4
B	3	7	10	6.83

C	2	3	5	3.17
D	4	7	9	6.83
E	12	16	20	16
F	2	5	8	5
G	2	2	2	2
H	2	3	4	3
I	2	3	5	3.17
J	2	4	6	4
K	2	2	2	2

Draw network diagram

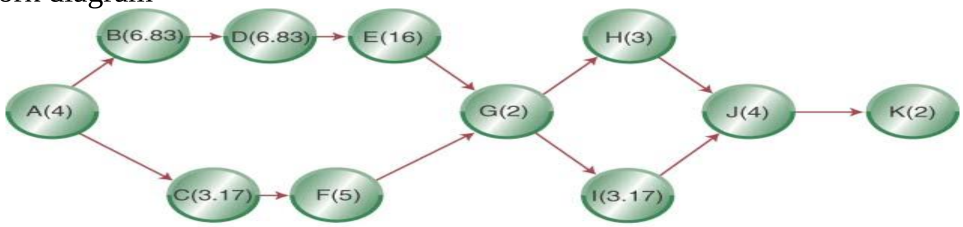


Fig. 4.19 Network diagram of problem 3

Step-2 Find Connected Paths and Calculate the Project Completion Times

1. A,B,D,E,G,H,J,G=44.66
2. A,B,D,E,G,I,J,G=44.83
3. A,C,F,G,H,J,K=23.17
4. A,C,F,G,I,J,K=23.34

ABDEGIJK is the expected critical path & the project has an expected duration of **44.83 weeks**

Now, We know that

- All **activities** on the **critical path** have **zero slack**
- **Slack** defines how long **non-critical activities** can be **delayed without delaying the project**
- **Slack** = the activity's **late finish minus its early finish** (or its **late start minus its early start**)
- Earliest Start (**ES**) = the earliest finish of the immediately preceding activity
- Earliest Finish (**EF**) = is the **ES plus** the **activity time**
- Latest Start (**LS**) and Latest Finish (**LF**) = the latest an activity can start (LS) or finish (LF) without delaying the project completion

Step-3 Draw ES, EF Network

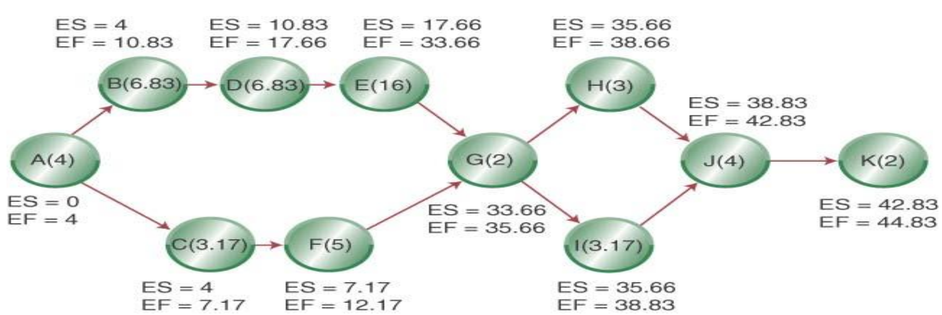


Fig. 4.20 Network diagram of problem 3 with ES & EF

Gantt Chart Showing Each Activity Finished at the Earliest Possible Start Date

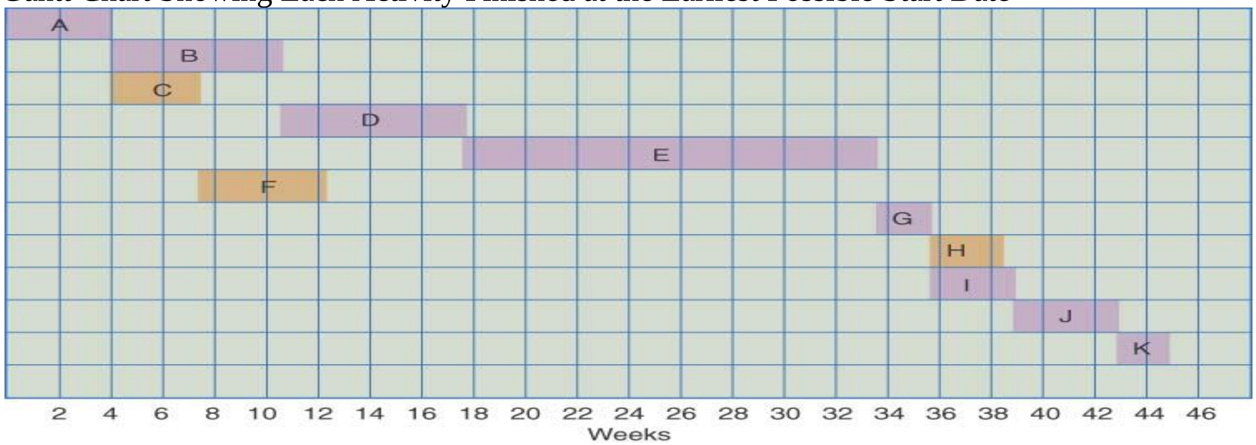


Fig. 4.21 Gantt Chart of problem 3

Step-4 Draw LS, LF Network

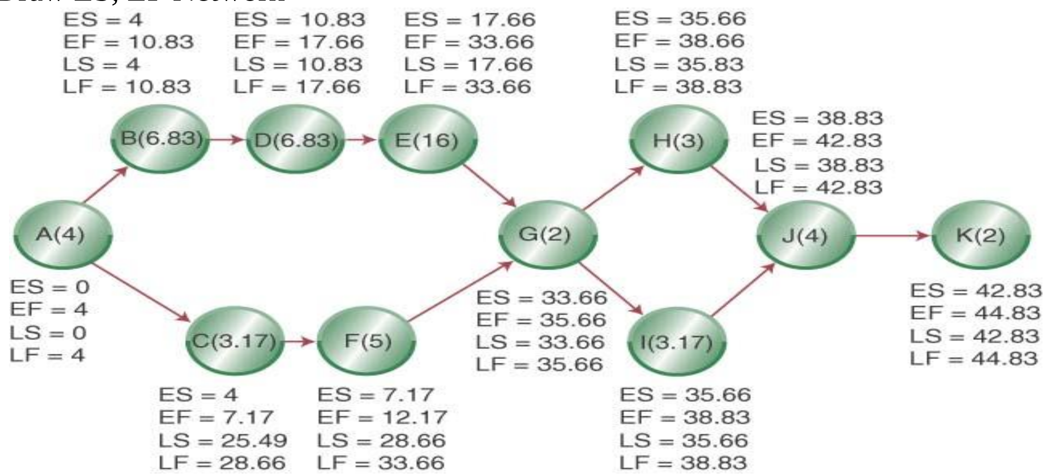


Fig. 4.22 Network diagram of problem 3 with ES, EF, LS & LF

Gantt Chart Showing the Latest Possible Start Times if the Project Is to Be Completed in <u>44.83 Weeks</u>

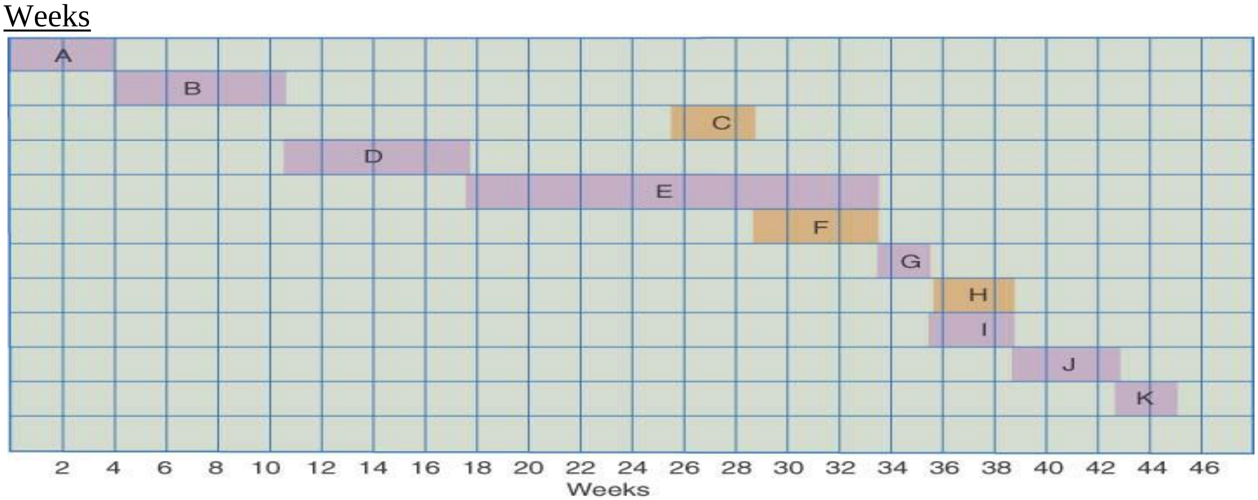


Fig. 4.23 Modified Gantt Chart of problem 3

Step-5 Calculating Slack

ACTIVITY	LATE FINISH	EARLY FINISH	SLACK (WEEKS)
A	4	4	0
B	10.83	10.83	0
C	28.66	7.17	31.51
D	17.66	17.66	0
E	33.66	33.66	0
F	33.66	12.17	21.49
G	35.66	35.66	0
H	38.83	38.66	0.23
I	38.83	38.83	0
J	42.83	42.83	0
K	44.83	44.83	0

4.3 Goldratt's critical chain: -

In the previous section, we showed that the problem of constrained resource scheduling of multiple projects could be reduced to the problem of scheduling activities using scarce resources in the case of a single project. However, the best-known attack on the resource constrained scheduling problem is Goldratt’s *Critical Chain* (1997). The celebrated author applies his Theory of Constraints to the constrained resource scheduling problem. The original focus of the Theory of Constraints to project management was the single project case, but it, too, is just as applicable to multiple projects. If we consider all the comments we have heard about the problems PMs have to deal with on a daily basis, many are brought up over and over again. Further, it is interesting to note that these statements are made by PMs working in construction, manufacturing, software development, R&D, marketing, communications, maintenance, and so on and the list of industries could easily be extended. For example, the following issues are raised with high frequency, and this short list is only indicative, not nearly exhaustive.

• Senior management changes the project’s scope without consultation, without warning, and without changing the budget or schedule.
• Project due dates are unrealistic and set with little regard given to availability of resources.
• There is no possible way of accomplishing a project without exceeding the given budget.
• Project workloads and due dates are set by the sales group, not by the nature of the projects and the level of resources needed.
• Project due dates are set unrealistically short as an “incentive” for people to work harder and faster.

It appears that these, and many other, problems are generic. They are independent of the area of application. Note that all of these issues concern trading off time, cost, and scope. To deal with the strong optimistic bias in many project schedules, let us consider just a few of the things that tend to create it.

1. Thoughtless optimism Some PMs, apparently with a strong need to deny that lateness could be their fault, deal with every problem faced by their projects as strict exceptions, acts of chance that cannot be forecast and hence need not be the subject of planning. These individuals simply ignore risk management.

2. Capacity should be set to equal demand Some senior managers refuse to recognize that projects are not assembly lines and are not subject to standard operations management line balancing methods. "Resource Loading/Leveling and Uncertainty," for proof of the need for capacity to exceed demand for projects.

3. The "Student Syndrome" This phrase is Goldratt's term for his view that students often delay starting school projects until the last possible moment. The same tendency is observed in projects where project team members delay the start of their work. The problem with delaying the start of a task is that obstacles are frequently not discovered until the work has been underway for some time. Delaying the start of a task diminishes the opportunity to cope with these unexpected obstacles and increases the risk of completing the work late.

4. Multitasking to reduce idle time Consider a situation where there are two projects, A and B, each with three sequential activities and with you as the only resource required by both projects. Each activity requires 10 days. In Figure 9.13 see two Gantt charts for sequencing the activities in the two projects. In the first, switch from project A (dark) to project B (light) for each of the three activities, that is, carry out Activity 1 for project A, then Activity 1 for project B, then Activity 2 for A, and so forth. In the second sequence, complete project A before starting project B. In both cases, the total time required will be 60 days. In the second, note that project A is completed after 30 days and B after 60 days. In the first chart, however, Project A will be finished after 50 days and B after 60 days. While the total time required is the same, project A has been delayed for 20 days by the multitasking. Further, this ignores the startup time and loss in efficiency that often accompanies switching back and forth between tasks.

5. Complexity of networks makes no difference Consider two different projects as seen in Figure 9.14. Assume that each activity requires 10 days and is known with certainty. Clearly, both projects are completed in 40 days though one is considerably more complex than the other. But let's get a bit more real. Assume that each activity is stochastic, with normally distributed times. The mean time is 10 days, and the standard deviation is 3 days. If we simulate the projects 500 times, we get the mean project completion time of about 40 days and for the simulation of the complex network, its mean completion time is about 46 days. Complexity, uncertainty and merging paths all join to make trouble.

6. People need a reason to work hard Senior managers of our acquaintance have been known to argue that project workers—and they include PMs in that category—"always" have enough slack time in their activity duration estimates to make sure that they can complete the activities on time and "without too much sweat." Therefore, it makes some managerial sense to cut back on the time allowances until they can serve as an incentive to the project team. It has, however, long been known that for people with a high need for achievement, the maximum level of motivation is associated with only moderate, not high, levels of risk of failure.

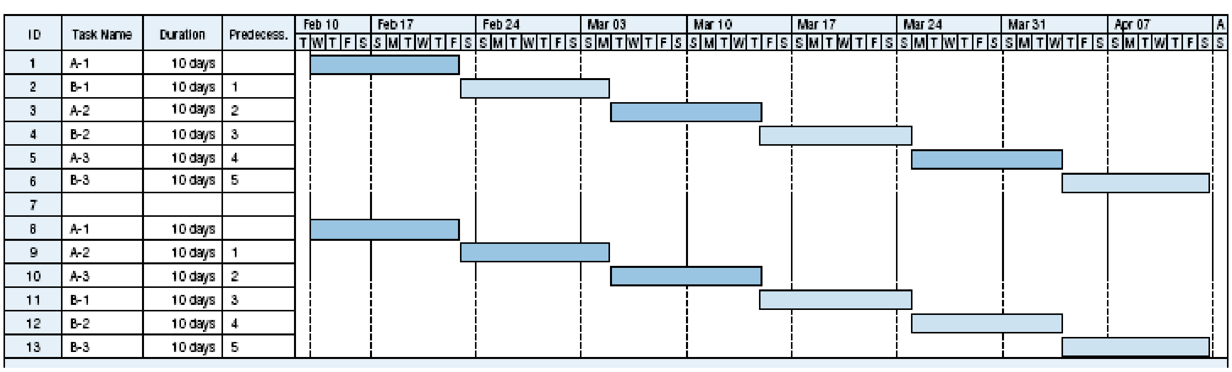


Fig.4. 24 Effect of multitasking on project completion.

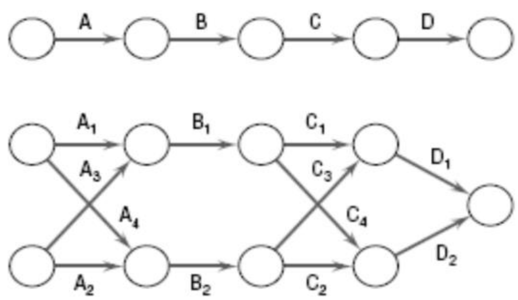


Fig. 4.25 Two levels of 40 days network complexity

7. Game playing This is possibly the most common cause of late projects. It is certainly a major cause of frustration for anyone involved in a project. Senior managers, firm in the belief that project workers add extra time and resources to activity time and budget estimates in order to insure a safe and peaceful life on their portion of a project, routinely cut schedules and budgets. Project workers, suspecting that senior management will cut schedules and budgets without regard to any logic or reason, increase their schedules and budgets as much as they guess will be allowed. Each assumes that the other is not to be trusted. The outcome is simple. Rather than practice careful risk management, each blames the other for any lateness or budget overage. As we noted in the "Aside" in Chapter 8, unbiased honesty in estimates on the part of both worker and manager is mandatory for any reasonable chance of on-schedule performance of projects.

Do Early Finishes and Late Finishes Cancel Out? So What?

One of the tacit assumptions of probabilistic networks is that early and late activity completions cancel out. This assumption might be sensible were it not for the matters listed in the previous subsection. Assume two activities, A and B. A is a predecessor of B. If activity A is late, then activity B will start late by whatever amount of lateness is bequeathed to it by A. Similarly, if in spite of all the forces tending to thwart such things, activity A finishes early, B will start early. The assumption, which is also a tacit assumption of both the analytical and simulation methods of finding a path's duration, is generally true for the first case, when A is late. But for the case when A is early, *the assumption is rarely true*. Unfortunately, a finish by A in less than its expected duration almost never translates to a start by B before its expected start time. With a few exceptions, the fact that early finishes do not become early starts is ignored by most people involved with projects. Goldratt writes about the phenomenon (1997, Chapter 13 and elsewhere), and a few others have also briefly discussed the matter. There is a mild debate as to the reason for this deplorable condition. Goldratt feels that project workers will avoid admitting that an activity has been completed early out of fear that future time estimates will be cut. Others point out that when the activity schedule is set; it is presumed that the activity will start immediately after the most likely finish date of its (latest) predecessor. The reason is simple—its resources will not be available until that date. There is also a logical explanation of why the start of a successor is usually delayed until its predetermined expected start time. Some say that project workers will not report finishes before the most likely duration. The logic of this position depends on an inherent distrust between project workers and senior management. If an early finish is reported, workers assume that the shorter-than normal activity duration will be the expectation for similar activities in the future. Senior managers, the argument proceeds, do not really understand the uncertainty faced by project workers. Senior management will assume that if an activity can be finished early once, it can be finished early again, or that they were correct in their assumption that workers "pad" their time and resource estimates. The chance event of an early finish is, thus, used to substantiate a shortened duration estimate in the future.

There is also a logical explanation of why a successor activity does not receive resources until its predetermined expected start, which is, by definition, equal to the expected finish of the latest predecessor activity. A stochastic network has little in common with an assembly line; nonetheless, we find some managers attempting to delay the deployment of resources to a project as long as possible. If we agree to start a project as soon as its predecessors are completed, we must contemplate having the resources available and waiting well before the activity's expected start. Idle resources, however, are not acceptable to managers trained in a just-in-time view of the world. Assembly lines are reasonably predictable; projects are not.

A Common Chain of Events

According to Goldratt, the behaviors and practices discussed above lead to the following chain of events:

1. Assuming that activity times are known and that the paths are independent leads to underestimating the actual amount of time needed to complete the project.

2. Because the time needed to complete the project is underestimated, project team members tend to inflate their time estimates by some "safety" time.

3. Inflated time estimates lead to work filling available time, workers not reporting that a task has been completed early, and the ever-present student syndrome.

4. An important caveat is that the safety time is only visible to the project workers and is often misused.

5. Misused safety time results in missed deadlines and milestones.

6. Hidden safety time further complicates the PM's task of prioritizing project activities.

7. The lack of clear priorities likely results in poor multitasking.

8. Task durations increase as a result of poor multitasking.

9. Uneven demand on resources—some overloaded and others underloaded—may also occur as a result of poor multitasking.

10. In an effort to utilize all resources fully, more projects will be undertaken to make sure that no resources are underutilized.

11. Adding more projects further increases poor multitasking.

According to Goldratt, this chain of events leads to a vicious cycle. Specifically, as work continues to pile up, team members are pressured to do more poor multitasking. Increasing the amount of poor multitasking, leads to longer activity times. Longer activity times lead to longer project completion times, which ultimately lead to more projects in the waiting line. It might have occurred to you that one way to reverse this cycle would be to add more resources. According to Goldratt, however, the appropriate response is to reduce the number of projects assigned to each person in an effort to reduce the amount of bad multitasking.

Incidentally, a simple way to measure the amount of bad multitasking is to calculate the difference between the time required to do the work for a task and the elapsed time actually required to complete the task.

Determining when to release projects into the system is the primary mechanism for ensuring that the right amount of work is assigned to each person. If projects are started too early, they simply add to the chaos and contribute to poor multitasking. On the other hand, if projects are started too late, key resources may go underutilized and projects will be inevitably delayed. Consistent with his Theory of Constraints, Goldratt suggests that the key to resolving this trade-off is to schedule the start of new projects based on the availability of bottleneck (scarce) resources.

While properly scheduling the start of new projects does much to address the problems associated with poor multitasking, it does little to address the problem of setting unrealistic project deadlines and the accompanying response of inflated time estimates. Relying on elementary statistics, it can be easily shown that the amount of safety time needed to protect a particular path is less than the sum of the safety times required to protect the individual activities making up the path. The same approach is commonly used in inventory management where it can be shown that less safety stock is needed at a central warehouse to provide a certain service level than the amount of safety stock that would be required to provide this same service level if carried at multiple distributed locations.

Based on this insight, Goldratt suggests reducing the amount of safety time workers add to individual tasks and then adding some fraction of the safety time reduced back into the system as safety buffer for the entire project, called the *project buffer*. The amount of time each task is reduced depends on how much of a reduction is needed to get project team members to change their behavior. For example, the allotted time for tasks should be reduced to the point that the student syndrome is eliminated. Indeed, Goldratt suggests using activity durations where in fact there is a high probability that the task will not be finished on time.

The Critical Chain

Another limitation associated with traditional approaches to project management is that the dependency between resources and tasks is often ignored. More specifically, Goldratt argues that two activities scheduled to be carried out in parallel and using the same scarce resource are not independent as the traditional theory would assume.1 If the supply of the scarce resource is not sufficient to allow both activities to be carried out simultaneously, then whichever of the two is given priority immediately lengthens the other activity's path but not its actual duration.

Assume that two parallel paths compose a project. One path consists of activities **A1** and **B** and the other path consists of activities **A2** and **C**. Activities **A1** and **A2** require the same scarce resource. Activities **B** and **C** use different resources. **A1** requires 7 days, **A2** requires 5 days, **B** needs 10 days, and **C** needs 6 days and thus, the path **A1-B** is 17 days and the path **A2-C** is 11 days. If there is not enough of the scarce resource to fund both **A** activities, they must be done sequentially. If **A1** is done first, **A2** cannot start until **A1** is complete, thereby adding 7 days to the **A2-C** path, making it 18 days long and increasing the project finish date by 1 day. If **A2** is done first, 5 days will be added to the **A1-B** path, making it 22 days, a 5-day increase over its original 17-day duration. If this problem seems familiar, it is. This is precisely the issue we dealt with when we examined the process of resource leveling in Section 9.4. Using Goldratt's meaning of the word "dependent," the activities of a project can be ordered into paths based on their resource dependencies as well as on their technological precedence requirements. The longest of these paths of sequentially time-dependent activities is known as the "critical chain." A project, therefore, is composed of its critical chain and of noncritical chains that feed into it—see Figure 9.15. There are two sources of delay for the project. One comes from a delay of one or more activities in the critical chain. The second results from a delay in one or more of the activities on a noncritical or "feeder" chain because such delays could delay activities on the

critical chain. A project buffer protects the critical chain, and feeding buffers protect the feeder paths.
Resources used by activities on the critical chain are given priority so that they are available when required.
In the next chapter, we move to the ongoing implementation of the project and consider the project information systems used for monitoring progress, costs, scope, and so on. The chapter also describes some available computer packages for this function.

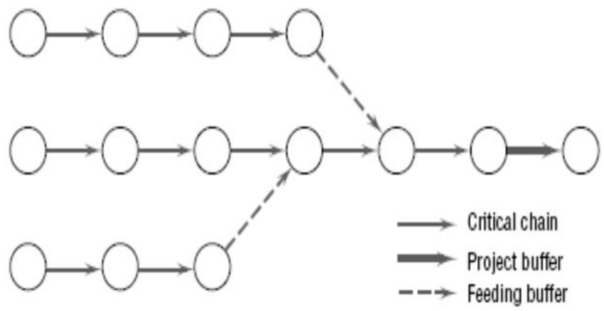


Fig. 4.26 Critical Chain, Project Buffer and Feeder Buffer

4.4 Project Stakeholders and Communication plan

A stakeholder is an individual, group, or organization that may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project. Project stakeholders may be internal or external to the project, they may be actively involved, passively involved, or unaware of the project. Project stakeholders may have a positive or negative impact on the project, or be positively or negatively impacted by the project. Examples of stakeholders include but are not limited to:
Internal stakeholders: Sponsor, Resource manager, Project management office (PMO), Portfolio steering committee, Program manager, Project managers of other projects, and Team members.
External stakeholders: Customers, End users, Suppliers, Shareholders Regulatory bodies, and Competitors.

Communication is the exchange of information, intended or involuntary. The information exchanged can be in the form of ideas, instructions, or emotions. The mechanisms by which information is exchanged can be in:
Written form- Either physical or electronic.
Spoken- Either face-to-face or remote.
Formal or informal (as in formal papers or social media).
Through gestures- Tone of voice and facial expressions.
Through media- Pictures, actions, or even just the choice of words.
Choice of words- There is often more than one word to express an idea; there can be subtle differences in the meaning of each of these words and phrases.
Communications describe the possible means by which the information can be sent or received, either through communication activities, such as meetings and presentations, or artifacts, such as

emails, social media, project reports, or project documentation. Project managers spend most of their time communicating with team members and other project stakeholders, both internal (at all organizational levels) and external to the organization.

Communication activities have many dimensions, including but not limited to:

Internal- Focus on stakeholders within the project and within the organization.

External- Focus on external stakeholders such as customers, vendors, other projects, organizations, government, the public, and environmental advocates.

Formal- Reports, formal meetings (both regular and ad hoc), meeting agendas and minutes, stakeholder briefings, and presentations.

Informal- General communications activities using emails, social media, websites, and informal ad hoc discussions.

Hierarchical focus- The position of the stakeholder or group with respect to the project team will affect the format and content of the message, in the following ways:

Upward- Senior management stakeholders.

Downward.-The team and others who will contribute to the work of the project.

Horizontal- Peers of the project manager or team.

Official- Annual reports; reports to regulators or government bodies.

Unofficial- Communications that focus on establishing and maintaining the profile and recognition of the project and building strong relationships between the project team and its stakeholders using flexible and often informal means.

Written and oral- Verbal (words and voice inflections) and nonverbal (body language and actions), social media and websites, media releases.

Communication develops the relationships necessary for successful project and program outcomes.

Stakeholder management refers to managing communications to satisfy the needs of, and resolve issues with, project stakeholders. Actively managing stakeholders increases the likelihood that the project will not veer off track due to unresolved stakeholder issues, enhances the ability of persons to operate synergistically, and limits disruptions during the project. The project manager is usually responsible for stakeholder management.

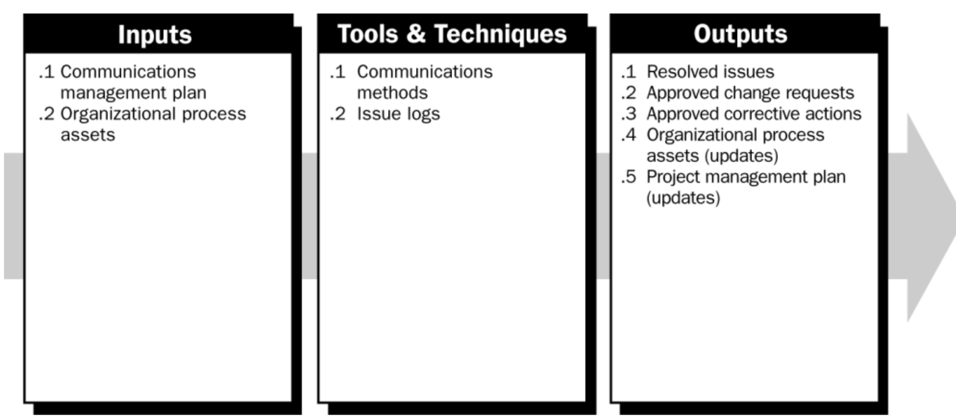


Fig. 4.27 Manage Stakeholders: Inputs, Tools & Techniques, and Outputs

Manage Stakeholders: Inputs

1. Communications Management Plan

Stakeholder requirements and expectations provide an understanding of stakeholder goals, objectives, and level of communication during the project. The needs and expectations are identified, analyzed, and documented in the communications management plan, which is a subsidiary of the project management plan.

2. Organizational Process Assets

As project issues arise; the project manager should address and resolve them with the appropriate project stakeholders.

Manage Stakeholders: Tools and Techniques

1. Communications Methods

The methods of communications identified for each stakeholder in the communications management plan are utilized during stakeholder management. Face-to-face meetings are the most effective means for communicating and resolving issues with stakeholders. When face-to-face meetings are not warranted or practical (such as on international projects), telephone calls, electronic mail, and other electronic tools are useful for exchanging information and dialoguing.

2. Issue Logs

An issue log or action-item log is a tool that can be used to document and monitor the resolution of issues. Issues do not usually rise to the importance of becoming a project or activity, but are usually addressed in order to maintain good, constructive working relationships among various stakeholders, including team members. An issue is clarified and stated in a way that it can be resolved. An owner is assigned and a target date is usually established for closure. Unresolved issues can be a major source of conflict and project delays.

Manage Stakeholders: Outputs

1. Resolved Issues

As stakeholder requirements are identified and resolved, the issues log will document concerns that have been addressed and closed. Examples include:

-Customers agree to a follow-on contract, which ends protracted discussion of whether requested changes to project scope are within or outside the scope of the current project

-More staff is added to the project, thus closing the issue that the project is short on required skills

-Negotiations with functional managers in the organization competing for scarce human resources end in a mutually satisfactory solution before causing project delays

- Issues raised by board members about the financial viability of the project have been answered, allowing the project to move forward as planned.

2. Approved Change Requests

Approved change requests include stakeholder issue status changes in the staffing management plan, which are necessary to reflect changes to how communications with stakeholders will occur.

3. Approved Corrective Actions

Approved corrective actions include changes that bring the expected future performance of the project in line with the project management plan.

4. Organizational Process Assets (Updates)

Lessons learned documentation includes the causes of issues, the reasoning behind the corrective action chosen, and other types of lessons learned about stakeholder management. Lessons learned are documented so that they become part of the historical database for both this project and the performing organization.

5. Project Management Plan (Updates)

The project management plan is updated to reflect the changes made to the communications plan.

4.5 Risk Management in projects: -

Project Risk Management includes the processes of conducting risk management planning, identification, analysis, response planning, response implementation, and monitoring risk on a project. The objectives of project risk management are to increase the probability and/or impact of positive risks and to decrease the probability and/or impact of negative risks, in order to optimize the chances of project success.

The Project Risk Management processes are:

1. Plan Risk Management-The process of defining how to conduct risk management activities for a project.
2. Identify Risks-The process of identifying individual project risks as well as sources of overall project risk, and documenting their characteristics.
3. Perform Qualitative Risk Analysis-The process of prioritizing individual project risks for further analysis or action by assessing their probability of occurrence and impact as well as other characteristics.
4. Perform Quantitative Risk Analysis-The process of numerically analyzing the combined effect of identified individual project risks and other sources of uncertainty on overall project objectives.
5. Plan Risk Responses-The process of developing options, selecting strategies, and agreeing on actions to address overall project risk exposure, as well as to treat individual project risks.
6. Implement Risk Responses-The process of implementing agreed-upon risk response plans.
7. Monitor Risks-The process of monitoring the implementation of agreed-upon risk response plans, tracking identified risks, identifying and analyzing new risks, and evaluating risk process effectiveness throughout the project.

KEY CONCEPTS FOR PROJECT RISK MANAGEMENT

All projects are risky since they are unique undertakings with varying degrees of complexity that aim to deliver benefits. They do this in a context of constraints and assumptions, while responding to stakeholder expectations that may be conflicting and changing. Organizations should choose to take project risk in a controlled and intentional manner in order to create value while balancing risk and reward.

Project Risk Management aims to identify and manage risks that are not addressed by the other project management processes. When unmanaged, these risks have the potential to cause the project to deviate from the plan and fail to achieve the defined project objectives. Consequently, the effectiveness of Project Risk Management is directly related to project success.

Risk exists at two levels within every project. Each project contains individual risks that can affect the achievement of project objectives. It is also important to consider the riskiness of the overall project, which arises from the combination of individual project risks and other sources of uncertainty. Project Risk Management processes address both levels of risk in projects, and these are defined as follows:

-Individual project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives.

-Overall project risk is the effect of uncertainty on the project as a whole, arising from all sources of uncertainty including individual risks, representing the exposure of stakeholders to the implications of variations in project outcome, both positive and negative.

Individual project risks can have a positive or negative effect on project objectives if they occur. Project Risk Management aims to exploit or enhance positive risks (opportunities) while avoiding or mitigating negative risks (threats). Unmanaged threats may result in issues or problems such as delay, cost overruns, performance shortfall, or loss of reputation. Opportunities that are captured can lead to benefits such as reduced time and cost, improved performance, or reputation.

Overall project risk can also be positive or negative. Management of overall project risk aims to keep project risk exposure within an acceptable range by reducing drivers of negative variation, promoting drivers of positive variation, and maximizing the probability of achieving overall project objectives.

Risks will continue to emerge during the lifetime of the project, so Project Risk Management processes should be conducted iteratively. Risk is initially addressed during project planning by shaping the project strategy. Risk should also be monitored and managed as the project progresses to ensure that the project stays on track and emergent risks are addressed.

In order to manage risk effectively on a particular project, the project team needs to know what level of risk exposure is acceptable in pursuit of the project objectives. This is defined by measurable risk thresholds that reflect the risk appetite of the organization and project stakeholders. Risk thresholds express the degree of acceptable variation around a project objective. They are explicitly stated and communicated to the project team and reflected in the definitions of risk impact levels for the project.

TRENDS AND EMERGING PRACTICES IN PROJECT RISK MANAGEMENT

The focus of project risk management is broadening to ensure that all types of risk are considered, and that project risks are understood in a wider context. Trends and emerging practices for Project Risk Management include but are not limited to:

Non-event risks-Most projects focus only on risks that are uncertain future events that may or may not occur. Examples of event-based risks include: a key seller may go out of business during the project; the customer may change the requirement after design is complete, or a subcontractor may propose enhancements to the standard operating processes. There is an increasing recognition that non-event risks need to be identified and managed. There are two main types of non-event risks:

Variability risk-Uncertainty exists about some key characteristics of a planned event or activity or decision. Examples of variability risks include: productivity may be above or below target, the number of errors found during testing may be higher or lower than expected, or unseasonal weather conditions may occur during the construction phase.

Ambiguity risk-Uncertainty exists about what might happen in the future. Areas of the project where imperfect knowledge might affect the project's ability to achieve its objectives include: elements of the requirement or technical solution, future developments in regulatory frameworks, or inherent systemic complexity in the project.

Variability risks can be addressed using Monte Carlo analysis, with the range of variation reflected in probability distributions, followed by actions to reduce the spread of possible outcomes. Ambiguity risks are managed by defining those areas where there is a deficit of knowledge or understanding, then filling the gap by obtaining expert external input or benchmarking against best practices. Ambiguity is also addressed through incremental development, prototyping, or simulation.

Project resilience- The existence of emergent risk is becoming clear, with a growing awareness of so-called unknowable-unknowns. These are risks that can only be recognized after they have occurred. Emergent risks can be tackled through developing project resilience. This requires each project to have:

-Right level of budget and schedule contingency for emergent risks, in addition to a specific risk budget for known risks;

-Flexible project processes that can cope with emergent risk while maintaining overall direction toward project goals, including strong change management;

-Empowered project team that has clear objectives and that is trusted to get the job done within agreed-upon limits;

-Frequent review of early warning signs to identify emergent risks as early as possible; and

-Clear input from stakeholders to clarify areas where the project scope or strategy can be adjusted in response to emergent risks.

Integrated risk management- Projects exist in an organizational context, and they may form part of a program or portfolio. Risk exists at each of these levels, and risks should be owned and managed at the appropriate level. Some risks identified at higher levels will be delegated to the project team for management, and some project risks may be escalated to higher levels if they are best managed outside the project. A coordinated approach to enterprise wide risk management ensures alignment and coherence in the way risk is managed across all levels. This builds risk efficiency into the structure of programs and portfolios, providing the greatest overall value for a given level of risk exposure.

TAILORING CONSIDERATIONS

Because each project is unique, it is necessary to tailor the way Project Risk Management processes are applied. Considerations for tailoring include but are not limited to:

1. Project size- Does the project's size in terms of budget, duration, scope, or team size require a more detailed approach to risk management? Or is it small enough to justify a simplified risk process?
2. Project complexity-Is a robust risk approach demanded by high levels of innovation, new technology, commercial arrangements, interfaces, or external dependencies that increase project complexity? Or is the project simple enough that a reduced risk process will suffice?
3. Project importance-How strategically important is the project? Is the level of risk increased for this project because it aims to produce breakthrough opportunities, addresses significant blocks to organizational performance, or involves major product innovation?
4. Development approach-Is this a waterfall project, where risk processes can be followed sequentially and iteratively, or does the project follow an agile approach where risk is addressed at the start of each iteration as well as during its execution?

Tailoring of the Project Risk Management processes to meet these considerations is part of the Plan Risk Management process, and the outcomes of tailoring decisions are recorded in the risk management plan.

CONSIDERATIONS FOR AGILE/ADAPTIVE ENVIRONMENTS

High-variability environments, by definition, incur more uncertainty and risk. To address this, projects managed using adaptive approaches make use of frequent reviews of incremental work products and cross-functional project teams to accelerate knowledge sharing and ensure that risk is understood and managed. Risk is considered when selecting the content of each iteration, and risks will also be identified, analyzed, and managed during each iteration. Additionally, the requirements are kept as a living document that is updated regularly, and work may be reprioritized as the project progresses, based on an improved understanding of current risk exposure.

4.4.1 Risk management planning: -

Careful and explicit planning enhances the possibility of success of the five other risk management processes. Risk Management Planning is the process of deciding how to approach and conduct the risk management activities for a project. Planning of risk management processes is important to ensure that the level, type, and visibility of risk management are commensurate with both the risk and importance of the project to the organization, to provide sufficient resources and time for risk management activities, and to establish an agreed-upon basis for evaluating risks. The Risk Management Planning process should be completed early during project planning, since it is crucial to successfully performing the other processes described here.

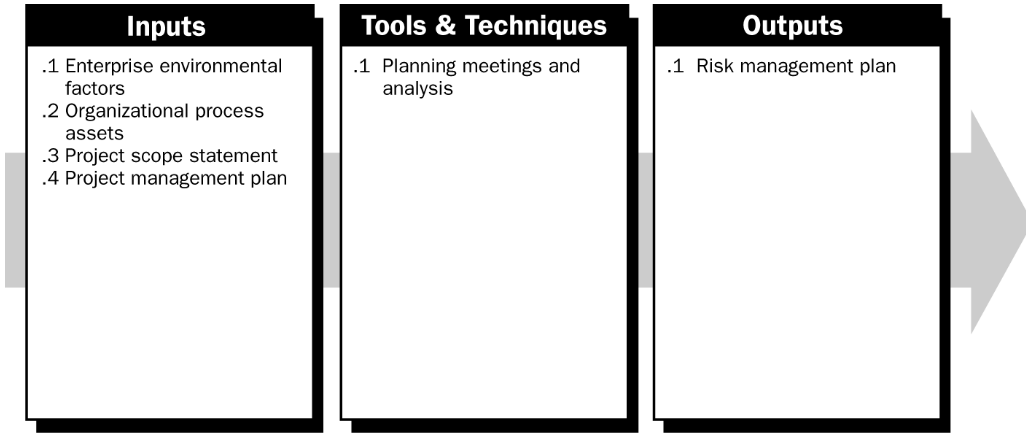


Fig. 4.28 Risk Management Planning: Inputs, Tools & Techniques, and Outputs

Risk Management Planning: Inputs

1. Enterprise Environmental Factors- The attitudes toward risk and the risk tolerance of organizations and people involved in the project will influence the project management plan. Risk attitudes and tolerances may be expressed in policy statements or revealed in actions.

2. Organizational Process Assets- Organizations may have predefined approaches to risk management such as risk categories, common definition of concepts and terms, standard templates, roles and responsibilities, and authority levels for decision-making.

3. Project Scope Statement- The project scope statement describes, in detail, the project's deliverables and the work required to create those deliverables. The project scope statement also provides a common understanding of the project scope among all project stakeholders and describes the project's major objectives. It also enables the project team to perform more detailed planning, guides the project team's work during execution, and provides the baseline for evaluating whether requests for changes or additional work are contained within or outside the project's boundaries. The degree and level of detail to which the project scope statement defines what work will be performed and what work is excluded can determine how well the project management team can control the overall project scope. Managing the project scope, in turn, can determine how well the project management team can plan, manage, and control the execution of the project.

4. Project Management Plan-The Develop Project Management Plan process includes the actions necessary to define, integrate, and coordinate all subsidiary plans into a project management plan. The project management plan content will vary depending upon the application area and complexity of the project. This process results in a project management plan that is updated and revised through the Integrated Change Control process. The project management plan defines how the project is executed, monitored and controlled, and closed. The project management plan documents the collection of outputs of the planning processes of the Planning Process Group.

Risk Management Planning: Tools and Techniques

1 Planning Meetings and Analysis- Project teams hold planning meetings to develop the risk management plan. Attendees at these meetings may include the project manager, selected project team members and stakeholders, anyone in the organization with responsibility to manage the risk planning and execution activities, and others, as needed. Basic plans for conducting the risk management activities are defined in these meetings. Risk cost elements and schedule activities will be developed for inclusion in the project budget and schedule, respectively. Risk responsibilities will be assigned. General organizational templates for risk categories and definitions of terms such as levels of risk, probability by type of risk, impact by type of objectives, and the probability and impact matrix will be tailored to the specific project. The outputs of these activities will be summarized in the risk management plan.

Risk Management Planning: Outputs

1 Risk Management Plan-The risk management plan describes how risk management will be structured and performed on the project. It becomes a subset of the project management plan. The risk management plan includes the following:

Methodology- Defines the approaches, tools, and data sources that may be used to perform risk management on the project.

Roles and responsibilities- Defines the lead, support, and risk management team membership for each type of activity in the risk management plan, assigns people to these roles, and clarifies their responsibilities.

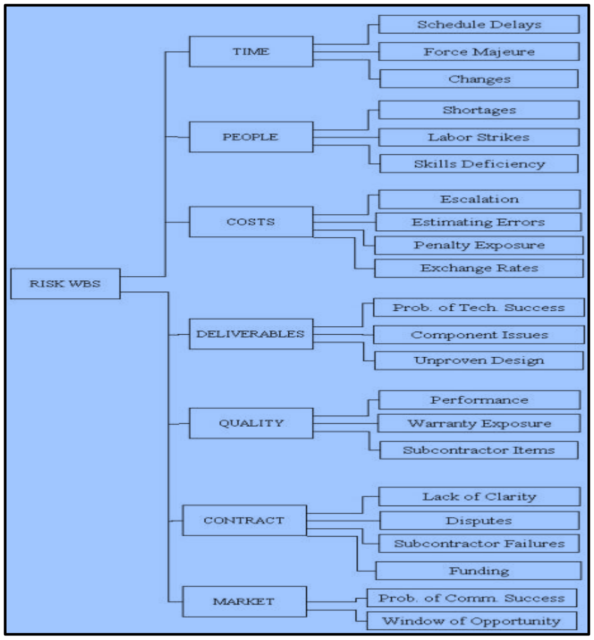
Budgeting- Assigns resources and estimates costs needed for risk management for inclusion in the project cost baseline.

Timing- Defines when and how often the risk management process will be performed throughout the project life cycle, and establishes risk management activities to be included in the project schedule.

Risk categories- Provides a structure that ensures a comprehensive process of systematically identifying risk to a consistent level of detail and contributes to the effectiveness and quality of Risk Identification. An organization can use a previously prepared categorization of typical risks. A risk breakdown structure (RBS) is one approach to providing such a structure, but it can also be addressed by simply listing the various aspects of the project. The risk categories may be revisited during the Risk Identification process. A good practice is to review the risk categories during the Risk Management Planning process prior to their use in the Risk Identification process. Risk categories based on prior projects may need to be tailored, adjusted, or extended to new situations before those categories can be used on the current project.

Definitions of risk probability and impact- The quality and credibility of the Qualitative Risk Analysis process requires that different levels of the risks’ probabilities and impacts be defined. General definitions of probability levels and impact levels are tailored to the individual project during the Risk Management Planning process for use in the Qualitative Risk Analysis process.

Probability and impact matrix- Risks are prioritized according to their potential implications for meeting the project’s objectives. The typical approach to prioritizing risks is to use a look-up table or a Probability and Impact Matrix. The specific combinations of probability and impact that lead to a risk being rated as “high,” “moderate,” or “low” importance—with the corresponding importance for planning responses to the risk -are usually set by the organization. They are reviewed and can be tailored to the specific project during the Risk Management Planning process.



RBS for Generic Project

RBS LEVEL 0	RBS LEVEL 1	RBS LEVEL 2
0. ALL SOURCES OF PROJECT RISK	1. TECHNICAL RISK	1.1 Scope definition
		1.2 Requirements definition
		1.3 Estimates, assumptions, and constraints
		1.4 Technical processes
		1.5 Technology
		1.6 Technical interfaces
		Etc.
	2. MANAGEMENT RISK	2.1 Project management
		2.2 Program/portfolio management
		2.3 Operations management
		2.4 Organization
		2.5 Resourcing
		2.6 Communication
		Etc.
	3. COMMERCIAL RISK	3.1 Contractual terms and conditions
		3.2 Internal procurement
		3.3 Suppliers and vendors
		3.4 Subcontracts
		3.5 Client/customer stability
		3.6 Partnerships and joint ventures
		Etc.
	4. EXTERNAL RISK	4.1 Legislation
		4.2 Exchange rates
		4.3 Site/facilities
		4.4 Environmental/weather
		4.5 Competition
		4.6 Regulatory
		Etc.

Sample RBS of a project

Revised stakeholders’ tolerances-Stakeholders’ tolerances may be revised in the Risk Management Planning process, as they apply to the specific project.-

Reporting formats-Describes the content and format of the risk register as well as any other risk reports required. Defines how the outcomes of the risk management processes will be documented, analyzed, and communicated.

Tracking- Documents how all facets of risk activities will be recorded for the benefit of the current project, future needs, and lessons learned. Documents whether and how risk management processes will be audited.

4.4.2 Risk identification and risk register: -

Risk Identification determines which risks might affect the project and documents their characteristics. Participants in risk identification activities can include the following, where appropriate: project manager, project team members, risk management team (if assigned), subject matter experts from outside the project team, customers, end users, other project managers, stakeholders, and risk management experts. While these personnel are often key participants for risk identification, all project personnel should be encouraged to identify risks. Risk Identification is an iterative process because new risks may become known as the project progresses through its life cycle. The frequency of iteration and who participates in each cycle will vary from case to case. The project team should be involved in the process so that they can develop and maintain a sense of ownership of, and responsibility for, the risks and associated risk response actions. Stakeholders outside the project team may provide additional objective information. The Risk Identification process usually leads to the Qualitative Risk Analysis process. Alternatively, it can lead directly to the Quantitative Risk Analysis process when conducted by an experienced risk manager. On some occasions, simply the identification of a risk may suggest its response, and these should be recorded for further analysis and implementation in the Risk Response Planning process.

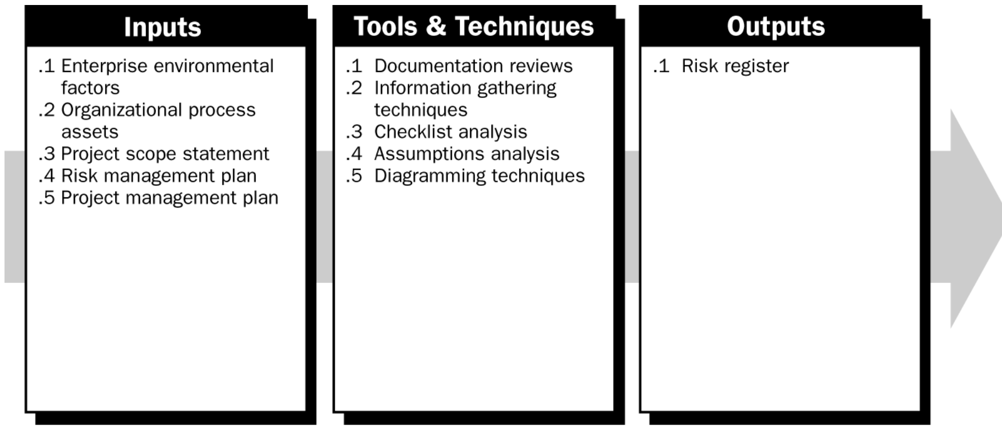


Fig. 4.29 Risk Identification: Inputs, Tools & Techniques, and Outputs

Risk Identification: Inputs

1. Enterprise Environmental Factors

Published information, including commercial databases, academic studies, benchmarking, or other industry studies, may also be useful in identifying risks.

2. Organizational Process Assets

Information on prior projects may be available from previous project files, including actual data and lessons learned.

3. Project Scope Statement

Project assumptions are found in the project scope statement. Uncertainty in project assumptions should be evaluated as potential causes of project risk.

4. Risk Management Plan

Key inputs from the risk management plan to the Risk Identification process are the assignments of roles and responsibilities, provision for risk management activities in the budget and schedule, and categories of risk , which are sometimes expressed in an RBS .

5. Project Management Plan

The Risk Identification process also requires an understanding of the schedule, cost, and quality management plans found in the project management plan. Outputs of other Knowledge Area processes should be reviewed to identify possible risks across the entire project.

Risk Identification: Tools and Techniques

1. Documentation Reviews

A structured review may be performed of project documentation, including plans, assumptions, prior project files, and other information. The quality of the plans, as well as consistency between those plans and with the project requirements and assumptions, can be indicators of risk in the project.

2. Information Gathering Techniques

Examples of information gathering techniques used in identifying risk can include:
Brainstorming- The goal of brainstorming is to obtain a comprehensive list of project risks. The project team usually performs brainstorming, often with a multidisciplinary set of experts not on the team. Ideas about project risk are generated under the leadership of a facilitator. Categories of risk, such as a risk breakdown structure, can be used as a framework. Risks are then identified and categorized by type of risk and their definitions are sharpened.

Delphi technique- The Delphi technique is a way to reach a consensus of experts. Project risk experts participate in this technique anonymously. A facilitator uses a questionnaire to solicit ideas about the important project risks. The responses are summarized and are then recirculated to the experts for further comment. Consensus may be reached in a few rounds of this process. The Delphi technique helps reduce bias in the data and keeps any one person from having undue influence on the outcome.

Interviewing- Interviewing experienced project participants, stakeholders, and subject matter experts can identify risks. Interviews are one of the main sources of risk identification data gathering.

Root cause identification- This is an inquiry into the essential causes of a project's risks. It sharpens the definition of the risk and allows grouping risks by causes. Effective risk responses can be developed if the root cause of the risk is addressed.

Strengths, weaknesses, opportunities, and threats (SWOT) analysis- This technique ensures examination of the project from each of the SWOT perspectives, to increase the breadth of considered risks.

3. Checklist Analysis

Risk identification checklists can be developed based on historical information and knowledge that has been accumulated from previous similar projects and from other sources of information. The lowest level of the RBS can also be used as a risk checklist. While a checklist can be quick and simple, it is impossible to build an exhaustive one. Care should be taken to explore items that do not appear on the checklist. The checklist should be reviewed during project closure to improve it for use on future projects.

4. Assumptions Analysis

Every project is conceived and developed based on a set of hypotheses, scenarios, or assumptions. Assumptions analysis is a tool that explores the validity of assumptions as they apply to the project. It identifies risks to the project from inaccuracy, inconsistency, or incompleteness of assumptions.

5. Diagramming Techniques

Risk diagramming techniques may include:

Cause-and-effect diagrams- These are also known as Ishikawa or fishbone diagrams, and are useful for identifying causes of risks.

System or process flow charts- These show how various elements of a system interrelate, and the mechanism of causation.

Influence diagrams- These are graphical representations of situations showing causal influences, time ordering of events, and other relationships among variables and outcomes.

Risk Identification: Outputs

The outputs from Risk Identification are typically contained in a document that can be called a risk register.

1. Risk Register

The primary outputs from Risk Identification are the initial entries into the risk register, which becomes a component of the project management plan . The risk register ultimately contains the outcomes of the other risk management processes as they are conducted. The preparation of the risk register begins in the Risk Identification process with the following information, and then becomes available to other project management and Project Risk Management processes.

List of identified risks- The identified risks, including their root causes and uncertain project assumptions, are described. Risks can cover nearly any topic, but a few examples include the following: A few large items with long lead times are on critical path. There could be a risk that industrial relations disputes at the ports will delay the delivery and, subsequently, delay completion of the construction phase. Another example is a project management plan that assumes a staff size of ten, but there are only six resources available. The lack of resources could impact the time required to complete the work and the activities would be late.

List of potential responses- Potential responses to a risk may be identified during the Risk Identification process. These responses, if identified, may be useful as inputs to the Risk Response Planning process.

Root causes of risk- These are the fundamental conditions or events that may give rise to the identified risk.

Updated risk categories- The process of identifying risks can lead to new risk categories being added to the list of risk categories. The RBS developed in the Risk Management Planning process may have to be enhanced or amended, based on the outcomes of the Risk Identification process.

4.4.3 Qualitative and quantitative risk assessment: -

Qualitative Risk Analysis

Qualitative Risk Analysis includes methods for prioritizing the identified risks for further action, such as Quantitative Risk Analysis or Risk Response Planning. Organizations can improve the project's performance effectively by focusing on high-priority risks. Qualitative Risk Analysis assesses the priority of identified risks using their probability of occurring, the corresponding impact on project objectives if the risks do occur, as well as other factors such as the time frame and risk tolerance of the project constraints of cost, schedule, scope, and quality.

Definitions of the levels of probability and impact, and expert interviewing, can help to correct biases that are often present in the data used in this process. The time criticality of risk-related actions may magnify the importance of a risk. An evaluation of the quality of the available information on project risks also helps understand the assessment of the risk's importance to the project.

Qualitative Risk Analysis is usually a rapid and cost-effective means of establishing priorities for Risk Response Planning, and lays the foundation for Quantitative Risk Analysis, if this is required. Qualitative Risk Analysis should be revisited during the project's life cycle to stay current with changes in the project risks. Qualitative Risk Analysis requires outputs of the Risk Management Planning and Risk Identification processes. This process can lead into Quantitative Risk Analysis or directly into Risk Response Planning.

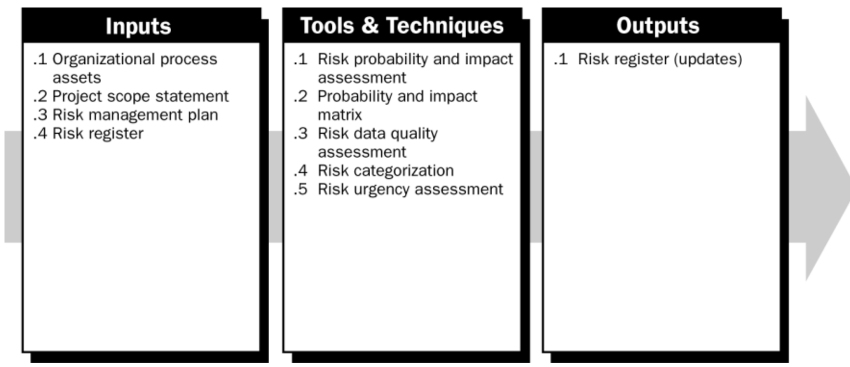


Fig. 4.30 Qualitative Risk Analysis: Inputs, Tools & Techniques, and Outputs

Qualitative Risk Analysis: Inputs

1. Organizational Process Assets

Data about risks on past projects and the lessons learned knowledge base can be used in the Qualitative Risk Analysis process.

2. Project Scope Statement

Projects of a common or recurrent type tend to have more well-understood risks. Projects using state-of-the-art or first-of-its-kind technology, and highly complex projects, tend to have more uncertainty. This can be evaluated by examining the project scope statement.

3. Risk Management Plan

Key elements of the risk management plan for Qualitative Risk Analysis include roles and responsibilities for conducting risk management, budgets, and schedule activities for risk management, risk categories, definition of probability and impact, the probability and impact matrix, and revised stakeholders' risk tolerances. These inputs are usually tailored to the project during the Risk Management Planning process. If they are not available, they can be developed during the Qualitative Risk Analysis process.

4. Risk Register

A key item from the risk register for Qualitative Risk Analysis is the list of identified risks.

Qualitative Risk Analysis: Tools and Techniques

1. Risk Probability and Impact Assessment

Risk probability assessment investigates the likelihood that each specific risk will occur. Risk impact assessment investigates the potential effect on a project objective such as time, cost, scope, or quality, including both negative effects for threats and positive effects for opportunities.

Probability and impact are assessed for each identified risk. Risks can be assessed in interviews or meetings with participants selected for their familiarity with the risk categories on the agenda. Project team members and, perhaps, knowledgeable persons from outside the project, are included. Expert judgment is required, since there may be little information on risks from the organization's database of past projects. An experienced facilitator may lead the discussion, since the participants may have little experience with risk assessment. The level of probability for each risk and its impact on each objective is evaluated during the interview or meeting. Explanatory detail, including assumptions justifying the levels assigned, is also recorded. Risk probabilities and impacts are rated according to the definitions given in the risk management plan. Sometimes, risks with obviously low ratings of probability and impact will not be rated, but will be included on a watchlist for future monitoring.

2. Probability and Impact Matrix

Risks can be prioritized for further quantitative analysis and response, based on their risk rating. Ratings are assigned to risks based on their assessed probability and impact. Evaluation of each risk's importance and, hence, priority for attention is typically conducted using a look-up table or a probability and impact matrix (Figure 4.31). Such a matrix specifies combinations of probability and impact that lead to rating the risks as low, moderate, or high priority. Descriptive terms or numeric values can be used, depending on organizational preference. The organization should determine which combinations of probability and impact result in a classification of high risk, moderate risk, and low risk. In a black-and-white matrix, these conditions can be denoted by different shades of gray. Specifically, in Figure 4.31, the dark gray area (with the largest numbers) represents high risk; the medium gray area (with the smallest numbers) represents low risk; and the light gray area (with in-between numbers) represents moderate risk. Usually, these risk rating rules are specified by the organization in advance of the project, and included in organizational process assets. Risk rating rules can be tailored in the Risk Management Planning process to the specific project. A probability and impact matrix, such as the one shown in Figure 4.31, is often used.

Probability and Impact Matrix

Probability	Threats					Opportunities				
0.90	0.05	0.09	0.18	0.36	0.72	0.72	0.36	0.18	0.09	0.05
0.70	0.04	0.07	0.14	0.28	0.56	0.56	0.28	0.14	0.07	0.04
0.50	0.03	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.03
0.30	0.02	0.03	0.06	0.12	0.24	0.24	0.12	0.06	0.03	0.02
0.10	0.01	0.01	0.02	0.04	0.08	0.08	0.04	0.02	0.01	0.01
	0.05	0.10	0.20	0.40	0.80	0.80	0.40	0.20	0.10	0.05

Impact (ratio scale) on an objective (e.g., cost, time, scope or quality)

Each risk is rated on its probability of occurring and impact on an objective if it does occur. The organization's thresholds for low, moderate or high risks are shown in the matrix and determine whether the risk is scored as high, moderate or low for that objective.

Fig. 4.31 Probability and Impact Matrix

As illustrated in Figure 4.31, an organization can rate a risk separately for each objective (e.g., cost, time, and scope). In addition, it can develop ways to determine one overall rating for each risk. Finally, opportunities and threats can be handled in the same matrix using definitions of the different levels of impact that are appropriate for each. The risk score helps guide risk responses. For example, risks that have a negative impact on objectives if they occur (threats), and that are in the high-risk (dark gray) zone of the matrix, may require priority action and aggressive response strategies. Threats in the low-risk (medium gray) zone may not require proactive management action beyond being placed on a watchlist or adding a contingency reserve. Similarly for opportunities, those in the high-risk (dark gray) zone that can be obtained most easily and offer the greatest benefit should, therefore, be targeted first. Opportunities in the low-risk (medium gray) zone should be monitored.

3. Risk Data Quality Assessment

A qualitative risk analysis requires accurate and unbiased data if it is to be credible. Analysis of the quality of risk data is a technique to evaluate the degree to which the data about risks is useful for risk management. It involves examining the degree to which the risk is understood and the accuracy, quality, reliability, and integrity of the data about the risk. The use of low-quality risk data may lead to a qualitative risk analysis of little use to the project. If data quality is unacceptable, it may be necessary to gather better data. Often, collection of information about risks is difficult, and consumes time and resources beyond that originally planned.

4. Risk Categorization

Risks to the project can be categorized by sources of risk (e.g., using the RBS), the area of the project affected (e.g., using the WBS), or other useful category (e.g., project phase) to determine areas of the project most exposed to the effects of uncertainty. Grouping risks by common root causes can lead to developing effective risk responses.

5. Risk Urgency Assessment

Risks requiring near-term responses may be considered more urgent to address. Indicators of priority can include time to affect a risk response, symptoms and warning signs, and the risk rating.

Qualitative Risk Analysis: Outputs

1. Risk Register (Updates)

The risk register is initiated during the Risk Identification process. The risk register is updated with information from Qualitative Risk Analysis and the updated risk register is included in the project management plan. The risk register updates from Qualitative Risk Analysis include:
Relative ranking or priority list of project risks- The probability and impact matrix can be used to classify risks according to their individual significance. The project manager can then use the prioritized list to focus attention on those items of high significance to the project, where responses can lead to better project outcomes. Risks may be listed by priority separately for cost, time, scope, and quality, since organizations may value one objective over another. A description of the basis for the assessed probability and impact should be included for risks assessed as important to the project.

Risks grouped by categories- Risk categorization can reveal common root causes of risk or project areas requiring particular attention. Discovering concentrations of risk may improve the effectiveness of risk responses.

List of risks requiring response in the near-term- Those risks that require an urgent response and those that can be handled at a later date may be put into different groups.
List of risks for additional analysis and response- Some risks might warrant more analysis, including Quantitative Risk Analysis, as well as response action.

Watchlists of low priority risks- Risks that are not assessed as important in the Qualitative Risk Analysis process can be placed on a watchlist for continued monitoring.

Trends in qualitative risk analysis results- As the analysis is repeated, a trend for particular risks may become apparent, and can make risk response or further analysis more or less urgent/important.

4. Quantitative Risk Analysis

Quantitative Risk Analysis is performed on risks that have been prioritized by the Qualitative Risk Analysis process as potentially and substantially impacting the project’s competing demands. The Quantitative Risk Analysis process analyzes the effect of those risk events and assigns a numerical rating to those risks. It also presents a quantitative approach to making decisions in the presence of uncertainty. This process uses techniques such as Monte Carlo simulation and decision tree analysis to:

-Quantify the possible outcomes for the project and their probabilities
-Assess the probability of achieving specific project objectives
-Identify risks requiring the most attention by quantifying their relative contribution to overall project risk
- Identify realistic and achievable cost, schedule, or scope targets; given the project risks
- Determine the best project management decision when some conditions or outcomes are uncertain.

Quantitative Risk Analysis generally follows the Qualitative Risk Analysis process, although experienced risk managers sometimes perform it directly after Risk Identification. In some cases, Quantitative Risk Analysis may not be required to develop effective risk responses. Availability of time and budget, and the need for qualitative or quantitative statements about risk and impacts, will determine which method(s) to use on any particular project. Quantitative Risk Analysis should be repeated after Risk Response Planning, as well as part of Risk Monitoring and Control, to determine if the overall project risk has been satisfactorily decreased. Trends can indicate the need for more or less risk management action. It is an input to the Risk Response Planning process.

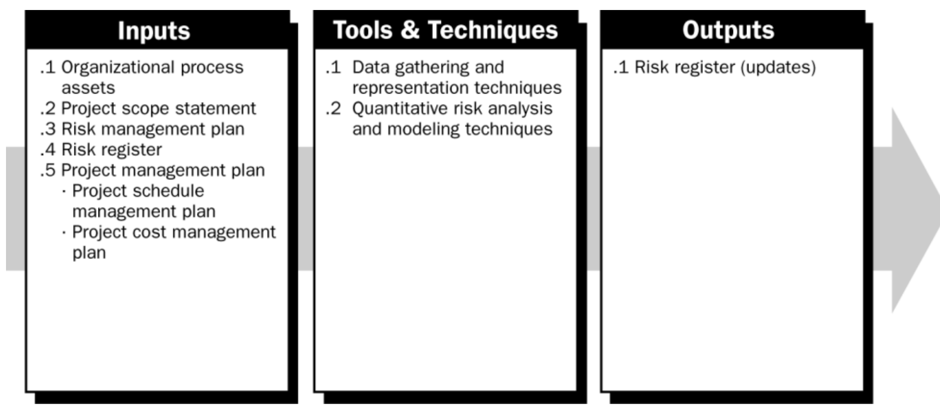


Fig. 4.32 Quantitative Risk Analysis: Inputs, Tools & Techniques, and Outputs

Quantitative Risk Analysis: Inputs

1. Organizational Process Assets

Information on prior, similar completed projects, studies of similar projects by risk specialists, and risk databases that may be available from industry or proprietary sources.

2. Project Scope Statement

Projects of a common or recurrent type tend to have more well-understood risks. Projects using state-of-the-art or first-of-its-kind technology, and highly complex projects, tend to have more uncertainty. This can be evaluated by examining the project scope statement.

3. Risk Management Plan

Key elements of the risk management plan for Quantitative Risk Analysis include roles and responsibilities for conducting risk management, budgets, and schedule activities for risk management, risk categories, the RBS, and revised stakeholders' risk tolerances.

4. Risk Register

Key items from the risk register for Quantitative Risk Analysis include the list of identified risks, the relative ranking or priority list of project risks, and the risks grouped by categories.

5. Project Management Plan

The project management plan includes:

Project schedule management plan- The project schedule management plan sets the format and establishes criteria for developing and controlling the project schedule.

Project cost management plan- The project cost management plan sets the format and establishes criteria for planning, structuring, estimating, budgeting, and controlling project costs.

Quantitative Risk Analysis: Tools and Techniques

1. Data Gathering and Representation Techniques

Interviewing- Interviewing techniques are used to quantify the probability and impact of risks on project objectives. The information needed depends upon the type of probability distributions that will be used. For instance, information would be gathered on the optimistic (low), pessimistic (high), and most likely scenarios for some commonly used distributions, and the mean and standard deviation for others. Examples of three-point estimates for a cost estimate are shown in Figure 4.33. Documenting the rationale of the risk ranges is an important component of the risk interview, because it can provide information on reliability and credibility of the analysis.

Range of Project Cost Estimates

WBS Element	Low	Most Likely	High
Design	\$4M	\$6M	\$10M
Build	\$16M	\$20M	\$35M
Test	\$11M	\$15M	\$23M
Total Project		\$41M	

The risk interview determines the three-point estimates for each WBS element for triangular or other asymmetrical distributions. In this example, the likelihood of completing the project at or below the traditional estimate of \$41 million is relatively small as shown in the simulation results (Figure 11-13).

Fig. 4.33 Range of Project Cost Estimates Collected During the Risk Interview

Probability distributions- Continuous probability distributions represent the uncertainty in values, such as durations of schedule activities and costs of project components. Discrete distributions can be used to represent uncertain events, such as the outcome of a test or a possible scenario in a decision tree. Two examples of widely used continuous distributions are shown in

Figure 4.34. These asymmetrical distributions depict shapes that are compatible with the data typically developed during the project risk analysis. Uniform distributions can be used if there is no obvious value that is more likely than any other between specified high and low bounds, such as in the early concept stage of design.

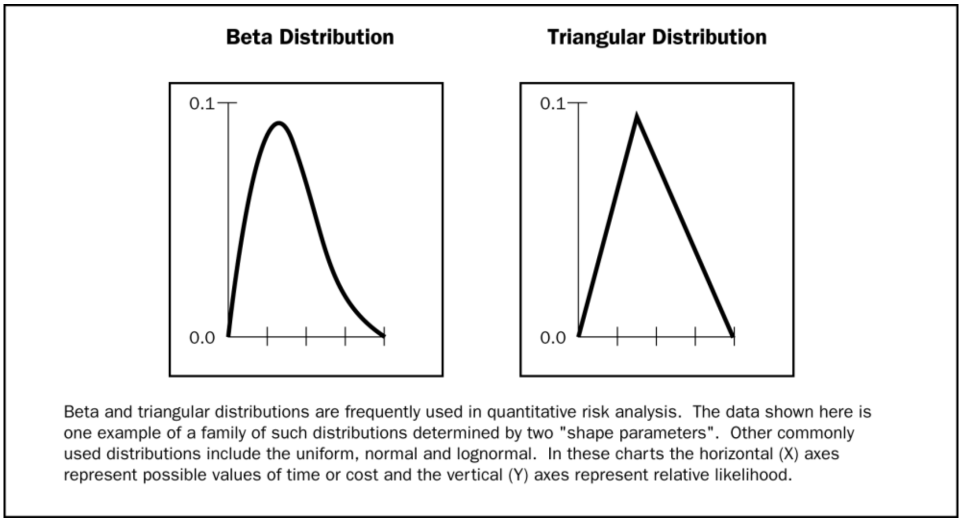


Fig. 4.34 Examples of Commonly Used Probability Distributions

Expert judgment- Subject matter experts internal or external to the organization, such as engineering or statistical experts, validate data and techniques.

2. Quantitative Risk Analysis and Modeling Techniques

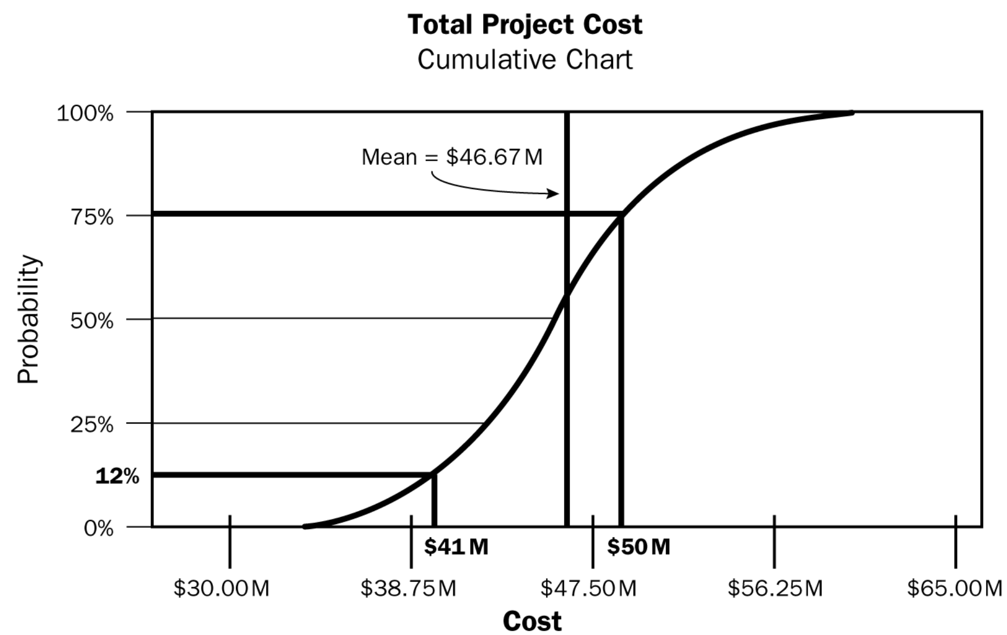
Commonly used techniques in Quantitative Risk Analysis include:

Sensitivity analysis- Sensitivity analysis helps to determine which risks have the most potential impact on the project. It examines the extent to which the uncertainty of each project element affects the objective being examined when all other uncertain elements are held at their baseline values. One typical display of sensitivity analysis is the tornado diagram, which is useful for comparing relative importance of variables that have a high degree of uncertainty to those that are more stable.

Expected monetary value analysis- Expected monetary value (EMV) analysis is a statistical concept that calculates the average outcome when the future includes scenarios that may or may not happen (i.e., analysis under uncertainty). The EMV of opportunities will generally be expressed as positive values, while those of risks will be negative. EMV is calculated by multiplying the value of each possible outcome by its probability of occurrence, and adding them together. A common use of this type of analysis is in decision tree analysis. Modeling and simulation are recommended for use in cost and schedule risk analysis, because they are more powerful and less subject to misuse than EMV analysis.

Decision tree analysis- Decision tree analysis is usually structured using a decision tree diagram (Figure 4.34) that describes a situation under consideration, and the implications of each of the available choices and possible scenarios. It incorporates the cost of each available choice, the probabilities of each possible scenario, and the rewards of each alternative logical path. Solving the decision tree provides the EMV (or other measure of interest to the organization) for each alternative, when all the rewards and subsequent decisions are quantified.

Modeling and simulation- A project simulation uses a model that translates the uncertainties specified at a detailed level of the project into their potential impact on project objectives. Simulations are typically performed using the Monte Carlo technique. In a simulation, the project model is computed many times (iterated), with the input values randomized from a probability distribution function (e.g., cost of project elements or duration of schedule activities) chosen for each iteration from the probability distributions of each variable. A probability distribution (e.g., total cost or completion date) is calculated. For a cost risk analysis, a simulation can use the traditional project WBS or a cost breakdown structure as its model. For a schedule risk analysis, the precedence diagramming method (PDM) schedule is used. A cost risk simulation is shown in Figure 4.35.



This cumulative likelihood distribution reflects the risk of overrunning the sum of the most likely cost estimate, assuming the data ranges contained in Figure 11-10 and triangular distributions. It shows that the project is only 12 percent likely to meet the $41 million estimate. If a conservative organization wants a 75% likelihood of success, a budget of $50 million (a contingency of nearly 22 %) is required.

Fig. 4.35 Cost Risk Simulation Results

Quantitative Risk Analysis: Outputs

1. Risk Register (Updates)

The risk register is initiated in the Risk Identification process and updated in Qualitative Risk Analysis. It is further updated in Quantitative Risk Analysis. The risk register is a component of the project management plan. Updates include the following main components:

Probabilistic analysis of the project- Estimates are made of potential project schedule and cost outcomes, listing the possible completion dates and costs with their associated confidence levels.

This output, typically expressed as a cumulative distribution, is used with stakeholder risk tolerances to permit quantification of the cost and time contingency reserves. Such contingency reserves are needed to bring the risk of overrunning stated project objectives to a level acceptable to the organization. For instance, in Figure 4.35, the cost contingency to the 75th percentile is $9 million, or about 22% versus the $41 million sum of the most likely estimates.

Probability of achieving cost and time objectives- With the risks facing the project, the probability of achieving project objectives under the current plan can be estimated using quantitative risk analysis results. For instance, in Figure 4.35, the likelihood of achieving the cost estimate of $41 million (from Figure 4.32) is about 12%.

Prioritized list of quantified risks- This list of risks includes those that pose the greatest threat or present the greatest opportunity to the project. These include the risks that require the greatest cost contingency and those that are most likely to influence the critical path.

Trends in quantitative risk analysis results- As the analysis is repeated, a trend may become apparent that leads to conclusions affecting risk responses

Quantitative Risk Assessment Methodologies

Commonly used techniques in Quantitative Risk Analysis include:

Sensitivity analysis- Sensitivity analysis helps to determine which risks have the most potential impact on the project. It examines the extent to which the uncertainty of each project element affects the objective being examined when all other uncertain elements are held at their baseline values. One typical display of sensitivity analysis is the tornado diagram, which is useful for comparing relative importance of variables that have a high degree of uncertainty to those that are more stable.

Expected monetary value analysis- Expected monetary value (EMV) analysis is a statistical concept that calculates the average outcome when the future includes scenarios that may or may not happen (i.e., analysis under uncertainty). The EMV of opportunities will generally be expressed as positive values, while those of risks will be negative. EMV is calculated by multiplying the value of each possible outcome by its probability of occurrence, and adding them together. A common use of this type of analysis is in decision tree analysis (Figure 4.34). Modeling and simulation are recommended for use in cost and schedule risk analysis, because they are more powerful and less subject to misuse than EMV analysis.

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Modeling and simulation- A project simulation uses a model that translates the uncertainties specified at a detailed level of the project into their potential impact on project objectives. Simulations are typically performed using the Monte Carlo technique. In a simulation, the project model is computed many times (iterated), with the input values randomized from a probability distribution function (e.g., cost of project elements or duration of schedule activities) chosen for each iteration from the probability distributions of each variable. A probability distribution (e.g., total cost or completion date) is calculated. For a cost risk analysis, a simulation can use the traditional project WBS or a cost breakdown structure as its model. For a schedule risk analysis, the precedence diagramming method (PDM) schedule is used. A cost risk simulation is shown in Figure 4.35.

Failure Mode and Effect Analysis (FMEA)

FMEA is the application of a scoring model such as those used for project . It is straightforward and extensively used, particularly in engineering, and is easily applied to risk by using six steps.

1. List the possible ways a project might fail.

2. Evaluate the severity (**S**) of the impact of each type of failure on a 10-point scale where "1" is "no effect" and "10" is "very severe."

3. For each cause of failure, estimate the likelihood (**L**) of its occurrence on a 10-point scale where "1" is "remote" and 10 is "almost certain."

4. Estimate the inability to detect (**D**) a failure associated with each cause. Using a 10-point scale, "1" means delectability is almost certain using normal monitoring/ control systems and "10" means it is practically certain that failure will not be detected in time to avoid or mitigate it.

5. Find the *Risk Priority Number* (**RPN**) where **RPN S L D**.

6. Consider ways to reduce the **S**, **L**, and **D** for each cause of failure with a significantly high **RPN**. (We discuss this in Step 5: Risk Response Planning.)

Table 4.1 FMEA Example table

Threat	Severity ,S	Likelihood , L	Ability to Detect , D	RPN
1. Tight schedule	6	7.5	2	90
2. Can't acquire tech knowledge	8.5	5	4	170
3. Client changes scope	4	8	5	160
4. Costs escalate	3	2	6	36
5. Recession	4	2.5	7	

Table 4.1 illustrates the use of FMEA for the same five threats we considered in Step 4 previously, but here we use more precise data. As we see from the RPN numbers, the biggest threats are: Can't acquire tech knowledge (2), and Client changes scope (3). Threat 2 has a great severity, should it occur, and threat 3 is quite likely, though the severity is much less damaging. The cost threat (4) and the recession threat (5) can probably be ignored for now since their likelihoods are so low. The tight schedule (1) will have some repercussions and is also quite likely, but we will see it coming early and can probably take steps to avoid or mitigate it. Some extensions of FMEA use additional scoring categories such as Ability to Mitigate (even if the threat cannot be detected).

4.4.4 Probability and impact matrix: -

Definitions of risk probability and impact- The quality and credibility of the Qualitative Risk Analysis process requires that different levels of the risks' probabilities and impacts be defined.

General definitions of probability levels and impact levels are tailored to the individual project during the Risk Management Planning process for use in the Qualitative Risk Analysis process. A relative scale representing probability values from “very unlikely” to “almost certainty” could be used. Alternatively, assigned numerical probabilities on a general scale (e.g., 0.1, 0.3, 0.5, 0.7, 0.9) can be used. Another approach to calibrating probability involves developing descriptions of the state of the project that relate to the risk under consideration (e.g., the degree of maturity of the project design).

The impact scale reflects the significance of impact, either negative for threats or positive for opportunities, on each project objective if a risk occurs. Impact scales are specific to the objective potentially impacted, the type and size of the project, the organization’s strategies and financial state, and the organization’s sensitivity to particular impacts. Relative scales for impact are simply rank-ordered descriptors such as “very low,” “low,” “moderate,” “high,” and “very high,” reflecting increasingly extreme impacts as defined by the organization. Alternatively, numeric scales assign values to these impacts. These values may be linear (e.g., 0.1, 0.3, 0.5, 0.7, 0.9) or nonlinear (e.g., 0.05, 0.1, 0.2, 0.4, 0.8). Nonlinear scales may represent the organization’s desire to avoid high-impact threats or exploit high-impact opportunities, even if they have relatively low probability. In using nonlinear scales, it is important to understand what is meant by the numbers and their relationship to each other, how they were derived, and the effect they may have on the different objectives of the project. Figure 4.36 is an example of negative impacts of definitions that might be used in evaluating risk impacts related to four project objectives. That figure illustrates both relative and numeric (in this case, nonlinear) approaches. The figure is not intended to imply that the relative and numeric terms are equivalent, but to show the two alternatives in one figure rather than two.

Defined Conditions for Impact Scales of a Risk on Major Project Objectives
(Examples are shown for negative impacts only)

Project Objective	Relative or numerical scales are shown				
	Very low /.05	Low /.10	Moderate /.20	High /.40	Very high /.80
Cost	Insignificant cost increase	<10% cost increase	10-20% cost increase	20-40% cost increase	>40% cost lincrease
Time	Insignificant time increase	<5% time increase	5-10% time increase	10-20% time ilncrease	>20% time increase
Scope	Scope decrease barely noticeable	Minor areas of scope affected	Major areas of scope affected	Scope reduction unacceptable to sponsor	Project end item is effectively useless
Quality	Quality degradation barely noticeable	Only very demanding applications are affected	Quality reduction requires sponsor approval	Quality reduction unacceptable to sponsor	Project end item is effectively useless

This table presents examples of risk impact definitions for four different project objectives. They should be tailored in the Risk Management Planning process to the individual project and to the organization's risk thresholds. Impact definitions can be developed for opportunities in a similar way.

Fig. 4.36 Definition of Impact Scale for four project objectives

Risk probability assessment investigates the likelihood that each specific risk will occur. Risk impact assessment investigates the potential effect on a project objective such as time, cost, scope, or quality, including both negative effects for threats and positive effects for opportunities.

Probability and impact are assessed for each identified risk. Risks can be assessed in interviews or meetings with participants selected for their familiarity with the risk categories on the agenda. Project team members and, perhaps, knowledgeable persons from outside the project, are included. Expert judgment is required, since there may be little information on risks from the organization's database of past projects. An experienced facilitator may lead the discussion, since the participants may have little experience with risk assessment. The level of probability for each risk and its impact on each objective is evaluated during the interview or meeting. Explanatory detail, including assumptions justifying the levels assigned, is also recorded. Risk probabilities and impacts are rated according to the definitions given in the risk management plan. Sometimes, risks with obviously low ratings of probability and impact will not be rated, but will be included on a watch list for future monitoring.

Risks can be prioritized for further quantitative analysis and response, based on their risk rating. Ratings are assigned to risks based on their assessed probability and impact. Evaluation of each risk's importance and, hence, priority for attention is typically conducted using a look-up table or a probability and impact matrix (Figure 4.37). Such a matrix specifies combinations of probability and impact that lead to rating the risks as low, moderate, or high priority. Descriptive terms or numeric values can be used, depending on organizational preference. The organization should determine which combinations of probability and impact result in a classification of high risk ("red condition"), moderate risk ("yellow condition"), and low risk ("green condition"). In a black-and-white matrix, these conditions can be denoted by different shades of gray. Specifically, in Figure 4.37, the dark gray area (with the largest numbers) represents high risk; the medium gray area (with the smallest numbers) represents low risk; and the light gray area (with in-between numbers) represents moderate risk. Usually, these risk rating rules are specified by the organization in advance of the project, and included in organizational process assets. Risk rating rules can be tailored in the Risk Management Planning process to the specific project. A probability and impact matrix, such as the one shown in Figure 4.37, is often used.

Probability and Impact Matrix

Probability	Threats					Opportunities				
0.90	0.05	0.09	0.18	0.36	0.72	0.72	0.36	0.18	0.09	0.05
0.70	0.04	0.07	0.14	0.28	0.56	0.56	0.28	0.14	0.07	0.04
0.50	0.03	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.03
0.30	0.02	0.03	0.06	0.12	0.24	0.24	0.12	0.06	0.03	0.02
0.10	0.01	0.01	0.02	0.04	0.08	0.08	0.04	0.02	0.01	0.01
	0.05	0.10	0.20	0.40	0.80	0.80	0.40	0.20	0.10	0.05

Impact (ratio scale) on an objective (e.g., cost, time, scope or quality)

Each risk is rated on its probability of occurring and impact on an objective if it does occur. The organization's thresholds for low, moderate or high risks are shown in the matrix and determine whether the risk is scored as high, moderate or low for that objective.

Fig. 4.37 Probability and Impact Matrix

An organization can rate a risk separately for each objective (e.g., cost, time, and scope). In addition, it can develop ways to determine one overall rating for each risk. Finally, opportunities and threats can be handled in the same matrix using definitions of the different levels of impact that are appropriate for each. The risk score helps guide risk responses. For example, risks that have a negative impact on objectives if they occur (threats), and that are in the high-risk (dark gray) zone of the matrix, may require priority action and aggressive response strategies. Threats in the low-risk (medium gray) zone may not require proactive management action beyond being placed on a watch list or adding a contingency reserve. Similarly for opportunities, those in the high-risk (dark gray) zone that can be obtained most easily and offer the greatest benefit should, therefore, be targeted first. Opportunities in the low-risk (medium gray) zone should be monitored. Risks are prioritized according to their potential implications for meeting the project's objectives. The typical approach to prioritizing risks is to use a look-up table or a Probability and Impact Matrix. The specific combinations of probability and impact that lead to a risk being rated as "high," "moderate," or "low" importance—with the corresponding importance for planning responses to the risk are usually set by the organization. They are reviewed and can be tailored to the specific project during the Risk Management Planning process.

4.4.5 Risk response strategies for positive and negative risks: -

Several risk response strategies are available. The strategy or mix of strategies most likely to be effective should be selected for each risk. Risk analysis tools, such as decision tree analysis, can be used to choose the most appropriate responses. Then, specific actions are developed to implement that strategy. Primary and backup strategies may be selected. A fallback plan can be developed for implementation if the selected strategy turns out not to be fully effective, or if an accepted risk occurs. Often, a contingency reserve is allocated for time or cost. Finally, contingency plans can be developed, along with identification of the conditions that trigger their execution.

1. Strategies for Negative Risks or Threats

Three strategies typically deal with threats or risks that may have negative impacts on project objectives if they occur. These strategies are to avoid, transfer, or mitigate:
Avoid- Risk avoidance involves changing the project management plan to eliminate the threat posed by an adverse risk, to isolate the project objectives from the risk's impact, or to relax the objective that is in jeopardy, such as extending the schedule or reducing scope. Some risks that arise early in the project can be avoided by clarifying requirements, obtaining information, improving communication, or acquiring expertise.
Transfer- Risk transference requires shifting the negative impact of a threat, along with ownership of the response, to a third party. Transferring the risk simply gives another party responsibility for its management; it does not eliminate it. Transferring liability for risk is most effective in dealing with financial risk exposure. Risk transference nearly always involves

payment of a risk premium to the party taking on the risk. Transference tools can be quite diverse and include, but are not limited to, the use of insurance, performance bonds, warranties, guarantees, etc. Contracts may be used to transfer liability for specified risks to another party. In many cases, use of a cost-type contract may transfer the cost risk to the buyer, while a fixed-price contract may transfer risk to the seller, if the project's design is stable.

Mitigate- Risk mitigation implies a reduction in the probability and/or impact of an adverse risk event to an acceptable threshold. Taking early action to reduce the probability and/or impact of a risk occurring on the project is often more effective than trying to repair the damage after the risk has occurred. Adopting less complex processes, conducting more tests, or choosing a more stable supplier are examples of mitigation actions. Mitigation may require prototype development to reduce the risk of scaling up from a bench-scale model of a process or product. Where it is not possible to reduce probability, a mitigation response might address the risk impact by targeting linkages that determine the severity. For example, designing redundancy into a subsystem may reduce the impact from a failure of the original component.

2. Strategies for Positive Risks or Opportunities

Three responses are suggested to deal with risks with potentially positive impacts on project objectives. These strategies are to exploit, share, or enhance.

Exploit. This strategy may be selected for risks with positive impacts where the organization wishes to ensure that the opportunity is realized. This strategy seeks to eliminate the uncertainty associated with a particular upside risk by making the opportunity definitely happen. Directly exploiting responses includes assigning more talented resources to the project to reduce the time to completion, or to provide better quality than originally planned.

Share. Sharing a positive risk involves allocating ownership to a third party who is best able to capture the opportunity for the benefit of the project. Examples of sharing actions include forming risk-sharing partnerships, teams, special-purpose companies, or joint ventures, which can be established with the express purpose of managing opportunities.

Enhance. This strategy modifies the "size" of an opportunity by increasing probability and/or positive impacts, and by identifying and maximizing key drivers of these positive-impact risks. Seeking to facilitate or strengthen the cause of the opportunity, and proactively targeting and reinforcing its trigger conditions, might increase probability. Impact drivers can also be targeted, seeking to increase the project's susceptibility to the opportunity.

Module-4 Planning Projects **(Question Bank)**

1. What is a project launch meeting? who are the invitees of this meeting? What are the outcomes of this meeting?
2. What is crashing of the project? Explain with a small example the process of crashing
3. What is resource loading? How does it differ from resource leveling?
4. What is Goldratt's critical chain method? What is meant by a project buffer?