CHAPTER 7

RISK MANAGEMENT

This chapter provides the framework and guidelines for managing project-related risks. It includes both an in-depth narrative of the key elements of risk management as well as the primary tools for identifying, assessing and managing risk. The philosophy and approach to risk management are consistent with the “Project Risk Management” best practices currently in use.

7.1 Introduction

Risk management is a major step in project planning. It is a complex process since the variables are dynamic and dependent on a variety of conditions such as: project size, project complexity, location, season of the year, …etc. As such, upon analyzing risks, a Time and/or Cost contingency should be added to cover unforeseen occurrences.

Generally, risk is defined as the exposure to the chance of occurrence of events adversely or favorably affecting project objectives as a consequence of uncertainty”. However, most definitions of risk have focused only on the downside effects associated with risk. Therefore, risk may be defined as: “Undesirable extra cost or delay due to factors having uncertain future outcome”.

Risk management is “A formal ordering process for systematically identifying, analyzing, and responding to risk events throughout the life of a project to obtain the optimum or acceptable degree of risk elimination or control”. The Major Steps of Risk Management includes:

- Plan risk management plan.
- Risk Identification.
- Qualitative risk analysis.
- Quantitative risk analysis.
- Development of responses to avoid, reduce, or transfer risk.
- Risk monitoring and control.

**Risk event** is a discrete occurrence that may affect the project for better or worse is a risk event. A risk event will have an impact on one or several of the objectives of the project. An example could be that a key team member is reassigned off the project before his/her work is completed. The reassignment is a “risk event.”

**Effective risk management** is guided by a set of principles that represent current “best practices.” Irrespective of the size or complexity of a project, the Risk Management Plan should reflect these principles. The Risk Management Plan is part of the Project Work Plan.

- **Global Perspective:** View each phase of a project as a means to the overall project success. View each project and its success in relationship to other projects.

- **Forward-Looking View:** Look ahead to anticipate risks and their potential impacts. More importantly, anticipate potential risks in time to successfully address them.

- **Open Communications:** Encourage a free flow of formal and informal information to make each individual a part of effective risk management.

- **Integrated Management:** Integrate risk management within the overall project management process.

- **Continuous Process:** Identify and manage risks routinely through all phases of the life cycle of the project.

- **Shared Project Vision:** Maintain a shared vision of the expected outcome of the project based on common purpose, shared ownership in results, and collective communication.
- **Teamwork:** Pool talents, skills, and knowledge to work cooperatively to identify and manage project risk.

### 7.2 Risk Management Process

The purpose of this subsection is to explain the risk management process. It is important to note that the process itself is built on a general approach that (Fig. 7.1):

- Begins with project planning.
- Requires a thorough development of project concept, scope, and level of effort.
- Identifies key uncertainties and risks associated with the project.
- Examines the identified risks to mitigate their probability and impact, or to build in risk allowances.
- Expects risk monitoring and response to be an ongoing part of the project.

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Identification</td>
<td>Determining which risks might affect the project and documenting their characteristics</td>
</tr>
<tr>
<td>Risk Analysis</td>
<td>Transforming risk data into decision-making information</td>
</tr>
<tr>
<td>Risk Response</td>
<td>Translating risk information into decisions and mitigating action plans</td>
</tr>
<tr>
<td>Risk Control</td>
<td>Monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle</td>
</tr>
</tbody>
</table>
7.2.1 Risk Identification

**Purpose:** Search for and locate sources of risks before they become a problem and provide a preliminary assessment of their consequences.

**Discussion:** It is normal to identify a large number of potential risks. It is not necessary to examine all of them in detail.

**Tools:**
- Affinity diagram
- Checklist of possible sources of risk
- Fishbone diagram

-Main categories of sources of risks are listed with examples in the following Table.
<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative</td>
<td>Delay in possession of site</td>
</tr>
<tr>
<td></td>
<td>Limited working hours</td>
</tr>
<tr>
<td></td>
<td>Troubles with public services</td>
</tr>
<tr>
<td>Logistical</td>
<td>Shortage or late supply of different resources</td>
</tr>
<tr>
<td></td>
<td>Site remoteness problems</td>
</tr>
<tr>
<td></td>
<td>Communications</td>
</tr>
<tr>
<td>Construction</td>
<td>Ground problems</td>
</tr>
<tr>
<td></td>
<td>Limited work space</td>
</tr>
<tr>
<td></td>
<td>Equipment breakdown</td>
</tr>
<tr>
<td>Physical</td>
<td>Placing fill in dry season</td>
</tr>
<tr>
<td></td>
<td>High tides, temperature, etc.</td>
</tr>
<tr>
<td></td>
<td>River diversion in time of low flow.</td>
</tr>
<tr>
<td>Design</td>
<td>Incompleteness</td>
</tr>
<tr>
<td></td>
<td>Design changes</td>
</tr>
<tr>
<td></td>
<td>Design errors</td>
</tr>
<tr>
<td>Financial</td>
<td>Inflation</td>
</tr>
<tr>
<td></td>
<td>Exchange rate fluctuation</td>
</tr>
<tr>
<td></td>
<td>Availability of funds</td>
</tr>
<tr>
<td></td>
<td>Delay payments by client</td>
</tr>
<tr>
<td>Management</td>
<td>Space congestion</td>
</tr>
<tr>
<td></td>
<td>Scheduling errors</td>
</tr>
<tr>
<td></td>
<td>Estimating based on standards</td>
</tr>
<tr>
<td></td>
<td>Errors in B.O.Q.</td>
</tr>
<tr>
<td>Contractual</td>
<td>Contract type</td>
</tr>
<tr>
<td></td>
<td>Liability to others</td>
</tr>
<tr>
<td></td>
<td>Co-ordination of work</td>
</tr>
<tr>
<td>Political</td>
<td>Change in local laws</td>
</tr>
<tr>
<td></td>
<td>Import restrictions</td>
</tr>
<tr>
<td></td>
<td>Use of local resources</td>
</tr>
<tr>
<td>Disasters</td>
<td>Floods, fire, landslip, earthquakes, etc.</td>
</tr>
</tbody>
</table>
7.2.2 Risk Analysis

**Purpose:** To transform risk data into decision-making information. A process which incorporates uncertainty in a quantitative manner, using probability theory, to evaluate the potential impact of risk.

**Basic Steps of Risk Analysis**

- The general approach is to identify the nature of the risk, the probability of its occurrence, and the likely impact of its occurrence. Estimate range of risk variables.
- Not all risks need attention.
- Begin with a qualitative analysis to decide which potential risks are worth further consideration. For most areas of potential risk, this qualitative analysis will be sufficient to determine the type of required response.
- When it is necessary to fully understand the extent of impact of a potential risk event, use a quantitative analysis. For example, a quantitative analysis that yields a total dollar impact of a particular risk event can be a powerful way to gain senior management support for adding project staff to manage the risk area.
- Choose the appropriate probability distribution which best fit risk variables,
- Define the affected activities by these risk variables, and
- Use a simulation model to evaluate the impact of risks (PERT, Monte Carlo Simulation). This step usually includes:
  1. Sensitivity Analysis.
  2. Probability Analysis.

<table>
<thead>
<tr>
<th>Outline for Identifying and Assessing Project Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of Potential Risk</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
There are instances when the impact of the potential risk is easy to evaluate qualitatively. Other times, it is not so clear. In those instances, it helps to use an analytical tool such as the “Consequences Wheel” shown in Fig. 7.2. This wheel helps the Project Team understand the variety of ways that a risk-related event could affect project performance.

Fig. 7.2: Consequence wheel

As the instructions in Fig. 4.1 suggest, begin by writing the name of the particular risk in the center of the wheel. Then, brainstorm all of the potential consequences to the project if this risk event occurred. These “primary” consequences become the first ring in the wheel. Continue the analysis by taking each primary consequence and identifying the
direct consequences of its occurrence. These “secondary” consequences become the second ring in the wheel.

At this point, the Project Team should have all the risks identified, as well as the probability and impact each risk carries. These risks can be inserted into the Probability-Impact Risk Analysis Matrix (Fig. 7.3) to get a global picture of the risks, and their impact relative to each other. Planning worksheets for the Probability-Impact Risk Analysis Matrix are only a planning tool and not included in the Risk Response Plan. The Probability-Impact Risk Analysis Matrix and the Risk Management Log rank the risks according to their impacts and probability and are to be included in the Risk Response Plan.

![Fig. 7.3: Probability-impact matrix]
Sensitivity Analysis

-A quick identification of those variables which affect mostly a performance criteria (project time and/or cost).

-The purpose is to eliminate those risk variables which have minor impact on the performance criteria and hence reduce problem size and effort.

-Procedure:
  - Three values of each risk variables are to be specified: a most likely, an optimistic, and a pessimistic.
  - For each risk variable:
    - Set all other risk variables at their most likely value.
    - Determine a value for the performance criteria when risk variable under consideration is set at its optimistic value.
    - Determine another value for the performance criteria when risk variable under consideration is set at its pessimistic value.
    - The difference between the obtained two values of the performance criteria is checked (subjectively).
  - Two cases can be encountered:
    1. The difference corresponding to a risk variable has a little effect on the performance criteria. Then, this risk variable can be eliminated from the probability analysis. The most likely value for this risk variable can be used throughout the analysis.
    2. A significant difference is found, and consequently this risk variable should be included in the probability analysis.

Probability Analysis

-The purpose is to determine the effect of those risk variables which have a significant impact on the performance criteria.

-Procedure:
  - Consider the risk variables as random variables.
- Specify the suitable probability distribution for each risk variable.
- Use a suitable simulation technique to determine the probability distribution of the performance criteria (PERT, Monte Carlo Simulation.)

7.2.3 Risk Responses

**Purpose:** To translate risk information into decisions and mitigating action plans. To implement those action plans.

For each project, develop a Risk Response Plan. Risk responses can be made at two stages:

*First Stage:*
- Develop responses to avoid, reduce, or transfer risk (before risk analysis).

*Second stage:*
- To deal with residual risks, one of the two following approaches can be adopted:
  1. Residual risks can be transferred through contractual arrangements and/or insurance policies.
  2. Cover retained risk impact by time and/or cost contingency.

**Possible response options include:**

**Acceptance:** Deciding to not change the project plan to deal with a risk or are unable to identify any other suitable response strategy. In other words, recognize the risk, but do not take any action because the impact or probability is small.

- **Active Acceptance** – Accept the risk, but include a contingency or contingency plan to execute, should the risk occur.

- **Passive Acceptance** – Accept the risk, and plan no action. Deal with the risks as they occur.

**Avoidance:** Changing the project plan to eliminate the risk or to protect the project objectives from its impacts.
- Take an alternate approach to delivering the project.
- Use alternative technology.

**Mitigation:** Modifying the probability and/or consequence of an adverse risk event to an acceptable threshold.

- Modify the project plan in such a way as to reduce the probability of the threat or its impact (or both).
- Modify the technology to reduce probability or impact.

**Transference:** Shifting the consequence of a risk to another party together with the ownership of the risk. Does not eliminate the risk, just transfers it.

- Modify the contract or agreement with contracting parties
- Purchase risk insurance
- Share the risk as in a joint venture partnership

Develop a sense of whether the potential risk is “triggered” by a particular event. For example, the risk of not having sufficient staff at a critical point in a project is frequently the result of one or several instances when key staff members were “temporarily” redirected to help with other projects. Triggering events like these help to identify when it is time to take action. That is, “What will need to be seen?” in the way of circumstances to know that action is needed. Triggering events are recorded in the Risk Response Plan and must be shared with the team members who will be responsible for monitoring the onset of such events.

### 7.2.4 Risk Control

**Purpose:** To correct for deviations from the Risk Mitigation Plans and to provide information on risk activities, current risks, and emerging risks. Risk control also includes monitoring risk indicators and the effectiveness of mitigating actions. Risk control could be done through:
- Risk monitoring/reporting
- Should be an ongoing activity
- Could be a standing agenda item for all project review meetings

The following questions can help determine the status of current risk activities and the potential of emerging risks.

- Are the project assumptions still valid?
- Are policies and guidelines being followed?
- Have new risks been identified?
- Have any triggering events occurred?
- Have risk responses been implemented as planned?
- Were the resulting response actions effective? Where they recorded (to capture the learning experience)?
- To what extent has the risk exposure changed since the last review?

**Tools:**

- Standing agenda for project review meetings to discuss the Risk Management Plan and the above-mentioned questions.
- Various existing project status reports that can be part of an “early warning” system against the onset of a risk event.

The Risk Management Process varies over the course of Capital Project Management Cycle. The risk management process evolves through three full cycles between Project Planning (Phase “0”) and Project Closeout.

### 7.3 Program Evaluation and Review Technique (PERT)

Some scheduling procedures explicitly consider the uncertainty in activity duration estimates by using the probabilistic distribution of activity durations. That is, the duration of a particular activity is assumed to be a random variable that is distributed in a
particular fashion. For example, an activity duration might be assumed to be distributed as a normal or a beta distributed random variable as illustrated in Figure 7.4. This figure shows the probability or chance of experiencing a particular activity duration based on a probabilistic distribution. The beta distribution is often used to characterize activity durations, since it can have an absolute minimum and an absolute maximum of possible duration times. The normal distribution is a good approximation to the beta distribution in the center of the distribution and is easy to work with, so it is often used as an approximation.

![Beta and normally distributed activity durations](image)

**Figure 7.4:** Beta and normally distributed activity durations

If a standard random variable is used to characterize the distribution of activity durations, then only a few parameters are required to calculate the probability of any particular duration. Still, the estimation problem is increased considerably since more than one parameter is required to characterize most of the probabilistic distribution used to represent activity durations. For the beta distribution, three or four parameters are required depending on its generality, whereas the normal distribution requires two parameters.
The most common formal approach to incorporate uncertainty in the scheduling process is to apply the critical path scheduling process and then analyze the results from a probabilistic perspective. This process is usually referred to as the Program Evaluation and Review Technique (PERT) method. As noted earlier, the duration of the critical path represents the minimum time required to complete the project. Using expected activity durations and critical path scheduling, a critical path of activities can be identified. This critical path is then used to analyze the duration of the project incorporating the uncertainty of the activity durations along the critical path. The expected project duration is equal to the sum of the expected durations of the activities along the critical path. Assuming that activity durations are independent random variables, the variance or variation in the duration of this critical path is calculated as the sum of the variances along the critical path. With the mean and variance of the identified critical path known, the distribution of activity durations can also be computed.

Both CPM and PERT were introduced at approximately the same time and, despite their separate origins, they were very similar. The PERT method shares many similarities with CPM. Both require that a project be broken down into activities that could be presented in the form of a network diagram showing their sequential relationships to one another. Both require time estimates for each activity, which are used in routine calculations to determine project duration and scheduling data for each activity.

CPM requires a reasonably accurate knowledge of time and cost for each activity. In many situations, however, the duration of an activity can not be accurately forecasted, and a degree of uncertainty exists. Contrary to CPM, PERT introduces uncertainty into the estimates for activity and project durations. It is well suited for those situations where there is either insufficient background information to specify accurately time and cost or where project activities require research and development.

In the original development of PERT approach, AOA notations are used. However, AON diagramming can be easily used alternatively. The method is based on the well-known “central limit theorem”. The theorem states that: “Where a series of sequential
independent activities lie on the critical path of a network, the sum of the individual activity durations will be distributed in approximately normal fashion, regardless of the distribution of the individual activities themselves. The mean of the distribution of the sum of the activity durations will be the sum of the means of the individual activities and its variance will be the sum of the activities’ variances”. The primary assumptions of PERT can be summarized as follows:

1. Any PERT path must have enough activities to make central limit theorem valid.
2. Any PERT path must have enough activities to make central limit theorem valid.
3. The mean of the distribution of the path with the greatest duration, from the initial node to a given node, is given by the maximum mean of the duration distribution of the paths entering the node.
4. PERT critical path is longer enough than any other path in the network.

PERT, unlike CPM, uses three time estimates for each activity. These estimates of the activity duration enable the expected mean time, as well as the standard deviation and variance, to be derived mathematically. These duration estimates are:

- Optimistic duration (a); an estimate of the minimum time required for an activity if exceptionally good luck is experienced.
- Most likely or modal time (m); the time required if the activity is repeated a number of times under essentially the same conditions.
- Pessimistic duration (b); an estimate of the maximum time required if unusually bad luck is experienced.

These three time estimates become the framework on which the probability distribution curve for the activity is erected. Many authors argue that beta distribution is mostly fit construction activities.

The use of these optimistic, most likely, and pessimistic estimates stems from the fact that these are thought to be easier for managers to estimate subjectively. The formulas
for calculating the mean and variance are derived by assuming that the activity durations follow a probabilistic beta distribution under a restrictive condition. The probability density function of beta distributions for a random variable \( x \) is given by:

\[
f(x) = k(x - a)^\alpha (x - b)^\beta, \quad a \leq x \leq b, \quad \alpha, \beta > -1
\]

where \( k \) is a constant which can be expressed in terms of \( \alpha \) and \( \beta \). Several beta distributions for different sets of values of \( \alpha \) and \( \beta \) are shown in Figure 7.5.

Using beta distribution, simple approximations are made for the activities’ mean time and its standard deviation. Using the three times estimates, the expected mean time \( t_e \) is derived using Eq. 7.2. Then, \( t_e \) is used as the best available time approximation for the activity in question. The standard deviation is given by Eq. 7.3, and hence the variance \( \nu \) can be determined as \( \nu = \sigma^2 \).
By adopting activity expected mean time, the critical path calculations proceed as CPM. Associated with each duration in PERT, however, is its standard deviation or its variance. The project duration is determined by summing up the activity expected mean time along the critical path and thus will be an expected mean duration. Since the activities on the critical path are independent of each other, central limit theory gives the variance of the project duration as the sum of the individual variances of these critical path activities.

Once the expected mean time for project duration ($T_X$) and its standard deviation ($\sigma_X$) are determined, it is possible to calculate the chance of meeting specific project duration ($T_S$). Then normal probability tables are used to determine such chance using Equation 7.4.

$$Z = \frac{T_S - T_X}{\sigma_X}$$  \hspace{1cm} (7.4)

$T_S = T_X + Z \times \sigma_X$ is an equivalent form of Equation 3.4, which enables the scheduled time for an event to be determined based on a given risk level. The procedure for hand probability computations using PERT can be summarized in the following steps:

1. Make the usual forward and backward pass computations based on a single estimate (mean) for each activity.
2. Obtain estimates for a, m, and b for only critical activities. If necessary, adjust the length of the critical path as dictated by the new $t_e$ values based on a, m, and b.
3. Compute the variance for event $x$ ($\nu_X$) by summing the variances for the critical activities leading to event x.
4. Compute Z using Equation 7.4 and find the corresponding normal probability.

Consider the nine-activity example project shown in Table 7.1. Suppose that the project has very uncertain activity time durations. As a result, project scheduling considering this uncertainty is desired.

Table 7.1: Precedence relations and durations for a 9-activity project example

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Predecessors</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Site clearing</td>
<td>---</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>Removal of trees</td>
<td>---</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>General excavation</td>
<td>A</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>Grading general area</td>
<td>A</td>
<td>7</td>
</tr>
<tr>
<td>E</td>
<td>Excavation for trenches</td>
<td>B, C</td>
<td>9</td>
</tr>
<tr>
<td>F</td>
<td>Placing formwork and RFT for concrete</td>
<td>B, C</td>
<td>12</td>
</tr>
<tr>
<td>G</td>
<td>Installing sewer lines</td>
<td>D, E</td>
<td>2</td>
</tr>
<tr>
<td>H</td>
<td>Installing other utilities</td>
<td>D, E</td>
<td>5</td>
</tr>
<tr>
<td>I</td>
<td>Pouring concrete</td>
<td>F, G</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 7.2 shows the estimated optimistic, most likely and pessimistic durations for the nine activities. From these estimates, the mean, variance and standard deviation are calculated. In Figure 7.6, PERT calculations are performed very similar to that of CPM, considering the mean duration of each activity.

Table 7.2: Activity duration estimates for the 9-activity project

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>m</td>
<td>b</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>F</td>
<td>10</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>G</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>H</td>
<td>4</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>I</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>
The critical path for this project ignoring uncertainty in activity durations consists of activities A, C, F and I. Applying the PERT analysis procedure suggests that the duration of the project would be approximately normally distributed. The sum of the means for the critical activities is $4.0 + 8.0 + 12.0 + 6.0 = 30.0$ days, and the sum of the variances is $(0.33)^2 + (0.67)^2 + (0.67)^2 + (0.67)^2 = 1.44$ leading to a standard deviation of 1.2 days.

With normally distributed project duration, the probability of meeting a project deadline can be computed using Equation (7.4). For example, the probability of project completion within 35 days is:

$$Z = \frac{35 - 30}{1.2} = 4.167$$

where $z$ is the standard normal distribution tabulated value of the cumulative standard distribution, which can be determined from standard tables of normal distribution. From Table 7.3, the probability of completing the project in 35 days is 100%.
Table 7.3: Area under the normal curve measured from the center

<table>
<thead>
<tr>
<th>SD</th>
<th>Area % from the center</th>
<th>SD</th>
<th>Area % from the center</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1σ</td>
<td>4.0</td>
<td>1.6</td>
<td>44.5</td>
</tr>
<tr>
<td>0.2</td>
<td>7.9</td>
<td>1.7</td>
<td>45.5</td>
</tr>
<tr>
<td>0.3</td>
<td>11.8</td>
<td>1.8</td>
<td>46.4</td>
</tr>
<tr>
<td>0.4</td>
<td>15.5</td>
<td>1.9</td>
<td>47.1</td>
</tr>
<tr>
<td>0.5</td>
<td>19.2</td>
<td>2.0</td>
<td>47.7</td>
</tr>
<tr>
<td>0.6</td>
<td>22.6</td>
<td>2.1</td>
<td>48.2</td>
</tr>
<tr>
<td>0.7</td>
<td>25.8</td>
<td>2.2</td>
<td>48.6</td>
</tr>
<tr>
<td>0.8</td>
<td>28.8</td>
<td>2.3</td>
<td>48.9</td>
</tr>
<tr>
<td>0.9</td>
<td>31.6</td>
<td>2.4</td>
<td>49.2</td>
</tr>
<tr>
<td>1.0</td>
<td>34.1</td>
<td>2.5</td>
<td>49.4</td>
</tr>
<tr>
<td>1.1</td>
<td>36.4</td>
<td>2.6</td>
<td>49.5</td>
</tr>
<tr>
<td>1.2</td>
<td>38.5</td>
<td>2.7</td>
<td>49.6</td>
</tr>
<tr>
<td>1.3</td>
<td>40.3</td>
<td>2.8</td>
<td>49.7</td>
</tr>
<tr>
<td>1.4</td>
<td>41.9</td>
<td>2.9</td>
<td>49.98</td>
</tr>
<tr>
<td>1.5</td>
<td>43.3</td>
<td>3.0</td>
<td>49.99</td>
</tr>
</tbody>
</table>

Figure 7.7: Normal distribution curve

Example 7.1

Suppose that a network has been developed for a particular project with nondeterministic durations for the activities and the completion time for that network is 320 days and the sum of the standard deviation for the activities on the critical path is 2130. Find the probability that the project will be completed in 300 days.
Solution

First, convert the normal random variable to the standard normal random variable.

\[ Z = \frac{T_S - T_X}{\sigma_X} = \frac{(300 - 320)}{46.2} = -0.43 \]

From Table 3, the corresponding probability = 16.5%

Then, the probability to complete the project in 300 days equals = 50 – 16.5 = 33.5%.

Example 7.2

Given the information from the previous example, what is the duration that you can give with 90 percent assurance?

Solution

From tables find the value of z corresponding to probability of 40%, thud yields

\[ z = 1.28 \]

then, apply z into equation 4: \[ 1.28 = \frac{(t - 320)}{46.2} \]

or \[ t = 46.2 \times 1.28 + 320 = 380 \text{ days} \].

While the PERT method has been made widely available, it suffers from three major problems. First, the procedure focuses upon a single critical path, when many paths might become critical due to random fluctuations. For example, suppose that the critical path with longest expected time happened to be completed early. Unfortunately, this does not necessarily mean that the project is completed early since another path or sequence of activities might take longer. Similarly, a longer than expected duration for an activity not on the critical path might result in that activity suddenly becoming critical. As a result of the focus on only a single path, the PERT method typically underestimates the actual project duration.
As a second problem with the PERT procedure, it is incorrect to assume that most construction activity durations are independent random variables. In practice, durations are correlated with one another. For example, if problems are encountered in the delivery of concrete for a project, this problem is likely to influence the expected duration of numerous activities involving concrete pours on a project. Positive correlations of this type between activity durations imply that the PERT method underestimates the variance of the critical path and thereby produces over-optimistic expectations of the probability of meeting a particular project completion deadline.

Finally, the PERT method requires three duration estimates for each activity rather than the single estimate developed for critical path scheduling. Thus, the difficulty and labor of estimating activity characteristics is multiplied threefold.

**7.4 EXERCISES**

1. All of the following are factors in the assessment of project risk EXCEPT:
   a. Risk event.  
   b. Risk probability.  
   c. Amount at stake.  
   d. Insurance premiums.

2. If a project has a 60% chance of a US $100,000 profit and a 40% chance of a LE100,000 loss, the expected monetary value for the project is:
   a. LE100,000 profit.  
   b. LE60,000 loss.  
   c. LE20,000 profit.  
   d. LE40,000 loss.

3. If a risk event has a 90% chance of occurring, and the consequences will be LE10,000, what does LE9,000 represent?
   a. Risk value.  
   b. Present value.  
   c. Expected monetary value.  
   d. Contingency budget.

4. All of the following are ALWAYS input to the risk management process EXCEPT:
   a. Historical information.  
   b. Lessons learned.  
   c. Work breakdown structure.  
   d. Project status reports.

5. Purchasing insurance is BEST considered an example of risk:
   a. Mitigation.  
   b. Transfer.

6. Workarounds are determined during which risk management process:

7. During which risk management process is a determination to transfer a risk made?

8. Monte Carlo analysis is used to:
   a. Get an indication of the risk involved in the project.
   b. Estimate an activity’s length.
   c. Simulate the order in which activities occur.
   d. Prove to management that extra staff is needed.

9. Watchlist is an output of which risk management process?

10. Which of the following MUST be an agenda item at all team meeting?
    a. Discussion of project risks.  b. Status of current activities.

11. Assuming that the ends of a range of estimate +/- 3\sigma from the mean, which of the following range estimates involves the LEAST risk?
    a. 30 days, plus or minus 5 days.  b. 22 – 30 days.
    c. Optimistic = 26 days, most likely = 30 days, pessimistic = 33 days.
    d. Mean of 28 days.

12. Risks will be identified during which risk management Process(es)?
    a. Perform Quantitative Risk Analysis and Identify Risks.
    b. Identify Risks and Monitor and Control Risks.
    c. Perform Qualitative Risk Analysis and Monitor and Control Risks.
    d. Identify Risks.

13. What should be done with risks on the watchlist?
    a. Document them for historical use on other projects.
    b. Document them and revisit during project monitoring and controlling.
c. Document them and set them aside because they are already covered in your contingency plan.

d. Document them and give them to the customer.

14. Risk tolerances are determined in order to help:
   a. The team rank the project risks.
   b. The project manager estimates the project.
   c. The team schedule the project.
   d. Management know how other managers will act on the project.

15. Purchasing insurance is BEST considered an example risk:
   a. Mitigation.
   b. Transfer.
   c. Acceptance.
   d. Avoidance.

16. Outputs of Plan Risk Responses process include:
   a. Residual risks, fallback plans and contingency reserves.
   b. Risk triggers, contracts and a risk list.
   c. Secondary risks, process updates and risk owners.
   d. Contingency plans, project management plan updates and change requests.

17. During which risk management process is a determination to transfer a risk made?
   a. Identify risks.
   b. Perform Quantitative Risk Analysis.
   c. Plan Risk Responses.
   d. Monitor and Control Risks.

18. A watchlist is an output of which risk management process?
   b. Perform Quantitative Risk Analysis.
   c. Perform Qualitative Risk Analysis.
   d. Plan Risk Management.

19. During project executing, a team member identifies a risk that I not in the risk register. What should you do?
   a. Get further information on how the team member identified the risk, because you already performed a detailed analysis and did not identify the risk.
   b. Disregard the risk, because risks were identified during project planning.
   c. Inform the customer about the risk.
   d. Analyze the risk.

20. You identified a technical risk in your project and assigned a contingency for that. Planning contingency reserves is part of which risk response strategy?
a. Active risk mitigation  

b. Passive risk avoidance  

c. Passive risk acceptance  

d. Active risk acceptance  

21. Recently, you were assigned to manage a project for your company. You have constructed a network diagram depicting various activities in the project. In addition, you asked various managers and subordinates to estimate the amount of time they would expect each activity to take. Their responses (in days) were as follows:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimistic (a)</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
</tr>
</tbody>
</table>

a. Compute the mean and variance in time for each activity.  

b. Determine the critical path and the expected length of the critical path.  

c. Assume that the time required to complete a path is normally distributed. What is the probability of completing the critical path in less than 17 days?  

d. If you wanted to be at least 95 percent sure of completing the project on time, what schedule durations would you quote?

22. Consider the project given in the next table. Find the probability that the project will be completed within 70 and 80 days. What is the project expected duration corresponding to 70% assurance.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Optimistic (a)</th>
<th>Most likely (m)</th>
<th>Pessimistic (b)</th>
<th>Dependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>16</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>24</td>
<td>32</td>
<td>42</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>22</td>
<td>32</td>
<td>40</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>B</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>C, D</td>
</tr>
<tr>
<td>F</td>
<td>13</td>
<td>16</td>
<td>19</td>
<td>A, B</td>
</tr>
</tbody>
</table>
REFERENCES