Chapter 7

Quantitative Risk Analysis

7

In This Chapter

- Quantitative Risk Analysis
- Critical Success Factors
- Perform Quantitative Risk Analysis Process

Quantitative Risk Analysis

Quantitative risk analysis quantifies the possible outcomes for the project and their probabilities and assesses the probability of achieving specific project objectives, such as a budget or schedule objective. Quantitative analysis identifies those risks needing the most attention and may also be used to determine project management decisions when conditions or outcomes are uncertain.

Quantitative risk analysis is performed on risks that have been prioritized through the qualitative risk analysis process as potentially substantially impacting the project. This analysis may be used to assign a numerical rating to those risks individually or to evaluate the aggregate effect of all risks affecting the project.

This analysis provides a numerical analysis of the highest risks on the project to:

- Determine which risk events warrant a response
- Determine overall project risk (risk exposure)
- Determine the quantified probability of meeting project objectives
- Determine cost and schedule reserves
- Create realistic and achievable cost, schedule, or scope targets

Quantitative risk analysis should be repeated after risk responses are planned and as risks are monitored and controlled to determine if the overall project risk has satisfactorily decreased. Trends can indicate the need for more or less risk management action.

Consider the following to compare qualitative risk analysis with quantitative risk analysis:

Qualitative Risk Analysis	Quantitative Risk Analysis
• Risk-level analysis • Subjective evaluation of probability and impact • Quick and easy to perform • No special software required • Leads to quantitative risk analysis	• Project-level analysis • Determines probabilistic estimates of time and costs • Time-consuming • Requires specialized tools • Identifies risks with greatest impacts on project

Critical Success Factors

Factors for success in quantitative risk analysis include:

High-Quality Data

If historical data is not available, information for quantitative analysis may be captured through interviews, workshops, etc. Data from unbiased sources is critical to the analysis.

Prioritized List of Risks

Risks must have been identified and then prioritized through qualitative analysis.

Appropriate Project Model

Project models used may include the project schedule, cost estimates, decision tree, and other total project models

Overall Project Risk

This overall project risk is derived from individual risks, based upon an appropriate methodology, such as a Monte Carlo simulation or a decision tree. Individual project risks are incorporated, and then the overall impact on the project is calculated.

Perform Quantitative Risk Analysis Process

The Perform Quantitative Risk Analysis Process further evaluates the effects of risks and assigns a numerical, or quantitative, rating to provide a probabilistic analysis of the project.

Perform Quantitative Risk Analysis: Inputs, Tools and Techniques, and Outputs

Inputs	Tools and Techniques	Outputs
1. Risk management plan 2. Cost management plan 3. Schedule management plan 4. Risk register 5. Enterprise environmental factors 6. Organizational process assets	1. Data gathering and representation techniques 2. Quantitative risk analysis and modeling techniques 3. Expert judgment	1. Project documents updates

Figure 7-1: Perform Quantitative Risk Analysis ITTOs

PMBOK® Guide, page 334

Perform Quantitative Risk Analysis: Inputs

Subsidiary Plans

Three subsidiary plans are identified as inputs to the Perform Quantitative Risk Analysis process. The risk management plan defines the approach to conducting any type of quantitative analysis, such as Monte Carlo simulations.

The cost and schedule management plans are also inputs. Because quantitative risk analysis evaluates risk in terms of the cost and schedule impacts, these plans are leveraged to understand the cost and schedule objectives, the level of detail and accuracy of the budget and schedule, and tolerances and the thresholds related to the budget and the schedule.

Risk Register

The risk register, an output of the Identify Risks process, is also an input here. When the Perform Qualitative Risk Analysis process is complete, the risks have been evaluated for probability and impact and have been prioritized. Only those risks prioritized as having a potentially significant impact are evaluated in the Perform Quantitative Risk Analysis process.

Enterprise Environmental Factors and Organizational Process Assets

Environmental factors that may be taken into consideration include the organization's appetite, willingness, or capabilities to perform quantitative risk analyses. Because quantitative analysis typically requires access to high-quality data and sophisticated tools, not every organization is capable of or desires to pursue quantitative analysis.

Organizational process assets that may be leveraged include past project files that can be leveraged to identify risks similar to those of previous projects and their associated quantified impacts.

Enterprise environmental factors and organizational process assets were discussed in Chapter 4.

Perform Quantitative Risk Analysis: Tools and Techniques

The *PMBOK® Guide* simply groups the quantitative analysis tools and techniques into data gathering and representation techniques and quantitative risk analysis modeling techniques. However, there are a number of techniques used to perform quantitative risk analysis, including the following.

- Bowtie analysis
- Decision tree and expected monetary value (EMV) analysis
- Fault tree analysis
- Monte Carlo simulation
- Risk-based critical chain analysis
- Risk-based earned value analysis
- Risk metric analysis
- Sensitivity analysis
- System dynamics

Bowtie Analysis

A bowtie analysis facilitates the discovery of predecessors to project problems by incorporating both sides of a risk scenario, what would come before and what would come after a specific risk event.

Typically, the left side of the diagram is a fault tree depicting the causes of the risk event and the measures that may be taken to prevent those causes. The right side of the diagram depicts the consequences of the risk event and the measures that may be taken to mitigate the consequences.

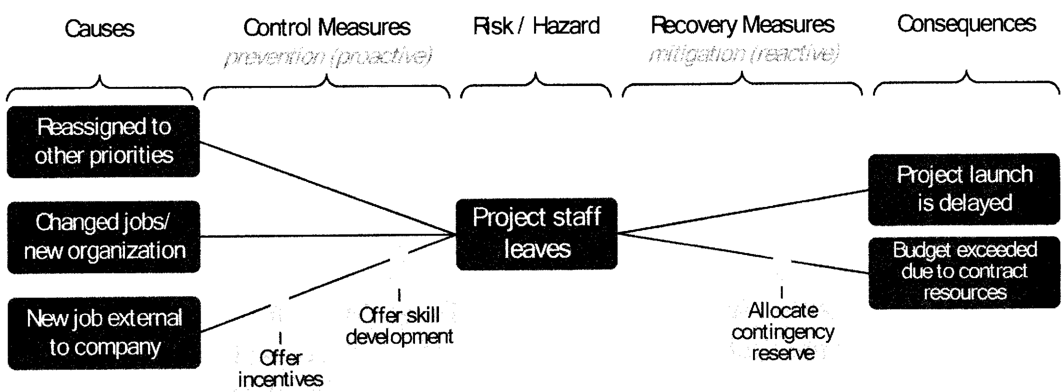


Figure 7-2: Bowtie Diagram

Decision Tree and Expected Monetary Value (EMV) Analysis

When only a small number of options or potential outcomes are possible, decision trees may be useful for quantitative risk assessment. Decision trees are generally used to evaluate alternatives before selecting one of them to execute.

Whenever there are points in the project where several options are possible, each can be planned and assigned a probability (the sum total of which is 100%). An expected estimate for either duration or cost may be derived by weighting the estimates for each option and adding these figures to get a blended result.

For this example, a project plan containing a generic activity, which could be any of the three options, with an estimate of 16 days would result in a more realistic plan than simply using the 12-day estimate of the "most likely" option.

The schedule exposure of the risk situation here may be estimated by noting the maximum adverse variance (an additional four days, if the activity is schedule critical) and associating this with an expected probability of 35%.

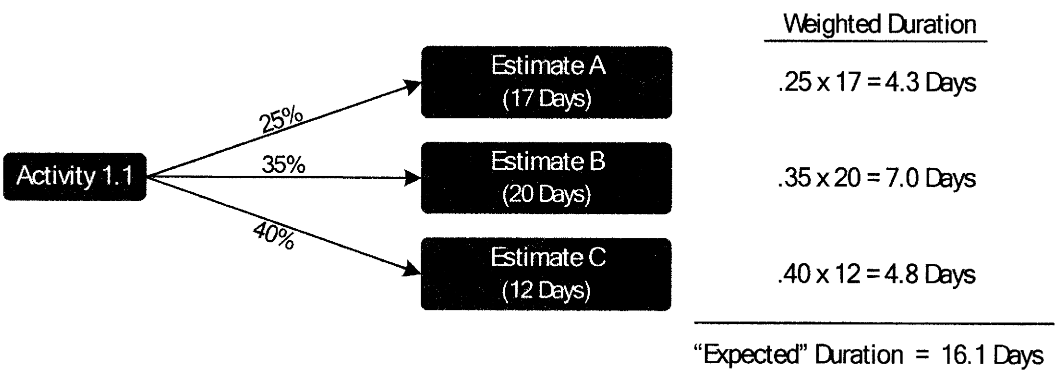


Figure 7-3: Decision Tree Analysis

PMBOK® Guide, page 339

Exercise: Decision Tree

Upon evaluation of the project requirements, the web development team lead provides you with the following duration information:

- If a senior developer is available full time, the estimated duration is four days.
- If a senior developer is available part time, the estimated duration is nine days.
- If a senior developer is not available and the work is completed by a junior developer, the estimated duration is 16 days.
- There is a 50% chance that the senior developer will only be available part time and a 10% chance that they will be available full time.

Considering the risk, what is the expected duration?

Expected Monetary Value

An expected monetary value (EMV) analysis is a statistical concept that calculates the average financial outcome or impact when the future includes scenarios that may or may not happen (i.e. analysis under uncertainty). EMV for a scenario is calculated by multiplying the value of each possible outcome by its probability of occurrence and adding the products together.

EMV requires a risk-neutral assumption, not risk-averse or risk-seeking. In EMV analysis, values may be positive or negative numbers, depending on the situation under analysis. Ascertain how the numbers should be represented requires a careful evaluation of questions about EMV on the exam.

For example, in a scenario in which you are evaluating the risk exposure on a new product that you are introducing to the market, positive values are good, reflecting increased profit, and negative values are bad, reflecting a loss of profit. However, if the scenario is evaluating money that will be spent, positive values are bad and negative numbers are good. Because of this, the first thing you need to do when presented with an EMV question is evaluate it to understand whether you are dealing with money that is being spent or money that is being made.

The second factor you need to take into consideration when faced with an EMV question is the value you need to determine. If the question is asking for the EMV of the risk scenario, the result will be the sum of the "branches" of the scenario under consideration. If it is asking you to determine the total value of the scenario, the EMV will need to be added back to the initial estimate.

As for any math question on the exam, use your calculator, double-check your math, and remember that I personally recommend marking the math questions for review. If the question is lengthy, as these tend to be, skip down to the bottom of the question to be sure of what they are actually asking you before you begin any math.

Example: EMV Analysis

You are evaluating three bids from potential vendors for your project.

- Vendor A provided a bid of $100,000.
- Vendor B provided a bid of $125,000.
- Vendor C provided a bid of $135,000.

Based on historical information and expert judgment, you determine the following.

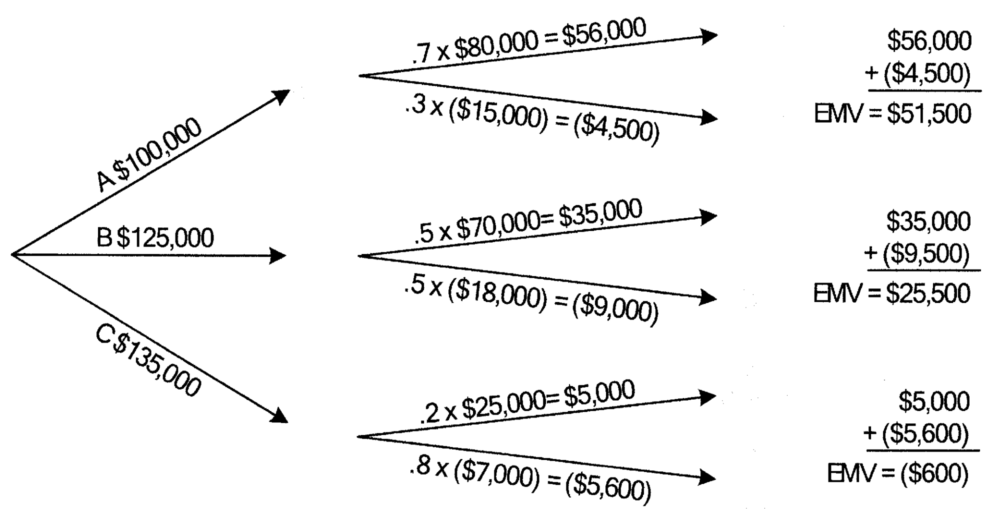
- Vendor A has a 70% probability of delivering late at an additional cost of $80,000 and a 30% probability of delivering early at a savings of $15,000.
- Vendor B has a 50% probability of delivering late at an additional cost of $35,000 and a 50% probability of delivering early at a savings of $9,000.
- Vendor C has a 20% probability of delivering late at an additional cost of $25,000 and an 80% probability of delivering early at a savings of $7,000.

To determine the <u>expected monetary value</u> (EMV) of the risk of working with each vendor, multiple probability by the financial impact and sum the results.

To determine the <u>total value</u> of each bid, add the EMV to the original bid amount.

- Vendor A EMV = $51,500 + Bid $100,000 = Total Value: $151,500
- Vendor B EMV = $26,000 + Bid $125,000 = Total Value: $151,000
- Vendor C EMV = ($600) + Bid $135,000 = Total Value: $134,400

Based on the analysis, you select Vendor C, as the total value of the risk scenario for Vendor C is $134,400, lower than the other two vendors.



Exercise: Expected Monetary Value

You are evaluating two potential profit scenarios for a new product launch. Product A is estimated to make a base profit of $30,000, and Product B is estimated to make a base profit of $50,000.

There is a 20% chance that Product A will be poorly received by the market at a loss of $10,000, a __% chance that it will be well received by the market at an increased profit of $20,000, and a 30% chance that it will exceed market expectations at an increased profit of $50,000. What are the EMV of the risk scenario and the total value for the product?

There is a 40% chance that Product B will be poorly received by the market for a loss of $20,000, a __% chance that it will be well received by the market at an increased profit of $30,000, and a 30% chance that it will exceed market expectations at an increased profit of $40,000. What are the EMV of the risk scenario and the total value for the product?

Fault Tree Analysis

Fault tree analysis is discussed in Chapter 6 on qualitative risk analysis. A fault tree can also be used in the Perform Quantitative Risk Analysis process to quantify the probabilities and impacts of the various faults.

Monte Carlo Simulation

A project simulation uses the project model to translate the specified detailed uncertainties of the project into their potential impacts on project objectives. One of the most common simulation tools or approaches used is known as the Monte Carlo simulation.

In a Monte Carlo simulation, the project model is computed thousands of times (iterated), with the input values (e.g., cost estimates or activity durations) chosen at random for each iteration from the probability distributions of these variables.

The output of a simulation is a probability distribution (e.g. total cost or completion date) that is calculated from the iterations.

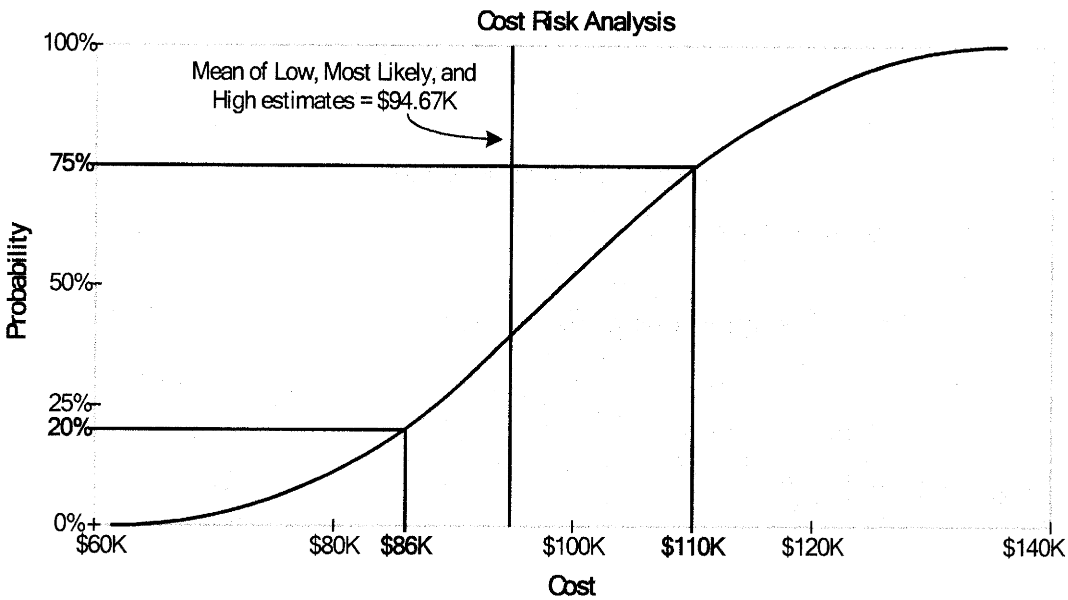
A Monte Carlo simulation iterates the project model thousands of times to compute the probabilities of all of the possible outcomes for the project based on the identified risks. The results are typically presented in a histogram showing a range of possible outcomes and the number of times a particular outcome is achieved. It may also be presented in an S-curve that plots the range of possible outcomes against the cumulative probability of achieving a given value.

For a cost risk analysis, a simulation uses cost estimates. For a schedule risk analysis, the schedule network diagram and duration estimates are used.

The output from a cost risk simulation is shown below. It illustrates the respective likelihood of achieving specific cost targets. Similar distributions can be developed for schedule outcomes.

WBS Element	Low	Most Likely	High
Design	$8,000	$14,000	$20,000
Build	$32,000	$40,000	$70,000
Test	$22,000	$32,000	$46,000
Total Project	**$62,000**	**$86,000**	**$136,000**

Interviewing relevant stakeholders helps determine three-point estimates for each WBS element. These estimates can be input into simulation software for a cost risk analysis as seen below.



This cumulative distribution shows that the project is only 20% likely to be completed at or below the $86k "most likely" estimate. If a conservative organization wants a 75% likelihood of success, a budget of $110k is required. That is a contingency of nearly 28% (($110k - $86k)/$86k).

Figure 7-4: Continuous Distribution

PMBOK® Guide, page 336, 340

Monte Carlo Simulation Example:

The project team has provided its estimates for each phase of the project, including its best case (optimistic), most likely, and worst case (pessimistic) estimates. Based on this information, the project manager submits a cost estimate of $164,000.

	Best Case	Most Likely	Worst Case
Phase 1	$18,000	$19,000	$31,000
Phase 2	$34,000	$35,000	$47,000
Phase 3	$41,000	$43,000	$54,000
Phase 4	$39,000	$41,000	$53,000
Phase 5	$24,000	$26,000	$42,000
	$156,000	**$164,000**	**$227,000**

From this information, it is known that the lowest possible cost is $156,000 and the highest possible cost is $227,000. Using this information, the mean can be calculated at $182,333 (11% higher than the most likely estimate) and the median at $191,500 (17% higher than the most likely estimate).

This information can be represented by a triangular probability distribution:

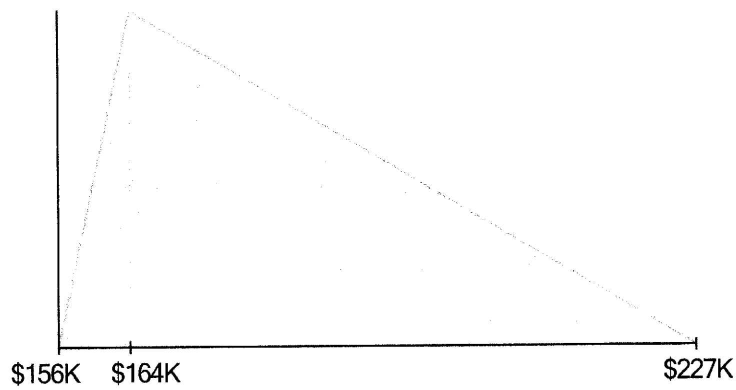


Figure 7-5: Triangular Distribution

A beta PERT of this same information would be represented in the following distribution:

Optimistic + 4(Most Likely) + Pessimistic / 6 = $173,167

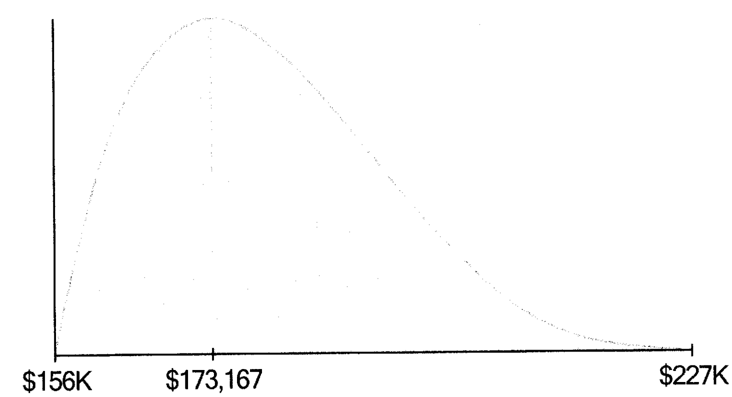
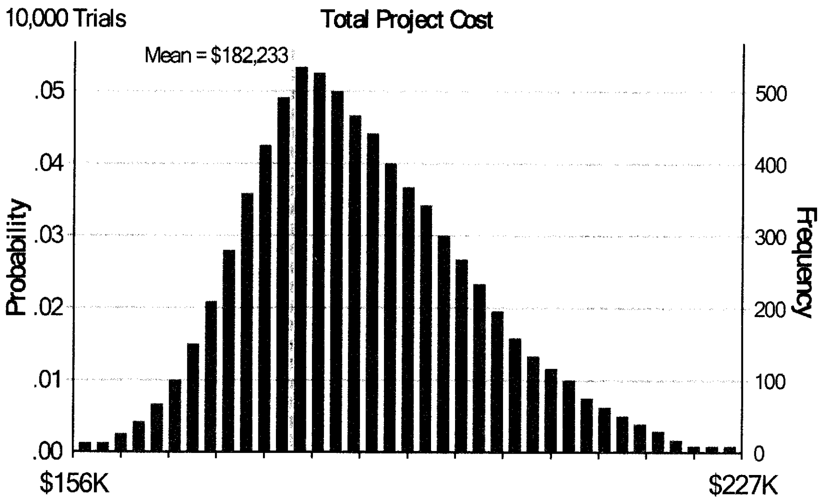


Figure 7-6: Beta PERT Distribution

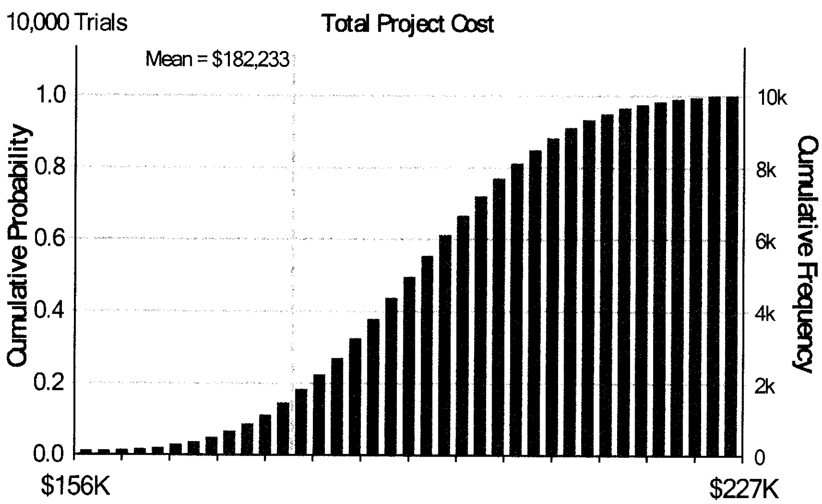
Using the same project information, the output of a Monte Carlo simulation would provide the probability confidence levels and the amount and percentage of contingency that would need to be allocated based on the submitted cost estimate of $164,000.



10,000 Displayed

Percentile	Forecast Values
0%	$156,000
10%	$168,000
20%	$173,000
30%	$182,000
40%	$189,000
50%	$194,000
60%	$197,000
70%	$201,000
80%	$210,000
90%	$221,000
100%	$227,000

Figure 7-7: Histogram from Monte Carlo Simulation



10,000 Displayed

Percentile	Forecast Values
0%	$156,000
10%	$168,000
20%	$173,000
30%	$182,000
40%	$189,000
50%	$194,000
60%	$197,000
70%	$201,000
80%	$210,000
90%	$221,000
100%	$227,000

Figure 7-8: S-Curve Graph

For example, if the organization seeks a 50% confidence level (P50), a contingency of $30,000 (18%) would need to be allocated to the project. If the organization were more conservative and sought an 80% confidence level, that contingency amount would increase to $46,000 (28%).

Probability %	Forecast	Contingency	%
P0	$156,000	-$8,000	-5%
P10	$168,000	$4,000	2%
P20	$173,000	$9,000	5%
P30	$182,000	$18,000	11%
P40	$189,000	$25,000	15%
P50	$194,000	$30,000	18%
P60	$197,000	$33,000	20%
P70	$201,000	$37,000	23%
P80	$210,000	$46,000	28%
P90	$221,000	$57,000	35%
P100	$227,000	$63,000	38%

The contingency amount is calculated by subtracting the original estimate of $164,000 from the forecast (Contingency $ = Forecast – Estimate).

To calculate the contingency percentage, divide the forecast by the estimate and subtract one (Contingency % = (Forecast ÷ Estimate) – 1).

Probability Distributions

A number of different probability distributions can be generated from project modeling and simulation. As seen previously, the probability distribution can be a continuous distribution, a triangular distribution, or a beta PERT distribution. Additional distributions that may be developed during a quantitative risk analysis include uniform distributions, normal (Gaussian) distributions, and log-normal distributions.

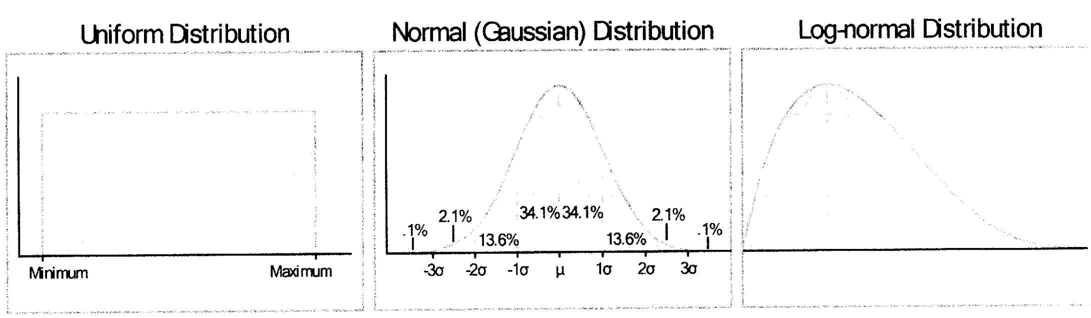


Figure 7-9: Other Probability Distributions

- Uniform distributions – Also known as rectangular distributions, these are distributions with constant probability, where no one outcome is any more likely than another.
- Normal (Gaussian) distributions – Also referred to as bell curves, these are common distributions for representing real-valued random variables whose distributions are not known.

- Log-normal distributions – Also known as Galton distributions, these are distributions with a positive skew that are often used to describe natural phenomena, such as in economics, where evidence shows that the income of 97-99% of the population is distributed log-normally.

Latin Hypercube Sampling

Because performing a Monte Carlo simulation requires running iterations thousands of times, an alternative option is to perform a Latin Hypercube sampling.

Latin Hypercube is a stratified approach, selecting a limited set of values from each strata or segment rather than pulling all random variables. This improves accuracy with a smaller sample size and is typically preferable over Monte Carlo simulations. This is a preference specifically when the speed of the computers running the computations is a concern.

Risk-Based Critical Chain Analysis

Critical chain project management (CCPM) is a method of planning and scheduling that places the emphasis on the resources that are required to complete the activities. In CCPM, the placement and use of time buffers account for limited or constrained resources. The result is a resource-constrained critical path known as the critical chain.

A buffer placed at the end of the critical chain is known as the project buffer and protects the target finish date from slippage along the critical path. Feeding buffers are added at the point of path convergence, where non-critical paths converge into the critical chain.

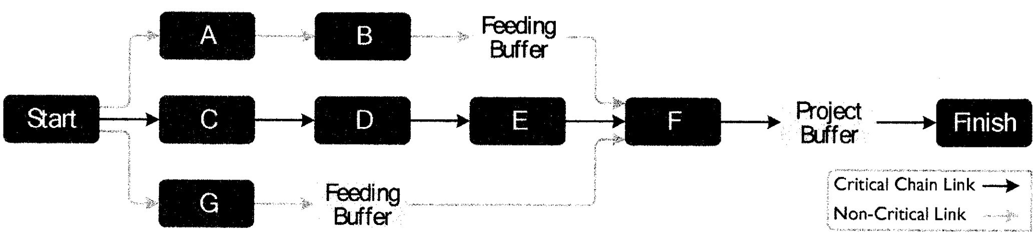


Figure 7-10: Critical Chain

In order to use CCPM, a fully resourced project schedule must be completed. In addition, team members need to be familiar with CCPM and have an agreement as to the sharing of the time buffers.

Risk-Based Earned Value Analysis

Earned value analysis (EVA) compares the value earned in the project to the planned value (to determine schedule status) and to the actual costs (to determine budget status). The earned value analysis can provide insight and quantify uncertainty about the project schedule and budget.

To evaluate the amount of schedule risk for a project that is in progress, the earned value (EV) of the project is compared to the planned value (PV) of the project as of the status date. To evaluate the amount of cost risk, the earned value (EV) is compared to the actual costs (AC) of the project as of the status date.

Earned Value

Earned value is calculated based on what percentage of the budgeted work of the project the team has completed. The completed percentage can be determined in terms of either time or effort.

For example, for an eight-month, $100,000 project, the project may be considered 25% complete after the second month of work or after the project has earned $25,000 in value. However, just because 25% of the time has passed, it does not necessarily mean that 25% of the work has been completed. A more accurate assessment of percentage complete would be based on completed effort.

Considering human behavior, the majority of the work typically occurs just prior to a deadline. It has been demonstrated that Thursday tends to be the most productive day of the week in environments that have status reports due on Friday. Thus, using a time-based percentage complete can be very misleading. However, capturing an effort-based percentage complete can be challenging in most environments, as reporting and progress is not captured at that level.

Schedule Analysis

Planned value is the budgeted spending of the project from the start date through the status date.

For example, the budgeted spend for a project is:

- Period 1: $10,000
- Period 2: $20,000
- Period 3: $30,000
- Period 4: $25,000
- Period 5: $15,000

The planned value (PV) after period 1 would be $10,000. The cumulative PV at the end of period 2 would be $30,000, etc. The total PV at the end of the project would be $100,000.

If the earned value (EV) is \$25,000 and the planned value (PV) is \$30,000, the project would appear to be behind schedule, as less has been earned than was planned.

- Schedule variance (SV) = earned value (EV) – planned value (PV)
- Schedule variance (SV) = \$25,000 - \$30,000 = (\$5,000)
- Schedule performance index (SPI) = earned value (EV) ÷ planned value (PV)
- Schedule performance index (SPI) = \$25,000 ÷ \$30,000 = 0.83

Based on the schedule performance index (SPI), the project is 17% behind schedule.

Variable	Acronym	Description
Planned Value	PV	The amount of money budgeted for a component between its start date and the status date. Typically cumulative.
Budget at Completion	BAC	The total amount of money allocated to the component. Equal to the total PV at the end of the component.
Earned Value	EV	Estimated value of the work completed. **EV = BAC x percent complete**
Schedule Variance	SV	The difference between the earned value and the planned value. **SV = EV – PV**
Schedule Performance Index	SPI	The ratio of earned value to planned value. **SPI = EV ÷ PV**

PMBOK® Guide, Glossary

Exercise: Earned Value - Schedule

Your 10-month project has a budget of \$20,000. You are evaluating progress of your project after two months. According to your team, the project is 30% complete. Based on your project budget, you planned to spend \$8,000 by this date.

Budget at completion (BAC) =

Percentage complete =

Earned value (EV) =

Planned value (PV) =

Schedule variance (SV) =

Schedule performance index (SPI) =

What is the status of the schedule?

Cost Analysis

To evaluate the status of the budget, compare the earned value (EV) to the actual costs (AC).

For example, the actual costs (AC) for the project are:

- Period 1: $7,000
- Period 2: $11,000

The total actual costs (AC) are $18,000. If the earned value (EV) is $25,000 and the actual costs (AC) are $18,000, the project would appear to be under budget, as more has been earned than has been spent. Essentially, it only cost $18,000 to complete $25,000's worth of work.

- Cost variance (CV) = earned value (EV) – actual costs (AC)
- Cost variance (CV) = $25,000 - $18,000 = $7,000
- Cost performance index (CPI) = earned value (EV) ÷ actual costs (AC)
- Cost performance index (CPI) = $25,000 ÷ $18,000 = 1.34

Based on the cost performance index (CPI), the project is 34% under budget.

Variable	Acronym	Description
Actual Cost	AC	The actual cost of the component to date. Typically cumulative.
Cost Variance	CV	The difference between the earned value and the actual cost. CV = EV - AC
Cost Performance Index	CPI	The ratio of earned value to actual cost. CPI = EV ÷ AC

PMBOK® Guide, Glossary

Exercise: Earned Value - Cost

You are the project manager for a six-month, $120,000 project. According to the work performance information, your team is roughly 40% complete with their work.

According to the project budget, estimated costs to date should be $50,000. Costs billed to date are $40,000.

Budget at completion (BAC) =

Percentage complete =

Earned value (EV) =

Actual cost (AC) =

Cost variance (CV) =

Cost performance index (CPI) =

What is the status of the budget?

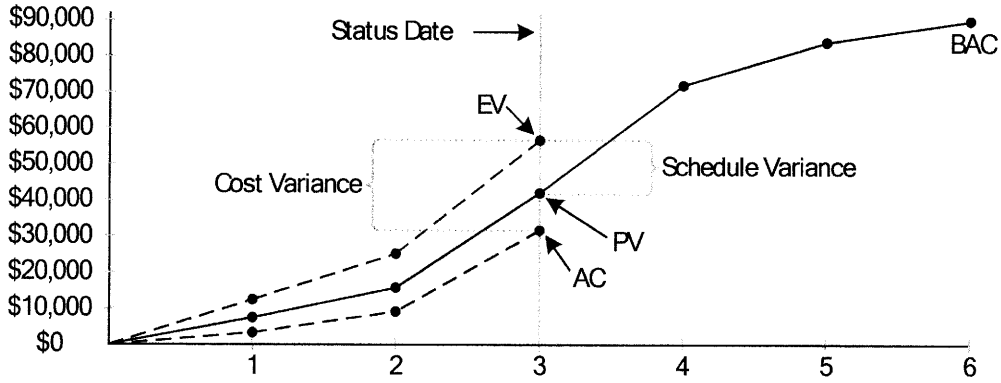


Figure 7-11: EVM Graph

Risk Metric Analysis

An evaluation of risk metrics provides insight into the risk exposure of a project. Three categories of metrics can be leveraged for quantitative risk analysis: predictive, diagnostic, and retrospective.

Predictive Metrics

Predictive metrics use current information to provide insight into future conditions. In other words, they use the current environment to predict the future. Because predictive metrics are based on speculation rather than empirical data, they can be unreliable. However, predictive metrics tend to be commonly employed in many environments as a quantitative risk technique.

Predictive metrics are used in project risk management to determine the project scale, identify situations that may require contingency planning, and justify schedule and budget reserves.

For scope or scale risk, predictive metrics can be used to complete size-based deliverable analyses of such factors as lines of code or component counts, assess project complexity, calculate the volume of expected changes, consider the number of planned activities, etc.

An example would be a project that has one half the possible numbers of lines of code and has experienced a risk-based budget variance of 5%. To assume that the current project, at double the current number of lines of code, may experience a 10% risk-based budget variance would be to leverage predictive metrics.

Schedule risk, project duration, total length, duration estimates, number of critical or near-critical paths, logical project complexity, external predecessor dependencies, project interdependencies, and total float, can all help predict the need for additional project contingency reserves.

Diagnostic Metrics

Diagnostic metrics are designed to provide current information about a system based on the latest available data. Diagnostic metrics may detect anomalies or reveal future problems based on the measurements taken throughout the project.

Diagnostic metrics can be used to detect adverse project variances either in advance or as soon as is practical. This is a common component of monitoring and controlling project risks, where the performance measurement baselines (scope, time, and cost) are established and then used as comparative measurements to the actual progress of the project.

These diagnostic metrics are used in risk management to trigger risk responses, assess the impacts of project changes, provide early warnings for potential problems, determine the need to update or develop contingency plans, and decide when to modify or cancel projects. Using earned value to evaluate risk exposure is an example of leveraging diagnostic metrics.

Retrospective Metrics

Retrospective metrics report after the fact on how the process worked and the process's overall health. Retrospective metrics are particularly useful in tracking trends and can be used to calibrate and improve the accuracy of corresponding predictive metrics for subsequent projects. This can be especially valuable for capturing lessons learned during and about the project risk management process to aide in organizational learning and growth.

Sensitivity Analysis

A sensitivity analysis evaluates the project risks against the project model to determine which risks would have the biggest impact on the project.

Not all risks are equally damaging. Schedule impact that does not affect resources is significant only when the estimated slippage exceeds any available float. For simple projects, a quick inspection of the plan using the risk list will determine what risks are likely to cause the most damage.

For more complex networks of activities, using a copy of the project database that has been entered into a scheduling tool is a fast way to detect the risks and combinations of risks that are most likely to result in project delay. Conducting a schedule "what if" analysis uses worst-case estimates to investigate the potential overall project impact.

Unlike activity slippage, which may or may not affect the overall delivery date (based on activities that have float), all adverse cost variances do have an impact on the budget.

It is important to understand your organization's cost accounting procedures, as not all cost impact is accounted for in the same way. If a risk results in an out-of-pocket expense for the project, then it impacts the budget directly. However, if the cost impact involves a capital purchase, then the project impact may be only a portion of the actual cost, and in some cases the entire expense may be accounted for elsewhere.

Overhead costs, such as conference rooms, copies, postage, etc., are rarely charged back to the project directly. Travel costs may be another expense that does not get allocated to the project. It may be beneficial to segregate potential direct cost variances from any that are indirect.

Sensitivity charts are used to visualize impacts (the best and worst outcome values) of different uncertain variables over their individual ranges. A tornado diagram is a type of sensitivity chart in which the variable with the highest impact is placed at the top of the chart and followed by other variables in descending order of impact.

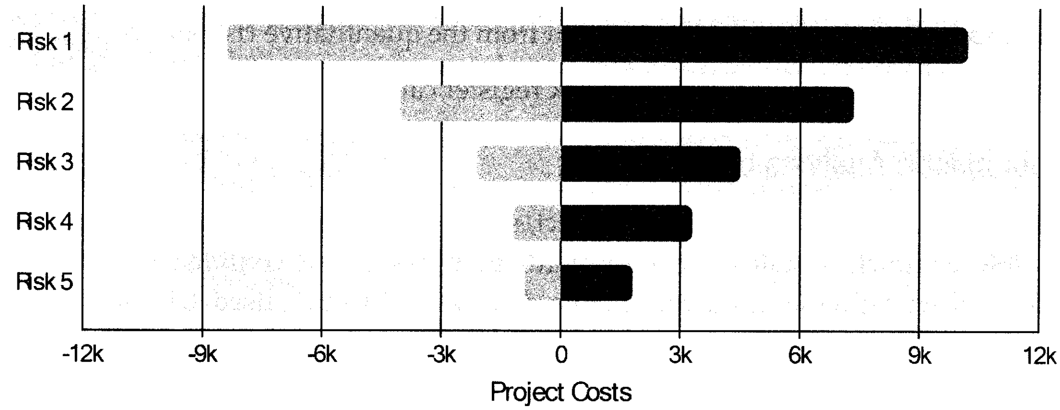


Figure 7-12: Tornado Diagram

PMBOK® Guide, page 338

System Dynamics

System dynamics are a particular application of influence diagrams used to identify risks within a project situation using feedback and feed-forward loops. System dynamics are utilized when there is a complex, non-linear relationship between entities and information and depict the impact of risk events on overall project results or a system's sensitivity to specific risks.

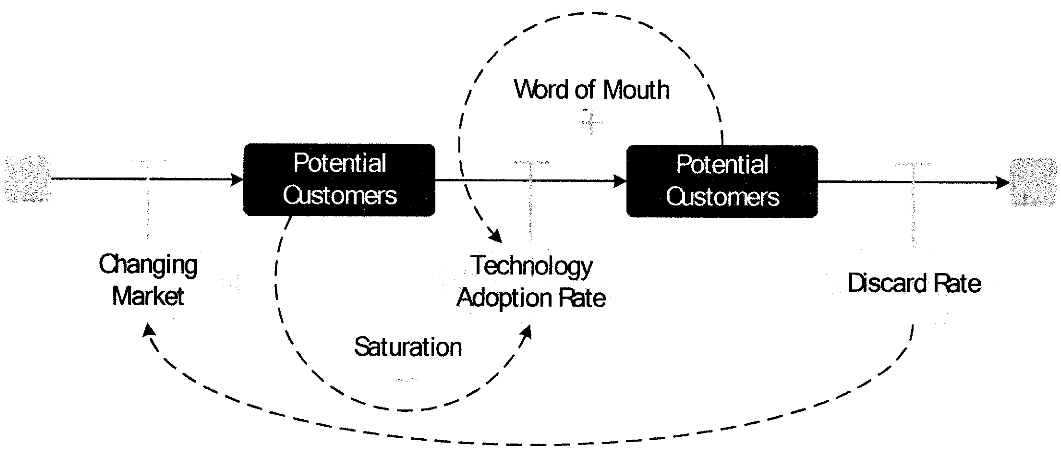


Figure 7-13: System Dynamics Model

Practice Standard for Project Risk Management, page 85

Perform Quantitative Risk Analysis: Outputs

The outputs of the Perform Quantitative Risk Analysis process are project document updates. Specifically, the risk register that was established during the Identify Risks process and updated throughout the Perform Qualitative Risk Analysis process is again updated with all of the information from the quantitative risk analysis.

After a quantitative risk analysis, the risk register can be updated with:

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, often expressed as a cumulative distribution, can be 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.

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.

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 may have the greatest effect on cost contingency and those that are most likely to influence the critical path. In some cases, these risks may be identified through a tornado diagram generated as a result of the simulation analyses.

Trends in Quantitative Risk Analysis Results

As the analysis is repeated, a trend that leads to conclusions affecting risk responses may become apparent. Organizational historical information on project schedule, cost, quality, and performance should reflect new insights gained through performing quantitative risk analysis. Such history may take the form of a quantitative risk analysis report. This report may be separate from, or linked to, the risk register.