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Risk Management for Engineering Projects

Procedures, Methods and Tools

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ISBN 978-3-319-05250-2 ISBN 978-3-319-05251-9 (eBook)
DOI 10.1007/978-3-319-05251-9
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014937668

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

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Chapter 1
Principles and Elements of Risk Management – Data and Initial Conditions

Abstract This chapter is devoted to furnishing background information on Risk Management, explaining the string of steps that comprise it, and the use of techniques within it, as well as their relationships. The chapter follows the widely accepted sequence for risk identification, assessment, execution, remediation and control; it starts with some basic definitions and, in its first topic, analyzes the sources for risks, considering internal and external risks and opportunities. It follows with a guide for identifying and managing risks in different areas of a project and suggests appropriate tools and techniques for each one. Completion of sequence sensitivity analysis, a subject developed in full in Chap. 6, is commented upon briefly just to give the reader an idea of its use and potential, the sequence finishes with steps for closing and reporting. Establishing a procedure that is a norm in this book, a real life example is proposed using SWOT analysis (This is a planning technique for assessing a firm capability for executing a project considering Strength, Weakness, Opportunities and Threats) to illustrate a firm self-evaluation regarding risks for a particular project. The chapter concludes with the definition of a project strategy, a fundamental step, since it will determine the road to follow for a successful project to be finished on time, under budget and with the required quality.

Keywords Risk • Identification, assessment and remediation • Sensitivity analysis • SWOT analysis • Project strategy

1.1 Background Information on Risk Management

Risk: Its most general definition is "*Probability Distribution of Loss*" (Paulos 2001).

Risk Management (RM) procedure: Its more general definition is "*the set of techniques for controlling the uncertainty in a project*" (Merritt and Smith 2004). It is necessary to take into account that risk management is not an exact science and is subject to the particular conditions of a project, conditions that will most likely be

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9_1,

different even from those of very similar projects. To this point, Kutsch (2008) asserts, "….. *this study offers evidence to counter argue the "self-evident" correctness of deterministic and rational risk management processed successfully by the PMI (2004), OGC or the APM (2005) and highlights the need to include behavioral aspects into the management of risk*".

However, according to Kwak and Dixon (2008), it appears that high-technology industries face many of the same challenges regarding uncertainty, complexity and risk as those faced by the pharmaceutical industry. It would thus be convenient, if possible, to have some sort of tabular information concerning these facts for different industrial sectors, which, if the facts really exist, will help in identifying risk and decreasing uncertainty.

Uncertainty has been mentioned, but what does it mean? The Dictionary gives different definitions for this word; however, for our purpose, we find that 'uncertainty', at least in the context of Project Management, is better expressed as a number of different values that can exist for a quantity, with 'risk' meaning the possibility of loss or gain as the result of uncertainties (Rodger and Petch 1999). It is generally accepted that uncertainty has two sources:

1. The uncertainty or randomness inherent to a process,
2. The uncertainty resulting from lack of information about that process, that is, the relationship between human knowledge and the process.

Once the project scope is established, project planning and scheduling begin, through definition and sequencing of the different tasks or activities with their corresponding durations, and assignment of resources along the project duration (Project horizon). This allows for computing the Budget Cost of Work Scheduled curve (BCWS), which includes direct and indirect costs and project reserves. The BCWS is used as a reference for checking construction advance and expenditures during construction, and should be in line with the Control Account Plan (CAP).

Normally, once the project is underway, it is periodically updated, with information about progress registered (by Monitoring) and assessed (by Project Control), and then exerted using Earned Value (EV), also in line with CAP. The work actually done, valued at actual costs, prices and time spent, gives a monetary value. These values, through successive updates, constitute the Actual Cost of Work Performed (ACWP) curve. Similarly, the amount of work done valued at budget cost gives the successive points that allow for drawing the Budget Cost of Work Performed (BCWP) curve. These three curves permit for associating the amount of work done with the money actually spent.

Thus, we have three curves, each one expressing a different concept of the work and allowing the computation of important metrics such as Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI), Schedule Performance Index (SPI), and Estimate at Completion Cost (EAC).

Thus, Earned Value Management (EVM)

(a) Measures performance and
(b) Forecasts how much the project will ultimately cost.

However, neither Planning, which in reality looks at a not-so-distant future, nor EV, which analyzes past performance, usually take into account uncertainty existing in all projects, and this is where RM enters into the picture. RM can look further into the future, although it is sometimes used as a prevention tool in certain activities, but is not usually considered at the same level of usage compared with the other two, perhaps because of its probabilistic nature, with which not everybody is comfortable. This book proposes approaching Project Management in a different way and taking into account two features.

Firstly, because of uncertainty, there is no project without risk, and this uncertainty may be due to different causes, such as an indefinite result or lack of sufficient information on a subject.

Most projects deal with uncertainties, and many projects depend, to a certain measure, on unforeseen circumstances that are beyond the control of the owners, stakeholders, project managers (PM), contractors and suppliers. In conclusion, a project of any kind is a risky endeavour and, as such, this paper suggests the use of RM in managing a project, because risk is present in practically all activities and estimates of every kind, from task duration to profit, from relationships with stakeholders, contractors and suppliers to exogenous factors.

What does this mean?

It means that risk should be routinely considered from the very beginning in all aspects of the project, including its development (to update risks, incorporate new ones or eliminate those already identified), and that **a project should be oriented toward managed risk**.

It is interesting to consider that, in its origins, Project Management, other than the initial utilization of **GANTT** Charts (after Henry Gantt, 1915), a **scheduling method**, began using **PERT** in 1957 (developed by Booze Allen Hamilton and the U.S. Navy) for very complex and uncertain projects, such as the Polaris nuclear submarine and the Ballistic Missile Program.

PERT is essentially a **planning and risk method**, since it considers estimates of not one, but three points for every task, that is, it considers some flexibility in recognizing that only one estimate, either in duration or cost, is not enough.

A little later, in 1958, du Pont de Nemours developed the Critical Path Method **(CPM)**, the other great management-planning tool, which complements the Gantt chart for scheduling. Both PERT and CPM are project modelling techniques and have most elements in common, as well as procedure; however, the first takes into account uncertainty in task duration while the second considers deterministic estimates for task duration, or, in another words, considers that those durations are reliable values, which unfortunately is not the case.

Earned Value Management (EVM) is not used for planning and scheduling, but as a project control tool for measuring performance based on past performance, allowing for corrective actions if necessary.

At present, it is true that Project Management has begun using some risk concepts in projects, but it is believed that there is incomplete acknowledgment and conviction about the need to include risk in every project and at each stage.

The second point in this work proposes using Planning and RM from the very beginning and throughout the project, as well as EVM starting with the first update. Thus, it is proposed that, in the initial listing of activities, a column should be added to compute risk for each activity or task. After each update, rescheduling the work will very often be required due to scope changes, or because there is better information on task duration, additions, etc. At the same time, past risks and their occurrence (or not) should be examined to take advantage of the information they can provide. For instance, it may be that, at the beginning of planning, the project team considered it necessary to add days to the duration of a task owing to a threat of risk involved. However, if during the update, it is confirmed that the task was completed and without any risk present, then excess duration in days can be transferred to the end of the project to be used in future tasks, if the need arises. At the same time, lessons are learnt about this type of task for better assessment in future projects or its forthcoming replication in the same project.

The above procedure keeps some similitude with **Critical Chain Project Management** (CCPM), developed by Elijahu Goldratt in 1997, a **resource-oriented planning tool** which establishes buffers in the planning stage for all activities or tasks, many of which are accumulated at the end of the project to be used whenever necessary.

As a summary, Fig. 1.1 depicts the superposition of the three methods and identifies an Integrated Project Management (IPM) common area indicating that the three methods participate, but under the Risk Management umbrella. In reality, RM is aimed at managing uncertainty, and then incorporating data into the other methods.

RM is concerned with the whole project from beginning to end; however, in this approach, the project is broken-down into areas and tasks, with RM affecting each of them. This is a way to make sure that the method is applied to everything and not just to the overlapping areas.

There is a path within a project from start to finish that leads to the attainment of the project objective; many factors act along this path, making it jagged and tortuous owing to deviations; with RM, we try to avoid or at least to minimize these deviations. Subsequently, RM must be embedded in a project, although, if there is certainty that something will not happen, it is not considered a risk.

As mentioned, this book suggests that a project should be oriented toward managed risk, with risk covering the following aspects: (1) Costs, (2) Economics and Finance, (3) Time, (4) Environment, (5) Societal Opinion, (6) Safety, (7) Quality, (8) Legal, (9) Communications, (10) External Factors, and (11) Closing. What now follows is a description, with brief comments, of diverse procedures proposed for dealing with risk in each aspect. It is necessary to take into account that these measures must be applied at the beginning of the project in the initial planning stage. In successive updates, the procedure is repeated, perhaps correcting pessimistic and optimistic prior estimates, saving buffers when forecasted durations did not materialize, recovering dedicated funds when costs did not increase, etc., and computing new values for risks up to the end of the project.

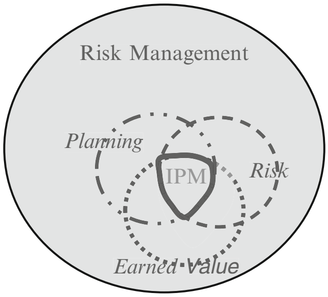

Fig. 1.1 Integrated Project Management (IPM) including the three main methods, enveloped by Risk Management

1. Cost. This refers to potential or actual threats related to the project not meeting the established project budget. Cost contractor's performance index (CPI) normally replicates in the future. According to some researchers, the CPI does not change by more than 10 % once 20 % of the project has been completed. The research found that, in most cases, it worsens as the project advances to its completion, and that the EAC tends to get larger when computed using the CPI in short periods (6 months).
   Therefore, this is something that should be considered in successive updates.
2. Economics and Finance. These refer to potential risks related to the project not meeting economic and financial expectations.
3. Time. This refers to potential or actual threats that can risk the established completion date of the project.
4. Environment. This refers to potential or actual threats related to the project not meeting standard environmental contamination limits or affecting the environment (soil, water, air, land use, wildlife, forests, and aquatic life) in various ways.
5. Societal Opinion. This refers to potential or actual threats related to public opinion on the project, which can even risk its very existence.
6. Safety. This refers to potential or actual threats that can risk the safety of personnel and structures or even the project itself, and to the safeguards that may require implementation.
7. Quality. This refers to the existing chances of a contractor or manufacturer not doing quality work.
8. Legal. This refers to potential or actual threats related to assorted legal issues that can not only endanger the project, but also paralyse it.
9. Communications. This refers to threats originated by a lack of proper communication between the contractor and stakeholders, owners, suppliers, vendors, etc. It is also related to the owner's organization, contracting, or consulting firm developing the project. In reference to this issue, De Bakker et al. (2011) mention that "*Analysis demonstrates stakeholders deliberately use risk management to convey messages to others, with the aim of influencing their behaviour, synchronizing their perception, and making them aware of the context and their responsibilities. Stakeholders perceive these effects as contributing to project success*".

10. External factors. This refers to threats linked to risks produced by the occurrence of factors and events that the owner, stakeholders or contractors cannot control or accurately predict, such as acts of nature, government regulations, weather, etc.
11. Closing. This refers to potential or actual threats that can risk well-ordered and efficient handover of the project to the owner or stakeholders, since the possibility exists that they may not be satisfied with the closing procedures, especially regarding project documentation and further contractor's obligations, if any.

1.2 Project Scope

The scope of the project must be thoroughly studied from the contractual point of view, owing to risk of the owner claiming that something that should have been done, as set down in the contract, was not. For instance, landscaping or improvement of certain municipal services (common in many cities that allow for some violation of city bylaw in exchange for execution of certain work, such as a roundabout, a water fountain, or opening of a new street).

1.3 Sources That Can Trigger Risk for a Project

It is almost impossible, because of the large variety of projects, to establish sources of risk; for that reason, it is proposed here that the following aspects should be considered in looking for these sources (U.S. Department of Transportation 2013).

- Performance, scope, quality, and technology issues.
- Environmental, safety, and health concerns.
- Scope, cost, and schedule uncertainty.
- Political concerns.

1.4 Internal and External Risks

Internal risks are an important concept, being those inherent to the project or the firm developing it and subsequently capable of being managed. There are many examples of internal risks, such as:

1. The scope of the project is not very well defined; it is not clear where it finishes, and responsibilities between owner and contractor/consultant are not clearly established,

2. The contractor does not have enough equipment to do the job and has to rent it (and this is internal, because this information must be included in the contractor's proposal, and the owner, therefore, knows about it),
3. There are uncertainties concerning the data or more data is needed (the owner is responsible for collecting reliable data),
4. The project incorporates new technology which has not been sufficiently tested, or, if it is well known, the contractor/consultant does not have the expertise necessary to use it,
5. There are many vendors from overseas, making their integration difficult (information known to the owner).
6. The contractor/consultant does not have the adequate structure for the project (information known to the owner).
7. Potential cash flow problem during construction owing to known and documented delays by the owner in paying work certificates (responsibility of owner's financial department),
8. Relationship with the owner is considered problematic, because of owner's reluctance to attend meetings with the contractor/consultant to iron out problems, believing that those must be solved entirely by the contractor/consultant (the main contractor or consultant must make an appraisal concerning the nature or difficulties of this relationship),
9. The project jobsite is in an isolated area, which will complicate logistics and personnel movement (owner'/consultant's responsibility, and a fact that must be clearly stated when tendering),
10. There will be a close watch from the environmental impact office, which will have a permanent representative at the jobsite, meaning special care must be taken to avoid problems or even closure due to infractions (owner/contractor/consultant's responsibility),
11. There is a necessity of sending very experienced staff to the job site, because decisions have to be made promptly and without the support of the contractor/consultant's head office, meaning the project manager must be carefully selected (owner/consultant's responsibility).

External risks can be very difficult or even impossible to manage. Examples include:

1. Government policies affecting the project, for instance, wages and salaries, inflation, etc. (there could be hints as to these policies, for instance, cost of life index, negotiations with trades and unions, etc.),
2. Weather, which, if severe enough, can delay or even stop the work (statistics have to be used here),
3. Supplier and vendor delays (this is a big unknown, unless the owner and consultant know about them),
4. Volume of sales of the product to be manufactured by the project, as well as prices (another big unknown, although examination of market trends for the product or similar products can be helpful, as can examination of the competition's prices and quality),

5. Inflation in both the country where the project takes place and that of the country of origin of the equipment (statistics and trends can be very helpful),
6. Political problems or factions fighting on the jobsite (this can be investigated with a little research, for instance, demands of a political group within a country or in the region),
7. Religions and cultural beliefs in region where the project takes place; an important aspect to investigate because of the potential they hold for endangering the project,
8. Differing site conditions (see Sect. 4.11).

1.5 Risks and Opportunities

It is common in the literature to associate potential risks with potential opportunities. We do not believe that this is correct; in fact, it is outright misleading, because it can make an individual think that there is always an opportunity behind each risk event, a contradictory concept difficult to assimilate.

A risk is a risk, a loss, something that we want to minimize, and not the origin of an opportunity, which is a gain that we want to maximize. What happens in reality is that acceptance of the possibility of a risk event occurring can lead to discovering sources of opportunity and the subsequent application of opportunity management.

For instance, consider expansion of an orange tree plantation. There are known risks related to strong winds, lack of water, insects, etc. (See Risk Breakdown Structure for this project in Sect. 4.6). Now, what constitutes a risk for this project may represent an opportunity for another similar project located in a nearby area that is protected from strong winds by a range of mountains. Thus we have two projects, and we are interested in the appearance of both risk and opportunity events in one project.

To illustrate the concept, assume, for instance, a cosmetics company that manufactures a line of products for skin, hair and dental care using its own equipment, which is currently underutilized, because the current volume of sales of products does not justify operating them at full capacity. The company is considering producing a face care cream based on a new type of the aloe vera specie, very valuable for restoring skin's natural pH and for very dry skin, and which, according to market studies, could be very profitable.

Normal internal and external risks are considered for this new product (such as raw material quality and quantity, percentage of production rejects, expected sales volume, share of the market, etc.) that the company naturally wishes to minimize through different policies. However, in investigating the issue, there could also be room for sources of opportunity, such as:

1. The addition of a new product to their existing line could be an advantage for the company, because large retailers prefer to offer their clients a complete line of products from one brand, instead of having several brands with a few products each.
2. There is opportunity to significantly reduce idle time for equipment and certain installations, which translates into a decrease in production costs for other company items, since equipment maintenance and operating costs will be shared by more products.

3. There is a chance to get a better price for emollients (mixtures of chemical products that soften the skin), also used in their other products, by increasing purchasing quantities.

Identified risks and opportunities must be detailed in the Risk Register (see Sect. 4.22). Naturally, for both risks and opportunities, there will be impacts that need to be assessed. For instance, impact from risk could be monetary losses if the new product does not sell well, and an impact from an opportunity could be enhancing the company prestige and improving the cash flow.

This can also be applied to projects in other fields, such as construction work. Consider, for instance, a company whose main business is road construction on flat or near flat terrain, a type of work for which they are very experienced. However, because the government is planning the construction of a system of mountain roads involving tunnels and viaducts, the company has decided to enter into that business. They have performed a SWOT analysis (see Sect. 1.12) and are convinced that they can afford this new type of construction, despite their inexperience.

They have identified the risks, as well as investigated the potential opportunities, as follows:

Risk: They are inexperienced in mountainous road construction and have only a relative expertise in managing explosives, which surely will be used extensively; therefore, there are two risks to consider. They have separately estimated the probabilities that both risks could harm the work, as well as having assessed the consequences, which are mainly related to potential delays in completing the job, and have managed to calculate the cost of remediation measures to greatly reduce the risks.

Opportunities: The Company considers that this job will give them much needed background to compete in other projects of this nature in the future. They have also computed the probability of being able to participate in the extensive government construction program and of the large positive potential impact on their cash flows and profits. Both risks and opportunities are introduced in the Risk Register (see Sect. 4.22).

1.6 Direct and Indirect Risks

Direct risks are those linked to the project, such as risk of personnel falling, being electrocuted, being struck by moving equipment, etc.

Indirect risks are those not directly related to the project, for instance, external risks.

1.7 Continuous and Discrete Risks

Continuous risks are those for which the interval between two values can take any value, for instance, percentages, durations, etc., and therefore, a continuous distribution can show a large quantity of values. Discrete risks are linked by the fact that they can happen or not; a discrete probability distribution will have only a few values, such as the number of workers labouring in a project, the number of accidents on a highway, the number of cars arriving at a toll station, etc., and consequently, discrete distribution take a discrete number of values. There are several discrete probability distributions, including those of Bernoulli, Poisson, Binomial, Geometric and many others.

Because of the large number of distributions, it could be difficult or cumbersome to select one. According to some researchers, results may differ greatly when a problem is solved using different distributions; others disagree, and affirm that examination of many Monte Carlo analysis (see Sect. 2.4) shows that results do not differ by a large measure. This book supports the second opinion, illustrated in Sect. 5.4.3, where the same problem is tackled with four different probability distributions, obtaining similar results. Nevertheless, in case of doubt, it is advisable to use the distribution that presents the maximum entropy formula (see Sect. 5.8.3), which is normally furnished with the description of each probability distribution.

Sometimes, there is known data that can be arranged by frequency of occurrence; however, it is difficult to ascertain which probability distributions apply. In this case, it is possible to make a statistical analysis to examine the appropriateness of the fit between the data and any of the distribution families.

1.8 Risks Normally Considered in Different Areas of a Project

From the very beginning, it is necessary to identify the riskiest areas of the project. Could it be financing, or technical aspects, or logistics? This prior analysis allows for a clear understanding of the weaker points of the project, in such a way so that they can be addressed before the project advances. Table 1.1 is a guide to subjects to be considered for risk management in each area.

Existing risk before any action is taken is called '*Inherent or Effective*', while the remnant risk after an action is adopted, such as remediation, is called '*Residual*'. To reiterate from above, risks are normally encountered in the following areas:

- Technical
- Execution (Performance)
- Economy/Financing
- Schedule
- Cost
- Environment Societal Opinion
- Quality
- Communications
- Legal
- Closing
- External factors

Table 1.1 Guide for risks in project areas

Project area	Risk identification and assessment tools	Risk analysis and remediation	Risk updating
Technical	Review project to make sure that methodology to be used is safe and proven with no risks envisaged If using new technology evaluate risk for unexpected results Analyze external conditions regarding project feasibility such as availability of water, sewage, power, etc. Identify potential risks and evaluate Rank risks	Establish adequate safeguards for proven and new technology Use SWOT analysis (1.12) to identify risks in your weak areas and find out which threats are significant	Look for new risks considering present day data and past experience
Performance	Investigate background of contractors, suppliers and vendors regarding reliability, competence and expertise to assess performance risks Identify and evaluate risks of higher costs, delays, poor quality Rank risks	Establish risk prevention safeguards (1.10)	Use Monte Carlo (3.3) to define the cloud of possible results and Earned Value Analysis (7.2) to learn about project performance When updating analyze CPI and SPI performance factors (7.3) and look for risk of delay in completion

(continued)

Table 1.1 (continued)

Project area	Risk identification and assessment tools	Risk analysis and remediation	Risk updating
Economy/ Financing	Study schedule for certificate payments and compare with cash flow; single out risk of funds shortage Detect potential risk for eventually decreasing working capital Ascertain risk for lack of communications with owner, stakeholders and suppliers Develop a 'B Plan' if there is risk that a potential partner may quit Examine risk for more capital needs than expected Examine risk for delay in completion time and fines to pay Examine acceptable period for losses at beginning of commercialization period. Evaluate risk Rank risks	Use Monte Carlo (3.3) for inputs and outputs such as: Interest rates Inflation IRR and NPV Financial indicators (5.3) (payback period, debt coverage, return per share, etc.) Develop project statement analysis for project horizon (5.3) Determine new risks	Revise certificate payments schedule Adjust data for inflation If new risks appear consider them Learn about past risks Perform a sensitivity analysis (6.1) on: Demand Price Public preferences Variations in operation costs Variations in accounts receivables and in accounts payable
Schedule	Prepare project schedule using CPM (2.2) with resources, and draw the S-Curve (7.1)	Use Monte Carlo (3.3) for inputs and outputs in PERT (2.3)	If past delay risk did not materialize, credit buffer time at the end of project

	Prepare probable project duration using β-PERT probabilities distribution (9.2.2) Assume a 95 % probability of finishing project on time using normal probabilities distribution (9.2.6) Make sure there are enough resources for each task. Evaluate risk if there aren't Rank risks	Concentrate your efforts on critical and sub critical tasks Concentrate your attention on most important risks as per ranking Compute buffers for critical tasks in function of calculated risk Ascertain probabilistic project duration and cost (5.9.1 and 9.2.6) If there is not enough time for project execution with a reasonable probability: Decide if go/no-go Assume the risk Consider crashing the schedule Consider using more resources Perform sensitivity analysis to identify probability that a task may become critical	
Cost	Use Work Breakdown Structure to identify work packages (5.9.2) Use Pareto principle (5.9.1) to select relevant costs Use normal distribution (9.2.6) for increasing costs considering: Inflation Transportation Rank risks	Use Monte Carlo (3.3) for inputs for increments in prices Determine buffers for tasks in the 20 % Pareto range (2.6) Perform sensitivity analysis (6.1)	If greater cost did not materialize credit savings Use past information to compute completion date and final cost, using Monte Carlo (3.3) model for contractor performance

(continued)

Table 1.1 (continued)

Project area	Risk identification and assessment tools	Risk analysis and remediation	Risk updating
Environment	Study ISO 14000 norms Establish risk for non-compliance of contamination limits in: Air (2.13) Water (5.4.1) Soil Noise (4.9.1) Consider carbon credits and assume risks by using them Rank risks	Use Monte Carlo (3.3) for inputs and outputs Try to negotiate	Find out about new limits, regulations and bylaws and if any incorporate them (4.14)
Societal Opinions	Examine potential risks when the project directly or indirectly affects population (4.14)	Use Monte Carlo (3.3) for potential public reaction Perform qualitative (5.16) and quantitative (5.16) interviews Conduct surveys (5.16)	Update information especially regarding public opinion (5.16) Try to negotiate
Quality	Establish measures to control quality in construction, equipment and materials and inherent risks Ascertain risk in purchasing ready mix concrete (5.4.1) Detect risk in pouring concrete (5.4.1) related to trapped bubbles Spot risk of offering a product in a competitive market (4.19) Rank risks	Reduce risk by close monitoring (2.9) of quality of work Establish norms for reception of materials and equipment Demand results from tests (8.1) in factory Consider using House of Quality (4.16) to recognize risk because of competition in a product of mass consumption	Learn from the past about contractors performance regarding quality Ascertain level of owner/stakeholder satisfaction with the development of the project

Communications	Analyze risk in communication problems (5.22) with owner, stakeholders and vendors Rank risks	Establish schedule of meetings Consider using Enterprise Resources Plan (ERP) (5.22)	Evaluate efficiency of past months regarding communications and improve if necessary. If there were buffers regarding this issue and they were not used recover them at the end of the project (1.1 and 2.6)
Legal	Analyze plot, site conditions, land use, municipal and provincial regulations regarding project viability and risks involved with property rights or municipal regulations and bylaws (4.17) Rank risks	Determine differing site conditions (4.11) Perform surveys on public opinion (1.10 and 5.16) Analyze public reaction (4.1) to project	Update information about pending legal issues
Closing	Forecast funds to be allocated for 'As built' drawings execution (8.2), manuals, spare parts, etc. Rank risks	List documents (8.1) to be delivered	Make sure that documents are delivered to owner's satisfaction (8.1)
External factors	Examine external factors (2.11) to be considered such as inflation, cost of living, import and regulations, environmental policies	Analyze influence and effects of such factors in the project	Update information

(xxxx) indicate sections in this book where the subject is commented upon exemplified

1.9 Steps for Implementing Risk Management

It is widely accepted by risk specialists that implementation of RM involves the following stages:

1. Data gathering about the project and initial conditions.
   This refers to collecting, screening and evaluating information relevant to the project.
2. Planning project development.
   This involves determining tasks for the development of the project, their sequence, and preparation of project budget and schedule.
3. Threat identification.
   These are hazards, menaces, or dangers that can affect the project.
4. Risk assessment and analysis.
   This deals with the probability of threat occurrence and the impact/s they can cause. Multiplication of probability by impact yields a risk value.
5. Execution and remediation.
   This refers to establishing remediation measures when executing the project.
6. Sensitivity analysis.
   This deals with determining the influence on the outcome of certain parameter variations.
7. Updating, Monitoring and Control.
   This relates to project updating in comparing progress against forecasted advances, costs and quality, and the analysis of potential measures that can be taken to attain an acceptable forecasted result, usually related to the project being completed on time, under budget and with the required quality.
8. Project closing.
   This deals with finishing the project in accordance with contractual terms and conditions, and to the owner's satisfaction.
9. Reporting.
   This consists of writing a technical report or memory about the whole project to be handed over to the owner.

Bear in mind that this is a natural sequence, with each one carrying its own risks, and that the process is not lineal in the sense that one step forcefully precedes another, since, as the process extends along the project life, it involves much often continuous feedback.

There are different techniques that can be applied at each step; they are briefly commented upon, their relationships examined, and finally, thoroughly mapped out and exemplified in different chapters, which follow this same sequence. The Chap. 9 shows a brief introduction to probability distribution and analysis, which can be consulted to understand certain techniques and procedures.

1.10 Guidelines for Performing Each Step and Techniques Suggested

The Synoptic guide below shows techniques that can be used in the different RM steps; however, consider that a technique might be used in more than one step.

The first series of numbers indicate the section of book where the subject is treated, followed by a sentence indicating the procedure and actions, while the text between the brackets indicates the technique name or acronym.

Synoptic guide for risks in Project Management steps

DATA AND INITIAL	1.12	Establish project objective
	1.2	Establish project scope
	1.12	Evaluate company capability and derived potential risks (SWOT analysis)
	4.20	Identify relationships between sources of risk and consequences (Bowtie model)
	5.2.1	Evaluate relative importance of threats (Analytical Hierarchy Process) (AHP)
PLANNING	2.12	Breakdown a project into its components. (Work Breakdown Structure) (WBS)
	1.1	Place activity execution as a function of time (Gantt) (Bar Chart)
	2.2	Compute the critical path, floats and completion date (Critical Path Method) (CPM)
	2.3	Ascertain probable completion date (Program Evaluation and Review Technique) (PERT)
	7.1	Compute project budget as a function of time (S-Curve)
RISK IDENTIFICATION	4.6.	Breakdown project risks into components (Risk Breakdown Structure) (RBS)
	4.9.1	Identify and evaluate serial risks (Z-Matrix analysis)
	4.10	Analyze creative ideas and different point of view (Brain storming)
	4.21	Look for individual expert analysis (Delphi method)
	4.22	Prepare risk inventory and data (Risk register)
	5.15	Utilize people expertise and knowledge (Expert's opinion)
	5.16	Consider public opinions, ideas and problems from polls and, surveys
RISK ASSESSMENT AND ANALYSIS	5.6.1	Collect statistical information (Statistics)
	5.15	Look for expert opinion
	5.16	Get information from people affected by the project (Qualitative interviews)
	5.16	Evaluate consequences (Quantitative interviews)
	3.3	Evaluate uncertainty (Monte Carlo analysis)
	1.1	Compute project budget (Capital budgeting)
	4.6.1	Ascertain relative and global risks (Probabilistic tree analysis)
	4.7	Represent relative importance of risks (Graphic risk comparison)
	5.9.3	Spot reliability of estimates (Entropy)
	5.10	Assess risk and visualize gains with remediation (Risk matrix)
	5.11.1	Evaluate risks in normally technically complex undertakings or projects such as nuclear plants, aerospace activities, chemical plants, complicated civil works, etc. (Event Tree Analysis) (ETA)
	5.11.2	Estimate risk and risk series from sources (Fault Tree) (FTA)
	5.12	Determine risks in product and processes (Failure Mode and Effects Analysis Method) (FMEA)
	2.2	Develop project network (CPM)
	2.6	Analyze select costs items (Pareto Principle)
EXECUTION AND REMEDIATION	2.5	Remediate delays and costs (Buffering)
	1.11	Negotiate risk ownership (Negotiations)
SENSITIVITY ANALYSIS	5.3	Analyze sensitivity of financial indicators (Financial statements)
	6.2	Analyze sensitivity to delays (Project schedule)
	7.1	Compare actual cost and work done on certain dates with project's original budget and schedule on that same date, and thus determine risk of not achieving expected results in time and on budget
UPDATING MONITORING AND CONTROL	7.1	Compute and compare advance of work (Earned Value Analysis) (EVA)
	7.2	Compute contractor, supplier's /vendor's performance (Performance Factors)
	5.8.1	and 7.3 Examine trends (Statistics)
CLOSING	8.3	Prepare 'As built' drawings

1.11 Guide for Understanding Relationships Between Different Techniques

We have considered and catalogued techniques by project areas (Table 1.1) and by steps in RM (Sect. 1.9). Now, we depict relationships between the different techniques as a flow chart (Fig. 1.2). The names of all the techniques commented upon in this book, as well as their relationships and precedence, indicated by arrows, are arranged within its boxes. The reader must take into account that this precedence is only an indication or best guess of what technique can be rationally considered, as well as which one follows, since RM is not an exact science and depends on the dynamics of each individual project and generally uncertain issues.

For instance, the 'Delphi method' (if used) (Sect. 4.21) employs data from the project scope, which is transmitted to experts for them to suggest the most probable threats and their importance; once this is done, the information is transcribed to the 'Risk Register' (Sect. 4.22). An arrow from 'Entropy' (Sect. 5.9.3) indicates that this technique could help in ranking the information for the Risk Register, but if this is not necessary, it can probably be ignored. The same can be said about 'Graphic comparison' (Sect. 4.7), 'Bowtie method,' (Sect. 4.20) and others; they are just there to be used if it is considered pragmatic to do so. In other words. Figure 1.2 shows an inventory of techniques that can be utilized and their relationships, and the analyst must decide which of them to apply.

Furthermore, the Risk Register can pave the way to the building of a 'Risk Matrix' (Sect. 5.10), which, in turn, could be useful in preparing the 'Financial Statement' (Sect. 5.3), together with information from the 'Monte Carlo' simulation model.

That is, the Register records the most important variables to be tested, while Monte Carlo takes care of their uncertainty. There could possibly be 'Negotiations' with vendors, contractors and suppliers based on the precedent information, and these negotiations are usually feedback-intensive, which is indicated by the large curved arrow, and so on.

In other words, there is no direct or unique path from the beginning to the end, but there could be several and most probably many feedbacks, or information interchanges indicated by a double arrow, as shown, for instance, between 'Brainstorming' and 'Negotiations'.

Each box has a series of numbers that correspond to Sections in the book where the technique is commented upon and often exemplified. Techniques are commented upon approximately following the classification shown in Fig. 1.2. However, it is necessary to consider that RM:

- As already mentioned, is not a lineal process.
- Does not advance in only one sense, say, from left to right.
- Is not a standardized process that can be followed for all projects; therefore, each project must select the techniques to be employed.

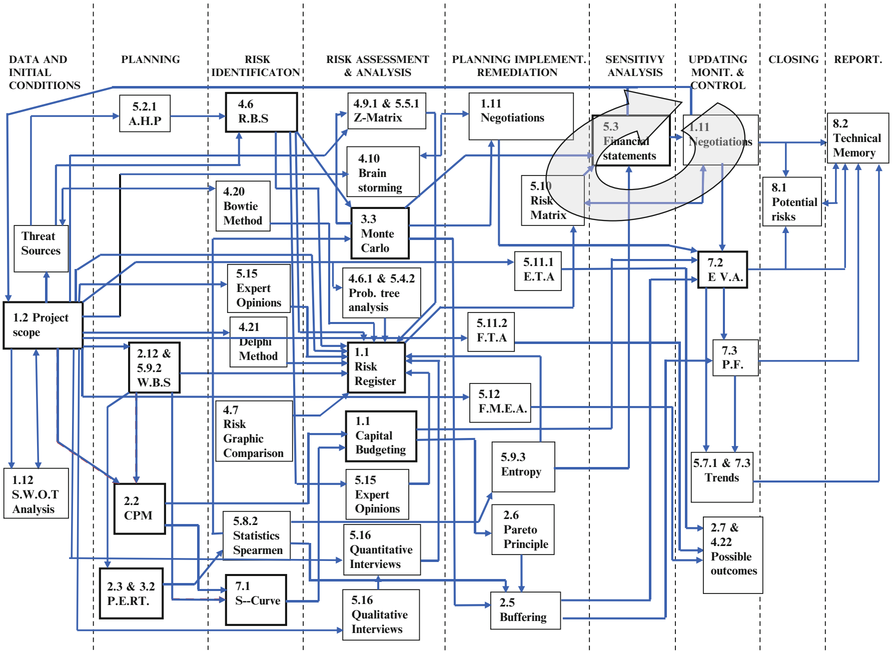

Fig. 1.2 Interrelations between different components

To apply RM to a project involves complex and, more often than not, continuous feedback; besides, the techniques are not always contained under a unique step (or label) because they could belong to two different steps.

Notice that techniques are beneath the step where they are used and that these steps are labeled on top of the Fig. 1.2. The starting document is the Project Scope and it follows the mentioned sequence.

1.11.1 Data and Initial Conditions

It is of paramount importance that the objective or goal of the project, the scope of the project, and the deliverables from the project be established, because the potential risks relate to them. The project must be perfectly defined in terms of objective/s, scope, duration and cost, as should the client's expectations regarding time, cost and quality. The possibility of attaining an established objective (with all the features that it implies) and ascertaining risks cannot be pursued if the analysts or project team have doubts about what must be done and what is expected, or if they ignore the occurrence of special circumstances regarding a project. For instance, in a project in certain African countries, it is of paramount importance to have knowledge of local conditions from different points of view, for example, cultural (locals do not work on certain religious days and/or must be allowed daily prayer time). Consider as well that sometimes it is necessary to pay a visit to the chief of the village where the project is located, even if all government permits are in order. The reason for this 'courtesy' is that the indigenous people can make it very difficult, if not impossible, to work in the area, by, for instance, not allowing native people to work on the project, something they often have the means to do.

There are other circumstances that must be known, such as water quality, local customs (for instance, if there are restrictions regarding women working together with men), existing chronic diseases and associated risk factors, environmental regulations, political climate, political unrest, possibility of hiring local skilled workers, etc. Naturally, this process leads to the possibility of eliminating or at least greatly reducing uncertainties by collecting information about the jobsite, the region and the country.

The company, firm, promoter, owner, etc., must establish the level of risk that they are willing to accept. For instance, it can be that a delay of up to 2 months for the duration of the project is acceptable, or an agreed upon maximum 12 % increase in production costs. Stakeholders can also say that anything less than top quality will be unacceptable, as well as anything less than the highest measures for personnel safety, environmental adherence to existing regulations, or strict compliance with provincial and local regulations and bylaws.

The company must make an honest appraisal of its expertise and experience (or lack thereof) to perform the job; in the last case, there could be risk that has to be acknowledged and assessed. As an example, it could be the case that a large construction company is well experienced in building residential buildings, but if the project calls for the construction of an industrial plant that may differ greatly in construction techniques from that which they are used to, then there is a risk that must be appraised. A similar situation could arise in the case in which a textile company is trying to enter into a completely different field, such as wanting to develop a metallurgical project.

Company structure is another aspect to consider; it is necessary to analyze the risk for attempting to execute this project with the actual structure or if it will be necessary for that structure to be changed.

Once this aspect has been taken care of, the process can be started as follows:

1. Determine the Threat Sources for a project. This can be done through historical data, expert's opinion, similar projects, thorough analysis of the project, etc.
2. The company or project promoter must perform a self-evaluation concerning its capability, ability, expertise, financial resources and available manpower for the project, in quantity and quality. This can be done using the Strength, Weakness. Opportunities and Threats analysis (SWOT) (Sect. 1.12.1), the results of which are fed back to the project, and therefore, a decision can be made considering the inherent risks.

1.11.2 Planning

3. From the Source, threats can be evaluated and ranked, using, for instance, the Analytical Hierarchy Method (AHP) (Sect. 5.2.1). Naturally, threats with the highest value are given preferential treatment.
4. The Work Breakdown Structure (WBS) (Sect. 5.9.2) is a fundamental tool for understanding a project by breaking it down into components at different levels.
5. In large projects, there could be thousands of tasks or activities that may be subject to delays and/or variations in cost, subsequently affecting the completion date and the estimated final cost of the project; most of the time, they are clear sources for threat. As a matter of fact, statistically a very large percentage of projects of different size fail to complete on time and under budget. The reason is that inherent risks were not taken into account. From this point of view, delays can be analyzed selecting really important tasks through the critical path (see CPM in Sect. 2.2). When dealing with costs, this selection can be performed using the Pareto Principle (Sect. 2.6).

   Capital Budgeting (Sect. 1.1) is the rate of disbursement over time, which is obtained from the CPM and its conversion to the Gantt Chart. Capital budgeting can also be built using the Monte Carlo model (Sect. 5.3.1).
6. Program Evaluation and Review Technique (PERT) (Sect. 2.3) is an effective method of considering risks in a project time-wise. It is highly effective when used in conjunction with the Monte Carlo model and combined with Statistics Gauss Probability Distribution (Sect. 9.2.6) to find either, the probability of completion when there is a certain time available for the project or the time needed to get a pre-established probability of completion.

1.11.3 Risk Identification

7. Once threats are known (notice that we speak of threats and not of risks, because risks are the product of a probability of occurrence of a threat through its impact or consequence, and at this stage, we know neither the probability nor the impact of each threat). A risk can be hierarchically depicted in the Risk Breakdown Structure (RBS) (Sect. 4.6). In this way, it is possible to detect the influence of initial threats or risks throughout the project.
8. The Bowtie Method (Sect. 4.20) is useful because it agglutinates potential causes (acting alone or jointly) and preventive actions (called barriers) with potential outcomes (produced independently or jointly) together with mitigating actions (called barriers), and considers holistically that an event can be produced by several causes which will also generate different consequences or outputs. Its results go to the Risk Register (Sect. 4.22).

9. Also considering Project Scope, Experts (Sect. 5.15) can make a valuable contribution considering their know-how and expertise on a particular subject. Similar results are obtained using the Delphi method (Sect. 4.21).
10. Different threats can be visually compared using graphic comparison, such as the Tornado and the Spider web diagrams (Sect. 4.7).

1.11.4 Risk Assessment and Analysis

11. Once threats are identified, it is necessary to assess or evaluate them. There are many different manners in which this can be done.
12. By using the Z-Matrix (Sect. 4.9.1), which allows for determining serial risks, that is, risks that affect others in a consecutive manner (this matrix works with risks that are the product of probability of occurrence and impact).
13. By Brainstorming (Sect. 4.10), which can produce valuable inputs and generate new ideas.
14. By using the Monte Carlo model (Sect. 3.3), a system designed to compute a probabilistic value of occurrence for a variable by repeating a mathematical formula hundreds or even thousands of times, subject to established limiting values for the variable and within a certain type of probability distribution.

    Monte Carlo can be applied to many different situations, however, the most common use in a project is the determination of its completion date and final cost.
15. Risks can be also analyzed through Probabilistic Tree analysis (Sect. 4.6.1), which indicates the probability of each branch and also a global probability.
16. Capital budgeting (Sect. 1.1) is a fundamental tool, since it displays disbursements as a function of time, and is obtained after CPM is solved. It is fundamental for evaluation of risks.

    To identify risks and evaluate them, expert opinion (Sect. 5.15) is solicited, and surveys are conducted through Qualitative Interviews (Sect. 5.16) to give an idea of the threats perceived by the people who will be affected by the project, albeit not using any mark. A Quantitative Interview (Sect. 5.16) is also sometimes computed to complement qualitative data with actual figures or for another type of survey when one is explicitly looking for numerical data.
17. Threats then undergo a qualitative assessment (Sect. 5.17) in which such aspects as probability of occurrence and impact are computed. Their multiplication gives a value for risk.
18. Further risks undergo a quantitative assessment (Sect. 5.17), which establishes priority, risk liability and existence of serial risks.
19. Once all main risks present in a project are evaluated considering their probability, severity of the potential impact, ranking, type of risk, etc., they are grouped in a Risk Register (Sect. 4.22). This document is an inventory of risks with all their characteristics.

1.11.5 Execution and Remediation

20. In the Planning, Implementation and Remediation stage, negotiations can be conducted to take actions against risk through several schemes, such as transferring the risk (at a cost), or accepting it, or developing remediation measures to avoid or reduce the risks, which usually involves Negotiations (Sect. 1.11). Whatever the decision, it allows for building a Risk Matrix (Sect. 5.10), which also permits visualization of final risk after remediation.
21. It is a fact that data is very often non-existent, incomplete, missing or inadequate. To measure the quality of data, the Entropy concept can be used (Sect. 5.9.3). It indicates the degree of knowledge that we have on uncertain issues.
22. In large projects, when dealing with costs, it could be an immense task to analyze all costs. Using the Pareto Principle (Sect. 2.6) can help in identifying those costs or cost items that are responsible for a very large part of the budget, for instance, 80 %. The Pareto Principle, tested in thousands of different situations, establishes that about 20 % of costs are normally responsible for 80 % of the budget.
23. When tasks are probabilistically analyzed, additional time for duration or increased costs (Buffers) (Sect. 2.5) must very often be allowed, considering that, in general, estimates for durations and costs are approximations. The probabilistic result of this action gives values of time that need to be added and costs that have to be increased. This buffering is usually done in the planning stage of the project, however, as with other actions, it is updated continuously, which is part of the control stage.

1.11.6 Sensitivity Analysis

24. Because there are large uncertainties in all projects due to unforeseen delays, increased cost, weather, etc., it is necessary to have an idea of how these events will affect the completion date, the final cost, the expected return, the payment to shareholders, etc. A sensitivity analysis is performed assuming a range of variation for certain critical parameters, say, sales, and is then used to find out how it affects the expected financial results. This is done using different tools, such as the Financial Statements (Sect. 5.3), the Z-Matrix (Sect. 4.9.1), and Monte Carlo (Sect. 3.3). As a result, Negotiations (Sect. 1.11) are usually performed with banks, vendors, suppliers, clients, etc., and many times, this has produced an alteration of the original scope of the project. As seen in Fig. 1.2, this activity, together with Financial Statements and Risk Matrix, generate an intense feedback shown by the large curved arrow.

So far, we have analyzed delays, costs and, albeit not mentioned, quality, because better quality normally means higher costs and delays. For instance, in a construction project, there are higher costs for hiring a dedicated worker closely monitoring pouring of concrete, or materials used, or finishing, or painting, or by using higher quality materials, etc.

However, there are activities in which structural safety is fundamental, such as in nuclear stations, chemical plants, biotechnology, sophisticated human plasma processing, etc. In these cases, other techniques have been developed, such as Events Tree Analysis (ETA) (Sect. 5.11.1), which is "*An investigation into the responses of a system to perturbations or deviations*" (Paulos 2001), and applies inductive logic; it is based on an initiating event, such as one provoked by human error (Chernobyl), Acts of God (Fukushima), or perhaps mechanical failures (The Space Shuttle Challenger). The analysis is based on something already built and analyzes and evaluates the different outcomes that the system can provoke.

25. Another technique is Fault Tree Analysis (FTA) (Sect. 5.11.2), which applies deductive logic, and commences with a postulate or presumed final event called ***'Top Event'***, advancing backwards in a top-down hierarchal analysis of sub-systems down to basic units or components, deducting or inferring the reasons or causes for the top event to happen in a cause-and-effect relationship.
26. Another related technique is Failure Mode and Effects Analysis (FMEA) (Sect. 5.12), used mainly in manufacturing. This inductive technique, especially focused toward products and processes (used heavily in pharmaceutical and medical research), is a systematic and powerful procedure that, following the bottom-up approach, investigates all possible manners and chances in which a failure can occur in all stages of a process, starting with the design and followed by production. The technique searches for potential failures, imagining situations in which they can occur or why they are produced and in which mode they can take place, and estimates frequency of occurrence.

1.11.7 Updating, Monitoring and Control

27. The control stage is continuous and extends along the project life, usually with established dates for updating information; at each date, past risk occurrence (or not) is analyzed, new risks contemplated, and forecasts made. At each pre-established update (say, for instance, at the end of each month), work scheduled (Sect. 7.1) is contrasted with work actually done, and also with actual costs. This is performed through Earned Value Analysis (EVA) (Sect. 7.2), which also allows for calculation of Performance Factors (Sect. 7.3) used to forecast the completion date, as well as final cost. It is necessary to take into account that there are also risks in the future, and these tools try to foresee and evaluate them. These actions also allow for the production of trends (Sects. 5.8.1 and 7.3), which are also used for forecasting purposes.

28. Possible outcomes (Sects. 2.7 and 4.22) refer to consequences resulting from risks. The term applies to everything, because an outcome can be related to delays, costs, and quality, and there could be different outcomes for the same risk. However, in Fig. 1.2, it refers to different outcomes related to successive failure of safety mechanisms in high technology projects.

1.11.8 Closing

29. Closing the project (Sect. 8.1) is about final details, such as the preparation of 'As built drawings' (Sect. 8.3), that is, drawings that may differ from the originals in as much as they indicate exactly how a construction was done, a machine foundation placed or the sewage system built, and may show substantial differences from the original drawings. It also has to do with verification that all contractual conditions have been met, all work certificates paid, no works pending, no outstanding balances, etc. There are many risks here that have to be properly addressed.

1.11.9 Reporting

30. Finally, there are risks when closing the project, especially in not complying with contractual documents regarding state of the work, documentation, drawings, etc. For this reason, it is necessary to prepare a Technical Memory (Sect. 8.2).

1.12 Establishing Project Objective and Conditions

One tool that a company can use to measure its ability to cope with a new project or enter into a new market is SWOT (Strength, Weakness, Opportunities and Threats) analysis, which considers both internal aspects (Strength and Weakness) and external (Opportunities and Threats). Again, risks can be identified here; for instance, the company recognizes a weakness because of a lack of expertise in the construction of large structures for a factory (risk of not being able to finish on time, risk because their project manager is experienced in tall buildings but has never managed a project such as a factory, etc.). At the same time, there could be opportunities because the client plans to build a series of these structures. There could be threats from a competitor because of its experience or because it owns the necessary machinery and consequently can do the job cheaper, while the company would have to rent large equipment (a circumstance that will also probably count against it in the eyes of the owner in the selection process). Therefore, not only is there risk in doing a job without expertise, but also in not having the adequate resources for it.

1.12.1 Case Study – SWOT in Risk Analysis – Car Maker Project

Project: Manufacture of a small electric car for urban use

XYZ Company manufactures small cars in the economy range. They have decided to develop a small electric car for urban use, with a capacity for two persons, that is, a driver and a passenger. They have in mind some innovative ideas, such as producing a very light vehicle using a carbon fibre body with a size adaptable to heavy congestion in city traffic. However, their strongest bet is in using a new Lithium-Nickel-Manganese-Cobalt (LBC) battery, which the company developed jointly with a university research institute. The advantage of this battery is that it offers a good efficiency as well as safety, life span, performance, and cost. One additional advantage, also developed in the university institute, is the charging time, which takes only 30 min; however, this speed requires an efficient cooling system, which has also been designed for this battery type.

Therefore, the company institutes a SWOT analysis to ascertain the feasibility company-wise of this endeavour. Tables 1.2 and 1.3 depict it, although with the aggregate of risk identified. The last column resumes the conclusion after analyzing each subject.

1.12.2 Conclusion

Analyzing Table 1.2, it is found that Strengths (S) and Weaknesses (W) are almost matching with a light difference in weaknesses, and therefore, it is not possible to extract any definite conclusion from here.

Examining Table 1.3, it is found that Opportunities (O) and Threats (T) are also similar, however, the competition can pose a serious risk, and the Board of Directors is divided concerning their approval or rejection; a vote cast between the Boards' members after recommending a cool appraisal of facts turned the project down.

1.13 Resources Available for the Project

Does the company have enough resources for this project? By 'resources', we mean everything from funding for the project to people, equipment, facilities, etc.

Table 1.2 Strengths and weakness

	Strengths	Weakness	Potential risks	Result of comparison Strengths (S) vs. Weakness (W)
Known product	The small car size is well known by its versatility in urban traffic because there exists similar two persons vehicles using gasoline and that have had a very good acceptance materialized in a large demand	Insurance companies are studying to rise premiums for these small cars because they argue that there is not enough protection, and because they are like motorcycles from the safety point of view	As mentioned, there is risk in increasing insurance premiums, which is something yet in the air since is not still in force. The reason is that insurance companies want to increase their revenues under the argument that this type of small vehicles are not safe, but on this aspect they do not have records or statistics of accidents or on personal injuries to sustain the claim. In addition, there is a motion at government level to prohibit this increase based in not realistic assumptions	S >> W It is considered than Strength compares very favorable to Weakness
Body	The carbon fiber body is a novelty in this field and offers a large reduction in weight. In addition, the vehicle will have a front honeycombed carbon fiber area that can absorb impacts in case of a front crash	This material is not cheap and its cost has a large incidence in the production costs	This absorbing impact capacity is a feature that the company will use to justify the safety of the vehicle, however it also significantly increases its cost, with the risk that prospective users may consider it unnecessary	S ≈≈ W It appears that Strengths are similar to Weakness
Price	According to the company the price will reflect the high quality and especial features of this vehicle. For instance the device that recovers kinetic energy as the car decelerates or brakes converting it into electric energy (regenerative braking), which is used to recharge the battery	Price is perhaps the main drawback since the electric car will cost 30 % to 40 % more than the conventional equivalent car powered by gasoline.	There is certainly a risk here. Perhaps the company should review its production figures in order to lower production costs if possible	W > > S It appears that Weakness are more important than Strengths The company has still to find ways to reduce costs. However, there is not a certainty at this stage that it could be done, especially considering that are many imported elements which variation in costs and availability is unforeseeable
Electric component	As said, this is the car strongest point. They will produce a silent, non-contaminant car that may compete with similar models	There is not still enough expertise or information in the industry regarding performance of the vehicle in extreme temperatures, especially in hot summers when clime can affect and decrease capacity of the battery cooling system	There is a risk here since the company has only fabricated ten prototypes that were tested during a 6 month period (including driving in summer and winter). Consequently, there is not enough data about how the vehicle will perform in longer periods and especially in very hot summers and in harsh winters	W > S More test and road trials are needed

(continued)

Table 1.2 (continued)

	Strengths	Weakness	Potential risks	Result of comparison Strengths (S) vs. Weakness (W)
Marketing	The vehicle aims at an especial sector of people in large cities, which are those that commute daily, drive to work and are tired of congestion and parking cost as well as gasoline prices especially in a country that does not have oil.	The fact that the vehicle is oriented to a particular sector of the market (urban vehicle) is also a disadvantage, since it is not thought as a car for long trips over 250/300 km without recharging	Risk may exist because the scarcity of recharge stations and recharge outlets on streets parking areas and in parking lots. This fact should be carefully examined	**S > W** This is a serious issue, however its drawback is compensated by the fact that owners can recharge the battery at home during the night.
Sales potential	It is considered that potential for sales is good considering the high rate of interested people from a survey over 10,000 people in many cities of the country	The company realizes that to boost sales it will be necessary to develop a financing scheme to help people to buy the car, as well as considering how much a client is willing to pay.	There is risk here. The company probably should reach an agreement with a bank for financing, unless it can finance by itself. In this case there is a financial risk due to potential defaults in monthly payments from buyers that needs to be analyzed and its consequences examined, from the cash flow point of view	**W > S** There is a risk here because own financing, since, even if there are big sales, money recovering might not match production expenses

Table 1.3 Opportunities and threats

	Opportunities	Threats	Potential risks	Result of comparison Opportunities (O) vs. Threats (T)
Taxes and licences	Because the government is very eager in reducing air contamination forced by environmental groups, they plan to offer a hefty discount (mot known yet) to electric vehicles in taxes and licenses		There is too much uncertainty regarding this issue since practically nothing is known about it, other that the intention of the government to enact it, but if enforced it could take years to implement	O > T However, there is a high degree of uncertainty
Safety	Just in two months time another firm will put in production a new plant to manufacture cooling system packages that probably can be adapted to the car, replacing the imported ones	There is a need of a campaign to inform people about safety in this type of vehicles, since there has been damaging reports about fires produced in electric cars because battery overheating		T > O However, it is not felt that there is a serious threat

(continued)

Table 1.3 (continued)

	Opportunities	Threats	Potential risks	Result of comparison Opportunities (O) vs. Threats (T)
Compe tition		There are rumors about a Chinese company plans to import hybrid cars	Because mass production and cheaper labor in China this is a threat to be considered. There is possibly not too much that the company can do in this respect, except perhaps submit their plans to the government and asking for establishing import restrictions for this vehicle.	Potential T
Cashflow	The company plans to market its car through established and reputable car dealers and from this point of view the answer has been very favorable. This is important because the dealers will also provide after-sale service, without any cost to the company	Unfortunately not many car dealers cancel their obligations on time, which make necessary to extend credit time and then compromising the cash flow	During preliminary conversations with some car dealers and just as a sample it was known that normally payment to the manufacturer is within a month after car delivery to purchaser, and on this assumption cash flow calculations must be done, to avoid the risk of inability to pay accounts payable for materials, power, services, salaries and wages.	O > T This is considered a weakadvantage of O over T
Managing the business		Members from the Board of Directors voiced their concern on the fact that the company does not have enough experience in this type of vehicles, especially considering logistics	There is an obvious risk for the company of producing a car, which because its innovative features could suffer mechanical and electrical problems after a certain time of use, which could mean recalling cars for their repair, replacing parts or fixing defects	There is a certain risk here

1.14 Project Strategy

It is also necessary to develop a strategy for maximizing success, as well as minimizing negative aspects and risks. This means that the consequences of risk for the whole project must be assessed regarding non-compliance with times, costs, quality, environment and social issues, etc. For instance, in a project related to the manufacture of a mass-consumed product, a strategy must contemplate how the product will be distributed, identify the most important and significant potential customers, appraise potential rejects during manufacture owing to defects, adopt a policy for a reasonable time to collect account receivables, etc. Embedded in this strategy are risks that have to be evaluated; for instance, there is risk in deciding if the product will be distributed by the company or if this activity will be contracted to a third party, risk of expenses from bad debt, risk in whether or not to advertise, risk in manufacturing one's own parts or outsourcing, etc.

The strategy also assumes that a qualified and experienced project manager with capacity to delegate will be selected for the project. The same applies for procedures to find a reputable, competent and reliable main contractor. No observance of these two aspects, project manager and main contractor, implies assuming unnecessary risks.

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Chapter 2
Planning

Abstract This chapter deals with project planning. It comments upon different approaches for planning normally used nowadays, such as Gantt, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and the Monte Carlo Model (MC), and lists many other techniques, for instance, Earned Value Analysis (EV), Probabilistic Trees, Risk Matrix, etc., as well as illustrating other tools, namely Work Breakdown Structure (WBS), Risk Breakdown Structure (RBS), and Z-Matrix. Using the same problem, a comparison between CPM, PERT and MC is proposed; it starts with CPM deterministic and consequently average durations and costs (and thus, with the same chance for success and failure). It moves on to probabilistic, but static PERT (because of its unique scenario), to Monte Carlo, with its hundreds of probabilistic scenarios (subsequently yielding a more reliable outcome). This analysis involves risks related to Time (Delays), Costs (Overruns), Quality, Social impacts, Project safety, Quality, Communications, External factors, Legal, and Environment, in other words, all components of a project. Needless to say, no technique will guarantee that a project will finish on time and under budget, since that technique has not been invented yet, and probably never will be, owing to the many predictable and unpredictable uncertainties in modern projects. However, the chapter offers the most advanced technology for the time being.

Keywords CPM • PERT • Monte Carlo • Uncertainty • Delays • Overruns

2.1 Planning a Project – Techniques and Tools

Planning a project consists of determining tasks to be performed from inception to completion, together with their durations, costs and resources needed, and establishing working relationships between tasks. This produces a network that is the

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9_2, © Springer International Publishing Switzerland 2014

basis for computing total duration, resource assignments and permitting project scheduling, that is, putting the whole project into a timeframe that is the basis for budgeting, monitoring and control.

There is a set of well-established and known techniques and tools for planning, such as:

- Work Breakdown Structure (WBS)
  Used to disaggregate a project into its components (work packages) and analyze each one cost-wise.
- Risk Breakdown Structure (RBS)
  Used to disaggregate a project into its components (risk packages) and analyze each one risk-wise.
- Z-Matrix
  Used to identify serial risks, that is, risk affecting or linked with others.
- Gantt Charts
  Fundamental tool for putting planning into a timeframe for scheduling.
- Budget or Baseline Curve, also known as Budget Cost of Work Scheduled (BCWS) or 'S-curve'
  This is a fundamental tool used as a basis for project monitoring and control.
- Critical Path Method (CPM)
  This is the universally used tool for project planning.
- Project Evaluation and Review Technique (PERT)
  This is the CPM probabilistic version, used for planning and RM.
- Critical Chain Project Management (CCPM)
  Used for planning resource-wise.
- Earned Value Analysis (EVA)
  Fundamental tool utilized to assess project performance and for forecasting completion time and final cost.
- Sensitivity analysis
  Used to compute how sensitive a result is to changes in certain variables.
- AGILE
  Planning tool used for IT projects.
- Trees analysis
  Used to determine partial and global probabilities of occurrence.
- Risk Analysis
  This is a fundamental approach for considering uncertainty and its consequences in projects.
- Monte Carlo Model (MC)
  Using a probabilistic approach, this is the most important tool in RM for treating uncertainty.
- Risk Matrix
  Used for risk assessment and to visualize improvement after remediation.
- Statistics and probabilities
  Used in many aspects throughout the life of the project, this is a fundamental aspect of RM, owing to the uncertain nature of projects.

These techniques, with the exception of RBS, Z-Matrix, Risk Analysis and Earned Value Analysis, are not explained here due to the abundance of available literature, as well as their widespread use.

2.2 CPM Approach

Assume planning a project using traditional planning/scheduling tools, such as CPM, PERT, Gantt, etc. Therefore, once the network is built, it is necessary to assign data, such as durations and costs, as well as resources that will be used in each task.

Characteristics:

- Uses a network to represent interrelation between tasks.
- Considers a balanced use of resources, in manpower, materials and equipment.
- Employs a deterministic approach, that is, assumes that durations for tasks are fixed values.

Advantages:

- Very well-known methodology at an international level, which makes it easy to combine networks and integrate them into a master schedule of suppliers and vendors from all over the world.
- Determines critical tasks and the critical path, as well as floats for non-critical tasks.
- Relatively easy to use.
- Many software programs to process it.
- Allows for crashing a project, that is, reducing its total duration, normally as a function of increased costs.
- Allows for building the Bar Chart (Gantt) for scheduling and for constructing the Master Schedule.
- Once budgeting is done, the method permits construction of the budget curve (BCWS) for the project.

Disadvantages:

- It considers only deterministic, usually average values for durations; for this reason, many practitioners consider that a very large percentage of projects are behind schedule and think that CPM is the culprit to some extent through the use of such a type of values.

Figure 2.1 depicts a network for a simple project. The critical path is formed by critical activities 0–2, 2–4, 4–5, 5–7.

Total project duration: $8 + 3 + 9 + 4 = 24$ days.

How accurate is this estimate? Not enough; the project may or may not meet the specified completion date.

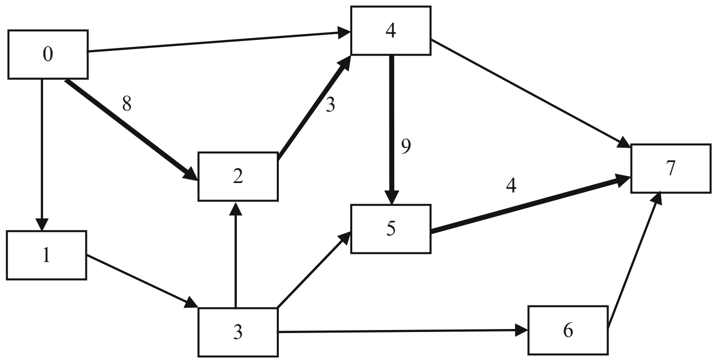


Fig. 2.1 CPM network using deterministic values for durations

What are the consequences? Delays and higher costs.

The key to explaining these two questions lies in the quality of data for durations. This data can be acquired through experience, expert opinion, similar projects or using budgeting software. For example, for a task such as '*Excavation of a trench 2 metres in depth and with a length of 689 metres*'; budgeting software gives average information by unit of work (for instance in m^3) concerning necessary personnel in quantity and trade, as well as equipment by type needed for each kind of soil and detailed costs.

However, when assigning a duration time to a task based on averages, statistics or detailed calculations, there is no guaranty that the duration of a task in the past or from another project will prove the same in a new project. Why?

Because many things can influence its replication, such as greater (or lesser) difficulty, less (or more) experienced workers, weather (fine or poor), quality of materials, different type of soil (better or worse than assumed), etc. That is, many things can provoke a variation in this duration, either shortening or lengthening it, and depending upon many impossible-to-forecast aspects. Thus, personnel performance, machine operator skills, actual soil characteristics (for instance, water may be found), overburden, equipment breakdown, lack of safe means for entering and exiting a trench, type of sheet piling, safety measures for workers and for the work, etc., can substantially produce different durations.

Normally, these estimates are made in good faith, although every so often analysts add some extra time and cost, '*just to be on the safe side*', and besides considering that, there could be incomplete or unknown data, that is, there is uncertainty regarding data. The problem is that too much attention is paid to single figures, but none to the uncertainty around this value (Rodger and Petch 1999). Consequently, an estimate is more accurate if expressed not as a single number but as a range (Gabel 2010), and this applies not only to schedule and costs, but also to any other estimate.

Therefore, the estimated duration for a task is just an approximation of the real duration, all things considered. This is one of the reasons projects get delayed, since task planning and the corresponding CPM reflect these uncertainties, omissions and incomplete values, but do nothing to address them properly. There is no method that can take into account all intervening factors; however, what can be done is improvement of the quality of information; the key word here is 'uncertainty', and this is the aspect to be tackled, reducing it as much as possible, but this is not possible just by using single deterministic values for task durations. There is no doubt that it is more realistic to use a duration window, since it reflects uncertainty, instead of a fixed or deterministic duration.

When a person, even an expert, does not definitely know how long it will take to perform a task, that person usually says, '*Well, I would say that, at a minimum or optimistically-that is, if we have fair weather, skilful personnel, machinery working properly, etc.-it could last 15 days, and it would be difficult to make it in less time*'.

'Now, considering that something could go wrong, such as the chance of bad weather for this time of the year, or personnel being not really very skilled in this type of work, or because equipment has not arrived in time, the work could take perhaps up to 23 days; therefore, as an average, I would say about 19 days'. That is, he/she gives a window of values based on his/her experience; then, this criterion should be applied to establishing durations.

2.3 PERT Approach

It is assumed that this methodology is also popular, although not as much as CPM. Nevertheless, it is believed that some comments are in order, especially regarding its connection to RM.

Characteristics:

- Uses a network to represent interrelation between tasks.
- Employs a statistical approach, that is, assumes that durations are probabilistic by nature, but in a limited scope, since it considers only one set of probable values per task.
- Uses the β-Pert probability distribution (Sect. 9.2.2).
- The result, that is, the most probable duration for the project, is found using the normal probability distribution (Sect. 9.2.6).

Advantages:

- Introduces uncertainty in task duration, thus increasing reliability of results.
- Determines the critical path with critical tasks, as well as floats for non-critical tasks.

Disadvantages:

- The model, because of its probabilistic nature, with concepts unfamiliar to many stakeholders, contractors, owners and project managers, is a hurdle for many people, explaining their reluctance to use it.
- There is not much software for PERT.

- Although originally developed separately and by different authors, PERT uses the same procedure as CPM; however, instead of one duration, it defines three durations for each task, as follows:
  - A most likely time value (ML) (perhaps based on past experience).
  - An optimistic time value (O), which, naturally, is the lowest possible (based, for instance, on space, resources, funds, etc.).
  - A pessimistic time value (P) (if something goes wrong), which is the maximum.

PERT uses formula (2.1) to determine the mean (see Sect. 9.1) and formula (2.2) for the standard deviation (see Sect. 9.1), according to a certain probability distribution, which is normally the 'β-Pert distribution' that defines an area containing all the probabilities of duration between O and P times.

$$\text{Mean} = \frac{(2O + 4ML + 2P)}{6} \tag{2.1}$$

$$\text{Standard deviation} = \frac{(P - O)}{6} \tag{2.2}$$

From the practical point of view, the two most important questions for RM are:

Regarding time

- Once the project duration is given by the critical path, what is the **probability** that the project will finish on a date corresponding to this and to other different durations?
  Assume, for instance, that the mean (average, see Sect. 9.1) for duration is 23.8 months.
  The probability that the project finishes on a date corresponding to this duration is 50 %, that is, it may be finished before or after, since it is an average.
  Say, for instance, that we still have 26 months ahead of us up to the desired completion date, what will the probability then be? Obviously, it will be more than 50 %, but how much? This answer is found using the normal probability distribution, which determines it is 75 %.
- If we are not happy with this probability, the question is now: How much **time** do we need from now to have at least 95 % probability? Obviously, it will be more than 26 months, but how much more? This answer is found using the normal probability distribution.

The same applies to costs, that is:

- What is the **probability** that total cost will be under budget?
  Assume, for instance, that our original budget is 36,901,777 Euros.
  The probability that the final cost at completion is under or above that value is 50 %, that is, it may cost less or more (unless we have firm prices for the largest items).

If, for instance, the available funds for this project are 38,589,000 Euros, what is the probability of completing the project under this budget? Obviously, it will be more than 50 %, but how much more? Say, for instance, that, with that budget, we get a probability of 71 %, figure computed using the normal probability distribution.

- What would be the **cost** for a given probability of compliance?
  If we are not happy with this probability, the question is now: What will be the **amount of funds** that we need in order to have at least 95 % probability? Obviously, it will be more than 38,589,000 Euros, but how much more? This answer is found using the normal probability distribution.

As can be seen, this powerful tool addresses uncertainty, and this fact allows us to compute realistic durations and attainable budgets. The model is more accurate than CPM, however, as valuable as this method is, results are the consequence of using only one set of numbers out of hundreds of possible sets.

Consequently, even when considering probabilistic values, it still is a static model, and in reality, we need a dynamic model, that is, one considering other alternative values as well. This is the Monte Carlo model.

2.4 Monte Carlo Approach

The Monte Carlo model was developed by Stanislaw Ulam while working on the Manhattan Project (The Atomic Bomb Project) for the US government. The methodology was kept a secret and was first published in 1949, after the end of WWII. Since then, it has had multiple applications in every scientific field.

Characteristics:

- If applied to networks, it is used to determine total probabilistic duration for the whole project, and can also be applied to determine final costs.
- Employs a statistical approach, that is, it assumes that durations are of a probabilistic nature, but in an unlimited scope, since it considers a large number of sets of values per task (between 500 and 1,000, but could be many more).
- Uses random numbers to compute mean durations.
- Utilizes any probability distribution.

Advantages:

- Very well-known methodology, useful in many areas of science.
- There are several reliable pieces of Monte Carlo software, combined with an Excel® spreadsheet.
- Introduces uncertainty in full by using random numbers, which greatly increase reliability of results.
- Allows for determining probability of criticality for non-critical tasks, that is, non-critical tasks that can become critical.

Disadvantages:

- Not very well known in the Project Management environment, perhaps because of its probabilistic nature.
- More complex than other methods.

MC works with the same initial three points estimates and β-probabilities distribution as PERT does, or else with other distributions. However, the difference lies in its performance of hundreds or even thousands of runs or iterations of the same formulas (for mean and standard deviation (Sect. 9.1)), choosing values generated at random from the same interval for each run. Each run result is saved, and at the end of all runs, the model shows the average value or mean (μ) and the average standard deviation (σ). It is understood that when the same formulas are calculated over and over, hundreds of times and each time with different values, the resulting mean mirrors reality more faithfully, since hundreds of different scenarios are contemplated, and not only one, as with PERT.

In addition, each task may follow any probability distribution and not necessarily be the same for all of them, that is, a task can have a certain distribution, while others can have the same or another. It is then understandable that this method is by far more reliable than both CPM and PERT, since it allows for managing uncertainties that are the very essence of risk, and for this reason, RM identifies with Monte Carlo by a large measure.

Monte Carlo is not only used for finding the probable duration and cost of a project. It has been applied to numerous disciplines, and it gives good results, provided that the mathematical model on which it works (for instance, a distribution formula for determining duration means) is correctly expressed; this model must incorporate all the variables related to the case under analysis, otherwise it cannot properly represent the phenomenon. A very simple model for another type of calculation using Monte Carlo can be seen in Sect. 5.3.1. See Savvides (1994) for an excellent analysis of forecasting models for Monte Carlo.

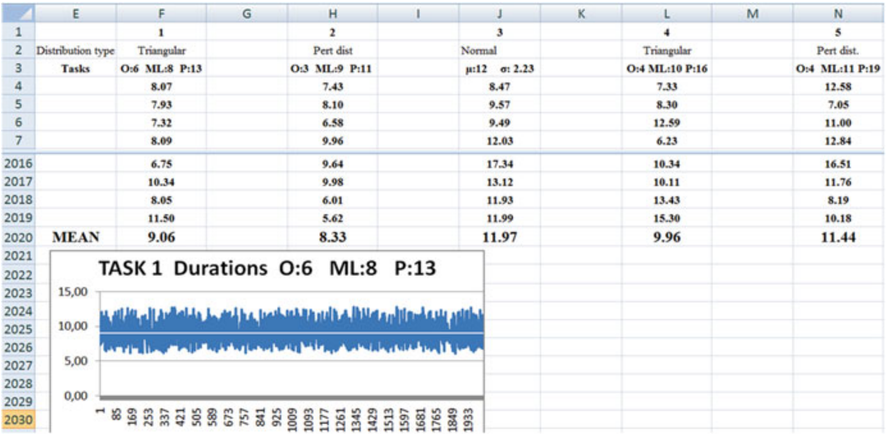
2.4.1 Example for Illustrating How the Monte Carlo Model Works

This is an elemental example to show the basic principles under which Monte Carlo works. Risk software is usually needed; in this example, the RiskAMP® is used.

Assume that a critical path is formed by five tasks, 1, 2, 3, 4 and 5, as shown in Fig. 2.2, with best estimate durations (ML) of 8, 9, 12, 10 and 11 days, respectively.

Let us now use Monte Carlo for task number 1. If the risk software is loaded, you will see 'Monte Carlo' in the bar menu.

1. Open an Excel spreadsheet, select any cell (in this case F4), and go to the top bar menu for Monte Carlo. Press it and you will be directed to '*Insert Random Distribution*'.



	E	F	G	H	I	J	K	L	M	N
1		1		2		3		4		5
2	Distribution type	Triangular		Pert dist		Normal		Triangular		Pert dist.
3	Tasks	O:6 ML:8 P:13		O:3 ML:9 P:11		µ:12 σ: 2.23		O:4 ML:10 P:16		O:4 ML:11 P:19
4		8.07		7.43		8.47		7.33		12.58
5		7.93		8.10		9.57		8.30		7.05
6		7.32		6.58		9.49		12.59		11.00
7		8.09		9.96		12.03		6.23		12.84
2016		6.75		9.64		17.34		10.34		16.51
2017		10.34		9.98		13.12		10.11		11.76
2018		8.05		6.01		11.93		13.43		8.19
2019		11.50		5.62		11.99		15.30		10.18
2020	MEAN	9.06		8.33		11.97		9.96		11.44

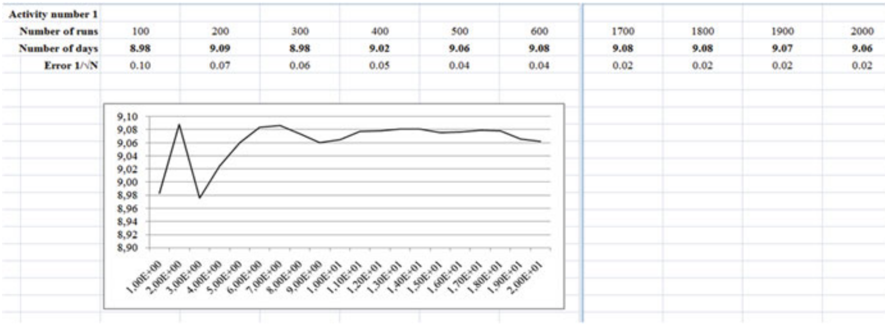
Fig. 2.2 Screen display of Excel spreadsheet with example data and results

2. The software will ask for data, that is, durations. Insert them (in this case O:6, ML: 8, P:13); the software will immediately show the mean (8.07) for that task and distribution.
3. Copy this cell for the number of runs or iterations wanted. In this case, we select 2000; the software will again compute the means using a different random number each time.
4. Look at the final average (9.06 days) in cell F2020.
5. Repeat procedure from step (2) on for tasks 2, 3, 4 and 5. Notice that they have different distributions. Find final results on corresponding cells in row 2020.
6. Add all these values up. Then, $9.06 + 8.33 + 11.97 + 9.96 + 11.44 = 50.76 \approx 51$ days for the whole project.

Therefore, for each task one at a time, the software produced a random number between 0 and 1, and using that number, along with the corresponding probability distribution formula, computed the mean and saved the result. That was for one run or iteration; the software repeated it 1999 times and finally found the average for each task.

At the bottom of Fig. 2.2, the 2000 results for task number 1 are shown; notice that all values are between the optimistic duration of 6 days and the pessimistic duration of 13 days. The white horizontal line is the trend line for the complete set of values.

Figure 2.3 provides another type of information. Notice the curve; it has been obtained computing the mean for different numbers of iterations for task 1, starting with 100, 200, 300,………………..up to 2,000. Notice how the mean is converging at a 'final' value of 9.06.



Activity number 1										
Number of runs	100	200	300	400	500	600	1700	1800	1900	2000
Number of days	8.98	9.09	8.98	9.02	9.06	9.08	9.08	9.08	9.07	9.06
Error 1/√N	0.10	0.07	0.06	0.05	0.04	0.04	0.02	0.02	0.02	0.02

Fig. 2.3 Curve showing the convergence to a steady value of the mean

This shows how errors are decreasing with the number of iterations. Errors are inversely proportional to the square root of the quantity of iterations (N) $\left(\text{Error} = \frac{1}{\sqrt{N}}\right)$. These values are shown in the first row of the table where it can be seen that the error starts at 0.10 and finishes at 0.02.

2.5 Buffering

Figure 2.4 depicts a task with estimated duration of 9 days (in solid black) (this is the CPM approach). In PERT, the estimates give this task an optimistic duration of 7 days, a most likely duration of 9 days, and a pessimistic duration of 12 days, and assume that it follows a β-Pert distribution.

In this case, the mean is: $(7+4\times 9+12)/6 = 9.17$ days

In the Monte Carlo approach, we find after 500 iterations that the mean is 9.77 days.

In both PERT and Monte Carlo, these values indicate that there is only a 50 % probability of finishing the job within those durations (given, respectively, by the left area of the normal probability distribution curve). Obviously, this is not enough, since we need at least, say, 95 % probability that the task will be finished in the stipulated time. If we do the calculations through Monte Carlo, we could find, for instance, that to have that probability, we need 11.2 days. The shaded area below the curve gives the 95 % probability, while, in abscises, it is found that it corresponds to 11.2 days. Therefore, there is a buffer of $11.2 - 9.77 = 1.43$ days.

It can be seen that a buffer forms part of the task duration, since the total duration of a task in reality is the summation of the estimated average plus uncertainty, the last being the buffer. Thus, task duration is 11.2 days.

If during an update, one finds that the risk in this critical task did not take place and that the task finished in 9 days, that additional time or buffer is added to the end of the project to be used later, if necessary. Observe that the buffer is not an arbitrary quantity but the result of a probabilistic computation that considers uncertainty.

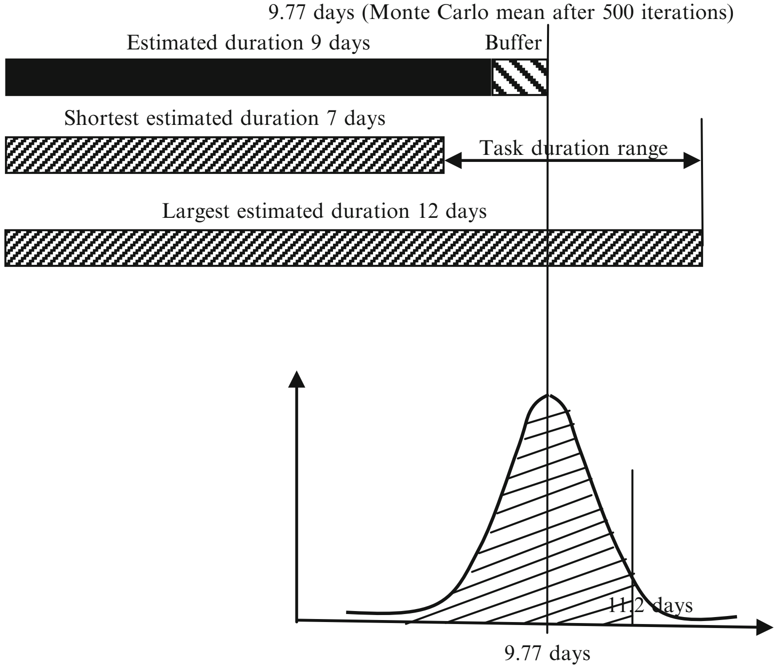


Fig. 2.4 Task duration range and mean for 95 % of confidence level

2.6 Tasks Cost Estimate

Project costs are based on the latest estimates from vendors, tables with unit prices for construction tasks, estimator expertise, regulations about wages and salaries, etc., with, if possible, all of them referred to work packages from the Work Breakdown Schedule (WBS) (see Sects. 2.12 and 5.9.2) built in line with the Control Account Plan (CAP). This estimate is called the Baseline Cost Estimate and does not include contingencies, which are often calculated without too much information and may be biased.

Naturally, from the time of estimate to project execution time, there is a period that can distort the values assigned owing to many different circumstances, such as inflation, wages updates, new prices for raw materials, transportation increases, etc. Therefore, this baseline cost of estimate is affected by price variations, more often than not positive increases, which modify the initial value. Consequently, in reality, costs are composed of two figures, one the base case as defined above and the other cost, due to uncertainty or risk component (Gabel 2010).

We can apply the same concept here as explained for durations, that is, considering that the cost estimate is subject to a variation that normally is different for each task. Thus, a task for the construction of a concrete foundation could be, for instance, between minus 5 % and plus 10 % of the estimated cost, depending on the company executing the work (of course, we refer to pre-bid estimates). Same as with durations, each task cost follows a probability distribution that could be particular for each one; we can then apply Monte Carlo to each one of these costs and compute a mean value.

Not all purchases are made prior to project initiation, because some of them can take place in a couple of months after the project starts, and according to a purchasing schedule and availability of funds. However, the initial budget has to consider these future acquisitions in order to prepare the project budget. In these cases, as well as in updates, it is possible to work with a baseline price and then consider that there will most probably be an increase due to the above-mentioned factors. In this case, it is convenient to work with a β-probability distribution and considering that there will be increases rather than decreases, so the variation range could be about, say, 5 % and 8 % above present day prices. Running Monte Carlo, the result will indicate the most probable increase.

In a large project, there could be thousands of tasks, each one with its own cost, and it would be very hard and time-consuming to perform this analysis for each one of them; as a result, there is a need to select which costs are significant enough to work with. However, there is no corresponding tool or guide for costs like the critical path one that shows the critical activities that have a direct incidence on the duration of the project, and for that reason, are the most significant. Nonetheless, another tool is proposed here that can be used to select tasks considering cost magnitudes; it is the Pareto Principle, which says that about 20 % of items are responsible for 80 % of total consequences, in this case, total project cost. Therefore, we can use it to select 20 % of activities or tasks, the accumulated costs of which account for 80 % of the total project cost.

Once these selected costs are identified, the procedure is similar to that explained for durations. Consequently, we can assign a variation for each cost, establish the probability distribution corresponding to this cost, and then use Monte Carlo. The difference between this resulting value and the original cost estimate (from the baseline) is then added to this original baseline cost as a buffer. When updating, if the actual cost was below the estimate plus the buffer, then the buffer (which in reality is only a foresight or precaution) can be recovered, since it has not been used and saved as another buffer, if need arises. Same as with durations, the cost buffer is not an arbitrary increase, but a result of a probabilistic computation. However, it can possibly happen that the buffer cost is not recoverable, since it has already been spent, as in the case of building a safety structure that, in reality, was not needed, and in this case, it is considered a loss.

Regarding selection of the 'adequate' probability distribution, there are cases in which the nature of the cost clearly calls for a determined one. For instance, if the cost will be subject to a series of circumstance about which there is much uncertainty, or unforeseen circumstances, or out-of-company-control factors, such as inflation, wage agreement with unions, weather, etc., the most acceptable probability distribution will likely be the normal or Gauss. In other cases, in which there is suspicion that there will be increases and with very little chance of a decrease in the actual cost, the suggested β-probability distribution would likely be the best choice. Nevertheless, experience shows that, in general, the chosen probability distribution for a cost does not produce many different values when compared with others.

2.7 Social Impacts Generated by the Project

Social impacts usually have a significant importance on a project in the sense that people can endorse, reject, facilitate, hamper or impede it. Therefore, not considering what people say, feel, complain or argue about, or dismissing their claims or reasons as not important and easily handled may have very serious consequences, which can even lead to halting a multimillion-Euro project, or ending up in court. There are many examples around the world of projects that could not even start or that were halted after millions had been spent because of public opposition.

Social impacts may also and usually do have positive impacts, such as creation of perhaps hundreds of direct jobs and thousands of jobs in indirect work. However, in spite of that, there could be negative aspects that people consider are paramount over the positive ones. As an example, assume that the City Hall of a densely populated area decides to install a domestic garbage incinerator in that area. How do you think people will react to that plan? Naturally, the project will generate new direct and indirect work, but also noise, heavy truck traffic, odours and air contamination. But the most damaging aspect will probably be the decrease in value of nearby real estate properties, thus directly hurting the neighborhood.

The City Hall in charge of the project may hear public complaints and seek another solution, or decide to ignore them and go ahead with the project. Is there a risk here? Of course, there is a risk, and this has to be properly pondered and evaluated in this early stage of the project. The risk may come from people threatening to enact different opposition plans, such as citizens revolting against the project, or picketing access roads and obstructing construction, or going to court, or sabotaging the project (as has happened with some pipelines), or asking for monetary compensation for the devaluation of their properties, etc.

2.8 Project Safety

This section does not refer to personnel safety, because as extremely important as that is, there are, in fact, stringent regulations regarding safety, including mandatory certifications on courses taken by working personnel, and therefore, widely known in the industry, meaning risk is minimal. This section deals instead with safety regarding the project itself, that is, with circumstances, events or features that can put the very existence of the project in danger. There are many examples of clearly stated and known threats, which, for whatever reasons, were set aside or considered unimportant, and that lead to catastrophes. For instance, threats that were not taken seriously, such as in the construction of the Vajont Dam project in Italy. Here, an announced risk took effect and caused the loss of thousands of lives and funds sunken forever without any return. Another example of announced threats is the Challenger disaster that took the lives of seven astronauts, as well as halting NASA programs and projects for several years.

There are risks in every project, and it is subsequently necessary to know them and examine the way to avoid or at least remediate or mitigate them. Naturally, it is also fundamental to assess the seriousness of a potential risk and make a decision about accepting it or not, otherwise, it could happen that the remediation cost is higher than the cost of the consequence produced by the risky event.

2.9 Project Quality

Where is the risk here?

In not satisfying a client's expectations regarding aspects such as buildings finishing, equipment performance, material resistance, quality painting, uneven sidings in buildings, elevators not properly working, pipes breaking or with insufficient capacity, flooding in strong rain because of poorly designed drains, air conditioning not working properly, etc.

As an example, we could consider a project to manufacture a mass-consumed item, such as a new portable phone. There is strong competition in this field, and quality, endurance, versatility, etc., are primary aspects to take into account. The risk could arise due to poor craftsmanship or because the device does not comply efficiently with the purpose for which it was designed; consequently, a large investment can go down the drain. If there is a threat, one way to avoid or reduce it is by conducting exhaustive tests for durability and reliability; this, of course, costs money, but it is one way to avoid courting disaster.

2.10 Project Communications

Communications have always been an important part of any project, but this significance has increased at present, because larger projects mean that many more people than before are involved. It is often found that a large project has an architectural design made in a country thousands of kilometres away, and employs people coming from very different countries and speaking many languages (remember the construction of the Tower of Babel!). An actual example is the Burj Khalifa (also known as the Burj Dubai tower) in Dubai. A Chicago firm designed it, it was built by a South Korean company as the main contractor, along with companies from Belgium and the United Arab Emirates, developed by an Emirates company, and built with materials and workers from half a dozen different countries. There is no doubt that language barriers were considered prior to its initiation; however, this is not the most important risk in large projects. We are referring here to communications, even when speaking the same language, between the different areas of a firm, or between a consulting company in charge of the management and contractors, suppliers and very often with owners and stakeholders, even if they are in the same location or building.

This last aspect in particular needs to be carefully examined; if there is prior experience of difficulties (for whatever reason) in communication with owner or stakeholders, there is a risk here, because it can cause delays, over costs and many problems and frictions. For this reason, it is necessary to establish a clear schedule of meetings with the owner and stakeholders, agreeing upon the number of days for responses or queries posed by any party. However, even if a risk is detected and communicated, it is not always perceived as relevant, most probably due to ignorance. Kusch (2010) analyzes this seldom-found subject in the literature.

The contractor or consulting firm needs to know who the stakeholders are, as well as the areas of responsibility level of authority and decision-making ability of each one. The contractor, on his part, usually has a sole person responsible, the project director or the project manager. In addition, within the construction company or the consulting firm, there must be a communications system in which each department receives information about what the other departments do, naturally respecting the principle of 'need to know'.

Regarding a manufacturing company, many projects are plagued with misunderstandings, errors, or work superposition. It may happen, for instance, that a department say, accounting, which has the right to know about inflow of raw materials and outflow from the warehouse does not receive this information, because of jealousy, lack of communications, or because somebody in the warehouse thinks that they do not have to inform anybody about the movement of materials because 'this is his/her territory'. Or perhaps it is the production department which is kept in the dark by sales and marketing about a high percentage of defective products returned by clients.

Nowadays, there are tools to put order into this chaos; the system is called Enterprise Resources Planning (ERP) (Sect. 5.22). Since it is expensive, the company, owner or developer must assess the convenience of its installation; that is, there is risk because of lack of communication, and ERP is one of the many ways to avoid the risk, naturally, at a cost. However, there is also a risk in installing a costly system if the company does not need it or is not technically or structurally prepared for its utilization, considering that a new system can bring confusion and chaos if not properly managed or understood.

2.11 External Factors That Can Affect Project

This is one of the most difficult areas, since a company does not have any control or capacity to modify events. There are many standard factors affecting every project, such as weather, inflation, political decisions, vendors' delays, transportation, new custom or import regulations, etc. Naturally, the risk lies in how to manage these uncertain events, and the answer is, again, not to assume a single value for inflation or weather or import duties, but to determine them by using a range of possible outcomes, meaning we are once again in Monte Carlo. Section 5.7.1 proposes an example of how to deal with this kind of nearly-impossible-to-foresee event.

2.12 Work Breakdown Structure (WBS)

This is a very well-known and widely used methodology in project management, and thus, it does not need any explanation. Very briefly, it consists of breaking down a project into its components, starting at the most elemental level, for instance, parts, concrete, bricks, etc., according to the Control Account Plan (CAP, see Sect. 1.1). These elements are assembled under the name 'work packages' (see application in Sect. 5.9.2).

2.13 Environmental Impact Generated by the Project

There are many circumstances in which there are environmental risks for projects, such as:

- Not considering environmental limits for discharges into bodies of water, soil and air.
- Not enough consideration given to alterations of an ecosystem.
- Dismissing the emigration of wildlife because of noise as insignificant.
- Not enough sound barriers in a new highway.
- No consideration of appropriate drainage in an area that actually serves as a basin drainage, and which will be interrupted by the project.
- Not enough rehabilitation or damage reduction when a lake – behind a dam to be built – floods a forest or part of it.
- Neglect in considering construction of a structure or device for fish spawning upriver, an actual activity, which will be stopped by the construction of a dam.

Normally, all projects of a certain size must endure an environmental impact assessment by a federal or provincial environmental agency, which must approve it; therefore, these aspects will most probably be detected by the agency or, more rationally, identified by the project team because of their obvious impacts.

However, there are impacts that are not so easy to identify, as the following case illustrates.

2.13.1 Case Study – Environmental Risk – Power Plant Construction

Project: Coal power house construction

Consider a company that proposes building a coal-burning steam power plant on the shore of a deep-water lake. The plant will take cold water from the lake for cooling steam condensers and discharge it back into the lake without any contamination and in the same volume as taken. All other environmental aspects from the power plant seem to be addressed, that is, emission of SO_2, NO_X, particulates, etc., which will be within environmental limits, thanks to expensive installed devices such as fluidized bed boilers, cyclones and electrostatic gas removers, and therefore, it is assumed that the project is environmentally risk-free.

In one of the last brainstorming meetings, John Little, the PM, expresses his satisfaction with remarks that everything has been addressed environmental-wise, and as a consequence, the project will get approved with flying colours by the environmental agency in its first reading. However, Edward Morrison, one of the analysts, says that he is not so sure of that, because there is at least one aspect that was not considered and is related to the use of water from the lake. This assertion surprises John, who asks Edward to explain to which aspect he is referring, since the water returns to the lake exactly as taken.

Edward: ‘*Not exactly. We are taking cold water and returning it hot from condensers*’.

John: ‘*So? We are not altering the quality of water just by discharging it at a warmer temperature*’.

Edward: ‘*I have done some research and I understand that, in fact, we are altering the water quality. It is not due to pollutants in the water, however; we are collecting cold water and returning it hot, and this change in temperature modifies the fish habitat, provoking their migration, and also helps eutrophication favouring algae growth. By the way, I think that we should review our water intake, because the way it is now will produce fish death in large quantities when they are driven to the intake grate by pump suction*’.

John: ‘*Yes, you could be right; contact the agency about this*’.

2.13.1.1 Conclusion

Edward contacted the environmental agency, which confirmed his concern and suggested reviewing the system before submitting the proposal, because otherwise it would be rejected on those same grounds. Consequently, the company contracted an environmental consultant to perform a study about the effect of hot water diffusion in cold water, and because of this study, the expert advised installing the hot water pipe far from the shore and discharging at a minimum of 20 m down the water surface, where the water was colder. This cost the company a good deal of money but avoided the risk.

2.14 Interference Risk

Interference risks develop when the project, during its construction stage, may interfere with existing operations or constructions related or not to the new project. It is common in urban environments where work must be interrupted during excavation for foundations or for building underground premises, because it encounters archaeological rests, cemeteries, ancient tunnels, or, more frequently, piping and cables the existence of which was not known. For instance, in one project, the digging bucket of a backhoe broke a water trunk the existence of which had been ignored and flooded the excavation. Even when the water discharge was stopped by the City Hall Water Department, there was damage to the project involving delays and unexpected repair costs for relocating a new trunk to replace the damaged one.

On top of that, City Hall fined the contractor because the incident caused an extensive populated area to be without water for nearly 24 h. Obviously, during planning, no risk of this nature was considered, although City Hall warned the contractor that, in this old part of the city, there were no reliable drawings regarding location of underground water or gas piping.

In another undertaking consisting of enlarging an existing underground hydro electrical plant in full operation, there was need to blast the adjacent rock to build the new machine room. There was an evident risk here, since the blasting, because of proximity to the operating turbines, could misalign them, with very serious consequences. Since it was not technically possible to stop the turbines (they were generating electricity for an aluminum smelter), the contractor acknowledged the risk and designed a more costly blasting process, consisting of small blasts that produced no effect in the running turbines. However, of course, this decision was based on geological studies, by contracting expert advice for this kind of blasting, and by installing sensors to detect vibrations in the operating room. Fortunately, the procedure worked well and without any consequences to the working units.

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Chapter 3
Probabilities in Risk Management

Abstract A project is generally a complex undertaking in which most things are uncertain (durations, costs, project and suppliers performance, weather, soil geology, public reaction, etc.), and thus, risk permeates everything. Risk is closely related to uncertainty, and the latter with probabilities and distributions the conceptual aspects of which are explained in Chap. 9. It is inconceivable to address risk without considering probabilities of occurrence, and the measures that must be taken to prevent or mitigate risk; in that sense, the 'buffer' concept is introduced. In Chap. 2, a comparison was mentioned between CPM, PERT and MC; now, Chap. 3 proposes a case for numerically demonstrating the advantage of working with probabilities using a network and its critical path for durations and costs; it is here in which the working of MC is explained in detail, using an Excel spreadsheet with commercial software. The chapter moves on to discrete distributions, and explains the mathematical expression of risk as the product of a probability of the occurrence of a threat and the impact that it can produce on human lives, assets, land, etc.; in other words, it puts a value to risk. The chapter finishes with the use of dedicated software and provides information about the companies that provide it.

Keywords Uncertainty • Probability distribution • Central limit theorem • Normal distribution • Monte Carl • Buffers

3.1 Background Information

Risk is always related to uncertainty, but it is obvious that, if there is certainty concerning a duration or a cost, there is no risk involved in this aspect. Nonetheless, even in this last case regarding cost or duration, there are other factors that, while not related to them whatsoever, can still have significant influence. For instance, there could be a fixed price for cost of equipment; therefore, there should be no surprises in this regard. However, what happens if the equipment suffers some

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*, DOI 10.1007/978-3-319-05251-9_3,

damage during transportation to the job site? Even if it is insured, the insurance does not always cover everything, and even then, parts of the equipment may not be insured, to say nothing of delays in delivering goods produced by the equipment and the corresponding consequences for sales.

Therefore, the equipment may suffer damages not covered, which have to be fixed at the owner's expense, thus increasing the equipment cost. These external factors are impossible to predict. Because of this, in this chapter, we introduce uncertainty into the system by using probabilities. Complete information on risk analysis for high technology can be seen in Bedford and Cooke (2001).

3.2 Using Program Evaluation and Review Technique (PERT)

PERT was likely the first application of probabilities in Project Management. This method considers three probable estimates for durations for each task called, respectively, the most optimistic duration (O), or the smallest value, the most pessimistic duration (P), or the largest value, and a most likely value (ML) between the two. PERT applies a probability distribution (see Sect. 9.2.2) called the β-Pert distribution and computes an average value for the mean using its mathematical formula; in this way, PERT considers uncertainty for each task. When there are many tasks, such as in large projects, with any precedence and even in parallel, the final result or duration of the critical path is the summation of the means, and its variance is the summation of the variances of all tasks. In this manner, the final duration considers the average duration of each task and also its variance. This fact allows for probabilistically determining the chances that, given a certain time to complete a project, it will be finished on time. Conversely, if a certain probability of compliance is required, it is possible to compute the span of time needed to complete the project, either by starting earlier or by finishing later, if this is acceptable or possible.

The same case is used in three different methods: CPM, PERT and Monte Carlo, in order to compare results.

Consider the project network depicted in Fig. 3.1. We used CPM here; therefore, task durations are fixed and its critical path determines a total duration of 24 days.

Total duration is $8+3+9+4=24$ days.

Notice that only one value is used, without any allowance for variation, and as Rodger and Petch (1999) say, *"….. a number on its own is half the picture; to fully understand the result, it is necessary to have an estimate of the uncertainty related to that number"*. For this reason, we now examine PERT.

As mentioned, PERT works with a three point estimate for each task, and these values for the same example are depicted in Table 3.1 for tasks on the critical path (see Fig. 3.2).

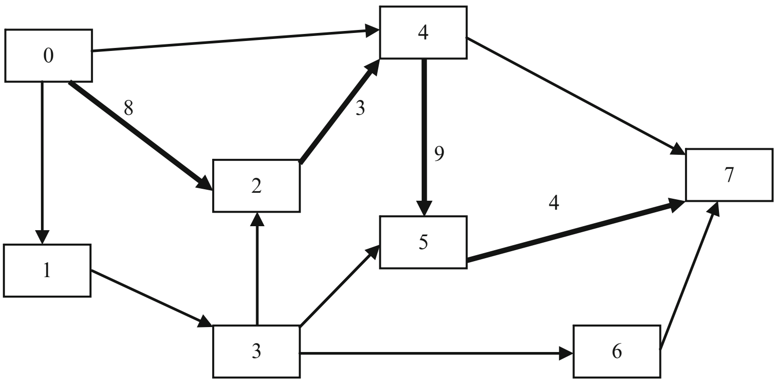

Fig. 3.1 CPM network using deterministic values for durations

Table 3.1 Optimistic, most likely and pessimistic durations for critical tasks

	Activities on critical path			
	0–2	2–4	4–5	5–7
Optimistic estimate (O)	6	3	8	2
Most likely estimate (ML)	8	3	9	4
Pessimistic estimate (P)	15	4	13	11

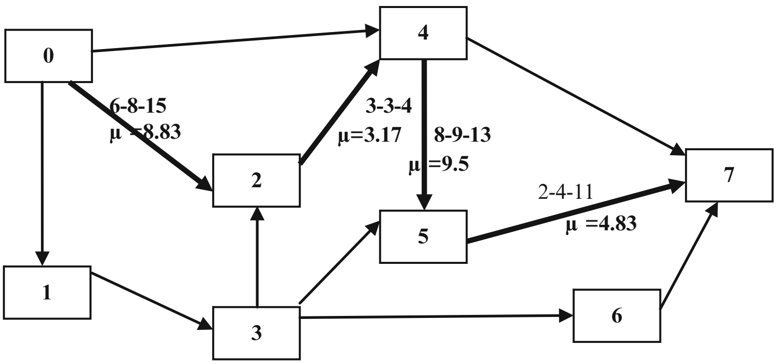

Fig. 3.2 Network using probabilistic values for durations

Steps:

1. Calculate mean and standard deviation for each task using corresponding β-Pert distribution formulas.
   Mean for each task:

$$\frac{(O + 4 * ML + P)}{6} \tag{3.1}$$

Table 3.2 Results applying Pert

	Activities on critical path				
	0–2	2–4	4–5	5–7	Total (days)
β-Pert mean (formula (3-1) (μ)	8.83	3.17	9.5	4.83	26.33
β-Pert standard deviation (formula 3-2) (σ)	1.50	0.17	0.83	1.5	4.00

Standard deviation for each task:

$$\frac{(P-O)}{6} \tag{3.2}$$

Table 3.2 shows result.
A theorem (Central Limit Theorem) establishes that means and variances of random variables (such as the durations of each task) follow a normal probability distribution. When this theorem is applied to random durations **on the critical path**, the total duration is assumed to be normally distributed, with mean (μ) being the sum of the means and with variance (σ^2) as sum of the variances. This fact is extremely important, because once these two values are known, it is possible to answer a series of questions related to uncertainty.

Consequently, the project has only a 50 % probability of finishing in $\mu_{total}=8.83+3.17+9.5+4.83=26.33$ days, that is, it could finish earlier or later. The basic question then becomes: how many days does the project need to have a 95 % probability of completion?

2. Since it is deemed necessary to have a 95 % probability, we must go to the probabilistic distribution table (Table 9.1) that gives the probabilistic values below the normal distribution curve. Enter 0.95 (identified in the Table with an oval), and check that the corresponding z score (See Sect. 9.2.6) is z = 1.65.
3. To determine number of days (‘x’), use formula (3.3)

$$x = z.\sigma + \mu \tag{3.3}$$

x: (The number of days we want to determine to have a 95 % probability)
z (z-score) = 1.65
μ (Mean) = 26.33 days
σ (Standard deviation) = 4 days

Then, we will need: $x = 1.65 \times 4 + 26.33 = 32.93$ days ≅ 33 days

4. Assume, for instance, that we only have 30 days left for the job. The question is, considering this available time, what will be the probability of completion?
We need to find the z-score, and for that, use this formula, which is also in Sect. 9.2.6.

$$z = \frac{(x-\mu)}{\sigma} \tag{9.1}$$

Where:
z = Score which we want to determine
x = 30
μ = 26.33
σ = 4

$$z = \frac{(30 - 26.33)}{4} = 0.9175$$

Enter this value into the normal distribution table and find that z = 0.8212 ≅ 82 %.

Therefore, because we do not have enough time, the probability of completion in 30 days is only 82 %, compared with the 95 % we could get if we were able to use 33 days.

3.3 Using the Monte Carlo Model

With PERT, we have used a more realistic approach considering uncertainty by establishing a range of possible values for each task and getting not a project duration or finishing date but different durations based on probabilities. However, that is not enough, because what PERT uses is just one of the hundreds or even thousands of possible scenarios, and because of that, there are other scenarios which could represent reality more accurately, which, however, are not examined.

The Monte Carlo simulation is a quantitative process based on a simple fact; since there is a range of values for each task, it assigns random values within each range, and then calculates the mean using the corresponding formula for the selected distribution in a way similar to PERT. However, this operation is conducted hundreds of times (instead of the one time, as with PERT), and the output reflects a value which is much more accurate than the result from PERT. Thus, if the range for a task varies between, say, 4 and 7 days with a most likely value of 5, Monte Carlo generates random numbers between 4 and 7, and for each run, determines a mean using the β-Pert distribution formula (3.1), as well as a standard deviation by using formula (3.2). The 500 or more runs for this task allows for the drawing of a probability distribution curve for said task. In this way, the model can build not one unique result, but rather a family of results which produces an average. We can make many runs, compare results, and stop when they are converging to a most probable value.

Each task may have a different distribution according to its nature. For instance, a task related to inflation or demand can use a normal distribution, while another related to Project Management can use β-Pert, or perhaps an exponential distribution in a task regarding the weather, and so on, and using their corresponding formulas. Risk software normally has a good selection of these distributions with their typical applications, for instance, Crystal Ball (by Oracle®) offers a gallery of

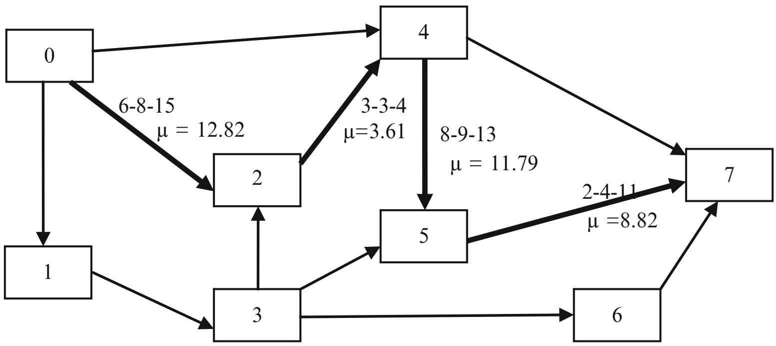

Fig. 3.3 Network with mean values from Monte Carlo for durations

Table 3.3 Values obtained using Monte Carlo model

	Activities on critical path				
	0–2	2–4	4–5	5–7	Total (days)
Using Monte Carlo and β-Pert probability distribution for all tasks	12.82	3.61	11.79	8.82	37.04

22 distributions, most of them continuous (that is, when the variable can take any value in a range interval), but there are also discrete distributions.

For more easy-to-understand and detailed information about the Monte Carlo model, its characteristics and resolution with Crystal Ball® software, consult Rodger and Petch (1999). To illustrate the method, we are using the same example depicted in Fig. 3.3 and applying Monte Carlo only to the critical path (of course, in an actual case, it is necessary to apply the method to all tasks, because it could be that some non-critical tasks become critical, and that some critical tasks are no longer in that category).

Consequently, we consider in this example tasks 0–2, 2–4, 4–5, 5–7, and assume that the same probability distribution apply to them all; we are utilizing, for this exercise, Crystal Ball® software. We are also using the same Optimistic, Most Likely and Pessimistic limits as adopted in the PERT exercise and detailed in Table 3.1. After 500 runs or iterations, and for a 95 % confidence level, the following values appear (see Table 3.3).

That is, the respective durations should be 12.82–3.61–11.79 and 8.82 days, which added up give a total of 37.04 days, for a 95 % probability of compliance (see Fig. 3.3).

Crystal Ball software can also indicate for a non-critical task its probability of being on the critical path, and this is important, since it indicates sub-critical activities that need to be controlled.

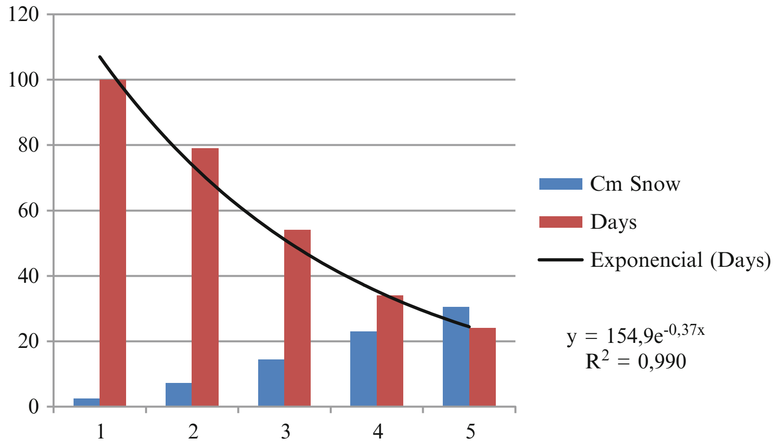

Fig. 3.4 Number of days that registered a certain amount of snow (in cm)

3.4 Discrete Distributions

A discrete distribution is formed by frequencies that can only take an integer value (for instance, number of people arriving every day at a doctor's office, or manhours in a job, or number of telephone calls between two cities, etc.), that is, without fractional or decimal values between two consecutives frequencies. Figure 3.4 shows a discrete distribution related to the centimetres of snow from a snowfall and the corresponding number of days that each quantity registered.

The trend of this distribution is an exponential curve, which is the frontier for maximum values. Once the format of the probability distribution has been determined and its corresponding equation found (it is automatically done in Excel), it can be used to compute the density function that better fits, and from there, the corresponding values for the future can be estimated.

3.5 Method Comparison

Since we are using the same example and with the same basic values (that is, probable durations), we can compare results (Table 3.4).

Naturally, the comparison regarding CPM is relative, since this method does not use probabilities as the other two do, and notice that, because CPM works with deterministic values, the result reflects this circumstance. However, since these values are normally averages based on past experiences and dedicated budgeting tables and software, in reality, we can consider that the total result has only a probability of 50 %, when in the other two methods, the probability is 95 %, which in part accounts for the difference in durations.

Table 3.4 Comparison of results with three different methods for estimating durations

Method	Reliability on estimates	Total duration	Difference with CPM	Probability of compliance (%)
CPM	One deterministic value (average duration)	24 days		50
PERT	Three estimates	33 days	37.5 % more time than CPM	95
MONTE CARLO	Three estimates and 500 iterations	37 days	54 % more time than CPM	95

What is certain is that the probability methods (PERT and Monte Carlo) take into account uncertainty while CPM does not, and this is a paramount concept, because projects do not always have certain values for durations, and even if some of them are certain, there are also unexpected and unpredicted events that influence the result. However, this does not mean that probabilistic methods are 100 % risk free, because they do not consider all possible uncertainties or unpredicted effects, but at least offer a way to tackle some of them.

There have been studies on numerous projects using only CPM indicating that about 66 % are delayed, which in a sense proves the need for using tools that are more sophisticated. Naturally, it does not mean than CPM should be abandoned, quite the opposite, because for planning, scheduling and cost, it offers undeniable advantages; instead, what is proposed here is that CPM should be complemented with other methodologies, such as PERT, Risk Analysis and Earned Value Analysis.

3.6 Analysis of Final Result

Assume a critical task with estimated duration of 45 days; if there is a delay in this task, it will replicate in the duration of the whole project, in other words, producing an impact that can have different degrees of severity depending on the nature of the project and expectations. Say, for instance, that this impact could be very serious since there is no allowance whatsoever for delays, and we then evaluate it with a 100 % severity, that is, maximum severity.

If the probability of occurrence is evaluated at 20 %, then the corresponding risk will be the product of this probability by the impact, that is:

$$R = 0.20 \times 1 = 0.20 = 20\%.$$

Since the task has a duration of 45 days, the effect of the inherent risk will be to increase this duration by 20 %. With this data, it is then logical to increase the duration of the task (time buffer) by $45 \times 0.2 = 9$ days, and the total duration of the task will then be $45 + 9 = 54$ days, which means that the task should start 9 days earlier than scheduled.

If there is another task that, albeit non-critical, is considered significant to the project duration (for instance, an important task that finishes in a node or gate where there is a critical task, or because a sub-critical task precedes many others), the computation is similar, but the impact will probably not be 100 %, but perhaps 75 %.

In this case, if the task has, for instance, a duration of 90 days and there is a 10 % probability of delay, the calculation gives:

$$R = 0.10 \times 0.75 = 0.075.$$

The buffer will be:

$$90 \times 0.075 = 6.75 \text{ days}$$

and the new total duration will be:

$$90 + 6.75 = 96.75 \text{ days.}$$

This could mean starting the project 7 days earlier.

Sometimes this information and conclusion are not very well received by PMs, who reason that they would possibly be able to comply with the initially-stated project duration without those extensions, because they think that certain assumptions are irrelevant, and consequently, an extension of the duration of a task should not be considered (Kutsch 2008, 2010).

Normally, projects are planned and scheduled using CPM, but if we want to work with PERT, we can use the above-computed values in a PERT network as pessimistic values. Remember that in PERT, and because of the Central Limit Theorem, the final time estimate for the project is the mean of a normal distribution. Now, let us analyze this result.

We assume here that there is only one probability value for a threat and one for impacts; however, in most cases, there is a range of probability values for both, thus the risk formula should be:

$$\text{Risk} = (\text{Range of probability values}) \times (\text{Range of impacts}).$$

Risks should be recalculated at each update, unless its estimate coincides with former risk assessments.

Since a new critical path must be computed when updating, it could be that formerly critical tasks are not in that category, while other tasks that were non-critical could appear. If a critical task already completed did not utilize the assigned buffer, it will mean that the project should be completed earlier in an amount of days equal to said buffer, and therefore, this buffer is transferred to the end of the project.

If a new critical task, or an older one, are newly appraised and demand more days, the saved buffer could be utilized to compensate for this larger duration. It could also be that a former critical task is delayed, and it becomes possible to use a recovered unused buffer from another task already executed, since the completion date for the project should have decreased because of the credit buffer.

We have analyzed the final result, which evidently is a function of the mean and the standard deviation. What happens if in estimating the three points per task, there are large gaps between optimistic and pessimistic estimates? Obviously, it would mean that there is a lot of uncertainty, and a question then arises. How will this uncertainty affect the final result?

Coming back to our example in Sect. 3.2, if the standard deviation were higher, implying larger differences between pessimistic and optimistic estimates, it would produce a flatter normal distribution curve (see Fig. 9.7), even with the same mean. What does this mean?

It means that the number of days needed to have a 95 % probability of completion would be larger, and may be 38 instead of 33 days. Thus, it is necessary to be cautious when establishing these estimates.

Conversely, if the standard deviation is small, the necessary number of days will be smaller. At the limit, that is, when there is no standard deviation, we get only one value (as in CPM), and the probability is 1, meaning there is no uncertainty.

3.7 The Use of Dedicated Software

Risk analysis, considering time, cost, quality and environment, is not an easily manageable issue, because of the number of calculations, and subsequently, it is advantageous to use risk software, such as Risky Project® (Intaver Institute 2013), Crystal Ball® (Oracle 2013), @Risk® (Palisades 2013), etc.

Risk software utilizes the Monte Carlo technique applied to scheduling programs – that is, CPM and PERT – by integrating with scheduling software engines such as Primavera® (Oracle 2013), Project (Microsoft)®, etc., and in so doing, finds the critical path/s, identifies critical and non-critical tasks, and determines the earliest starting and latest finishing dates based on probabilistic data. That is, they can introduce uncertainties into the network and find the most probable duration and cost for the whole project, as we have done here by hand.

These risk management software are sophisticated programs that introduce the risk concept for projects, providing all the necessary elements, such as:

- Monte Carlo simulation routine.
- Different probability distribution curves for the user to choose (most with more than 30 in their galleries).
- Probability calculations and values of main parameters, such as mode, mean, and standard deviation.
- They also give a series of alerts, usually with colour coding, about non-critical tasks that can become critical, even estimating their probability of reaching that condition, as well as many other features, including accepting discrete variables and distributions from historical data (since it integrates with scheduling software, changes made in these networks reflect in the Excel worksheet used for RM).

The visual displays of the project include the resulting format or shape of different distributions, according to data entered for each task, as well as their cumulative values, and considering the level of confidence established by the user. They can also depict the project's CPM network, including task definition, durations, costs, milestones, etc., and are capable of creating the Gantt Bars.

They usually allow for working with the different calendars and working hours that are proper for each project, and furnish a large variety of diagrams, which allow for the visual inspection of different results, greatly improving understanding of the process.

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Chapter 4
Risk Identification

Abstract This chapter introduces the first step of the Risk Management process, the detection or identification of risks in a project. It starts building a risk-linking matrix in which every sector is compared with the others in order to determine if there is a risk-wise relationship. This is a good starting point that obliges us to engage in a mental exercise to look for potential risks. It follows an analysis of different types of risks and their limits measured by their impacts. The proposed Risk Breakdown Structure analyses risks and determines their relative importance through a real-life case based on tree analysis. Relative significance is important, and to that effect, two types of diagrams are proposed. A new tool, the Z-Matrix, is used to detect and evaluate a series of impacts where one influences others. Situations are analyzed for identifying risks in construction, environmental, society, project safety, geological risk, quality, legal issues, communications and external factors in projects, and some of them are illustrated with case examples. It moves on for identification and mitigation measures for more complex cases involving transportation, with an example using a tool called 'The Bowtie Diagram'. The chapter finishes with the explanation and exemplification of the 'Risk Register', a fundamental tool for Risk Management.

Keywords Risk identification • Risk breakdown structure • Impacts • Risk register • Z-Matrix

4.1 Introduction

RM aims to identify potential risks; it consists of a thorough review of every aspect of the project to detect, discover and expose risks, since they are often not readily apparent, followed by deep analysis of every task. It is a time-consuming activity, but necessary, since it is the fundamental stone for further analysis.

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9_4, © Springer International Publishing Switzerland 2014

Identification starts with finding sources of potential threats that can trigger risks. For instance, in a chemical project, one source could be the potential failure of safety devices designed to avoid accidental spewing of poisonous gases into the atmosphere. What could be the outcome or consequences? The deadly poisoning of hundreds of people.

In another project, such as the construction of a surface highway in a city, what could be the source of threats? Public reaction to the project.

How do we assess this reaction? By a qualitative interview, that is, an unstructured meeting where the interviewer tries to get 'into the skin' of the interviewee, who can freely express his/her opinions on a certain subject. No marks are obtained from this interview; it only permits for elaborating a hypothesis of how the individual/s feels about this new highway, to know in what way an individual thinks that it could be favourable or unfavourable for the neighbourhood. From here, it is possible to identify significant risks. For instance, if from these interviews, it is hypothesized that, in general, there is animosity against the project and that a certain threat exists that people might react violently against it, then there could be serious consequences for the project, and subsequently a risk.

Timing for a risk occurring is another aspect to consider, that is, will it materialize at the beginning, middle or end of a task or project? For instance, for a road tunnel construction, several drillings have been conducted so as to know the nature of the underground, consistency, existence of aquifers, fault zones, etc. From there, it is perhaps possible to presume that there could be risk of water percolating in the last 1/3 of the tunnel.

There are several procedures and techniques for enacting risk identification, such as risk-linking matrices, RBS (Risk Breakdown Structure), Project analysis, Z-matrices, Brainstorming, and Delphi.

We will comment on some of these methods.

4.2 Risk-Linking Matrix

This square matrix has twelve areas of the project in both columns and rows. It permits, in a preliminary analysis, for determining potential relationships between areas. That is, if, for instance, we study the project schedule, we can determine that its risks, mainly in delays, link to Cost, Economy/Finances, Environment, Societal Opinion, Quality and External factors.

Why?

Well, for the reason that the schedule is related to:

- Costs, because it is often possible to crash a task, that is, reduce its execution time, and then there is risk of greater cost.
- Economy and Finances, since, for instance, a task can be delayed – if it has float – in order to postpone its execution and defer the corresponding payment of work certificates, which can lessen the financial obligations in a certain period.

Table 4.1 Risk linking matrix

	Tech.	Perf.	Pla./Sch.	Cost	Eco./Fin.	Env.	Social	Qual.	Comm.	Legal	Clos	Ext. factors
Tech.	1		1	1					1			1
Perf.	1	1	1	1				1	1		1	1
Plan./Sch.			1	1	1	1	1	1				1
Cost		1	1	1	1	1	1	1	1		1	1
Eco./Fin.					1	1	1	1	1			
Env.				1	1	1						
Social				1	1	1	1			1		
Qual.								1				
Comm.	1								1			1
Legal			1	1			1	1		1		
Clos.										1	1	
Ext. Fact.		1							1			1

- Environment, since the project undoubtedly will affect the environment to a greater or lesser degree, and for the project to be approved, it may need to incorporate some features, such as bag houses in a metallurgical project to avoid sending dust up into the atmosphere.
- Societal Opinion, because there could be a need to perform additional work complying with social claims and demands, such as the construction of a sound barrier on a highway.
- Quality, because high quality most probably means greater control measures and additional time for it. For instance, in pouring concrete, additional time could be allotted for a thorough check to make sure that no air bubbles remain in the mix.
- External factors, because strikes, unusual weather conditions, regulations, etc., can extend the length of a task and its corresponding execution in the time frame.

Considering these relationships, and after thorough examination, there is the possibility of finding threats that can produce risks. Table 4.1 shows a sample of this matrix.

4.3 Types of Risk

- Independent
  That is, unrelated, for instance, the length of a drought that could affect a cultivated area, and the chances of cooling equipment failure in the refrigerated truck transporting this produce.
- Dependent
  When a risk depends upon another. For instance, traffic on a mountain highway is dependent on intensity of snowfall.

- Conditional
  When for a risk to materialize, another risk must happen. For instance, there could be a risk of heavy hailstorm. If that really happens, there is a risk of cars being damaged by the phenomenon.
- Correlated
  When two or more risks vary in the same sense. For instance, stocks of companies in the same industrial area, say, printers and ink manufacturers. It is obvious that a shortage of ink may cause a decrease in printer sales, or that an increase in price of printers could follow an increase in ink prices.

4.4 Limits or Thresholds for Risks

There will most probably be different kinds of risk in a project and with different importance measured with respect to the consequences they can create. There are different ways to assess which risks a firm or company is willing to consider, albeit no rules to follow, because a firm on a very large project can state that they will only consider risks the economic value or threshold of which exceeds a certain amount, which amount could be excessive for a smaller project. The same applies to the schedule when a delay of one month could be negligible in a large, say, 4-year construction project (such as a hydro-electric plant), while it could be very significant in another, and of course, it also depends if that delay i*s* allowed or not. For instance, in organizing the World Cup, there is no room for delays, since inauguration time, invitations to attend, reservation of hotel rooms for delegations, catering services contracted, etc., have been established well in advance and cannot be modified, to say nothing of the loss of prestige for the organizers.

On the other hand, and regarding costs, a company can acknowledge that it is very difficult to set a fixed amount for investment, since, especially in large projects where construction lasts years, many things can happen differently than as planned, even expected factors such as inflation, since nobody can predict how much it will be with reasonable accuracy. For this reason, it is usual, for financial and economic calculations prior to project initiation, to accept a certain percentage of cost increase. Section 5.5.1 proposes a case study addressing this issue.

4.5 Decision Variables

Decision variables are those variables that can be modified by the decision-maker, such as prices, production costs, working capital, etc. They must be differentiated by parameters that are entities used to analyze behaviour of a system, for instance, debt coverage, Net Present Value (NPV), Internal Rate of Return (IRR). etc.

4.6 Using the Risk Breakdown Structure (RBS) for Risk Identification

The very well-known Work Breakdown Structure (WBS) (Sect. 2.12) is an indispensable tool for assigning costs to different work packages, that is, elemental units – like bricks – of a project. It is also an excellent way to break-down the project, allowing for detailed study. Essentially, it links scope hierarchically (what to do) with budget (how much it costs), and in this way, the total cost can be computed, and more importantly, costs can be controlled.

By the same token, a similarly hierarchical structure can be used for risk, in the sense that risk can be categorized and broken down for each category. This is the Risk Breakdown Structure (RBS), and it is a very useful tool, allowing for clarification and understanding of the relationships between risks, while at the same time acting as a powerful device for identifying and ranking risks. It links scope and budgeting hierarchically from the risk point of view, and in this way, the total risk can be estimated. With this approach, it is also possible to identify correlated risk (Sect. 4.3).

In this structure, some elements of a lower level are grouped together to form a superior level; thus, the RBS diagram very efficiently shows how risky an element is at a certain level, how it is formed, and what the elements are that jointly create it. RBS arranges risks hierarchically into Categories, Factors and Severity or Consequences. Another level can be added to identify risk-triggering factors, as shown in Fig. 4.1, which illustrates the procedure.

4.6.1 Case Study – Risk Identification and Assessment – RBS in Orchard Project

Project: Orange tree plantation project

A company located in a Mediterranean country plans to grow 5,000 orange trees. The plot of land is well located, with enough space for that number of trees, the right soil and the adequate climate for this endeavour. However, these plants are very sensitive to weather conditions, and, as with any other plantations, they might be subject to a series of infections that can ruin or even destroy the plants. Another potential problem is that, because rain is scarce, the plantation needs water from irrigation ditches, which are managed by a water committee, and supply of which depends on water stored behind a spate irrigation dam, a potentially serious problem in times of drought if there is insufficient accumulated water.

Therefore, the company prepared an RBS, as illustrated in Fig. 4.1, and an analysis performed for the three most important categories, as follows:

1. Natural disasters and adverse weather conditions
2. Economy
3. Infections

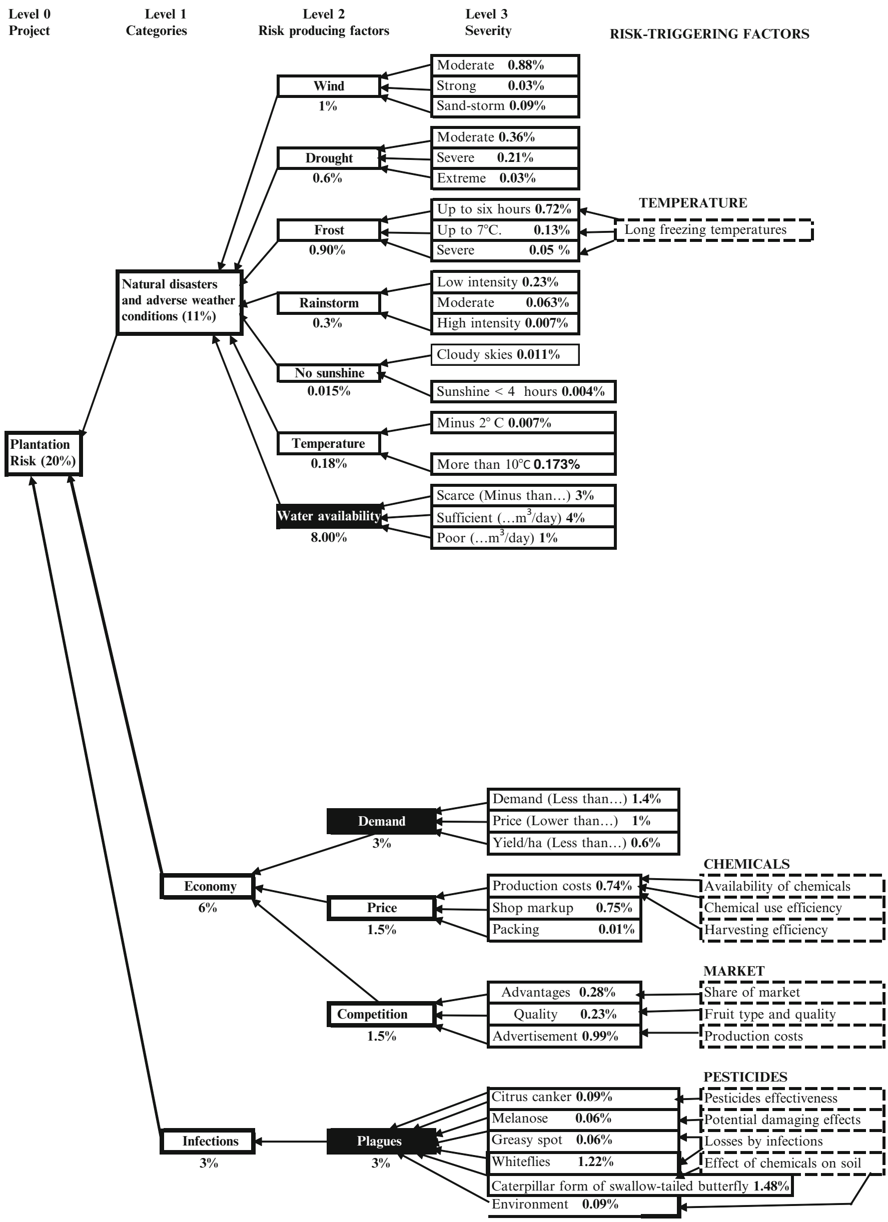


Fig. 4.1 Risk breakdown Structure for a fruit plantation

These categories, in turn, are respectively composed by risk-producing factors, as follows:

1.1	***Wind***
1.1.1	Moderate
1.1.2	Strong
1.1.3	Sandstorm
1.2	***Drought***
1.2.1	Moderate
1.2.2	Severe
1.2.3	Extreme
1.3	***Frost***
1.3.1	Up to 6 h
1.3.2	Up to 7 °C
1.3.3	Severe
1.4	***Rainstorm***
1.4.1	Low intensity
1.4.2	Moderate
1.4.3	High intensity
1.5	***No sunshine***
1.5.1	Cloudy skies
1.5.2	Less than 4 h of sun
1.6	***Temperature***
1.6.1	−2 °C
1.6.2	More than 10 °C
1.7	***Water availability***
1.7.1	Scarce
1.7.2	Sufficient
1.7.3	Poor
2.1	**Demand**
2.1.1	Less than…
2.1.2	Price lower than…
2.1.3	Yield less than…
2.2	***Price***
2.2.1	Production cost
2.2.2	Supermarket and store mark-up
2.2.3	Packing
2.3	***Competition***
2.3.1	Advantages
2.3.2	Quality
2.3.3	Advertisement
3.1	***Plagues***
3.1.1	Citrus canker
3.1.2	Melanose
3.1.3	Greasy spot
3.1.4	Whiteflies
3.1.5	Caterpillar form of swallow-tailed butterfly
3.1.6	Environment

Figure 4.1 illustrates this hierarchy. The last column depicts potential risk-trigger factors, as follows:

- Temperature
- Chemicals
- Market
- Pesticides

Each one has been broken down into risk-triggering sub-factors. For instance, for Chemicals, there are three sub-factors that affect production costs: chemical availability, chemical use efficiency and harvesting efficiency, any of which can trigger a threat for production costs.

Let us consider some insight into these triggering factors.

TEMPERATURE

Freezing temperatures:
Extending longer than normal, and thus posing a risk.

CHEMICALS

Availability of chemicals:
Some of these brands are imported, and it could be difficult to purchase them because of high demand, so there exists a risk of shortage.

Chemical use efficiency:
A non-rational use can cause a product of lower quality, affecting its taste, which is another risk.

Harvesting efficiency:
Harvesting is done by hand (manual picking) over a limited period, therefore, efficiency is important and risky.

MARKET

Share of market:
This is a geographical area with many orange producers; consequently, there is strong competition for the existing regional market, although very large plantations are more prepared for export. Therefore, there is a potential risk of not having enough sales volume.

Fruit type and quality:
Different types of oranges can be cultivated, and thus, a decision needs to be made about the most sensible type to produce or even a mix of different types. This is a risky decision. Quality is another aspect to consider, taking into account that there is a quality grade for the domestic market and another for export.

Production costs:
This is always a risky aspect, considering that production cost depends upon several aspects, and that the entrepreneur can do nothing regarding issues such as fertilizer costs, efficiency in collection of fruit during harvesting, fruit damaged, etc.

PESTICIDES

Pesticide effectiveness:
Different pests require different pesticides; therefore, this item is important and poses some risk, because it may not be possible to get the right pesticides for a particular pest.

Potential damaging effects:
A pesticide can be effective for one or more pests; therefore, there is a risk of purchasing different pesticides that may become useless, because certain pests might not occur in a particular year.

Losses by infections:
This could possibly be the most important and difficult risk to assess, since it may vary from one year to another, but it is possible to estimate an average.

Effect of chemicals on soil:
An excess of pesticides can not only damage the fruit but also the soil, since it may permeate through the ground and contaminate aquifers. Therefore, there is potential environment risk.

Arrows indicate how each trigger factor contributes to form the risk severity on level 3. For instance, the temperature risk trigger is divided into a range of diverse degrees of damage (Up to 6 h, Up to 7 °C, and Severe), each one with its own probabilities of occurrence derived from historical data or another source.

Thus, severity of threat on level 3 compose the risk-producing factors of level 2. In turn, seven risk factors contribute an 11 % probability risk to the 'Natural disasters and adverse weather conditions' category, while three contribute 6 % to the 'Economy' category, and one contributes 3 % to the 'Infections' Category.

Finally, the three categories contribute 20 % to the project risk materialized in the 'Plantation risk' box. Using ranges for all values on level 3, assigning probability distributions to each one and applying Monte Carlo, it is then possible to have a final mean for the plantation risk. We have now identified risks, and thus, it is possible to establish a ranking of priorities, since not all risks deserve the same attention or the same procedure. It can be seen that the largest risk lies in the water availability area, with 8 %, followed by demand and plagues, each with 3 %.

The RBS allows for a clear identification of risk, because its structure demands a thorough analysis of the whole project, step by step.

4.6.1.1 Conclusion

Measures proposed here, as with other 'conclusions' in this book, are naturally only examples, and they do not pretend to be a guide to orange tree management or any other issue. They only try to illustrate how to use information given by risk analysis.

In examining this case, and considering that water availability is the factor that poses the largest risk, it is evident that measures have to be contemplated to reduce this risk.

Suggested measures could be:

- Evaluate the importance of a lack of water threat and determine consequences.
- Determine how much water the orange tree needs and take into account that this amount varies between young and mature trees, the amount generally being larger for young trees.
- Check the moisture level of the surrounding soil area.
- Think about hiring a hydrologist to conduct a scientific study of the existence of fresh water aquifers on the property.

The second most important risks are plagues and demand. For the first, it could be convenient to study the historic presence of plagues in the region regarding quantity and type, and consult with a specialist about the most efficient method for fighting them.

Regarding demand, the problem looks more serious, because it depends on a variety of factors. However, it is possible to study trends in public preference in the area or in supermarkets. It also could be useful to study competition and correlation between sales and the economy, etc.

This way, the fruit company is taking preventative measures to protect its investment, based on information of importance and the characteristics of threats.

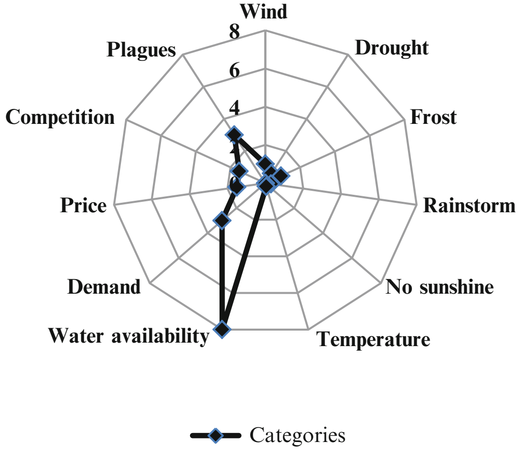
4.7 Risk Comparison

It is important to make a comparison of risks in order to allocate more time and attention to risks that are genuinely significant.

4.7.1 Spider Web Diagram

Figure 4.2 shows the same data in a different manner, and permits for comparing values relative to a baseline.

Fig. 4.2 Spider web diagram for orange trees plantation



4.8 Risk Identification in Infrastructure Projects

Infrastructure projects usually present many risks. Large undertakings, such as roads, railways, hydroelectric dams, pipelines, sewage, etc., are normally huge projects, employing hundreds of workers, using heavy road and construction machinery, cranes, and explosives, and subject to soil conditions. Consequently, they are fertile fields for a diversity of risks, and because of that, their identification, ranking and assessment are extremely important; these include personal safety risks, as well as technical (for instance, in the operation of large cranes), environmental (since the work usually provokes a strong modification of land use and hydrographic and geological alterations), social (for instance, building a highway near populations and altering their way of life), and political (for instance, sabotaging of the construction of a pipeline on disputed territory).

4.8.1 Application Example: Risk Identification – Track-Laying in Railway Project

Project: Construction of a high-speed train

In a project such as the construction of a high-speed train (cruiser speed 300 km/h), it is of fundamental importance before laying tracks to study subsurface conditions and materials through geotechnical engineering and soil mechanics. If the soil, despite the use of the right materials and equipment, as well as good engineering practices, has not been sufficiently compacted, there could be voids; this is one risk, but it gives way to another much more serious one. When trains start running, the soil will probably support the dynamic load produced by the train, but as time goes by, and because of the weight of the train, it is possible that the soil will compact even more. This is good, however, it can produce track misalignment with very serious consequences.

Naturally, risk estimates concerning this issue need to be performed by knowledgeable experts in each area, as well as consulting firms specializing in risk identification, who can better determine the nature and impact of the risk posed by this threat.

4.9 Serial Risk Identification

In many cases, risks are isolated; however, in other circumstances, risks are linked in a serial sequence. For instance, in an actual case that happened in the Essequibo River in Guyana, a tails pond dam overflowed and discharged lethal tailings heavily laced with cyanides into a nearby river. This event killed aquatic life in the river, and still worse, poisoned native populations living along the river. It can be seen that the first risk produced the others. For this reason, in complicated projects, it is not enough to analyze a direct threat; the series of threats produced by the first one must also be analyzed.

In this book, we are using a tool called 'Z-Matrix', which allows for the identification and assessment of serial risks.

4.9.1 Z-Matrix for Determining Serial Impacts

In many cases, a threat generates a risk which is analyzed only by itself. But in many other cases – probably in most – a threat generates a chain of risks the final effect of which can be unpredictable. In chaos theory, the 'butterfly effect' is well known, meaning that small causes can provoke huge results through a chain of events. The very well-known example from which the effect takes its name states that a butterfly flapping its wings in one part of the world can be responsible for a storm thousands of kilometers away. Popular knowledge put it in verse a long time ago, as such:

For want of a nail, the shoe was lost.
For want of a shoe, the horse was lost.
For want of a horse, the rider was lost.
For want of a rider, the message was lost.
For want of a message, the battle was lost.
For want of a battle, the kingdom was lost.
(Wikipedia)

In general, initial conditions can have a large influence on future events.

Applying this concept to Project Management, we can use the example of a gold floatation process, which can have unsuspected effects kilometers away from the plant; poisonous tailings from the process are fed into tailings ponds, which in turn may kill birds when they drink the liquid, and also contaminate aquifers, which in turn can contaminate drinking water used by a nearby population, which in turn................

Thus, it is necessary to analyze the chain of events to learn about these sequential risks.

The Z-Matrix is a tool designed to do that. It is a set of matrices the objective of which is to identify serial risks generated by a project; the matrix works using five basic concepts.

- *Actions* generated by a project, for instance, construction, transportation, manufacturing, procurement, etc., identified as a vector.
- *Effects* produced by those actions, such as pouring concrete, water consumption, dust generation, chemical reactions, personnel hiring, etc. This is the 'Effects Matrix'.
- *Receptors* of those effects, for example, people, wildlife, the environment, etc. This is the 'Receptors Matrix'.

- *Consequences* on receptors, such as alteration of the ecosystem, wildlife migration, diseases, etc. This is the 'Consequences matrix'.
- *Responses* taken to decrease these consequences. This is the 'Response Matrix'.

Thus, the system involves one vector and four matrices (see Fig. 4.3). Once these aspects are defined (say, for instance, 3 actions, 3 effects, 2 receptors, and 3 consequences), the matrices are built.

Suppose that a project calls for using existing and abandoned railway tracks in a city to develop an electric urban passenger train service. Actions as a result of the project are: 'Train traffic', 'Installing lighting', 'Setting up of a signal system', 'Station construction', etc. However, one of the problems with this project is that the tracks are very close to inhabited dwellings, which, without a doubt, will be affected by noise due the trains, as well as vibration, light contamination, etc.

Thus, starting with the action vector where we have all the actions in rows, select the action we want to analyze. Choose 'Train traffic', and now determine which effects this action will produce; say, for instance, that there are three, namely 'Air contamination', 'Noise' and 'Vibration', which are then identified in columns of the effects matrix.

Now 'Noise' is selected as the effect to analyze; at the intersection of the 'Train traffic' row and the 'Noise' column, a value of this effect is placed, for instance, 78 dB, meaning that the level of noise for each passing train will be 78 dB.

Assume that in the receptors matrix, we have (in rows) 'Neighbours' and 'Wildlife' (because of a very close forest). Select, say, the first one and place a value, such as 1,781, which represents the number of people that will be affected by this noise, at the intersection of column 'Noise' and row 'Neighbours'.

Now, let us go to the consequences matrix, where in columns, we have 'Structural damage in dwellings' (owing to vibration), 'Public complaints', and 'Light contamination' (because the tracks are lit up all night), etc. These consequences, if materialized, may signify serious risks, because the City Transportation Department in charge of the project may be obliged by a court decision to take measures to eliminate or reduce these effects, which could mean a good deal of money. Place a value for studies to correct this situation (5,897 Euros) at the intersection of the row 'Neighbours' and the column 'Public complaints'.

Finally, at the intersection of column 'Public complaints' and row 'Install effective sound barriers', place the value of this remediation measure (194,810 Euros).

Therefore, influence of the action 'Train traffic' can be tracked through the direct impacts it produces, followed by the effect of these impacts on diverse receptors (secondary impact), consequences of these effects (tertiary impact), and so on. Put a monetary value for remediation for consequences and repeat the procedure for each action, effect, receptor, consequences and response where it corresponds. In the end, we will have:

- An indication of how each action directly interrelates with the effects that it produces, as well as a quantification of those effects.

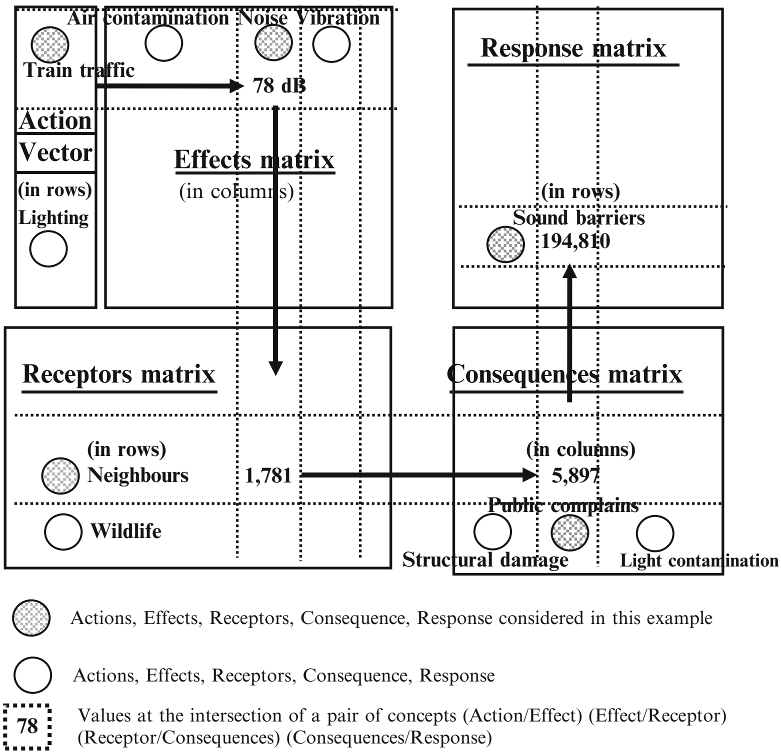


Fig. 4.3 The Z-Matrix for an urban rail system

- A clue of the secondary, tertiary, quaternary, etc., impacts produced by an action. This way, the whole impact of an action can be followed and quantified, and a final amount of money for remediation established.
- If each action is examined in this manner, it is possible to identify the most important actions and rank them with the assurance that we have considered all relevant links.
- Each action can be assigned a risk, and thus, a final risk value for each one can also be determined (see applications in Sects. 5.5.1 and 5.6.1).
- The last step consists of selecting the most important risks and their remediation costs, and then, applying Multi Criteria Decision Making, determining which risks should be addressed in order to minimize remediation costs. By applying the concepts explained, see how the Z-Matrix can be used in Risk Management through another example. In this case, the project calls for the construction of a pulp mill in a remote location (see Sect. 5.6.1). We are interested here in probable delays caused by diverse potential threats, since there is little room for finishing the project after the agreed-upon date.

4.10 Brainstorming

This very well-known technique was developed in 1939 by Alex Osborn (1963) and had ample diffusion for the generation of creative ideas in order to address a subject from different and new points of view. Given a subject, ideas are freely expressed by a group of persons without any type of restrictions, with the goal of generating as many ideas as possible in regard to it; further on, these ideas are selected and evaluated.

In a sense, the system works similarly to Monte Carlo, since ideas are generated at random within the scope of the subject or problem being posed; the result is a range of ideas from which the best one can be selected. It could be a good tool for identifying threats. See Rodgers and Petch (1999) for more information about risk identification and procedures for conducting brainstorming workshops.

4.11 Risk Identification in Construction Projects – Differing Site Conditions

Many construction projects are uncertain owing to a number of factors; however, there is one factor that most often poses uncertainty, and that factor is the nature of the soil and ground where the construction will take place. This is typical of DBB projects (Design – Bid – Build projects), such as road construction, railways, water, sewage, hydroelectric dams, subway tunnelling, etc., where a great deal of the risk lies in the nature of the terrain. Naturally, tests are done before preparing a project, however, they usually do not cover 100 % of the scope of the project (in length, depth, hydrological conditions, time, etc.), and it is not uncommon that the acceptable conditions found through testing have changed a few meters away. Another feature is time, since the contract must take into account the precise time of the year that the project will take place, since snow, flooding and other events can impede construction.

This circumstance is called 'Differing Site Conditions', and in essence means a change in the contractual conditions. Its consequences can be better understood through the words of (Exponent 2010), who says:

> Differing site conditions in construction projects can cause schedule delays, cost increases, and dangerous working conditions, or invalidate design assumptions. Construction projects necessarily involve the assessment of site surface (and subsurface) conditions to select the best means and methods to develop a construction schedule and bid and to complete the Project.

Most construction contracts have a clause about this, in the sense that a contractor should perform an assessment of the site independently of what the call for bids indicates. Two main categories of differing site conditions are generally contemplated.

Type 1: When the conditions encountered at the site are substantially different from those specified in the contract.

Type 2: When the conditions encountered at the site are substantially different from conditions that would normally be found.

4.11.1 Type 1 Condition

The same authors, in the above-mentioned publication, report a case involving time. A contractor was awarded a contract by the Corps of Engineers to construct a levee along the Mississippi river in 150 days; the work had to be performed using a barge that needed a certain depth of water, which was controlled by locks and dams. Bidders were provided historical records of the depths of the river in the area, which showed that its level fell below the low water mark in certain periods. Soon after the contractor started work, the Corps of Engineers dropped the level of the river below the low water level. Consequently, the contractor had to shutdown operation for 69 days. The Corps of Engineers granted a time extension but refused to pay for incremental costs. The Court ruled that the contractor had no right to an increase in costs, because the information available at the time of bidding indicated that there was a chance there could be shallow water. Therefore, there was a clear chance for a threat and the corresponding risk, but none of this was considered.

4.11.2 Type 2 Condition

Asselin and Cahalan (2000) mention a case that went to Court in which a contract called for a sewer construction tunnel. It was anticipated that contaminated soil might be encountered, and so a clause was included for the contractor to consider containment of contaminants. During construction, the contractor found toxic creosote that leaked into the tunnel, provoking a work stoppage. The contractor claimed additional costs, but the owner refused, under the assumption that the contractor assumed the risk of differing site conditions. The Court, however, ruled that the contractor could not have anticipated this condition and awarded him for the claim. Obviously, the contractor could not foresee the appearance of toxic creosote, however, he did assume a risk, since, considering that he would be working with contaminated soil, he should have made a more thorough study and looked for potential risk.

For a deeper analysis of this subject from a legal point of view, consult Asselin et al. (2000).

4.12 Application Example: Risk Identification – Construction Work

Task: Pouring concrete at high ambient temperature.

Assume, for instance, the provision of concrete for a dam construction in hot weather, where the thermometer can reach high marks. In these cases, there is a very tangible, although difficult to measure, risk, if the concrete is not poured sufficiently cooled, because concrete curing is an exothermic reaction and excessive heat can damage the poured concrete. This happens because concrete at higher temperatures hardens rapidly and requires more water, which, if not supplied in the right quantity, can affect concrete strength and durability. Something similar happens with cold weather.

What is the risk in hot weather? It could be that the concrete cooling plant cannot provide the material in the amounts needed and at the right temperature. In case of cold weather, one solution could call for using antifreeze products, and then a risk could be not having enough stock of the antifreeze product.

4.13 Risk Identification Associated with Environmental Impacts (Environmental Risks)

The environmental risk corresponds to the chance that the project could badly impact the environment. To be sure, any project will harm the environment; however, limits or thresholds are established to keep the damage within controlled limits. In a coal-fired power plant project, there could be risk that emissions or flue gas generate more than the allowed amount of noxious gases. If the completed plant effectively produces more than the allowed deleterious gases, it risks closing by environmental authorities, therefore, it is best to prevent that from occurring. Suppose, for instance, that level of noxious gases is below upper limits because the boilers are equipped with fluidized beds, however, there is concern about particulate production. In that case, the solution possibly lies in installing cyclones of larger size or perhaps baghouse equipment or both, but naturally, it means an increment in cost. However, the level of particulate can probably be calculated with fair exactitude through experience and by modelling, and if the level of particulate is very close to the upper limit or perhaps greater, it would be advisable to study new solutions, perhaps changing, if possible, to natural gas. This type of analysis is done routinely from the environmental point of view, however, here we emphasize evaluating it considering the risk and consequences for the developer.

The main point is to address and study the problem from the point of view of analysing the risk and not necessarily to tackle it through conventional mathematical formulas or procedures, because most of the time, they are not applicable or do not accurately reflect the problem, however, mathematical formulas are indeed used in risk analysis when considering uncertainty and probabilities.

4.13.1 Application Example: Risk Identification and Mitigation – Environmental Degradation

Study: Environmental risk posed by visitors to a cave
(Adapted from Munier 2004)

Over the last 15 years, visitors to a system of caverns discovered 80 years ago were allowed to enjoy them for free, only paying a nominal fee for a tour guide, with the opportunity to walk on selected trails and observe huge stalagmites, stalactites, underground rivers and lakes, some rare species of insects, etc. Unfortunately, the increasing number of visitors was causing rapid deterioration in the caves, because human bodies were introducing humidity into the ecosystem, and the natural oils on their fingertips was degrading the surfaces of the stalagmites and stalactites when they touched them. Additionally, the normally constant temperature in the caves began to fluctuate with the presence of the visitors' body heat. These facts gave clues about the threat to the ecosystem, as well as hints of risk of destruction.

Therefore, preventive measures were undertaken to mitigate risk and protect the site, by providing more security, establishing a mandatory circuit in the caves using electric cars, preparing the people through a prior lecture before the visit, and especially restricting admittance to only a certain number of people per day.

4.14 Risk Identification Associated with Society

This refers to an adverse attitude being expressed by the public towards a project, as the result of the belief that it will hurt their interests, or a feeling of vulnerability (real or imagined) in regard to their rights, or frustration with government policies (social risks), or because of environmental concerns.

Society may be in favour of a project, indifferent to it, or against it, and if there is hint that the latter can happen, it is necessary to evaluate such risk. If there is a threat by means of press communications, meetings, letters, protests, picketing roads, etc., that threat must be seriously considered and evaluated.

The following are actual true-to-life examples enunciated and commented upon here to make the project analyst aware of the existence of potential threats, and the need for an exhaustive examination of each project.

4.14.1 Mining Operation

Given a proposed mining venture, people may be not against the project itself, since it will bring jobs and a better quality of living for them in the area, but may express a problem with it because of its scope. As an example, if the project only consists of mining a mineral, concentrating and exporting it to be refined in another country, people can argue that the project will exploit their wealth, contributing nothing but a very low value, and probably just leaving a big hole. People can even threat or boycott the project construction with the measures mentioned above, with the capacity to generate serious consequences. There is subsequently a risk that must be evaluated, considering a real threat and with a high probability.

4.14.2 Oil Exploitation

In another case, an oil company could be considering exploitation in an off-shore area, obviously being aware that, after some years, well production will decrease to a limit that will make continuing operations not worthwhile. In addition, the company also knows that it will not be able to abandon the site, since an agreement must be signed with the local government in which there is a minimum period for the company to stay, because the government is interested in the jobs that the undertaking will generate. This is a real threat, and with the consequence that the company will conclude the project almost at a loss because of declining well production.

4.14.3 Building Construction

All cities have bylaws regarding the maximum height of tall buildings in certain areas. If an entrepreneur decides to build a 22-story building in an area where the maximum allowed is 15-story constructions, there is certainly the threat that City Hall will prohibit it, unless the entrepreneur offers the city something in compensation. Naturally, this implies an additional cost that has to be added to the project budget, and which will certainly affect the economic and financial analysis. Therefore, there is a threat and there are consequences, since, if the entrepreneur goes ahead with his plans, there is a risk of City Hall halting the work – if the offer is not accepted – or even ordering its demolition.

4.14.4 Application Example: Social Risk Identification – Public Reaction

Project: Construction of a chemical plant.

A multinational very active in agribusiness developed a project to build a factory for producing pesticides and fertilizers. The selected location was a small city in an agricultural area very close to a large city. Everything was considered, such as the technical aspects, getting the necessary city permits, purchasing a plot of land and developing the engineering for the plant, as well as the economic and financial aspects.

The project looked very promising, because the plant would supply a huge agricultural area (since all of these products were imported), with the additional probability of exporting a portion of its production. However, the feasibility study did not take into account public opinion, although there were hints that the population in the small city were strongly against the undertaking out of fear of contamination, fuelled by an accident in another country (the Bhopal disaster in India in 1984).[1]

The company knew the risk for the undertaking provoked by public opposition, and in an effort to convince the citizens, held some conferences and workshops to explain the scope of the project. During those events, it was pointed out that there was no reason whatsoever for fear, as something similar to the Bhopal disaster could not happen due to new technology and safety provisions for this new plant, and the benefits that it would bring to the city with the creation of 270 new jobs were emphasized.

After these meetings, 90 % of the population were still against the project, while City Hall, despite acknowledging that certain specific questions were not satisfactorily addressed by the company, approved the project, supported by a favourable Provincial Environmental Impact Analysis report. The population made it clear that, if the plant were built there, no workers from the area would participate and that they additionally intended to stop paying municipal taxes, along with whatever other measures of force were deemed necessary.

With the City Hall endorsement, the multinational did not even consider that there could be any significant risk for the project and continued with its plans. When the company began construction, the city population initiated a very strong action against the project, picketing the access road to the construction site day and night, therefore impeding trucks and construction machinery from entering the plot, and sabotaging some company equipment. These events convinced the company that construction would not be possible and they abandoned the project.

It is obvious that even when the threat was very clear and the consequences very serious, the multinational dismissed the risk. This behaviour not only made the company abandon the project but also caused them to incur heavy losses because of the acquisition of land and equipment.

4.14.5 Application Example: Social Risk Identification – Population Relocation

Project: Relocation of shantytown dwellers

In a large city, City Hall officials devised a project with different options for improving life for people living illegally in shantytowns very close to downtown

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[1] The Bhopal disaster in India in 1984 was a consequence of unforeseen circumstances that probably nobody had anticipated. In this case the combination of several factors such as the accidental contact of water with methylisocyanate caused a chemical reaction which, combined with other chemicals, generated gases that could not be contained and escaped to the surrounding area, a working-class neighbourhood. It is assumed that more than 3,000 people died and perhaps another 500,000 suffered severe injuries.

on public land, and consequently without an ownership deed. The plan aimed to build small modest houses for these people, along with all services, a school, paved streets, lights and sewage, and located on a vacant public lot on the outskirts of the city.

A poll was conducted amongst these city dwellers, which made clear that the people without a doubt preferred to stay in the same place, but that they did desire clear titles, water, electricity and paved roads. Their argument was that they had established close links with their neighbours, forming a sort of tight fabric of community, and they did not want to lose so many years of friendship. On top of that, they argued that, because of their long stay on the land, they had earned rights as owners, and thus, had to be considered legal dwellers, even without titles.

One of the most compelling arguments was that, if moved, they had to change schools for their children, and worst of all, they would be far away from their humble jobs, mainly gathering board, paper, and bottles from the city streets and shops and selling them to recyclers. Therefore, there was a strong opposition to any change, and they voiced their threat that, if moved, they would come back to the same place.

Notwithstanding and not considering the identified threat, the project was approved and construction work commenced. When finished, City Hall relocated families into the new settlement while the old place was bulldozed; surprisingly, and even though they now had decent dwellings, many people complained, and some families who opposed the relocation scheme refused to move, staying at the old site. After a couple of months, several people from the new settlement came back to the old premises and built new dwellings from cardboard, discarded wood and zinc roofs held in place with big stones.

Therefore, the threat materialized, producing a social impact for people and a financial impact for City Hall.

What failed here? Obviously, nobody considered the certain risk of wasting money and upsetting people, when there was a considerably high probability that people would refuse the scheme. Had City Hall taken action based on the polls, less money could have been spent by giving the people that for which they were asking.

4.15 Risk Identification Associated with Project Safety and Integrity

This label usually refers to safety for personnel working on a project to avoid construction-related accidents. There is a large inventory of these accidents, such as falls from tall areas (high-rises, industrial installations, catalytic crackers in oil refineries, etc.), electrical shocks, traffic accidents (with working equipment), fire, etc. The label also refers to elemental and compulsory safety measures for personnel protection (such as blocking devices for machines that do not start when the operator can access moving parts), electrical equipment and tools, as well as mandatory safety courses for workers, etc. There are many norms about safety of this kind, such as stringent penalties for violating them, and they are normally considered in all kind of projects because of those severe penalties; ISO 13100 also standardizes this aspect.

However, this is not the kind of risk addressed here, because we refer to risk inherent (or generated) by the project itself or by nature. Some actual examples will better clarify this issue with the purpose of illustrating how risk management works in different situations.

Examples are:

- Tunnel collapsing (for instance, an aqueduct tunnel).
- Structural weakness against tremors or high winds that can endanger the works (such as petrochemical towers during construction).
- Equipment tune-up after start up and personnel training.
- Waste of raw material during testing runs (for instance, with a paper mill machine).

There are usually threats to consider that can be neutralized through safeguards. A couple of actual examples are used to clarify this issue.

4.15.1 Application Example: Risk Identification – Project Safety

Project: Construction of a subway tunnel under a river

This example refers to the construction of a subway tunnel under a river using a TBM machine. At first sight, it appeared that it was just a tunnel for which the customary set of safety construction measures should be taken, and the project started. However, when the tunnel was approaching the river, the City Hall construction department decided to have a closer look at the imminent excavation under it, and thought that perhaps some risk could exist as the result of the eventual percolating of water from the river into the tunnel, which could produce catastrophic flooding and quite likely loss of human lives.

Considering that there would be only 8 m from the bottom of the river down to the tunnel ceiling, additional geological studies were performed in that area, and it was found that the geological structure was not as strong as suggested by preliminary studies, and that, indeed, there could be a light chance of percolation.

Although the probability of occurrence was low, the impact would be extremely high. City Hall was firm in not taking chances, and decided to eliminate the risk by reinforcing the riverbed above the tunnel with the construction of a thick concrete slab over the path of the tunnel and along the width of the river. This was an example of preventive safety measures at work and a paradigm of best practices in risk management.

4.15.2 Application Example: Geological Risk – Civil Construction

Project: Construction of a dam.

This example refers to the Vajont[2] Dam in Italy (see Sect. 2.8), the largest in Europe, which, having just been finished, suffered a disaster provoked by a large rockslide during filling of the lake behind it. There were, even during construction, symptoms that led to a threat of consequences owing to the lack of stability in one of the mountains forming the lake *that strongly suggested the existence of a structural risk,* but was not considered, or perhaps dismissed as unimportant.

This was obviously an example in which a threat was detected with a high probability and with the certainty that, should it materialize, the impact would be catastrophic, and unfortunately, it was, in human lives and destruction.

4.16 Risk Identification Associated with Quality

Quality is rarely considered, however, it is very important and usually not very difficult to compute, since most of the time, it refers to real and measurable facts. Take construction work where concrete plays a fundamental role; the risk lies, for instance, in the quality of pouring concrete, which must be as compact as possible and poured in a way as to force out air bubbles trapped inside. There is always the threat of a weak concrete structure when this operation is not properly done. For that reason, to avoid or at least to decrease the risk significantly, the project must contemplate the presence of a trained tradesman during the pouring operation (acting as a safeguard). The risk is not measured here in percentage, and the prevention can be easily computed, considering the additional labor cost for the tradesman and for the appropriate use of the poker vibrator[3] in its insertion into and withdrawal from the concrete.

If the project refers, for instance, to the manufacture of consumer goods, say, ladies' bags, the quality of the product can be estimated when compared with similar products. If, from comparison, using, for instance, the 'House of Quality' method,[4] it is considered necessary to change the type and quality of fabric, decorations, fittings, clips, etc., the additional cost to improve quality may be estimated.

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[2] The Vajont Dam in Northern Italy was finished in 1963. While the reservoir was being filled, a lack of stability in the mountains enclosing the lake that had formed behind the dam materialized, resulting in the fall of a large quantity of boulders into the reservoir. The water wave produced by this plunge killed thousands of people both up and downwards of the dam.

[3] Construction equipment used to vibrate freshly poured concrete.

[4] Developed by Mitsubishi and extensively used for a large variety of manufacturers.

4.16.1 Application Example: Quality Risk – Building Construction

Project: Building construction

A developer hired a construction company to erect a 10-story building with a complex geometry and concrete walls, but with hexagonal openings irregularly distributed, forming an intricate pattern, and enclosing a glass structure to accommodate the offices.

The contractor finished the structure on time and under budget, but many quality details in the joints of the concrete structure dulled the beauty of the building. Unfortunately, there was no clause in the contract concerning the quality of the final structure, and therefore, it was not thought of as a risk when planned. However, this should have been considered, because there was a high possibility of quality risk in this type of complex structure, especially because of the very short period allowed for its construction. Naturally, the contractor had to remediate the situation through concrete polishing and filling spaces between concrete slabs, but it also translated into an additional delay in inaugurating the building.

4.17 Risk Identification Associated with Legal Issues

This usually involves a dangerous risk with non-predictable consequences. It is normally related to land use other than that permitted, such as:

- Installation of light industry in a residential area.
- Constructing buildings of heights larger than allowed by City Hall in that area.
- Non-compliance with noise production standards.
- Starting construction without proper approval from the competent City Hall office or from the Environmental Impact Assessment office.
- Utilization of land settled by illegal dwellers, who, because of their years of permanence on the site, might have acquired rights.

4.17.1 Application Example: Political Risk – Housing Development

Subject: Use of public land

A provincial government called for a bid to sell vacant public land (it had previously billeted military installations, no longer there) in a posh area of a provincial capital city. Once the site was awarded to the best bid, the city's Mayor, known for his firm position against the sale (he had wanted it to be turned into a public park), declared the site not fit for construction, and only suitable to be developed as a green area. This bylaw halted the construction, and the entrepreneur found himself in a difficult position, because the land had been paid for in full, not to mention the significant real estate taxes that had been charged for what would now be unproductive land.

It can be argued that the provincial government was not honest prior to the sale concerning restrictions for land use, as they were never made public. However, this was not the case, since the government did not know the intentions of the City Council, dominated by the party in power, and with authority to legislate land use in the city, although it was aware of the Mayor's comments. It later appeared that the Mayor's initiative was a product of a personal grievance with the governor of the province.

What about the entrepreneur? Everybody likely thought that he was the innocent victim of a power struggle. It could be, however, that while preparing the proposal, the entrepreneur did not pay much attention to the words of the Mayor, who had repeatedly and publicly announced that he would not allow construction on the site. Therefore, the threat was there, and he should have seriously considered it, because, although it was provincial public land, land use within the city was the jurisdiction of the city. Clearly, the entrepreneur did not consider the threat and the corresponding impact on his finances, or perhaps he bet that the city would change its position when he submitted his building proposal because election time was very close and the current Mayor might not be re-elected.

Whatever the conclusions, this example shows that legal aspects should have been carefully considered, especially when there was a certain threat and a corresponding risk.

4.18 Risk Identification Associated with Communications

This risk arises due to a series of circumstances, such as:

1. *It is foreseen that there could be communication problems with stakeholders, such as:*
   (a) Presuming, perhaps through previous experience, that there would be difficulties because stakeholders would always be busy, and thus, it could be difficult to arrange for meetings to discuss project issues.
   (b) Solving issues of uncertainty. This is a difficult issue, however, *"involvement of the project owner and communicating information about uncertainty are important for the effective management of uncertainties and achieving project success"* (Karlsen 2010), and from here, it is quite important that the openness of communication channels between owner and contractor be considered (see also Krane et al. 2012 and Papadopoulos et al. 2012).
   (c) Assuming that there will be delays from the owner in responding to specific questions posed by the contractor, who cannot proceed further until receiving an approval or a response.

(d) Anticipating communication problems with vendors and suppliers, especially if they are in another country or countries. On a large construction project, such as a hydroelectric dam, there could be subcontractors and suppliers from a half a dozen countries who must themselves be in contact, if some of them, as usually happens, provide equipment or hand over work done to another. There must be a previous agreement regarding the way information will be submitted by each subcontractor, as well software used, mechanics on how to update progress, etc.

Steffey and Anantatmula (2011) conducted a deep analysis of the relationships in international projects, providing a "*scholarly research into the risks that inherently affect an international project's success and provides insight into the effective measures that project managers may employ to assist in analyzing and mitigating these multinational risks during the bid and proposal process*".

2. *Within the construction company there could be communication problems if:*

(a) The organization is not adequate. This is a fundamental factor, and many projects fail because the owner and/or contractor or consultant organization is not adequate for a certain type of project. This is an old problem, first pointed out by Sayles and Chandler in 1971 and revisited by Söderlund (2012), who manifests that the ideas posed in that work seem ignored in Project Management research, and nowadays, have more impact on organizational theory than on Project Management.

(b) There is no easy flow of information, as, for instance, when two departments overlap in preparing the same document or analyzing the same problem.

(c) In a production project, a warehouse can deliver materials to the production line without reporting to the accounting department, or reject incoming material without informing the production department.

4.19 Risk Identification Associated with External Factors

Potential threats exist due to external factors over which the stakeholders do not have any control, however, as Gabel (2010) states, "*We may have little or no control over the external environment but we do have control over how we interact with it*".

These external risks are usually included in all the other aspects analyzed. For instance, external factors affecting delays may be weather, suppliers' delays (for whatever reasons), new government regulations regarding imports, unexpected results (especially in R&D projects), strikes, sabotages, etc.

In economics and finance, there could be higher interest rates than expected, banks rejecting a request for a loan, less demand for the product produced by the project than expected, competition launching a similar product, etc.

Cost of living, inflation, new custom duties, fuel increments, etc., usually affect costs.

External factors from the environment and the natural world can materialize in different and unexpected ways, such as wild animals intruding on the job site, mudslides, different quality of soil in comparison with what was assumed, heavier rains than assumed, etc.

External factors from society could be a strong reaction against the project, people unhappy with solutions offered (such as population relocation), people putting forth arguments that were not considered in the feasibility analysis (for instance, an urban highway to be built at ground level that divides a populated area in two), etc.

Regarding project safety, external factors can be threats of tremors (even between large intervals), constructions on very steep terrain and supported by tall concrete columns, projects than can be affected by mudslides, etc.

External factors affecting quality could be the threat that a competitor launches a similar product with better quality and at a competitive price, or offering more functions than our product.

4.20 Identification of Causal Relationship Between Sources of Risk and Consequences – The Bowtie Method

An event has a 'before' and 'after'. The before links **threats** to the **event** backwards, that is, they are the causes through which the event could happen, while the after links the **event** forwards to the **consequences** if the event occurs. This is schematized in Fig. 4.4.

However, this simple scheme is often not realistic, because it considers only one cause and its effects, while an event may normally be provoked by different causes acting alone or together, with the potential to produce several different consequences. Consequently, a more rational proposal would be such as that depicted in Fig. 4.5.

The bowtie or butterfly diagram takes its name from its similitude with these two subjects. The trapezoid at the left envelops all scenarios which can produce threats and, as we see, all the prevention measures (barriers) taken to avoid them happening. The trapezoid at the right envelops all the consequences, and the mitigation measures or barriers resulting from the occurrence of the event (called Top 'Event' in this method's parlance).

Prevention and mitigation measures are, as one might have guessed, very important, and their evaluation is often necessary. As Dianous and Fiévez (2006) put it:

> An evaluation of their performance (response time, efficiency, and level of confidence) is performed to validate that they are relevant for the expected safety function. Ultimately, the evaluation of their probability of failure enables assessing the frequency of occurrence of the accident.

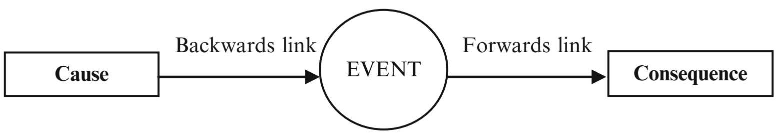

Fig. 4.4 Causes before an event and consequences after it

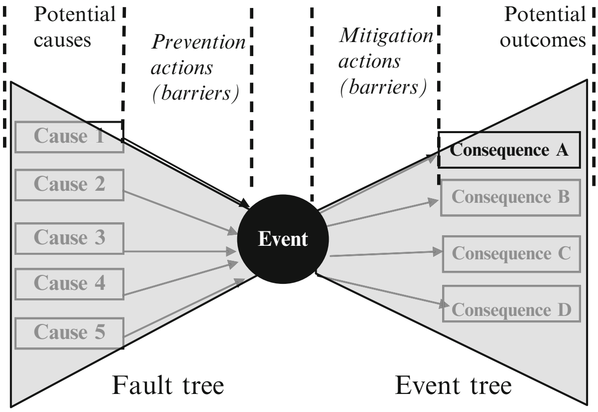

Fig. 4.5 Bowtie or butterfly diagram

4.20.1 Case Study – Risk Identification – Truck Transportation – Bowtie Diagram

This case examines potential risks in transporting fruit and produce from California to New York, a 4,600 km trip, which takes an average of 3.5 days, and using refrigerated 16-m trailers. What is the event? The possibility of delays, which, in this business, is unacceptable.

Let us start by considering the sources, causes or scenarios than potentially can pose threats for complying trips schedules. Figure 4.6 shows at the left different scenarios and threats.

These threats involve weather conditions along the route that traverses the Rocky Mountains, as well as personnel failure, mechanical problems, accidents, etc., which if materialized most certainly will produce delays in delivering the merchandise (Top Event). Naturally, there could be more and different, but in this fictitious example we are assuming that after a detail examination, only these threats have been identified, and with different degree of importance and probability.

While causes on the extreme left could provoke occurrence of the top event, the consequences on the extreme right show the effects of the impacts if, indeed, the top event occurs, and again, they have been selected by the analysts.

The second column of boxes on the left lists the possible prevention measures that can be taken to avoid occurrence or decrease the probability. For instance, there could be notice of heavy traffic and significant backup in one sector of the long route that can hamper on-time delivery, produced by work being done to repair the highway carpet along 17 km, and which can last at least a week. Thus, the preventive measure could consist of trying to bypass that section of the highway, choosing, if possible, an alternative route.

Assume, for instance, that the warehouse in California learns through a meteorological service bulletin that the forecast warns of heavy snowfall for the next two days in the Rockies, and that traffic delays are foreseen of at least 12 h. Thus, one

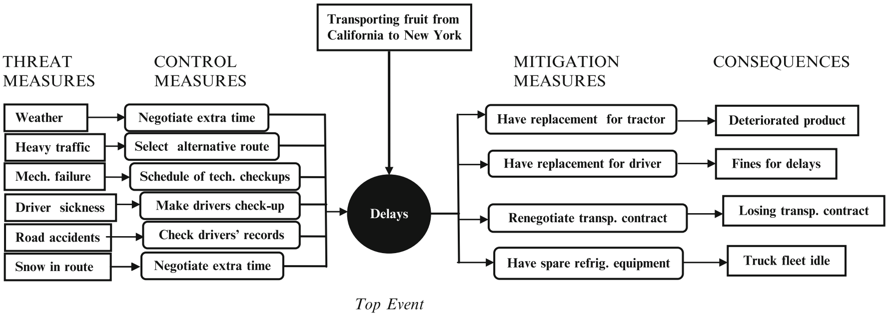

Fig. 4.6 Bowtie scheme for transporting fruit from California to New York

way to prevent the effects of this threat is to contact the customer in New York to alert him of this inevitable delay not attributable to the transport company and negotiate a new delivery date.

Another threat could be related to the potential frequency and magnitude of mechanical failure of refrigeration equipment on board trailers. If there are historical data regarding this issue, a preventive measure could be taken in the form of a mandatory check-up of all equipment before each trip. Another preventive measure could be to stock spare equipment at diverse points along the road; thus, in case of failure, replacement equipment could be brought to the trailer and installed in a couple of hours, instead of waiting for a new trailer to be sent from California, with the additional cost of unloading one trailer and loading another. It can be seen that more than one preventive measure can be applied for a single threat.

There could also be a threat to any preventive measure to cause it to fail itself, for instance, the risk of not having replacement equipment at that very moment. In the parlance of the bowtie method, preventive measures are called 'Control measures'.

In the unfortunate event that the risk does happen, we need to go to the right side of the bowtie diagram. Granted, there is nothing that can be done about it except to decrease the consequences by fixing the problem as soon as possible, and to the extent of 'As Low As Reasonably Practicable' (ALARP), a common acronym on this subject in risk analysis.

There are one or more consequences with different degrees of severity, from negligible to serious to catastrophic; 'Mitigation measures' are needed to reduce or lessen the impact or damage, or to recover time lost, as in the case of the refrigeration equipment failure.

The bowtie method is a very good tool, easy to use and understand, and its main advantage is that it demands a thorough analysis of the project. It has some similarities with the Z-Matrix method (Sect. 4.9.1), although their workings are different, but both demand an in-depth analysis of the project and work with cause-effect relationships.

There are many uses of bowtie diagrams in petrochemicals (as a matter of fact, The Royal Dutch/Shell Group was the first large company to adopt this system), as well as in safety, health, environment, security, etc. For a very good example on security, see Papas (2005) and Zuijderduijn (2000).

4.21 Delphi Method

Essentially, this is an iterative communication system that works with *groups of experts, spatially located,* in order to get their *independent* input about certain issues through response to a coordinator. It can be used to detect and even evaluate risks for a project.

It works using a *questionnaire*, which is prepared concerning some specific subject and then sent by mail or email to this panel of experts, whose *members are not known to each other.* The experts are allotted some time to answer the questions posed, make their evaluations and comments, and send them back to the coordinator. Once the responses of one round are received, they are analyzed, aggregated, and then returned to the experts. The experts work with this information and refine their estimates.

The system continues until the responses from the panel of experts are getting close to each other, or in other words, when the responses satisfy the entire group. Finally, an average value is adopted. The system has proved very useful and more reliable and accurate than other conventional methods of forecasting, which is understandable considering that the experts in different fields are distilling years of experience and knowledge, and are *usually in a better position to forecast from facts rather than with theoretical methods.*

Even when the system can be used for identifying and assessing risk in a given scenario, it is believed that it is biased, since the conclusions are subject to external influences, that is, an expert must refine his/her findings until the final result satisfies the whole group, which, in our opinion, does not fully represent the opinions of all experts.

4.22 Risk Register

Once identified, foreseen risks are detailed in a document called the 'Risk Register' (Table 4.2). This is set up as follows:

- Detail factor/s that can trigger the risk (see Sect. 1.2 and Fig. 4.1 in Sect. 4.6.1).
- Set name of risk.
- Write a thorough description of the risk event.
- Identify the risk as positive (opportunity) or negative (threat).
- Explain the risk.
- Determine risk category – Structural (refers to company structure for developing the project).
  Internal (Refers to the project itself, if we can control it).
  External (Refers to external factors over which we have no control).
- Indicate risk ownership, that is, who is or will be responsible for it.
- Estimate when the risk will take place, that is, at the beginning of a task, during its execution or at the end. Explain why this assumption is made (see Sect. 5.14).
- Indicate how the risk has been identified and reasons for its classification, as well as supporting material; for instance, add documentation related to risk occurrence and consequences on a similar project.
- Determine if the risk belongs to a critical task or affects the most important costs (see Sect. 2.2).
- Determine the chances that a delay stemming from a risk belonging to a non-critical task can turn that task into a critical one (see Sect. 3.2).

- Determine the strategy for response best taken with this risk, mitigation, transferral, or dismissal, and justify reasons for selection.
- Determine the cost for transferral and mitigation, and how much the project risks by ignoring it.
- Determine if the risk affects only one issue, say, for instance, time, or whether it also affects other issues, such as cost, quality and environment.
- Determine the number of outcomes the risk could have.
- Carefully check and appraise a non-critical task finishing in a gate or node from which one or more critical tasks depart.
- For the task affected by a risk event, determine what type of probability distribution can be assumed by using the Monte Carlo model.
- Specify risk category, that is, if there is a tolerance for it or not.
- Indicate in a risk matrix the effect of remediation (see Sect. 5.10).

Table 4.2 depicts an example of a Risk Register form that can be applied to any project, in which different techniques in Project Management are shown under the umbrella of RM. The condensed table comprise several areas, as follows:

PROJECT PREPARATION (Project areas)
PROJECT SECTORS INVOLVED
RISK IDENTIFICATION

- Potential threats found
- Determination of opportunities
- Phase

PLANNING STRATEGY
RISK ASSESSMENT AND ANALYSIS
Qualitative

- Probability of occurrence
- Impact

Quantitative

- Risk calculation
- Risk priority
- Risk liability
- Serial risks

RISK RESPONSE

- Risk response
- Risk avoidance
- Risk minimization
- Risk acceptance
- Cost of mitigation
- Measures to take

RISK CHECKING AND UPDATING

- Risk monitoring
- Risk control

Table 4.2 Example of risk register

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
Stakeholders	Knowledge, experience	The company does not have yet enough experience in this type of project	Project failure	Decision	Planning/RM				
	Project feasibility	Not enough reliable data	Doubtful results	Decision	RM				
	Available data	Incomplete data	Doubtful results	Decision	Planning/RM				
Project charter	New procedures	Little background information	There could be danger for using not totally proven methodology	Decision	Planning/RM				
Technical	Relationships	The necessity to deal with many stakeholders located on diverse locations and not always available	There could be communication problems	Decision	Planning RM				
	Specify main target, that is, if the project is time or cost constrained or both	There is not a clear definition of what we want to accomplished with this project	Not defining the target may lead to not giving due importance to the main purpose of the project, and then risking too much	Preparation	Planning				
	Assigning responsibilities for tasks durations and costs	Our organization is not suitable as it is for this project. There are too many people without a clear definition of their responsibilities	The PM could assume that a task is taken care of by someone when in reality there is nobody in charge or assigned or there could be there is overlapping	Preparation	Planning WBS				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Appraise capability Train personnel		
									Make SWOT appraisal Revise figures		
									Analyse existing data about reliability influence in the project and validate		
									Apply RM – look from similar projects completed		
									Establish procedures and schedule meetings with stakeholders		
									Learn about stakeholders participation in the project and find who is allowed to make decisions. Same for client		
									In a project for organization of the World Cup, cost is very important indeed, however complete. in due time is paramount		
									Link by a matrix the WBS with the organization breakdown structure (OBS); in this way each work package has a responsible. It is suggested to do this when building the CPM using computer software		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
	Tasks duration	There are tasks which durations and even scope depend on technical studies not done yet	New type of project and not too much reliable data Delays	Preparation	RM SWOT CCPM				
	Task duration Repetitive tasks	We have experience and we should use it	Threat of overestimating durations	Preparation	Planning				
	Project duration	There is a fixed finish date which most likely we will not be able to honour	We will be heavily fined if the project is not finished by the contractual date	Preparation	Planning				
Data acquisition	Time appraisal	A random cost auditing of this proposal reveals that our costs are in general too conservative	We could perhaps have the lowest offer, but we risk cost overrun	Preparation	EVM				
	Project performance	Erratic performance	Time delays Time gains		EVM				
	Project scheduling	Milestones and deliveries agreed with the client will be difficult to comply because lack of resources when needed	We could pay fines if milestones are not respected It will also provoke that integration with other contractors will be time diphase. This certainly will bring the necessity to pay them company station for idle time of personnel and mainly for heavy equipment	Preparation	Planning WBS Planning Scheduling				
	Verify data	Our data is incorrect	Wrong data is a dangerous threat	Preparation	Planning				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Compute risk and lengthen the task duration according to the risk, through a buffer. If the buffer is not used and when the task is complete transfer buffer to the end of the project and thus keeping it available for another task		
									Use SWOT analysis Use CCPM If data is available use the learning curve for repetitive tasks		
									Redefine completion date Try to breakdown tasks to see if a large task can be partitioned in 'cascade'		
									Compute duration including risk. Check scope of work (WBS). Make sure that a same task cost does not repeat in different work packages Update CPI ratio monthly. It can give you early signs about overruns		
									Update SPI monthly. It can give you early signs about project delays		
									Establish new milestones keeping finish date or modify it Merge networks from all contractors and have them to sign and update it Prepare a master schedule and make it part of contractual documentation		
									Check and validate data for project		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Prob. of occurrence		Impact (damage)	
						Low	High	Low	High
Planning and scheduling	Project too long	Threat of no compliance with an established date	Heavy fines Prestige		Planning				
	Project performance	Tasks poorly defined	Potential for proj. behind schedule Project actually behind schedule Will difficult monitoring	Preparation Execution	Planning EVM WBS				
	Drawings	Shortage in production capacity	Delays in getting drawings approved for construction	Preparation Execution	Planning WBS				
	Equipment suppliers	Delayed deliveries	Delays in equipment installation	Preparation Execution	RM EVM				
	Weather	Heavy, avalanches affecting road to the site	Deliveries of equipment, fuel, personnel transfer in R&R	Preparation Execution	RM				
	CPI	Correct evaluation of contractor's CPI	Difficulty in forecasting final completion cost	Execution	EVM				
	Project total duration		Uncertainty	Preparation Execution	Planning/RM				
	R&D project	Nature of this kind of projects	Costly research needed Uncertain times and costs	Preparation	Planning RM				
Economic and Financing	Project return	Too high expectations	Potential project rejection because IRR /NPV are lower than expected	Preparation	RM				
		Uncertainty regarding market acceptance	Demand for the product could be lower than expected	Preparation	RM				
		No estimate of rejects in our initial production	Higher unit price could make our product no competitive	Preparation	RM				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Make project crashing Observe increment in costs after crashing and add them to budget		
									Perform EVM and take appropriate-private correction measures Check scope of work (WBS)		
									Prepare schedule for preparation, approval and delivery of drawings. Include this task in project schedule		
									Use risk formula and make a schedule for visiting suppliers premises		
									Apply risk formula to lengthen the duration based on this threat		
									No guaranty that recent CPI will replicate in future. Analyse CPI trend		
									Use Pert and analyse the final date to get a 90 % probability of compliance		
									Schedule partial results deliveries from research		
									Lower expectations and execute sensitivity analysis Revise figures		
									Revise figures and execute sensitivity analysis		
									Check with marketing about existing chances for this price. If it is poor revise estimate		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Prob. of occurrence		Impact (damage)	
						Low	High	Low	High
		Uncertain data	Uncertain cash flow	Preparation	Planning				
		Overdue account receivables	There could be decreasing working capital and this could jeopardize the project	Preparation	RM Planning				
	Economic and financial feasibility	Most of our engineers are not very knowledgeable about finances	Lack of understanding of relationships between the different financial components of project	Preparation	Financial statements				
	Breakeven point	Uncertain data	Breakeven point for units sold is too high	Preparation					
	Work certificates	Too tight reimbursement schedule	Problems with payment of work certificates	Preparation	Planning				
	Bank interests	Our last balance sheet was not very favourable	Increase in banks interest rates for construction loans	Preparation	Planning				
	Partners	Our partner A&B Ltd. are losing steam	Potential break of joint venture Equity capital shortage	Preparation	RM				
	Payback period	Changes and greater costs	More time than accepted	Preparation	RM				
	Debt coverage		Less that expected	Preparation	RM				
	Inflation	Higher prices in raw materials that will affect our production cost	Increases cannot be transferred to our prices. Incidence in revenues and expected profit	Preparation	RM				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Revise figures. Identify 'hot' items		
									Revise figures, especially those related with current assets and current liabilities		
									Develop financial statement for the project planning horizon and explain them to everybody		
									Perform Break Even Point analysis for both price and production		
									Check with planning and scheduling for using floats to modify the S-Curve to get a flatter curve, with lower slope		
									Use sensitivity analysis to determine impact on IRR		
									Use sensitivity analysis to find impact on cash flow and on IRR and NPV		
									Change expectations		
									Revise figures		
									Use sensitivity analysis and RM		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
	Import duties and taxes	There are rumours that the government will increase duties for importing acetate, our main input	Increase in our production costs If materialized our local competitor using local acetate will get a comparative advantage Because our proprietary process. We also get a by-product which is not locally available and rumour says that its import will be forbiden to protect local industry	Preparation Execution	RM				
	External or exogenous factors	Nowadays competition do not have the capacity to satisfy the market which is opportunity for us		Preparation Execution					
Cost and cost control	Project performance			Execution	EVM				
	<u>Monitoring</u> Measuring work done	Evaluation of work done could show differences with that from the contractor	Contractor could be using a different norm to evaluate work done and this can alter our perception about how the work advances	Execution	Planning WBS				
	<u>Measuring performance</u> EVM management	There is a trend that shows contractor's CPI >1	A CPI >1 is good news, however when it is too high, it could also mean a very conservative budget	Execution	EVM WBS				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Make sure to consider import duties and even if a certain equip. or material is allowed to enter the country Learn about national, state, municipal taxes and if they can be deferred		
									Analyse government measures that can affect the project. Poll population to gather opinions about the project and how it affects them		
									Use RM and EVM		
									Establish a norm for measuring degree of advance in monitoring work done. A criterion could be assume no credit if job is not cmplete while another could evaluate work done in %, or consider done if the task started		
									Revise figures. It can bring problems with a client since it could mean that unnecessary funds were tied up and not available for other uses. It denotes a poor job in budgeting		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Prob. of occurrence		Impact (damage)	
						Low	High	Low	High
	EAC Not versalite	Using the last contractor's to forecast cost at completion	Danger in using a performance factor from work already done because there is no guaranty that said CPI will maintain in the future It could be equal, higher or lower and will affect the EAC value	Execution	EVM				
	Labor	Contractor's monthly report shows lower man-hours than scheduled	Contractor is using less workers which will affect duration of work	Execution	RM				
	Equipment				RM				
	Materials		Inflation affects equipment	Execution	RM				
	Indirect costs – Also EAC computation		May be they were omitted in the baseline	Preparation	Planning EVM				
	Materials direct costs. Also for EAC compute		May be they were omitted in the baseline	Preparation	Planning WBS				
	Change orders (immediate and foreseen)		Not considered (by omission) in the new base line when updated	Execution	Planning WBS				
	Research R&D in universities and enterprises		Uncertain costs and times	Preparation	RM				
			Loosely defined tasks		RM				
			Approximate milestones		RM				
			Uncertain results		RM				
			CPI too low		EVM RM				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									One way to manage uncertainty is finding out the necessary performance factor to complete the work. This can be done using the 'To Complete Performance Index' (TCPI) It is also suggested to estimate the new performance factor through its trend considering historic values, Some investigation with a large series of projects show that a contractor usually replicates the last values		
									Use RM		
									Use RM		
									Use RM		
									Make sure that indirect costs are included in the baseline		
									Make sure materials from inventory or stocked in the warehouse are included		
									Consider cost and duration in the new baseline update		
									Use RM. Usually research is a continuous effort and therefore EVM is not suitable, however it can be used if the work may be broken-down in 'work packages' Talk to researchers		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
	EAC		Uncertainty	Execution	RM EVM Planning				
	Cost of implementing risk	Implementing risk means loosing money	It could be that implementation costs are larger that the benefits		RM Planning				
	Mitigation costs	Implementing risk means losing money	It could be that implementation costs are larger that the benefits		RM Planning				
			Remember loss in case that risk do not occur						
Environment	Air		Contamination exceeds limits	Preparation	RM				
	Soil		Contamination by oil, fuels and chemicals	Preparation	RM				
	Water		Contamination exceeds limits	Preparation	RM Planning				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Use RM Determine area of potential outcomes Use labor performance factor		
									Make a rational cost analysis and comparing expenses and benefits If a cost item was allowed a risk mitigation but it did not materialized there will be a loss		
									If there is risk either in delays or in costs, mitigation of these risks will cost money either by creating a buffer for delays or by increasing the cost of the task		
									Reduce contamination. Consider purchasing carbon credits		
									Develop measures such as tough control to avoid contamination during construction and operation Consider constructing a sewage plant		
									Revise figures. Consider construction of a water treatment plant		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
	Ecosystem		Damage to forests, lakes, rivers	Preparation	RM Planning				
	Wild life		Migration/ Disappearance	Preparation	RM Planning				
	Noise		There could be complaints from population including law suits because of noise	Preparation	Planning				
Society	Population		People against project	Preparation	Planning				
			Negatively affected by project	Preparation	Planning				
			Legal issues (land occupancy)	Preparation	Planning				
			People relocation	Preparation	Planning				
			Potential damage to population	Preparation	RM				
			Potential for sabotage	Preparation	RM				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Consider remediation measures such as reforestation, erosion control, etc. and add corresponding cost to budget		
									Mitigation plans reducing probability of an event happening in a percentage as well as reducing impacts in a certain percentage mean additional costs		
									Consider remediation measures such as relocating large animal o creating a wild life protection zone add corresponding cost to budget		
									Determine noise levels and if too high consider building noise barrier, as those used in urban highways and rail		
									Try to negotiate- Do not ignore them		
									Try to negotiate or compensate		
									Try to negotiate- Do not ignore them		
									Negotiate but consider costs		
									Develop compensation package		
									Security measures and costs. In a pipeline project for instance consider changing design such as burying oil pipes instead of in surface		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
Safety	Workers		Detect potentially dangerous areas for workers	Preparation	Planning				
				Preparation					
	Work		Detect potential for serious damage to project	Preparation	Planning				
				Preparation					
	Equipment		Detect dangerous areas for equipment	Preparation	Planning				
				Preparation					
Quality	Materials		Materials could not adjust to quality standards	Preparation	Planning				
				Preparation					
	Construction procedures		Construction procedures might not follow best practices	Preparation	Planning				
				Preparation					
	Equipment		Equipment might not perform as expected	Execution	Planning				
Legal	Legal aspects about land, people occupancy, compensation, complaints		Project could be halted by Court ruling because people actions against the project, or be sabotaged	Preparation Execution	RM				
	Sale of product	Complaints from users	Fines Law suits						
Commu-nications	Information to/from project team involving organisation, stakeholders, client and suppliers		Lack of an adequate flow of information between interested parts may Jeopardize the project	Preparation	Planning				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Make observance of safety instruction mandatory. Establish stiff safety norms		
									Establish safeguards and remember the corresponding additional costs		
									Use protection devices Make stiff safety norms for drivers		
									Establish routine procedures for checking materials arriving at the site		
									Establish routine procedures for checking construction aspects		
									Make inspections at manufacturer's site. If not possible, demand from manufacturer a certified documentation on equipment test results		
									Make sure that there are clear titles on land to be used by the project. Analyse cases for which people have solid arguments such as an old cemetery		
									Analyse purchasing product liability Risk is then transferred to a third party		
									Establish a plan to keep all interested parties informed such as organizing meetings. Consider using an Enterprise Resources Planning (ERP) system		

(continued)

Table 4.2 (continued)

Project areas	Project sectors involved	Risk identification			Planning strategy	Risk assessment and analysis			
						Qualitative			
						Prob. of occurrence		Impact (damage)	
		Chances or potential threats or for something to happen	There could be the following risks (opportunities)	Phase	Project management techniques	Low	High	Low	High
Closing	All sections		It is dangerous to leave loose ends when the project is finished	Closing	Planning				

Quantitative				Risk response						Risk checking and updating	
Risk prob × Impact	Risk priority	Risk liability	Serial risks	Risk response	Risk avoidance	Risk minimize	Risk acceptance	Mitigation cost	Measures to take	Risk monitoring	Risk control
									Make sure a memory is handled over to the client as well as all documentation and that there are not outstanding work certificates. Leave the site free of debris, construction materials and garbage and dismantle all temporary installations and services		

Notice that comments are made for each column and each area of Table 4.2 in a very general manner, just to give an idea of its construction.

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Chapter 5
Risk Assessment and Analysis

Abstract Once threats are identified, they must be assessed or evaluated, which is the objective of this chapter. There is usually a large number of threats, making it impossible or unprofitable to analyze them all, meaning selection of the threats that will be addressed is important. It is a decision-making process; an example is proposed and solved by one of the many techniques available. The chapter proposes a very standard requested study, which is the assessment of the economic and financial risks of a project. This is done through a real-life-example, followed by another appraisal, this time devoted to economic issues, as well as another for transportation, introducing the important concept of conditional probability. The chapter moves on to the assessment of risk associated with costs related to Labor, Materials and Equipment. A still more realistic approach contemplates the simultaneous analysis of all risk costs in a project, introducing the reliability of estimates concept through the use of entropy. It also explores the notion of Probabilistic Risk Assessment together with Tree Analysis and Fault Tree Analysis, which are tools designed for situations that are more complex. Finally, Failure Mode and Effects Analysis are also examined, together with more advanced concepts, such as Correlation Risks and Qualitative and Quantitative assessments. The chapter finishes with the development of the best strategy regarding remediation costs.

Keywords Risk assessment • Remediation • Economic and financial analysis • Tree analysis • Qualitative and quantitative assessment

5.1 Risk Assessment

It is a quantitative appraisal as to which object should assign a value to an identified risk considering uncertainty (see Downey and Slocum 1975). As Gabel (2010) states, "*The risk assessment replaces general and vaguely defined contingency with explicitly defined risk events*". By considering the probability of a threat and the

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9_5,

impact (or benefit) that it can create, this step produces a value of risk and its effects on the schedule, costs, quality, etc. It is necessary to consider that the output of a risk analysis is not a single value, but a probability distribution of many scenarios, that is, there could be several results or outcomes for the same risk and affecting completion time, costs, quality, environment and society. Thus, the analyst gets a complete range of possible outcomes, instead of a single value.

Regarding assessment, The U.S. Department of Transportation (2013) points out a useful distinction for better understanding risks, between random risks (related to uncertainty of the data used in risk calculations) and epistemic risks (related to knowledge or inability to calculate a value accurately). As an example, this Agency proposes that "*one may know precisely the soil characteristics and still be unable to calculate precisely the number of compactor passes needed to attain a certain compacted soil density*". In other words, risks are related to threats, and a probability can normally be defined and impacts appraised. Uncertainty is related to imprecise knowledge, or the absence of information (Downey and Slocum 1975).

5.2 Threats – Relative Importance

Threats affect firm assets with a certain probability of occurrence and provoking different kinds of damages or impacts at different levels of severity; therefore, we have probabilities and impacts the product of which has been defined as risk. These assets can be of different natures, such as installations, company prestige, cash flow, contracts, etc., and, of course, of different significance cost-wise. Many times there are different threats affecting the same asset, and thus, it is convenient to learn about the relative importance of threats on assets. This is illustrated through an example.

5.2.1 Application Example: Threat Evaluation – Airport Traffic Expansion

A small regional airport located in a valley in scenic mountainous country wants to increment its operations, increasing the number of flights coming in and out of the airport, and with that, the correlated number of passengers After an examination of the issue, the project team arrives at the conclusion that one of the main threats or hurdles is noise, which will increase with the greater frequency of flights.

Assets that noise impacts are:

- The actual commercial airport operations risk a decline in traffic if fewer passengers come to the nearby resort because the noise disturbs their vacations.
- The wildlife in a nearby natural and protected forest that together with the resort attracts large quantities of people.

Threats are:

A. Noise, especially at night, will certainly provoke protests from the permanent population in the area, many of whom work providing services to the resort district.
B. More air traffic results in more people arriving and leaving, which will generate road congestion to/from the airport.
C. Noise through increased operations will unquestionably disturb forest wild-life, almost certainly provoking a campaign against the project by ecological groups who have a particular interest in this area.
D. There will be more air contamination in the valley, which doesn't have strong prevailing winds that can cleanse the air.

As noticed, there could be more traffic and more economic benefits for the airport and the hospitality business community, since there will be more patrons for hotels, restaurants, organized tours, etc., therefore, airport expansion is supported by these activities. However, there is also a strong opposition from villagers and ecological groups, helped by the fact that the project has not received a strong endorsement from the regional Environmental Impact Assessment office, although they have not rejected the project, depending upon whether it shows that it is environmentally friendly and feasible.

Therefore, it is decided that each threat should be appraised to determine its relative importance or significance; the procedure consists of comparing threats individually with respect to airport operation. This is a decision-making problem, and is solved, in this example, using a methodology called 'Analytical Hierarchy Process' (AHP), developed by Saaty (1990). It is then necessary to establish some scale for numerical weight to evaluate the decision made in regard to each pair of threats appraised (see Table 5.1).

For instance, in comparing threats A and B, the following question is posed:

Considering airport operation*, which is more important, noise or congestion?*

The answer could be any of those in Table 5.1. For instance, assume that A is definitely considered more important than congestion, and thus, a '5' is assigned to this pair, which also indicates that the importance of B over A is the inverse, that is 1/5 or 0.20.

Next, we compare A and C, and assume that the answer, for the same question, is that both are equally important, and consequently a value of '1' is assigned to this pair, either for the importance of A over B or for B over A.

The relationship between A and D is then analyzed, and we assume that the answer is that A is moderately more important than D, and thus, the valuation of A over D is 3, and that of D over A is 1/3 or 0.33. Naturally, it could also be that there are integer values for B, C and D over A, and a fraction for A to B, C and D.

The same procedure is applied to pairs B – C, B – D and C – D, which allows for building the decision matrix (Table 5.2).

Table 5.1 Preference scale

Judgment of importance between each pair	Assigned value
Equally important	1
Moderately more important	3
One is definitely more important that the other	5
One is much more important than the other	7
One is absolutely more important than the other	9

Table 5.2 Decision matrix

	A	**B**	**C**	**D**
A	1	5	1	3
B	0.2	1	7	3
C	1	0.14	1	1
D	0.33	0.33	1	1

Table 5.3 Calculation of impact of each threat

	A	**B**	**C**	**D**	**1** **Π of each row values**	**2** $\sqrt[4]{\neq}$	**3** **Impact (%)**
A	1	5	1	3	15	1.97	42.9
B	0.2	1	7	3	4.2	1.43	31.2
C	1	0.14	1	1	0.14	0.61	13.3
D	0.33	0.33	1	1	0.11	0.57	12.5
					Total	4.59	

The root degree is equal to the number of threats, in this example, 4

The next step (Table 5.3) consists of calculating the geometric mean for each row by multiplying all its values, as shown in column 1 (labeled with the mathematical product $\prod$ operator). Columns 2 and 3 are self-explanatory.

Therefore, the most significant threat is identified as (A), the potential reaction of the population living in the area, followed by problems posed by protests over road congestion (B), noise (C) and air contamination (D).

The AHP method adapts well to this type of analysis in which the examination is mainly qualitative. In a more complex project, the AHP software can be used for determining solutions, that is finding the most appropriate.

This aspect is intimately linked with Multi-criteria Decision-Making Techniques used to make decisions when data is somehow contradictory and interrelations complicated. This is an area that is beyond the scope of this book. Fernández and Munier (2011) address the problem to some extent.

5.3 Assessment of Risk Associated with Financial Issues

These risks are mainly related to the profitability of the venture. That is, when considering a project, an entrepreneur is mainly concerned about the best use for the capital available for investment. By analyzing costs of opportunities[1] for different undertakings, he/she can make an educated decision about the best option; however, other than the information given by the opportunity costs, each project normally has different risks attached to it related to its performance.

Projects are undertaken with an objective, such as manufacturing (vehicles, steel, electronics, machinery, clothing, etc.), generation (electricity and gas), construction (dwellings, factories, pipelines, etc.), consumer product production (food, shoes, beverages, etc.), results (in an R&D project) (see Zhang 2001), social welfare, education, etc. Since the usual way of measuring the profitability of a project is through computation of its Internal Rate of Return (IRR) and Net Present Value (NPV), and because of inherent risks, it makes sense to analyze risks associated with each project. This can be done through computation of projected financial statements along the project's life cycle, which gives the values of these two indicators (and others) based on estimates for forecasted variables, such as demand for the product to be manufactured or services rendered by the project, as well as other variables, such as price, operating costs, working capital, etc.

The procedure consists of making reasonable and educated guesses concerning potential variations for each of these parameters and observing the corresponding variations they provoke on the two indicators; this procedure, called *'sensitivity analysis'*, also determines the most sensible variable for the venture.

Consider, as an example, that demand is the variable that triggers the largest variation in the two indicators. Say, for instance, that the IRR was established (according to cost of opportunity), aiming at no less than 8.7 %. If a certain variation in demand indicates that this return can go as low as 6.9 % (that is, producing an impact that is 8.7 – 6.9 % = 1.8 %, which means, say, a difference of 2,810,000 Euros less than expected), and with a probability of this happening of 15 %, then it is possible to evaluate the risk, which will be: 0.15 × 2,810,000 = 421,500 Euros. If the entrepreneur accepts this risk, fine; if not, he can try to reduce exposure by decreasing his expectations (that is, accepting a lower IRR), or transferring the risk (for instance, purchasing insurance), or perhaps revising the figures (for instance, decreasing production costs, negotiating lower interest rates, etc.), or avoiding the risk (for instance, abandoning the project), etc.

Remember, however, that there could be not just one, but several threats with different probabilities of occurrence and corresponding impacts, and therefore,

[1] This very important concept in economics indicates the foregone economic development opportunity, when a resource, that is, capital, land, labor or time, is applied to a specific use, and thus, is not available for additional utilization.

risks, perhaps acting simultaneously. These threats can be based on uncertainties, such as those related to prices, operating costs, problems in production, difficulties in collecting receivables, manufacturing rejects, quality, raw material prices, distribution, etc., and thus, it may be that, considering all of these potential drawbacks, it is more convenient for the entrepreneur to abandon the project, looking for other less risky ventures.

5.3.1 *Cash Flow Prediction Using the Monte Carlo Method*

To predict cash flow using the Monte Carlo model, we start by using information from the Project Analysis financial statement. This financial statement is dynamically linked to all other projected statements, such as the Balance Sheet, Cash Flow, Earnings, Loans Schedule, Assets, Depreciation and Amortization, etc., which are normally prepared by the Accounting and Financial Departments for project evaluation, and for presentation to credit institutions when asking for bank loans. Because they are dynamically linked, when certain variables change in any statement, this change is reflected in the Project Analysis statement, which is the basis for performing a sensitivity analysis (see Sect. 6.3.1).

5.3.1.1 Application Example: Financial Risk – Car Assembly Plant

In this example, initial investment for a project takes place during its 3 years of construction, and thus, considers 10 years of production (naturally, this is not the life cycle of the project, but is used only to illustrate the procedure).

Net Present Value (NPV) and the Internal Rate of Return (IRR) are the two parameters selected to evaluate the project from the economic and financial point of view. Financial statements were prepared for the whole life of the project (for a total of 13 years). Table 5.4 shows the values for the NPV and the IRR obtained using financial software packages and assuming a discount rate of 8 %. All values are in millions of Euros.

The result shows that:

$$\text{NPV} = 28,560,000\,\text{Euros}$$

$$\text{IRR} = 9.38\,\%$$

However, these results are obtained assuming that given cash flow values are certain, which, of course, is a great simplification, since there are many aspects than can change them. For this reason, the Monte Carlo model was applied, presuming that there are three cash flow values for each year (optimistic, most likely and pessimistic). These values were calculated as percentages in plus (optimistic) and minus (pessimistic) of the original cash flow values, and assuming that the most likely value coincides with that originally calculated through financial statements (given cash flow values).

Table 5.4 Expected cash flow and net present value using Monte Carlo Model

Years of plant operation:				1	2	3	4	5	6	7	8	9	10
Years of plant construction + operation	1	2	3	4	5	6	7	8	9	10	11	12	13
Data													
Initial investment(*)	**−145,720**	**−159,218**	**−83,890**										
Cash flow during operation (*):				**62,320**	**57,896**	**58,663**	**65,385**	**64,870**	**69,992**	**74,231**	**83,965**	**83,320**	**88,965**
(*) Values in thousands of Euros													
Discount rate, equivalent to cost of capital				8.00 %									
NPV, using calculated net cash flow from financial statements				**28,560**									
IRR, using calculated net cash flow from financial statements				**9.38 %**									
Net present value computation using Monte Carlo Model													
* Optimistic estimate: 8 % more than above													
* Most likely value Same as obtained from financial statements above													
* Pesimistic estimate: 10 % less as above													
Cash flow as per pessimistic estimate:				**56,088**	**52,106**	**52,797**	**58,847**	**58,383**	**62,993**	**66,808**	**75,569**	**74,988**	**80,069**
Cash flow as per most likely estimate:	−145,720	−159,218	−83,890	**62,320**	**57,896**	**58,663**	**65,385**	**64,870**	**69,992**	**74,231**	**83,965**	**83,320**	**88,965**
Cash flow as per optimistic estimate:				**67,306**	**62,528**	**63,356**	**70,616**	**70,060**	**75,591**	**80,169**	**90,682**	**89,986**	**96,082**
(*) Values in thousands of Euros													
Cash flow from Monte Carlo	**−145,720**	**−159,218**	**−83,890**	**56,320**	**59,984**	**54,789**	**64,521**	**68,157**	**73,112**	**77,952**	**77,854**	**84,563**	**81,654**
NPV using Monte Carlo:		**22,854**											

Percentages are as follows:

- From the optimistic point of view, cash flow can increase up to a maximum of 8 %.
- From the pessimistic point of view, cash flow can decrease down to a minimum of 10 % (that is, we are giving a greater chance to the pessimistic than to the optimistic approach, and, of course, this is concluded after studying many internal and external conditions that can affect production and marketing).
- These values follow a β-distribution (see Sect. 9.2.1).

Average cash flows are obtained running Monte Carlo, performing 500 iterations for each year; partial results are depicted in the 'Cash Flow from Monte Carlo' row.

The Present Value for the total cash flow generated by the project during the operation period is obtained by discounting these values using an 8 % discount rate.

The Present Value for the total cash flow for investment during the construction period is obtained by discounting these values using an 8 % discount rate.

The difference between these Present Values gives the Net Present Value using the Monte Carlo Method.

The results are:

$$\mathrm{NPV} = 22{,}854{,}000\,\mathrm{Euros}$$

$$\mathrm{IRR} = 9.10\,\%$$

5.3.1.1.1 Analysis of Result

As seen, the NPV from Monte Carlo is 20 % lower than expected from the financial statements (from 28,560,000 to 22,854,000 Euros) in the 13-year period, however, it is still positive, and thus, from this point of view, the project is feasible.

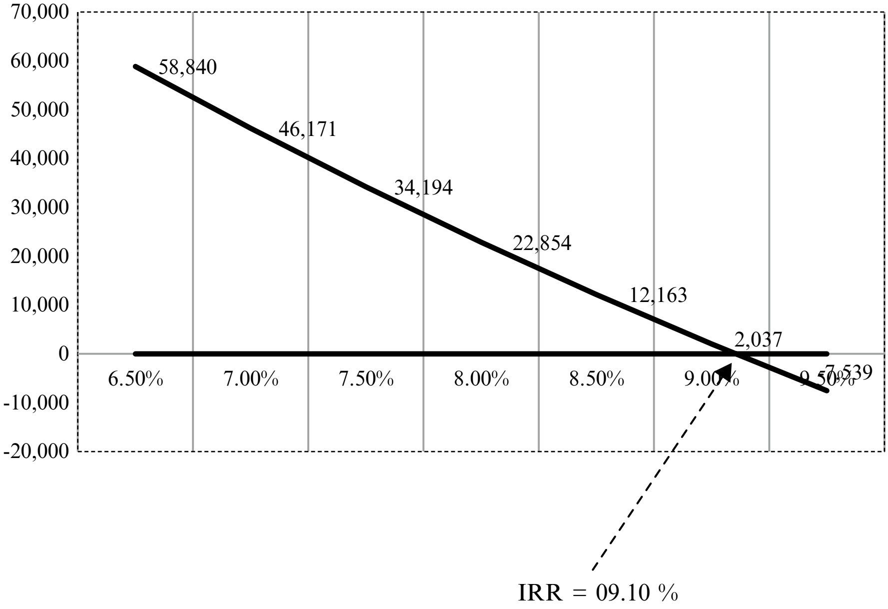

Fig. 5.1 NPV for different discount rates

By the same token, the IRR anticipated drops from 9.38 to 9.10 %, that is, 3 %.

Both parameters define the feasibility of the project, although in different forms (one is expressed in Euros, the other in percentages) and concepts.

The NPV indicates that the project is worth pursuing, since it has a positive discounted value (360,849,000 Euros) superior to the invested discounted capital (337,995,000 Euros), thus adding 22,854,000 Euros to the company assets.

The IRR indicates that the project is profitable, since the capital return (9.10 %) is greater than the cost of capital invested (8 %).

5.3.1.1.2 Conclusion

Analysis shows that there is 95 % probability that the project is economically and financially feasible.

Computing the NPV for several discount rates produces the curve in Fig. 5.1.

Observe that the curve cuts off the abscissa at 9.10 %, which is also the IRR, and this is correct because, by definition, the IRR value corresponds to NPV = 0.

The ordinate shows NPV amounts corresponding to different discount rates. Notice that for discount rates smaller that 8 % the NPV benefit increases and on the opposite how the NPV decreases for greater that 8 % discount rates. These two parameters can also be used to compare different projects, naturally the larger NPV and the IRR for a given discount rate, the better.

This analysis is a common and old practice to evaluate projects, however, in this example we have also used Monte Carlo to have a better grasp of uncertainty, which is inherent to all projects.

5.4 Assessment of Risk Associated with Economic Issues

In a project, there are several issues which present great interest for analysis. In this book, several areas are addressed, as follows:

- Economic risks, that is, risks than can appear related to the economic aspect of the project, which are the object of this section and illustrated with an actual example.
- Schedule risks, associated with task's duration.
- Economic and financing risks, related to returns produced by the project when it is in operation.
- Environmental risks, in which the project interacts with the ecosystem, the atmosphere, soil, water, wildlife, forests, etc.
- Costs, examining risks for predicted or foreseen increases, influence of uncertain increases due to cost of life, labor, equipment, etc.
- Risks associated with use of resources.
- Risks associated with legal factors.
- Risks associated with communications.
- Risks associated with closing the project.

What follows is a case used to illustrate the working of risk software, in this case, 'Crystal Ball'® from Oracle (2013)®. Risk software is an indispensable tool when working with the Monte Carlo model in which a large number of iterations are needed, as well as the automatic generation of random numbers.

5.4.1 Case Study – Economic Risk – Meatpacking Plant Water Discharge

Issue: *Determining fines to be paid for water contamination*

A meatpacking plant is discharging wastewater loaded with organic matter (mainly fat) into a river. This raw waste, when discharged into this body of water, consumes its oxygen, provoking fish migration and death, as well as disturbing aquatic life. This is a risky business, since the company is liable to be heavily fined and even closed for this illegal discharge. However, environmental regulations permit a maximum limit of contamination, through the paying of a fee, but if this limit is violated, fines no longer apply and the plant risks being shut down.

Because of this threat, the company is considering installing a wastewater treatment plant, together with chemical treatment to reduce contamination that, at that time, averages 250 mg/m^3 of BOD_5 (Biological Oxygen Demand in 5 days). The maximum allowed is 150 BOD_5, and there is a fine of 0.13 Euros/m^3 if contamination exceeds this amount up to a maximum of 275 mg/m^3. From then on, no fines will be issued, but closure applies. The new equipment can reduce this contamination to 180 mg/m^3, which exceeds the maximum, but which is within the permitted additional paid allowance.

The owner of the meatpacking plant wants to know how much money they will have to pay, considering three variables: Level of contamination in raw water, daily volume of raw water discharged, and level of contamination in treated wastewater. The three variables can have a range of values due to a series of technical conditions, as well as the production schedule, as depicted in Table 5.5. Observe that each variable has a different probability distribution.

5.4.1.1 Analysis of Scenarios

Scenario 1

Discharged wastewater contamination level is below or equal to 150 mg/m³
Amount payable will be:
Allowed contamination: $150 \times 475 = 71{,}250$ mg.
Discharge water contamination: $150 \times 475 = 71{,}250$ mg.
Fine: $71{,}250 - 71{,}250 = 0$
Since the difference between contaminations will be subject to a fine of 0.13 Euros/m^3, the amount to pay is 0 Euros.

Scenario 2

Discharged wastewater contamination level is above 150 mg/m³

To formulate the problem, insert data into an Excel spreadsheet, as well as the mathematic model (the objective). Use the Monte Carlo model and compute through Crystal Ball software. See Fig. 5.2.

Problem assumptions (see data in Table 5.5).
Place in cell C4 the average value of raw water contamination (250) (without units).
Place in cell C5 the average value of daily volume of wastewater (475) (without units).
In cell C6, multiply C4 and C5.
Place in cell C8 the average value of allowed contamination in discharged water (180).
In cell C9, multiply C5 and C8.
In cell C10 (the objective cell), place the following formula:

$$= \mathrm{IF}\big((\mathrm{C6} - \mathrm{C9}) < 47{,}500; (\mathrm{C6} - \mathrm{C9}) * 0.13; 0\big).$$

Table 5.5 Wastewater data for meatpacking plant

	Low limit (mg/m^3)	Most probable value(mg/m^3)	High limit (mg/m^3)	Type of probability distributions
Waste water contamination level (mg/m^3)		250		Normal
Daily volume of waste water (m^3)	350	475	600	Triangular
Treated water contamination level (mg/m^3)	145	180	220	β distribution
Assumed limits for payment (Euros)	2,000	2,800 (objective)	3,500	

			First run Payment range 2000/3500		Second run Payment range 3500/6500		Third run Payment range 6500/9000	
Raw water contamination	250	mg/m^3	245	Monte Carlo	250	Monte Carlo	245	Monte Carlo
Daily volume	475	m^3	590	Monte Carlo	605	Monte Carlo	600	Monte Carlo
Total potential contamination	118,750	mg	144,550		151,250		147,000	
Treated water contamination	150	mg/m^3	172	Monte Carlo	174	Monte Carlo	174	Monte Carlo
Total potential contamination	71,250	mg	101,480		105,270		104,400	
IF' condition	0		3,930		4,423		4,310	
			Sensitivity values		*Sensitivity values*		*Sensitivity values*	
			Raw	-57%	Raw	-29%	Raw	-11%
			Treated	-3.60%	Treated	-11.20%	Treated	-0.60%
			Volume	-76.60%	Volume	-72.40%	Volume	-87.00%
			Probability of achieving specific values within a range	12.61%	Probability of achieving specific values within a range	95%	Probability of achieving specific values within a range	0%

Fig. 5.2 Determination of the most probable payment range for water contamination

Thus, if the difference between C6 and C9 is <47,500, payment is (0), but if this difference is larger than 47,500, then multiply (C6–C9) by 0.13. (47,500 is the difference between expected discharge and allowable discharge, that is: 118,750−71,250).

Run Crystal Ball and indicate 500 iterations or trials. Results are depicted within the boxes in Fig. 5.2.

By far, the most significant variable is wastewater volume, the next most significant variable is level of contamination in raw water, and the third, the variation in treated water.

The software also gives the probability that the result will be between the established limits; in this case, there is only 12.61 %.

We can proceed with our analysis to see what happens if different ranges for limits are used. The second run is now between 3,500 and 6,500 Euros. From the sensitivity point of view, the same pattern maintains regarding significance of variables. However, the probability is now 95 % that fees will be within this range.

The third run takes as limits 6,500 and 9,000, and the same sensitivity pattern subsists. However, now the probability of fees with this interval is zero, that is, there is no probability of this happening. This is logical, since the range lies outside the expected fees.

Therefore, expected fees with the new equipment will be between 3,500 and 6,500 Euros, that is, larger than originally assumed.

5.5 Assessment of Risk Associated with Durations (Schedule)

This is probably one of the most common and accountable aspects – in a high percentage of cases – for the project not being completed on time. Risks are inherently associated with delays (Schedule risks).

We have already analyzed in Sects. 5.3, 5.4 and 5.5 risks involved in the determination of durations for tasks and the corresponding uncertainty for total duration. In the next section an example is proposed for risks in both time and cost:

- *Quality of the mix*
  Potential risk: Poor quality concrete affects its strength and reliability.
- *Temperature according to the destination of each batch and weather*
  Potential risk: In summer time, and because concrete reacts exothermically with water, there is the risk of insufficient cooling.
- *Not enough water once concrete is poured*
  Potential risk: It can produce a poor quality concrete.
- *Ready-mix supplier experience*
  Potential risk: Delays in supply of a mix of unacceptable quality.
- *Pouring concrete. Is there any trained supervisor for pouring?*
  Potential risk: Is there risk in using a vibratory or a stirring rod to get rid of air bubbles?
  Potential risk: Bubbles trapped inside the concrete.

Note that this risk identification is linked to quality, an aspect that must always be present.

5.5.1 Case Study – Assessment of Risk Associated with Time and Costs – Transportation of Heavy Machinery

Issue: Potential poor weather affecting transportation of heavy machinery on mountain road

A large tunnelling project in South America will use a Tunnel Boring Machine (TBM), a huge piece of equipment weighing hundreds of tons, which, together with its components, is manufactured in Europe. Transportation of the equipment involves the following steps:

- Land transportation from the manufacturer's plant (MP) to a seaport. This is done by truck through a mountainous road, with a pass that is eventually closed for several days in wintertime because of snowfall and ice. The trip normally takes 1 day, but in wintertime, it can also take up to 6 or 7 days because of the closing of the pass and the potential danger of rock and mudslides. The schedule calls for transportation starting on October 15, winter-time in the Northern Hemisphere.
- The load is shipped on an ocean freighter up to its destination port (DP) (a South American port), a trip that normally takes 24 days, but the duration of which could also vary due to stormy weather, winds, delay in intermediate ports, etc.
- When the ship arrives at its destination, the equipment is landed and loaded on a truck and must comply with custom regulations (1 day).
- Once this last step is completed, it is hauled to the job site over a 1.5 day trip.
- Upon arrival, the equipment is unloaded, checked and assembled, which can take up to 2–3 weeks.

The equipment is a vital part of the project without which it cannot start, and for that reason, there is keen interest in determining its arrival date.

5.5.1.1 Analysis of this Activity

5.5.1.1.1 Regarding Delays

The analysis of the route between the manufacturer and the shipping port involves two aspects. The first is related to the *probability of snowfall and its intensity*, the second deals with the *road traffic condition* owing to the snowfall intensity.

According to historic data, the chances of snowfall between the dates we are interested in – that is, between October 15 and November 10 – are 80 %. In a case of snowfall, its intensity can produce the following effects on the road, with data also extracted from historical records during that period:

With snowfall (A)

Traffic slow and heavy **(B):**	Between 75 % and 90 %
Traffic moderate and light **(B′):**	Between 9 % and 12 %

Without snowfall (A′)

Traffic slow and heavy **(B):**	Between 9 % and 12 %
Traffic moderate and light **(B′):**	Between 75 % and 90 %

These ranges of values, as well as the definition of the probability distribution used (in this case, normal), allows for using Monte Carlo analysis, which, after 500 iterations, produces these values:

Probability of snowfall in this period (A) = 69.82 %
Probability of slow and heavy traffic (B) = 86.04 %
Probability of traffic moderate and light (B′) = 11.21 %

Probability of no snowfall in this period (A′) = 29.85 %
Probability of traffic slow and heavy (B) = 11.21 %
Probability of traffic moderate and light (B′) = 86.04 %

These conditions are graphically depicted in a tree diagram, as shown in Fig. 5.3. In this case, since the traffic on the road largely depends on the intensity of snowfall, there exists a conditional probability, that is, traffic on the road will have certain values if there has been snowfall, which will be different if this event does not take place.

Conditional formulas are:

$$P(B \cap A) = P(B/A).P(A) \tag{5.1}$$

That is: The probability of B (Traffic slow and heavy) with the probability of A (Snowfall) is equal to the probability of B once A has occurred, times the probability of A. Consequently:

$$P(B \cap A) = P(B/A).P(A) = 60\%.$$

Similarly:

$$P(B' \cap A) = P(B'/A).P(A).$$

That is: the probability of B′ (Traffic moderate and light) and the probability of A (Snowfall) are equal to the probability of B′ once A has occurred times the probability of A, consequently:

$$P(B' \cap A) = P(B'/A).P(A) = 8\%.$$

Similar analysis can be executed if snowfall has not occurred.

Therefore, there is a 60 % chance that the truck trip will take 3/5 days (1 day of normal trip, plus 1 or 2 days minimum delay because of pass closing), that is, the machinery will arrive 1 day or 2 days late, since the ship has a fixed departure date. In this case, the load will miss the ship and will be unloaded on the wharf or stored in a depot, where charges apply for storage, safety and insurance. Since there will be a waiting period of 13 days (15 days waiting – 2 days delay) until the next sailing, the charges will be as indicated in Table 5.6. Similarly, if the delay is 7 days, the waiting period will be 15–7 = 8 days, and therefore, charges will apply for that period.

Therefore, the analysis goes like this (see Fig. 5.3).

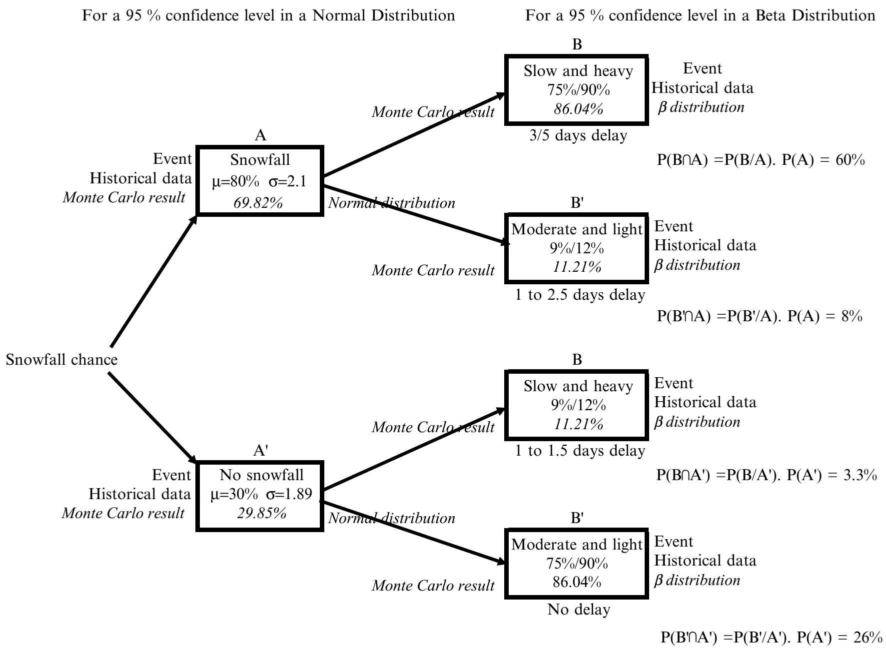

Fig. 5.3 Tree analysis of problem

5.5.1.1.2 Regarding Costs

Table 5.6 depicts – considering that there is a chance of snowfall and with different intensities – how much delay can be expected, as well as related costs. Figure 5.4 sketches the scenario.

Ship service is every 15 days. Therefore, if the ship is missed, it is necessary to wait for 15 days, and thus, these charges apply:

- Wharf occupancy: 5,000 Euros/day
- Security against theft, fire, vandalism: 675 Euros/day
- Insurance: 450 Euros/day

5.5.1.1.3 Mitigation

Since at this time of the year, there is a 60 % risk of the equipment arriving at the wharf with 4/5 days' delay, producing the maximum costs, it is reasonable to make efforts to mitigate this impact. A solution could be to anticipate the delivery of the equipment from the factory in 5 days (buffer). If, in reality, the threat materializes and the load arrives at the wharf after 5 days, there is still time to ship it on schedule.

Table 5.6 Costs for different probabilities of occurrence

Chance	Road	Probability of occurrence (mutually exclusive)	Consequences	Outcome	Impact on costs (wharf + security + insurance) (Potential loss)	Risk: Potential loss × probability
Snowfall (A) (69.82 %)	Slow and heavy (B)	60 %	3/5 days delay	Ship is missed and the load has to wait on the wharf for 15–5 = 10 day	10 × 5,000 + 10 × 675 + 10 × 450 = 61,250 Euros	61,250 × 0.60 = 36,750 Euros
	Moderate and light (B′)	8 %	From 1 to 2 days delay	Ship is missed and the load has to wait on the wharf for 13 days	13 × 5,000 + × 675 + 13 × 450 = 79,625 Euros	79,625 × 0.08 = 6,370 Euros
No snowfall (A′) (29.85 %)	Slow and heavy (B)	3.3 %	From 1 to 2 days delay	Ship is missed and the load has to wait on the wharf for 13 days	13 × 5,000 + 13 × 675 + 13 × 450 = 79,625 Euros	79,625 × 0.03 = 2,628 Euros
	Moderate and light (B′)	26 %	No delay	N/A	N/A	N/A

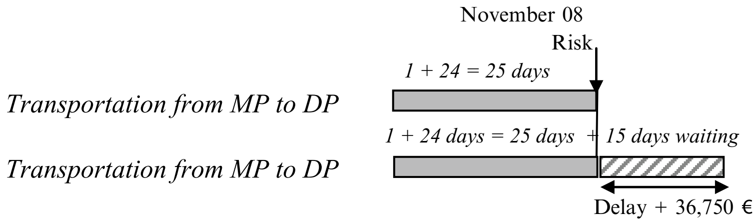

Fig. 5.4 Potential expansion and additional cost of the transportation task owing to risk

If the threat does not materialize, there could be a waiting period on the wharf for 4 days, at a total cost of 4 × 5,000 + 4 × 675 + 10 × 450 = 27,200 Euros, which is the mitigation cost, and a loss, since it is unrecoverable.

Options

1. Do nothing: There is risk of the equipment arriving at the job site 15 days later at an additional cost of 36,750 Euros, which is rarely an option.

   - Transfer the risk by buying insurance.

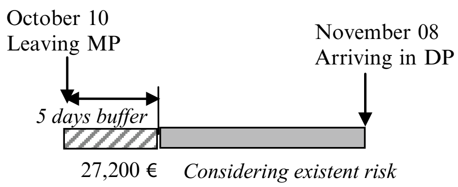

Fig. 5.5 Remediation through commencing trip earlier and additional cost

- Negotiate delivery of the equipment with the manufacturer 5 days earlier than the contractual date. There is a risk of $27{,}200 \times 0.4 = 10.880$ Euros. (In case the trip can be made in 1 day (40 % probability), the wharf will charge for 4 days.)

Considering the calendar (Fig. 5.5), delivery and start of transportation should take place on October 10.

We are assuming here that the maritime trip takes a fixed time, however, it is not so, because many different factors can make the ship arrive earlier or later. We can also model this assumption, considering, for instance, that the most likely time will be 24 days, but it could also be 23 or 25 or 26. We can ponder this circumstance, assigning a normal distribution to the task and making it related to the land trip probabilities. There are other additional risks, as follows:

1. History of punctuality (or lack thereof) of the shipping company, regarding ship arrivals at port of destination.
2. Average delay (from shipping agents) for unloading the equipment from the ship.
3. Average delay for custom clearance (from custom broker), etc.

In general, impacts are assessed evaluating the damage caused by the materialization of the risk, for instance:

1. Extremely serious, for example, in the case that a large sporting event (such as the World Cup) is scheduled for a certain date, with local authorities invited, people coming from far away for the inauguration, artists hired, catering contracted, hotel rooms reserved, etc. A maximum value of 100 % could be given to the impact in this case.
2. Very serious, for instance, when the air-conditioned system will not be ready on inauguration day in summer time, or when hefty fines have to be paid for each day of delay. Value: 80 %.
3. Serious, for instance, a contractor that receives work done from another contractor and has to wait with all his equipment idling, because the former will not finish in time. Value: 50 %.
4. Moderate, for instance, heavy rainfall that stops work on a mountain road construction. Value: 30 %.
5. Light, for instance, delay in paving the office area in a construction camp. Value: 5 %.

Assume now another scenario for which part of a different project's critical path is depicted with a duration of 64 days, considering the 7 days' buffer of task 2 (number of days are shown below each task and underlined) (Fig. 5.6).

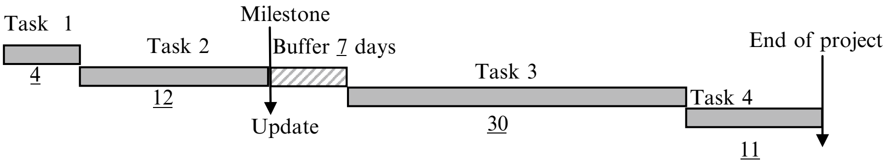

Fig. 5.6 Expansion of a task owing to risk affecting the whole project

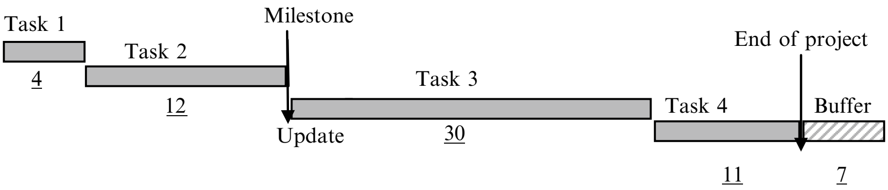

Fig. 5.7 Transferring the gain in days to the end of the project

Table 5.7 Comparison of results using different probability distributions

Probabilities for delays on road between October 15 and November 10

Chance	Percentages historic inputs	Selected probabilities distribution	Percentages MonteCarlo outputs	Percentages outputs P(B∩A)	Percentages outputs P(B′∩A)	Percentages outputs P(B∩A′)	Percentages outputs P(B′∩A′)	
Snowflow	60–85	β	78.41	67	9			Conditional 01
No snowflow	27–35	β	32.89			4	28	
Snowflow	$\mu = 80, \sigma = 2.1$	Normal	83.34	72	9			Conditional 02
No snowflow	$\mu = 30, \sigma = 1.89$	Normal	33.01			4	28	
Snowflow	60–85	Triangular	78.94	67	9			Conditional 03
No snowflow	27–35	Triangular	39.06			4	28	
Snowflow	70	Pareto	70	60	8			Conditional 04
No snowflow	30	Pareto	30			3	26	

If, during an update, it is verified that risk did not materialize or is not going to be a threat, and if task 2 actually finished in 12 days, the 7 days' buffer is a gain, task 3 can start immediately, as well as task 4, and the whole project gained 7 days (Fig. 5.7).

This buffer can be put at the end of the project to be used for another critical task, if necessary.

5.5.2 Comparison of Results Using Different Probability Distributions

Table 5.7 shows results for the same problem analyzed in Sect. 5.5.1 – although with different historic percentages – when considering different probability distributions. It can be seen that percentage outputs show very little variation, from which it can be deducted that the chosen probability distribution does not greatly impact results.

5.6 Assessment of Risk Associated with Economy and Financing

This is based on the methodology called 'Z-Matrix' and explained in Sect. 4.9.1.

This section examines risks in economy and financing aspects of a project and their assessment. It is, of course, a critical issue, and normally this analysis deals mainly with parameters such as the Net Present Value (NPV) and the Internal Rate of Return, that is, the entrepreneur or owner of a project is usually interested in analyzing the recovery of his/her capital after a certain period, which is normally taken for granted, due to the results of the previous analysis conducted to decide the economic and financial feasibility of a project, as well as its technical aspect.

In fact, what is normally done is to determine annual values for cash flow, and then discount them at a certain rate to get the Net Present Value (NPV) of the venture, which includes investments and benefits produced by the project. If this amount is positive, it is considered that the project is economically and financially feasible.

It is also usual to fix a certain return in percentage of the invested capital, called the Internal Rate of Return (IRR), that is, a percentage based on different aspects, mainly cost of capital and/or cost of opportunity (that is, the benefit forgone when funds are invested in one project instead of another). It is also customary to work with the Pay-Back Period (PBP), which means the elapsed time since the project has been in operation or in production, to recover the funds invested.

However, all of these methods are based on estimates, be it sales, prices, production, demand, etc., which are uncertain by nature. For this reason, the Monte Carlo Model is used in order to work with more realistic values, since hundreds of possible scenarios are considered, instead of only one, or even several.

5.6.1 Case Study – Economic/Financial Risks – Pulp Mill Project

Action: Pulp mill construction (see Fig. 5.8).
Factors matrix: Demand of pulp, price, operating costs, and working capital.
Variations, assigned to each factor according to historical data, external factors and expert estimate.
Probabilities of occurrence are from market study and statistics, as well as foreseen domestic and international conditions and expectations.

One way to make this assessment is by using projected financial statements, which are normally prepared for a project's economic and financial feasibility. These statements, in this actual example, are:

- Balance sheet
- Cash flow statement
- Statement of earnings
- Long term loan schedule
- Assets, depreciation and amortization schedule

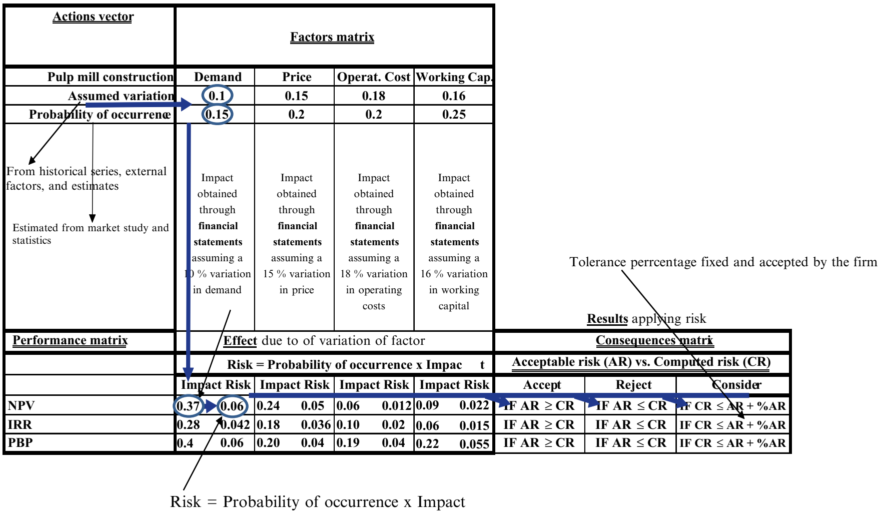

Fig. 5.8 Z-Matrix for a pulp mill project applied to economy and finances

With these documents, it is possible to prepare the Project Analysis schedule, in which values for the main chosen parameters, such as Net Present Value, Internal Rate of Return, Pay Back Period, Debt Coverage, Cash Flow per Share, and others, can be depicted along the project horizon, which, in this example, spans 17 years, including three years for construction.

Assumed variations are:

Demand:	−10 %
Price:	−15 %
Operating Costs:	18 %
Working Capital:	16 %

The outcomes of this analysis are impacts, in percentages, based on the difference between the expected NPV and the NPV obtained owing to corresponding variation.

Consequences of demand variation

Impact: NPV decreases 37 %;	Risk = 6 %
Impact: IRR decreases 28 %;	Risk = 4.2 %
Impact: PBP increases 40 %;	Risk = 6 %

Consequences of price variation

Impact: NPV decreases 24 %;	Risk = 5 %
Impact: IRR decreases 18 %;	Risk = 3.6 %
Impact: PBP increases 20 %;	Risk = 4 %

Consequences on cost variation

Impact: NPV decreases 6 %;	Risk = 1.2 %
Impact: IRR decreases 10 %;	Risk = 2 %
Impact: PBP increases 19 %;	Risk = 4 %

Consequences of working capital variation

Impact: NPV decreases 9 %;	Risk = 2.2 %
Impact: IRR decreases 6 %;	Risk = 1.5 %
Impact: PBP increases 22 %;	Risk = 5.5 %

Therefore, considering **demand**, the greatest risks correspond to both NPV and PBP.

Considering **price**, the greatest risk relates to NPV, closely followed by PBP.

Considering **operating costs**, the greatest risk relates to PBP.

Considering **working capital**, the greatest risk corresponds to PBP.

With these values, it is possible to compute the inherent risks, as shown in Fig. 5.8.

We consider the assumed variation values and their probability of occurrence estimated through a market study and statistics, and taking into account the percentages obtained from the Project Analysis schedule. Thus, for Demand, the risk will be Pro bability × Impact = 0.15 × 0.37 = 0.06. The same procedure gives the risk values for Price, Operating Costs and Working Capital.

The Consequences matrix offers results when risk is applied, and portrays results comparing acceptable risk (AR) vs. computed risk (CR) for each chosen parameter (NPV, IRR and PBP). For instance, for NPV, the decision to accept the result is based on the comparison between AR and CR, and actions taken according to these rules:

If accepted risk is larger than computed risk, the project is accepted.
If accepted risk is lower than computed risk, the project is rejected.
If accepted risk plus a certain tolerance percentage is larger than computed risk, then the project should be reconsidered, perhaps changing certain assumptions and expectations

5.6.1.1 Conclusion

For this case (Fig. 5.8), we have found the risks for NPV, IRR and PPB. As a bottom line, it appears that:

Risk for NPV are more significant for demand and price, and are assumed to be normal and within expectations. However, the company should perhaps review its estimates, especially the discount rate of return.

The IRR looks too low, with an average risk of 2.8 %. The company should review calculations to make sure that unrealistic data has not been input.

The PBP appears to be the most sensitive indicator, since it has high-risk values in all factors. The company should possibly lower its expectations regarding capital recovery time.

Anyway, if the accepted risk (AR) for NPV is, say, 7 %, this is satisfactory, since AR > CR (Computed risk).

The same is true for IRR.

However, if the original PBP is, say, 10 %, meaning that the company is willing to accept a 10 % increase in time for recovery, then, since cumulative risk is 19.5 %, it almost duplicates the original estimate. That is, the original PBP is, for instance, 5 years; this value means that the company will have to wait for another year, since $5 + 0.195 \times 5 \cong 6$ years to recover its capital.

5.7 Assessment of Risk Associated with Social, Environmental and Logistic Issues

We have examined risks linked to costs, time and financial issues; there are, however, other aspects that require risk management. The next section shows the same project risk applied to social, environmental and logistics issues. Z-Matrix is once again used.

5.7.1 Case Study – Society/Environment/Logistic Risk – Pulp Mill Project

This case (see Fig. 5.9) illustrates the use of the Z-Matrix for aspects other than economy and financing, as demonstrated in Sect. 5.6.1. Again, this example refers to the construction of a pulp mill in a remote forested and tourist area and on the shore of a river discharging into the ocean. There is abundant rainfall as well as heavy snowfall in the area, and poor dirt roads. Marks for different concepts are based on technical considerations; the 1–10 system is used, the higher being the more important.

5.7.1.1 Action Vector

Action: Pulp mill construction (only this very general action is examined here, but many others can be considered, such as Excavation, Construction, Transportation, etc.).

5.7.1.2 Factor Matrix

Society, environment and logistics are the main factors ‘participating’ or involved in this project. At the intersection of each column with the action, enter the following data:

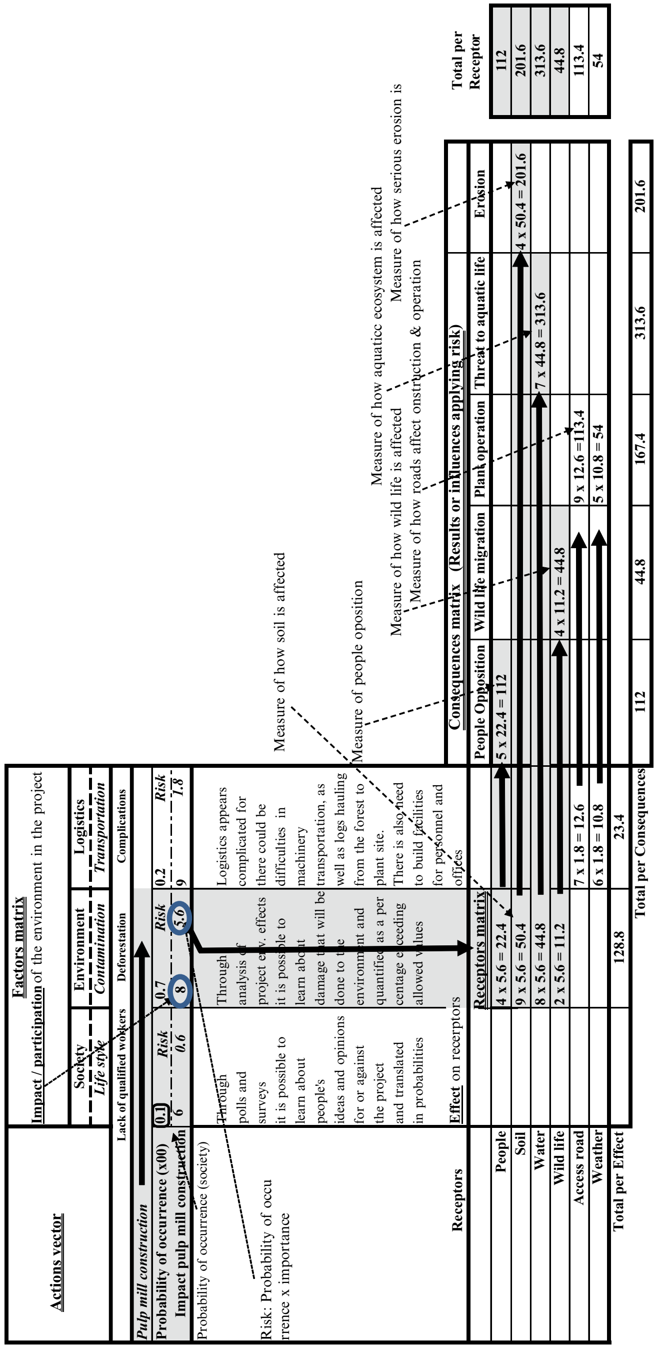

Fig. 5.9 Z-Matrix for a pulp mill project applied to society, environment and logistics

Probabilities of occurrence

Probability of project disturbing local population lifestyle and economy (10 %), determined after opinion polling of the people in the are9.

Probability of project disturbing the area's ecology (70 %), because of contamination of river water, odours, noise and erosion.

Probability of project problems related to logistics (20 %), through analyzing road conditions and expected heavy industrial traffic.

Impacts

Impact of project on society: (6). Participation is not high, since this is a non-labour intensive plant due to process automation.

Impact of project on the environment: (8). Participation or impact is obviously high, since it will log a forest, and thus, alter the local ecology.

Impact of project on road infrastructure: (9). Participation or impact is high, because log trucking will destroy existing roads and increase heavy traffic.

Since we have probabilities of occurrence and impacts (measured by the degree of participation), their product gives the respective risks as 0.6, 5.6 and 1.8 (see Fig. 5.9). That is, the project carries 70 % probability of damaging the environment, and thus, environment has a participation or impact valued at 8 points, meaning the risk for the environment will be $0.7 \times 8 = 5.6$ points. Similar calculation can be done for society and logistics.

5.7.1.3 Receptor Matrix

This groups the receptors or receivers of the effects described above and evaluates them. The matrix is formed by:

- People, who can be socially affected (in a positive and/or negative sense).
  Impact or participation (4). Since the risk is *0.6,* people weighted participation will be $4 \times 5.6 = 22.4$.
- Soil, since land could be barren after deforestation.
  Impact or participation (9). Since risk is *5.6,* weighted participation will be $9 \times 5.6 = 50.4$.
- Water, due to river contamination, because pulp mill wastewater (even if treated) can affect villages down the river.
  Impact or participation (8). Since risk is *5.6,* weighted participation will be $8 \times 5.6 = 44.8$.
- Wildlife, as a consequence of migration owing to logging and noise.
  Impact or participation (2). Since risk is *5.6,* weighted participation will be $2 \times 5.6 = 11.2$.
- Access road. Logistics are affected, since it is not paved and becomes muddy and impassable with heavy rain, and will also be degraded by heavy traffic of trucks.
  Impact or participation (7). Since risk is *1.8,* weighted participation will be $7 \times 1.8 = 12.6$.
- Weather, because the zone has harsh winters with heavy snowfalls and mudslides.
  Impact or participation (6). Since risk is *1.8,* weighted participation will be $6 \times 1.8 = 10.8$.

5.7.1.4 Consequence Matrix

The consequences in this case are:

- Public opposition, because of the belief that the undertaking will alter the local way of life and degrade properties.
  Impact or participation (5). Since valuation is 22.4, weighted participation will be $5 \times 22.4 = 112$.
- Wildlife migration, since the local fauna will have to migrate when their habitat (the forest to be logged) is destroyed.
  Impact or participation (4). Since valuation is 11.2, weighted participation will be $4 \times 11.2 = 44.8$.
- Plant operation, which will be affected due to access road conditions.
  Impact or participation (9). Since valuation is 12.6, weighted participation will be $9 \times 12.6 = 113.4$.
- Plant operation, which can be affected by weather conditions.
  Impact or participation (5). Since valuation is 10.8, weighted participation will be $5 \times 10.8 = 54$.
- Threat to aquatic life, produced by traces of chlorine in the river water, as a consequence of pulp mill waste water discharge.
  Impact or participation (7). Since valuation is 44.8, weighted participation will be $7 \times 44.8 = 313.6$.
- Erosion
  Impact or participation (4). Since valuation is (50.4), weighted participation will be $4 \times 50.4 = 201.6$.

5.7.1.5 Conclusion

Values in the last matrix indicate the diverse consequences that the project can generate, and more importantly, give their evaluation. It can be seen that 'Threat to aquatic life' has the largest value, followed by 'Erosion', 'Plant operation', 'Wild life migration' and 'People opposition'. Although this result was predictable owing to the very large probability for Environment, it was unknown as to how it would be distributed. On the other hand, the result is not always so evident from the outset, because there could be other factors with similar or even smaller probabilities that, nonetheless, have the largest value at the end, not only because of their participation, but also due to the number of receptors and consequences.

Analyzing these results, it looks as if provisions should be taken to reduce 'Threat to aquatic life'. This could mean calling for studies to decrease water contamination by means of more intensive purification, or replacing Chlorine with other chemicals, as other processes for pulp-making do. There is probably also particulate in this discharge that causes turbidity to the receptor body of water and that is noxious for fish, calling for a more thorough filtration or perhaps centrifugation of wastewater, which will, perhaps, pay for itself through the recovery of valuable pulp fibres.

Erosion is also a serious consequence, even when the forest to be logged is not in the path of surface runoffs, because heavy rains can also sweep the vegetal soil and make the soil barren. It is, thus, necessary to find a way to prevent this from happening, which could be by erecting dirt dykes. In addition, it would perhaps be advisable to perform a study to better manage the slope on the plot, which can help erosion when related to runoffs.

Plant operation can be seriously affected by access road conditions; for instance, stoppage of the supply of logs to the plant because of rock blockades, snowfall or dangerous conditions for driving the huge trucks, or because the road is cut off due to intense rains. This could call for studies performed as to how to improve road conditions, perhaps improving the road surface with a gravel layer, excavating drainage ditches, or even paving it.

Therefore, the Z-Matrix acts as a magnifying glass to detect problems that can create risky situations, and, at the same time, evaluate them.

5.8 Assessment of Risk Associated with Costs

Costs in projects include four main categories (a) labor (manpower), (b) installations (building construction and production equipment), (c) materials (ready-mix concrete, masonry, steel, sidings, aluminum sheets, electric wire, architectural glass, plumbing, etc.), and (d) construction equipment and apparatus (trucks, forklifts, computers, laboratory instruments, surveying tools, etc.). A risk factor should be applied to them.

5.8.1 Labor

In the planning phase, budgeting uses actual scales for salaries and wages. Manpower for a particular and typical task, such as excavation, concrete pouring, equipment installation, etc., is usually established through dedicated software with updated tables, which give a fair value of the amount of labour and materials that a certain job demands. Consequently, knowing the quantity of people in the different trades and crafts that will be employed in a certain task, and applying current hourly rates for man hours and equipment used, it is possible to calculate the cost of the task (naturally, including workers' benefits, mark-up and taxes). Without a doubt, expertise also plays a main role in defining these costs, which aggregated constitute the budget of the project, and from which the S-Curve or Budget Curve or Budget Cost of Work Schedule (BCWS) curve can be drawn (see Sect. 7.1).

However, prices change with time. Hourly rates for labour will most probably be updated according to the annual increase because of cost of living indexes, and materials and equipment could register an increment due to inflation, which could be estimated, possibly considering expectations as to government measures and trends.

Consequently, the planning must take these increments for corresponding future periods into account, although, needless to say, it is often impossible to know with certainty how much these increases will be. For instance, the cost of living, often computed based on the Consumer Price Index, could be forecasted to be about 1.74 % for next year, 1.9 % for the following year, and so on. Sources for these values are government publications, and it is useful to consider how the index was developed in the previous years in order to know its trend. When estimating the budget, the analyst must take into account the region where the project will be built, because the cost of living is normally different from one city to another; however, it is certainly impossible to predict exactly how much the index will be, even working with approximations. As usual, the project cost analyst is confronted with uncertainties, and for that reason, it is convenient to add a risk factor for labour.

Now, if for labor, it is assumed that the cost of living next year will be say, 1.74 %, and the basic wage is 7.50 Euros/h., then the wage for next year will be:

$$7.5 + 7.5 \times 0.0174 = 7.63\,\text{Euros.}$$

If we assume that the probability of this increase is 90 % (of course, it could be more or less, and this assumption could be validated checking the historical evolution of the index, evaluating the political and economic situation of the country, government announcements, union claims, etc.), the impact will be:

$$7.63 - 7.5 = 0.13\,\text{Euros}$$

and the risk:

R = Probability of occurrence × Impact
R = 0.90 × 0.13 = 0.117 Euros.

Then, total hourly cost will be 7.63 + 0.117 = 7.747 Euros, and, of course, this calculation can be done early for all costs of the system.

5.8.2 Materials

Because large projects employ a large quantity and variety of materials, from concrete to bricks, from sidings to plumbing, from lighting to roofing, etc., and many different equipment that must be installed, forecasting cost for these items is a difficult task. In addition, there is generally no index affecting them all, especially when coming from different countries and different vendors.

Unfortunately, we do not have something similar here to the critical path that identifies critical activities regarding project duration; but we would need a way to identify those materials and equipment that account for most of the project's cost. For this reason, it is proposed here an 'equivalent' system based on the Pareto' Principle that says that '*roughly 20 % of something is responsible for 80 % of the results*'. Applying this principle to a project, it will be possible to identify 20 % of materials and equipment, the costs of which are responsible for 80 % of the project's total materials and equipment cost estimate. This is easily done, adding up all material and equipment costs, ranking them from highest to lowest, and then calculating the accumulated value starting with the largest cost.

Once identified, the forecast is based on considering the evolution of more difficult factors, such as inflation, which can be estimated studying the trends and economy of the country. For instance, it is perhaps possible to find a correlation between inflation and the Gross Domestic Product (GDP) that will permit this forecast inflation, and thus, this value can be applied to materials and equipment.

Naturally, if materials such as ready-mix concrete, bricks, steel, etc., have already been purchased or contracted, there will be no variation and no risk with them (at least from the cost point of view), but for those items that have not yet been purchased, it will be necessary to estimate the risk of higher prices.

When analyzing correlation between two variables from historical data, examine the way they vary, since both may be linearly correlated or non-linearly correlated, and for each case, a different method is applied, that is, Pearson's correlation coefficient for linear correlation, which measures the intensity or level of association between two variables.

The Spearmen Rank Order Correlation measures the level of similarity or correspondence between two different rankings, and in so doing, it is able to assess significance. Rodger and Petch (1999) explain this important concept when they state that "……*the rank order correlation is a measure of the importance of the input to both the level and variance of the output. The advantage of this technique is that only one model run is required to evaluate all the sensitivities and that all the inputs are varying simultaneously so that the relationships between the different inputs are being taken into account*". The Spearman Rank Order Correlation (Spearman 1904) is the most used in Monte Carlo Simulation Analysis. Remember that a high correlation, either positive or negative, does not necessarily mean that there is causal relationship between variables.

On some occasions, two risks have a dependency in which one risk is contingent to another that already has taken place; this is not correlation, but dependency, and an example can be found in Sect. 5.5.1.

5.8.3 Desegregation

It happens quite often that a risk is composed or formed by different risks. In this case, it is useful to breakdown or disaggregate the risk into its components, as is done using RBS (Sect. 4.6), because the risk for the result may be not the same as the risks for its components.

5.8.4 Equipment

For equipment, risk analysis is perhaps more difficult, but it can be ascertained according to consultation with suppliers if a purchase has not yet been settled for a known fixed price. If the final price for equipment has not yet been agreed upon, consider adding inflation not only in the project country but also in the country where the equipment is manufactured, if it is imported. Of course, it is convenient to check with tax authorities regarding potential increases or the creation of a new tax for importing goods, or new and increased fees for freight forwarding, temporary deposit in port warehouses, transportation to the site, etc.

5.9 Simultaneous Analysis of All Costs for a Project

We have been analysing costs by sectors, but in reality, what is needed is an appraisal of costs for the whole project involving different sectors. Section 5.9.1 comments upon a methodology considering all costs simultaneously.

5.9.1 Case Study – Cost Risk – Brewery Project

Assume, for instance, an undertaking involving the construction of a large brewery; the main components of the project are:

- Design and economy. A pre-feasibility study is done.
- Labour. Necessary labour has already been defined with sufficient accuracy, based on company expertise.
- Civil works. Preliminary estimate has been done.
- Equipment. Although already selected according to the firm's experience, equipment will be purchased from a variety of vendors and with a wide span in prices, because of differing capacities, speed and degrees of automation. This equipment is not custom-made and is readily available considering no more than 6 months' time since placing the purchase order.
- Site. Land plot has to be purchased, albeit certain data already exists on places and availability.

The estimate for the duration of the whole project is 3 years, with heavy equipment being installed in about 2.5 years from the beginning of civil construction work. Table 5.8 depicts the components of the project in Euros, with three point estimates.

Running Monte Carlo, the result from the final normal distribution shows a mean of 79,131 Euros (x000) with a standard deviation of 2,013 Euros (x000). See Fig. 5.10. (From now on, all cost figures are in thousands of Euros, although not indicated).

In analyzing these figures, one realizes that the best estimate for the whole project (76,781 Euros) is lower than the mean computed by Monte Carlo (79,131 Euros). Consider that this mean or average value has only a 50 % probability, that is, the cost could be lower or higher than that.

Table 5.8 Three points cost estimates for major components of project

Components or sectors	Lowest estimate Euros (x000)	Best estimate Euros (x000)	Highest estimate Euros (x000)
Design	2,420	2,500	2,600
Civil works	18,545	19,537	20,112
Labor	9,527	9,601	9,707
Equipment	41,896	42,643	50,605
Site	2,000	2,500	3,200
Total		76,781	

Now, it is obvious that the company estimate is too low, since it indicates that there is only 38 % probability that the final cost will be 76,781 Euros or lower. This percentage comes from computing the Z score (see Sect. 9.2.6).

$$Z = \frac{79{,}131 - 76{,}781}{2{,}013} \cong 1.17$$

Entering this value into a normal distribution table (Sect. 9.3), it is found that said score has a probability of 0.88[2] − 0.5 = 0.38. This is obviously too low, therefore, if the company wants to get at least a 50 % probability of compliance, it will have to make provisions for contingency as follows (see Fig. 5.10).

Contingency will be:

$$\text{Mean value} - \text{Best estimate} = 79{,}131 - 76{,}781 = 2{,}350\,\text{Euros.}$$

Or:

$$\frac{2{,}350}{76{,}781} = 0.0306 \cong 3.1\% \;\; \text{more than the best estimate.}$$

However, as commented above, this amount will have only 50 % probability of achieving that final cost. Most probably, the company will not be happy with this result, and will request at least a 95 % probability of success, that is, accepting only a 5 % risk (Fig. 5.11), which, of course, will mean a larger contingency.

To compute this cost, we again use the normal distribution table (see Table 9.1). For 95 % probability of occurrence, the Table shows a Z value of 1.65. Then, using formula (9.2) (Sect. 9.2.6):

$$x = \sigma . z + \mu \tag{9.2}$$

$$x = 2{,}013 \times 1.65 + 79{,}131 = 82{,}452$$

$$\frac{82{,}452 - 79{,}131}{79{,}131} = 0{,}0419 \cong 4.2\ \%$$

[2] Since the Table starts with Z = 0, with this score, the probability is 50 %.

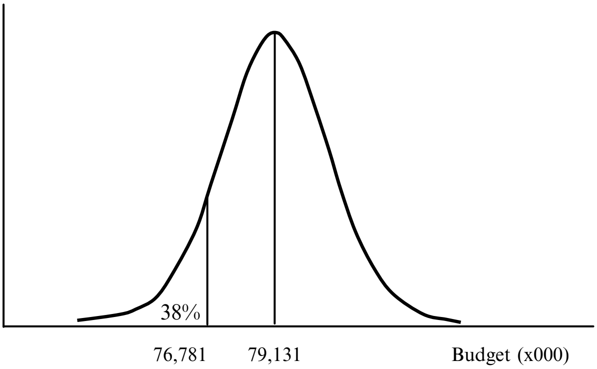

Fig. 5.10 Normal distribution curve

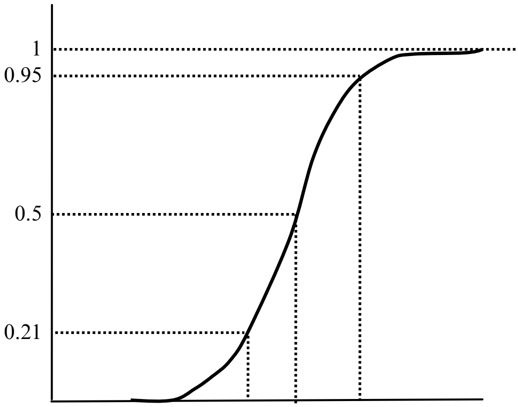

Fig. 5.11 Normal cumulative curve

That is, the company needs to increase its budget by 4.2 %.

If the firm has in mind accepting a top value for contingency of, say, 3.5 %, obviously this project result will not match its expectations; however, the firm may accept or reject it. Perhaps the company opts not to accept it, but if really interested in the project, and since the difference is not so big, the firm might decide upon cost reduction, for instance, by decreasing the size of the plant, or by purchasing used equipment instead of new.

In another scenario, it could be that the firm has in mind a top amount for investment that cannot be surpassed, say, for instance, 80,000 Euros, and wants to know what the risk will be considering this maximum disbursement. In that case, and using formula (9.1), from the same section and considering that x = 80,000, the unknown is now the probability, thus:

$$z = \frac{(x - \mu)}{\sigma} \tag{9.1}$$

$$z = \frac{(80,000 - 79,131)}{2,013} = 0.43$$

From the normal distribution table (Fig. 9.1), the probability is $0.666 \cong 67\ \%$ for this z value. Therefore, because of the maximum amount of money available, the probability of success dropped from 95 to 67 %. Naturally, it is up to the firm to decide what to do, but now they have the elements to make an intelligent decision.

5.9.2 Cost Scheduling Considering Work Breakdown Structure (WBS) and the Budget Cost of Work Scheduled (BCWS)

It is necessary to consider that, in order to compute costs in large projects with duration of several years, the cost analyst must take into account that costs will most certainly increase year by year, and thus, must be discounted to get present day values for the whole project.

Therefore, the cost computed when making an initial analysis will probably be lower than the cost when the project starts. Next year increments in costs due to labor, materials, fuel, etc., need to be considered, and the same for the subsequent years; it is on this assumption that the project budget must be calculated. In other words, costs are not fixed (except when an offer has been issued by vendor and accepted by client), and relate to time of purchasing materials and equipment, wages and salaries, future payment of services, etc.

All of this is reflected in the Budget Cost of Work Scheduled (BCWS) curve (see Sect. 7.1), which incorporates planning, costs and scheduling, that is, time of execution or purchase. It is because these increments as a function of time are sometimes not correctly considered that the Actual Cost of Work Performed (ACWP), that is, the work actually done, does not match the work scheduled in time and in cost. Figure 5.12 shows a simple and certainly partial WBS for our brewery superimposed upon a BCWS curve.

For its analysis, assume the same example as in the last Section, with a total plant cost of 79,131,000 Euros. The starting point for the construction of the BCWS is the project scope and the corresponding Work Breakdown Structure (WBS) (Sect. 2.12). The disbursement plan is as follows:

End of first year: 25 % of total cost, that is, 19,782 Euros (all values in 000s).
Work to be done: Clearing and grubbing, excavation for foundations and concrete work up to El. 23 m.

End of second year: 85 % of total costs, that is, 67,261 Euros (accumulated cost).
Work to be done: Roofing, cladding, siding and ancillaries (water and sewage piping, electrical wiring, boilers and steam piping, etc.).

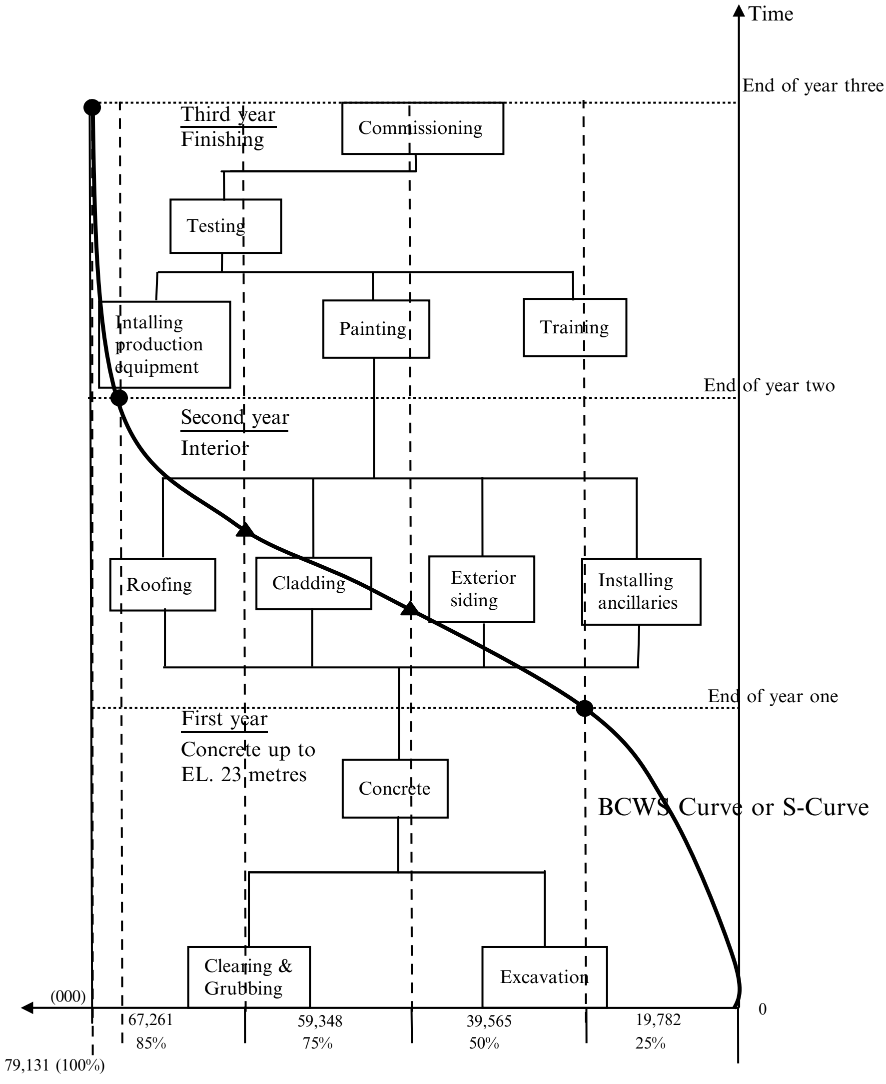

Fig. 5.12 Partial work breakdown structure for the brewery with budget cost of work schedule (BCWS) curve

End of third year: 100 % of total costs, that is, 79,131 Euros (accumulated cost).

Work to be done: Installation of equipment, ordered 6 months before; painting and training for personnel, testing the equipment and plant commissioning.

Notice which activities must be performed during each year in WBS and their correspondence with values of the BCWS curve.

5.9.3 Assessment of Reliability of Estimates

It is necessary to remember that, no matter what method for estimating probabilities of compliance in cost, duration, quality, environment, etc., is used, the results are only as good as the data. In many cases, data are only estimates, including using three point values for costs, and founded on assumptions of what could happen in the future. For instance, labour costs in the 3-year duration of the project can vary, as well as costs for materials, services, etc.; for that reason, we are proposing here a method for learning about the reliability of these estimates. It is based on use of the 'entropy' concept from the point of view of Information Theory, which can measure the amount of information contained in an estimate. This is related to data uncertainty; therefore, we can use entropy to measure its degree of uncertainty. The entropy (S) for the normal distribution is expressed as:

$$S = \frac{1}{2}\ln\left(2\pi e\sigma^2\right) \tag{5.2}$$

Table 5.9 depicts different values for entropy (S) corresponding to different values for the standard deviations (σ).

Plotting these values in Excel results in Fig. 5.13. Notice how the entropy (S) in abscissa decreases as standard deviations decrease. What does that mean? Standard deviations are linked with uncertainty; the larger the standard deviation, the greater the uncertainty indicated by a large entropy; conversely, a small entropy means less uncertainty, a smaller standard deviation and more reliability.

For the computed standard deviation of 2,013 (Sect. 5.9.1), we can also and more exactly compute the entropy value using formula (5.3).

$$S = \frac{1}{2}\ln\left(2\pi e\sigma^2\right) \tag{5.3}$$

$$S = \frac{1}{2}\ln\left(2\times 3.1416\times 2.71\times (2{,}013)^2\right) = 9.02$$

This value of entropy is too high, since the closer to zero, the better, and indicates large uncertainty. Examining Table 5.8, obviously, the most important items are civil works and equipment, so we should work on them. The highest estimate for civil works was 20,112 Euros, and this amount will be maintained by the bidder over 45 days. If the purchase order is not placed during that period, the total amount will escalate, because there will be an increase in steel bars.

The highest estimate for equipment is 50.605 Euros, and notice the large range (from 41,896 to 50,605 Euros), that is, 8,709 Euros (remember that we are talking millions!); there is no doubt that this wide range is due to considerable uncertainty. In this case, this is due to different characteristics of available equipment, but also because this equipment will be purchased in 2 years' time from start of

Table 5.9 Relationship between entropy and standard deviation

Standard deviation (σ)	Entropy (S)
10,000	10.28
3,333	9.18
1,111	8.08
370	6.99
123	5.89
41	4.79
14	3.69
5	2.59
2	1.49
1	0.39

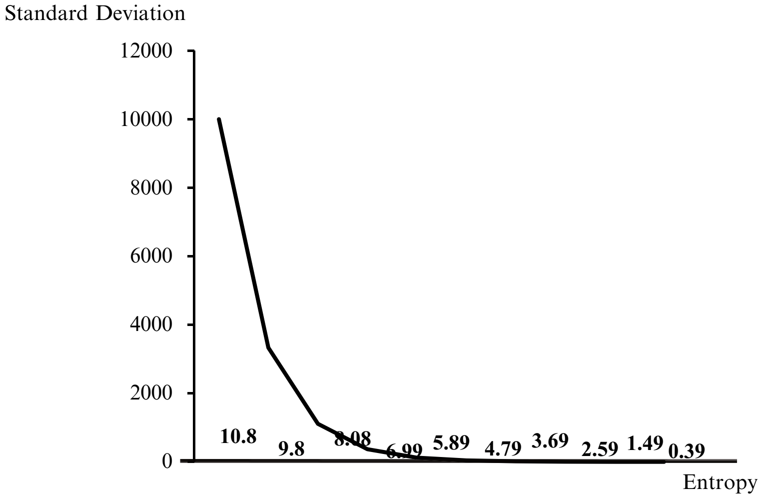

Fig. 5.13 Plotting standard deviations and corresponding entropies

construction, and nobody knows how much the final price will be at that time. According to research into recent prices, this equipment will have a cost of about 42,643 Euros, but it will most probably have an increment of about 19 % if purchased in 2 years' time.

If the company decides the immediate purchase, then there will be a reduced standard deviation computed at 386 Euros instead of 2,013 Euros. To this reduced standard deviation corresponds entropy of 7.03. Consequently, a reduction of 80.8 % in the standard deviation will produce a reduction in uncertainty of 22.1 %, thus dropping risk.

Therefore, the entropy concept can be used to gauge uncertainty, and thus, help in making decisions about different purchase policies. Having already introduced the main concepts, the method proceeds as follows:

It is assumed that the project's main components or sectors have probabilistic distribution of costs and times according to a triangular distribution (which is normally used in practice), that is, there exists a most likely value computed, taking into account construction tables for times and costs, costs information from vendors, expertise, etc., as well as an optimistic cost value assuming that there could be a probability that an item could cost less than expected, as well as a pessimistic value assuming the opposite, and the fact that certain circumstances may exist for this increment, such as inflation, life cost index, scarcity, etc. Therefore, there are three cost points, and the result for each sector, after processing via Monte Carlo, is a mean value and a variance.

All these probabilistic costs must be combined in order to get a final figure for the whole project (involving all sectors). This is done using the Central Limit Theorem, which establishes that the summation of these parameters from different sectors leads to a normal distribution, the mean of which is the summation of the component's means and with a variance that is the summation of the component's variance. This is the system used by PERT.

As already mentioned, the project under study is the construction of a brewery, a process that has been broken down into five sectors, as shown in Table 5.8, which are repeated here.

1. Design
2. Civil works
3. Labor
4. Equipment
5. Site

1. As mentioned, for each sector, there are three values, and we will now work with them. These have been selected after a thorough examination of existent conditions, for instance, for:

   Design. Values are estimated by the owner company of the project, based on its expertise and considering the newest advances in the brewery field.

   Civil Works. Pre-tendering consultations were done in order to have an in-house estimate mean (that is, the most likely value) to establish bases to call for tenders, and considering that there could be lower and higher prices, because of expected, although unknown, variations in steel, cement and aluminum, producing uncertainty.

   Labor. Pessimistic value takes into account expected, although unknown, variations in wages and salaries during the 3-year construction period, which produces a large uncertainty.

   Equipment. Because the project establishes that there will be a sole vendor supplying all equipment. There is a special circumstance here, because the equipment will be needed two and a half years after the project starts, therefore, it is very difficult to guess the prices in 2 years' time, and this produces a very large uncertainty.

   Site. Negotiations are under way to select amongst several locations, but the final price is still unknown.
2. The next step consists of assigning a probability to each optimistic and pessimistic cost value. Again, this is done considering the characteristics of the market

and the available information about prices. In this way, for each sector, there are two probabilities of occurrence, the optimistic and the pessimistic.

3. We now compute the impact that those probabilities of occurrence can generate. This is done finding the differences between the most likely value for a sector and the corresponding low and high cost values for that sector. Since we have probabilities of occurrence and their impacts, a risk can be computed for each sector, multiplying probability of occurrence and impact, with the result expressed in Euros.
4. Risk deviation is now calculated for each as the difference of these two risks.
5. The next step is the calculation of the entropy for each sector using the triangular distribution, entering the risk deviation by using this formula:

$$S = \frac{1}{2} + \ln \frac{(\text{high risk} - \text{low risk})}{2} \tag{5.4}$$

These values allow for making a ranking of sectors. The ideal entropy 'S' is zero, which offers the maximum amount of information, and correspondingly the lesser uncertainty. Therefore, the larger the entropy, the more uncertain the information we have.

In our example, we have this ranking:

Design : 4.15
Civil Works : 5.75
Site : 4.78
Labor : 4.28
Equipment : 7.87

Therefore, we have been able to put a number to uncertainty.

This result was expected, because of the large uncertainty for equipment derived from the chance to buy it now, in a year's time or in 2 years' time, this uncertainty being due to potential variation in costs.

6. Calculations show that the entropy for the whole system is 9.02, denoting that there is significant uncertainty in cost evaluation for the different sectors. Uncertainty is then linked with deviations, and it can be understood that, if there were no variations, that is, certainty in the mean values, then the entropy would be zero.

5.9.3.1 Analysis

Because of this information, it is evident that the first attempt to reduce uncertainty will be regarding equipment. The most likely value we have is 42,643 (x000), that is, the value after tenders were opened, and it reflects the lowest quotation; thus, we have to make a decision here. Does the company wait 2 years to place the P.O. with this risk of paying 19 % more or try to secure a contract now even with 2 years' time, but which will fix the price at 42,643?.

The answer appears to be straightforward, since it would certainly be better to have the price secured, but for that, the company must place the P.O. and pay 42,643 Euros now.

In our case, assume that the company possesses that kind of money, but invested in stocks which yield, as an average, 6 % annually. Therefore, if the company pays now, it will have to sell stock, and in so doing, will lose the interest that those funds would have generated.

How much will that loss be?

Calculation, assuming that the company receives an annual capitalization for its money, will be:

Estimated price in 2 years' time:	$42{,}643 \times 1.187 = 50{,}617$ Euros
Best actual offer:	42,643 Euros.

Because the company has these funds in stocks yielding 6 % annually, then, if used, the cost of opportunity lost will be:

First year:	$42{,}643 \times 0.06 = 2{,}558$ Euros
Discounted at the beginning of the first year:	$2{,}558 \times 0.9615 = 2{,}459$ Euros

Second year	$(42{,}643 + 2{,}558) \times 0.06 = 2{,}712$ Euros
Discounted at the beginning of the first year:	$2{,}459 \times 0.9246 = 2{,}274$ Euros.

Thus, at the end of the second year, the opportunity cost will be $2{,}459 + 2{,}274 = 4{,}733$ Euros.

Since by paying for the equipment up front, the company will not receive an amount of 4,733 Euros, then it is a cost that must be added to the total cost of the project, which, according to the Monte Carlo simulation, is: 79,131 Euros. Therefore, total cost will be $79{,}131 + 4{,}733 = 83{,}864$ Euros.

When time for the potential purchase of equipment arrives, it could happen:

1. If the company decided to risk it and not pay for the equipment up front, trusting that the increase will not be so big, and if the price effectively increased 18.5 % to 50,413 Euros. In this case, the company should pay:

   $$50{,}413 - 42{,}643 = 7{,}770 \text{ Euros more, and the project cost will jump to}$$
   $$79{,}131 + 7{,}770 = 86{,}901 \text{ Euros.}$$

2. If the price went up to more than 50,413, in which case, the cost of the project will obviously increment even more.
3. If the price did not reach the level assumed, then the company will suffer a loss, since the foregone money that could have been used for other purposes is larger than the amount that should be paid for the equipment.

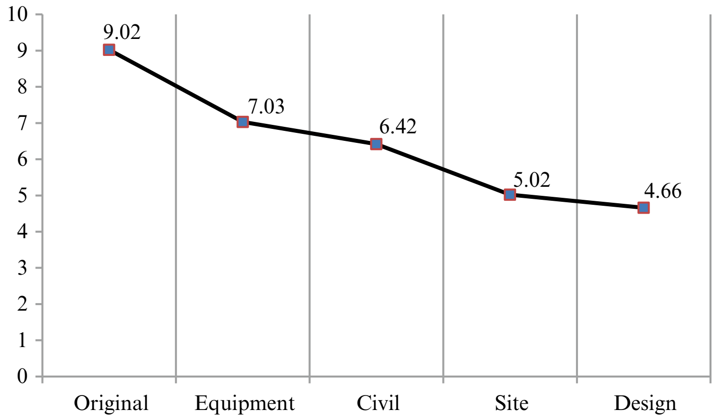

Fig. 5.14 Graphic showing progressive decreasing uncertainty

If the company is able to fix prices for everything except labor, since it depends on external factors, the entropy reaches these decreasing values successively:

$$\begin{aligned}&\text{Original : 9.02}\\&\text{After fixing Equipment : 7.03}\\&\text{After fixing Civil Works : 6.42}\\&\text{After fixing Site : 5.02}\\&\text{After fixing Design : 4.66}\end{aligned}$$

Thus, uncertainty originally at 9.02 has decreased to 4.66.

Figure 5.14 shows, by examination of slopes, the influence of each sector in the reduction of uncertainty. Notice that the most influential sector is Equipment, with 22 %, followed by Site with 21.8 %, Civil Works with 8.6 %, and final Design with 7.2 %.

5.10 Risk Assessment by Risk Matrix

Another way to evaluate risk and the corresponding measures and especially to quantify improvement when performing mitigation is the risk matrix portrayed in Fig. 5.15.

This device is very often used for risk assessment that merges probabilities of occurrence (in ordinates) with impacts (in abscises). The mathematical definition of risk (or at least, the most common definition) says that risk is the product of a probability of a threat and the impact that it produces. That product is represented in the cell located at the intersection of a column and a row where L stands for 'Low', M for 'Medium' and 'H' for high risk.

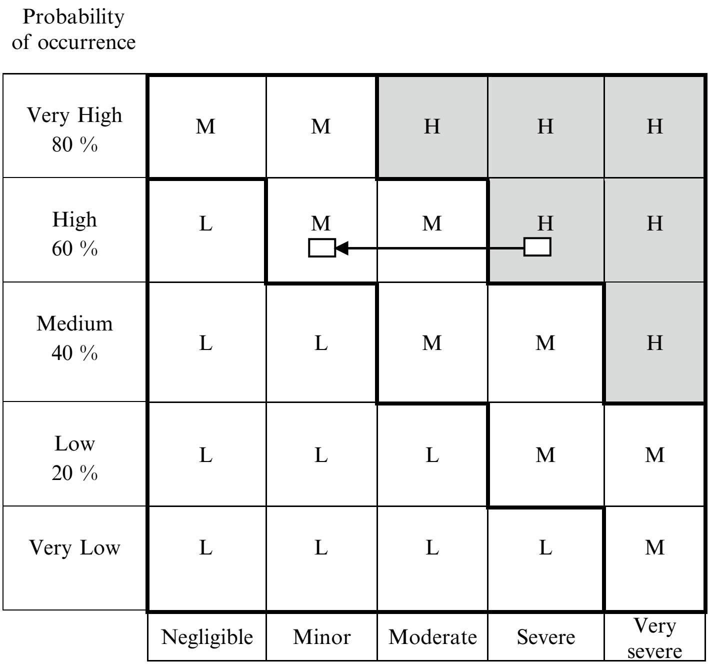

Fig. 5.15 Risk matrix

This matrix has drawbacks, especially because there is not a large discrimination compared with numerical risk values, since it only says that some events are more harmful than others. However, in many circumstances, this is enough, and it is valuable because it clearly and quantitatively depicts the combination of probabilities and impacts, with the shaded area showing the most dangerous situations.

This matrix is especially useful for showing the gain that remediation measures produce. For instance, assume that a situation presents a high risk (60 %) because it has a high probability of occurrence and severe impact. Their intersection or product produces a qualitative 'High value H' in the corresponding cell. After remediation measures are taken, the total risk decreases to a value shown in a cell located at the intersection of 'High risk' and 'Minor impact', which helps in learning about the effectiveness of remediation. Normally for a risk event, remediation will not change the probability of occurrence as in this case; however, there could be situations where it is possible to change the probability of occurrence. For instance, consider an air festival project that is scheduled to take place in winter and which has a medium chance of bad weather. A remediation measure could be to hold the event in autumn when the probability of bad weather is considerably reduced.

5.11 Probabilistic Risk Assessment (PRA)

This is a procedure for evaluating risks in normally technically complex undertakings or projects, such as nuclear plants, aerospace activities, chemical plants, complicated civil works, etc. Given a complex project, it tries to answer three very important questions about it:

* What can happen?
* What is the probability of it happening?
* If this, indeed, does happen, what are the consequences?

These questions are not exclusive to this methodology, since they are at the core of every project; however, it introduces elements that are not found in other scenarios, such as the sequence of events or accident sequences. The technique has two phases, *'Forward analysis'* and *'Backward analysis'*. The first one is formed through 'Events trees' while the second is formed through 'Fault trees'.

5.11.1 Risk Identification and Assessment – Events Tree Analysis (ETA)

A straightforward definition of an events tree is given by Paulos (2001), who states that it is, "*.....an investigation into the responses of a system to perturbations or deviations*".

The events tree analysis begins by assuming that something has happened, and this is indicated as the 'Initiating event', which is, according to Eidgenössiche Technische Hochschule (ETH) (2011), "*….an incident which necessitates automatic or operator actions in order to bring the plant into safe steady state conditions; without such actions, damage of the core may occur*". This definition applies in particular to a nuclear power plant, but can undoubtedly be applied to any other complex undertaking.

An initiating event may have different origins, since it can be produced:

Internally, as in the case of Chernobyl (Ukraine), which was produced by a test.
Externally, as in the case of Fukushima (Japan), which was the result of a tsunami.
Internally, but without human participation or mechanical failure, as in the case of fire.

The methodology goes forward examining how this initiating event affects a sequence of events or accidents called *'Pivotal events',* from the initiating event to the final or end state. These pivotal events may be able to mitigate the consequences of the initiating event, in which case, there will be success, or aggravate them, in which case, there will be failure. Thus, these pivotal events fulfil a function upon which the outcome of the initiating event depends, hence the name 'pivotal'.

The sequence of these events finishes in several *'End states'* that reflect the result of the intermediate events. Since there are usually combinations of pivotal events, to quantify risk, it is necessary to take this interaction into account, which is done through logical analysis involving Boolean logic, wherein intervening variables have only two values, (0, False) or (1, True).

As an example of an event tree, consider this scenario, which is similar to an actual case and possibly not technically correct, but is used simply to illustrate the method.

5.11.1.1 Application Example of (ETA): Simulation of Earthquake Risk – Nuclear Power Plant

A nuclear power plant is located close to the seashore in an earthquake-prone country. Its center for electrical distribution for plant operation consists of three main transformers (only one is needed, but they are redundant for safety reasons) connected to off-site electric sources through dedicated transmission lines. The main transformers are located at 50 m from the reactor dome and two emergency transformers are positioned on a 10-m high platform and at 80 m from the reactor dome.

To extract the heat produced in the reactor core, which is further used to generate electricity, it is necessary to utilize high pressure water pumps which are redundant, to assure service if some of them fail. That is, a water pumping subsystem is employed to absorb the heat produced by fission in the reactor core (in a primary closed cycle), which in turn transfers part of this heat to a separate water system (in a secondary closed cycle) that generates steam for the prime movers (steam turbines driving electrical generators). If heat from the reactor core is not properly removed, its accumulation can produce melting of the fuel rods and cladding, as well as an explosion, releasing radioactive materials into the atmosphere. Consequently, cooling pumps are an essential part of the plant operation, and this case refers to them. The sequence of equipment to feed the water pumps in case of an initiating event is detailed below as follows: Equipment with a higher ID will enter into operation only if the precedent ID equipment failed. Figure 5.16 depicts the sequence of these safety mechanisms.

ID	Equipment
1.	Main transformer
2.	Emergency transformer
3.	Diesel electric generators
4.	Set of batteries
5.	Seawater flooding

It is assumed that the initiating event is an earthquake (the plant has been built to withstand a level 7 earthquake on the Richter magnitude scale). In this simulation, the initiating event has been assumed with a 7.5 magnitude, that is, much higher than the design level of 7 (a 7.5 earthquake releases more than three times the energy of a 7 magnitude earthquake). After the earthquake, surveillance satellites detect a quake-produced tsunami advancing toward the coast where the plant is located.

Plant operators have a series of mitigating mechanisms which can be used sequentially, and even proceed with an emergency shutdown of the plant by

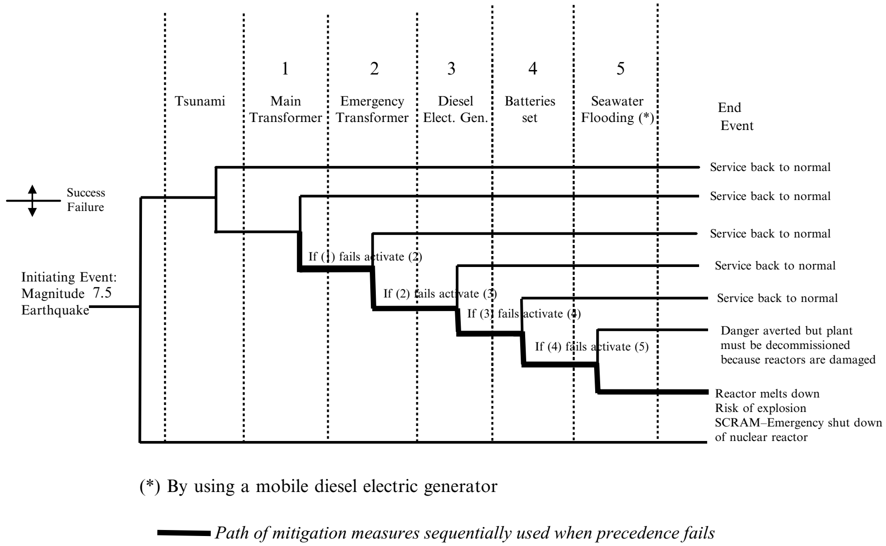

Fig. 5.16 Events tree for water pumps in a nuclear power plant

lowering the control rods in the reactor, thus reducing, but not eliminating, the need for cooling the reactor core, since even with the rods lowered, there is heat from radioactive decay. Because of the strength of the tsunami, there is a chance that the main transformer (1) (see Fig. 5.16) could be flooded, rendering it inoperative. This event has two possible outcomes and corresponding probabilities: success, if it is not flooded by the tsunami waves, or failure, if it is. In the first case, nothing will probably happen, because the transformer will continue feeding the water pumps, without any interruption of service.

If it fails, then the emergency transformer (2) will be put into service by the operators, and again, there could be two possible outcomes depending upon whether or not it is damaged by flooding. In the first scenario, electricity will not be interrupted to the pumps, and the end event will be a return to normal service. Notice that there is a conditional probability (see Sects. 4.3 and 5.5.1) for the emergency transformer, because it will be put into service only if the main transformer fails.

If the emergency transformer fails, then the operator will start the diesel engines (3), which, again, have two outcomes: they can work or not, in this second case, because they could also be flooded by the tsunami waves, which is what happened in Fukushima.

Following the sequence, the operator activates the batteries (4), provided that the diesel engines fail, once again a conditional probability. If these batteries also fail, for whatever reasons, the last resort is to cool the reactor core with seawater (5) (also done in Fukushima), which fortunately worked in that case. If this last event does not work, the reactor core in our example will most likely suffer a meltdown and an explosion releasing radioactive materials into the atmosphere will probably occur, as unfortunately happened in Chernobyl. Examining this example, notice that this events tree provides information such as:

1. Probabilities of intermediate events. As mentioned, they are conditional probabilities, that is, the probability of success of an event B depends on the probability of failure of an event A that precedes it.
2. Quantified risk. As a product of frequency or probability of occurrence times severity of consequence.
3. Analysis of uncertainty, because it examines the relationship between human actions and mechanisms (see 'Uncertainty' in Sect. 1.1) and reveals the relative significance of each accident sequence.
4. Computation of frequency or probability of occurrence of the end state, since it reflects the frequency of the initiating event and those of the intermediate events.
5. Dynamic analysis of a process.

Thus, the PRA technique, in giving probabilistic information on each stage of a sequential process, can be considered a decision-making tool.

5.11.2 Risk Identification and Assessment – Faults Tree Analysis (FTA)

The other component of Probabilistic Risk Analysis (PRA) is the '*Fault tree*', which is usually depicted in combination with the '*Events tree*' (see Sect. 4.20, Fig. 4.5).

As we have seen, the events tree commences with an '***Initiating event***' and advances forward in a bottom-up analysis of the sequential events, inducing or inferring the consequences of each one and the result at the end state. Thus, an events tree applies *inductive logic*, assuming that something has **already happened**, and consequently, it goes from particular or specific to general.

The fault tree analyzes a system and commences with a postulate or presumed final event called the '***Top Event***', advancing backwards in a top-down hierarchal analysis of sub-systems down to the basic units or components, deducting or inferring the reasons or causes for the top event to happen, that is, in a cause-and-effect relationship. Thus, a fault tree applies *deductive logic*, and consequently, it goes from general to particular or specific, assuming that **something can happen**, albeit with neither proof nor a knowledge of the causes that can provoke it, which Paulos (2001) appropriately calls *"End-state of concern"*. In this deductive process, and if, at a certain hierarchical level, the events are not enough to explain the causes for the top event, then one goes lower in the hierarchy, and thus, it is a *"Hierarchal depiction of ways in which system perturbation can occur"* (Paulos, cited). Boolean logic is also used in fault trees.

Since a fault tree is a combination of all aspects the failure of which may influence the top event, it is important to analyze those failures and their combinations, and for this reason, these systems are evaluated using logic or Boolean algebra. Vesely (2002) provides useful information on this subject.

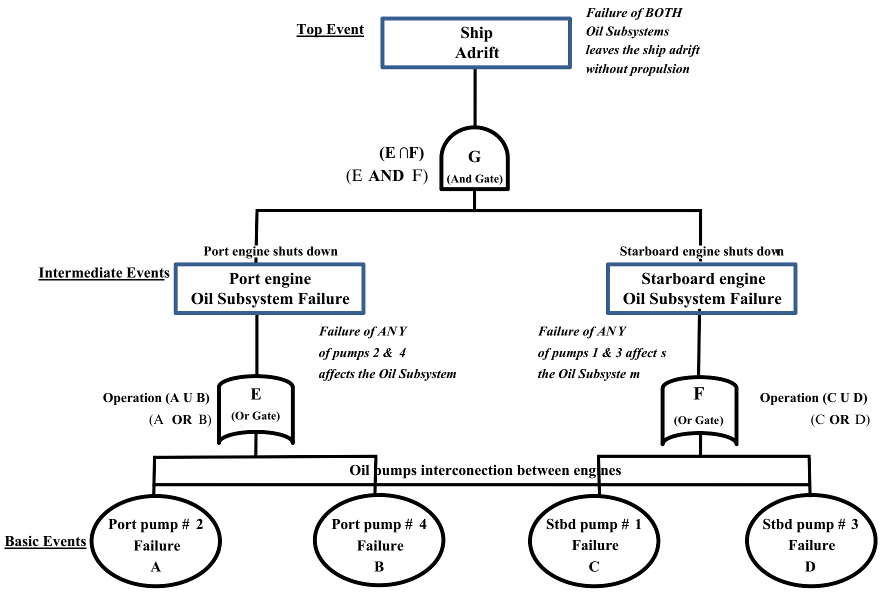

Fig. 5.17 Examining a potential problem using logic analysis

5.11.2.1 Application Example of (FTA): Marine Risk – Ship Propulsion

Figure 5.17 shows an example that evaluates how the failure of oil pumps can affect the safety, maneuverability and sailing ability of a ship, since these pumps are essential for the diesel engines used for propulsion. This type of representation is called '*Master Logic Diagram*' (MLD).

In this example, the ship has two port pumps (2 and 4) and two starboard pumps (1 and 3). Each pump is an independent unit, but they are interconnected; therefore, any of them can serve any engine, however, two pumps are needed per engine. The logic diagram shows that if any of pumps 2 OR 4 fail, the port engine must be shut down, an action that cuts the ship speed in half. This is indicated by the symbol that represents the additive $\cup$ operator. What happens if one (or both) of the starboard pumps also fail? Then, the symbol that represents the multiplicative $\cap$ operator shows that, when port AND starboard engines are shut down, the end event is a ship without propulsion, that is, it becomes adrift, which is then the top event. Paulos (2001) resumes fault trees characteristics, saying that "*Fault trees are very efficient at logically defining the specific combinations of component level failures which can lead to system failure*".

FTA is a well-developed and complex procedure and, to take advantage of its potential fully, it is necessary to have a thorough knowledge of its structure, something that is beyond the scope of this book. For a comprehensive and easy-to-understand explanation of FTA, consult Vesely (2002).

5.12 Risk Identification and Assessment – Failure Mode and Effects Analysis (FMEA) in Manufacturing and Transportation

Failure definition: "*The loss of an intended function of a device under stated conditions*" (Wikipedia)

Failure mode: "*The specific manner or way by which a failure occurs in terms of failure of the item (being a part or (sub) system) function under investigation; it may generally describe the way the failure occurs*" (Wikipedia).

Failure effect: The immediate consequences or outcomes on other mechanisms or parts of the system in their operation or behavior.

This inductive technique, specially focused toward products and processes (often used in pharmaceutical and medical research), is a systematic and powerful procedure that, following the bottom-up approach, investigates all possible manners and chances in which a failure can occur at all stages of a process, starting with the design (for instance, realizing that, as it has been designed, the driver of a car has a limited view of the dashboard instruments and controls, because they are partially blocked or obstructed by the steering wheel), and followed by production (for instance, the uneven finishing of a freezer). The technique searches for potential failures, imagining situations in which they can occur or why they are produced and in which mode they can take place, and estimates frequency of occurrence.

It is said that it is inductive because, as in many scientific procedures, it tries to infer conclusions for a whole starting from a part or component. For instance, consider a common failure: a tire blows out while driving on a mountain highway after hitting a piece of rock that fell on the pavement. It affects the steering of the vehicle and its stability, and can be fatal if the driver loses control; therefore, its study is paramount.

The invention of a tubeless tire was most probably a consequence of an analysis of this type, since the blowing out is unlikely when the rim of the wheel is in good condition and appropriated to a certain tubeless tire type. As can be seen, this qualitative analysis applies to the design stage of the steering system.

Sometimes, the failure is detected when the product is already on the market and identified by users. A typical and well-known example is when car companies order a recall of thousands of vehicles to fix something; it is a headache and usually costs millions of dollars, to say nothing about the loss of prestige and sales. For instance, suppose that, owing to wear and tear, dirt, or a weak coil spring, a gas pedal in a car does not return to its idle position when the driver's foot is no longer pressing it.

That is, an analysis and hypothesis of failure should have been done in the design stage, taking into account the possibility of the system failing after thousands of kilometers, although it proved to work satisfactorily in vehicles rolling off the assembly line. If this potential failure were detected in such a critical component, perhaps it could be avoided with an inexpensive sensor measuring the correct displacement of the gas pedal back to its idle condition, and alerting the driver with a luminous signal when there are symptoms that this movement, for whatever reason, is not happening at the required speed.

FMEA works (thinking about the unthinkable) as a qualitative procedure for examining failures and operates as a sort of WBS (see Sect. 2.12), that is, breaking down a system into its components, examining potential failure modes and how they can affect other components of the system in detail, and finding responses for eliminating or mitigating the problem, not only at present but considering its potential deterioration over time as well, as in the gas pedal example.

An FMEA worksheet is illustrated in Table 5.10 and refers to transportation of perishable goods by truck. A list of failure modes is prepared for each analyzed mechanism, in this case, the refrigeration system. There are many different forms for preparing this worksheet, and this is only one example. A very good source of information on transportation is given Federal Highway Administration (2013).

5.13 The Risk Priority Number (RPN)

Sometimes, to assess risk, the Risk Priority Number (RPN) is used. It differs from the classical risk computation, that is, as a product of likelihood of occurrence times severity (Impact), in that it also considers the likelihood of detecting a failure before it reaches the user.

Thus, the formula is:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection} \tag{5.5}$$

These three parameters are qualitatively valued using a 1–10 scale, the highest being the worst; therefore, RPN has a minimum of $(1 \times 1 \times 1 = 1)$ (the best), to $(10 \times 10 \times 10 = 1{,}000)$ (the worst).

See FMEA-FMECA.com (http://www.fmea-fmeca.com/fmea-rpn.html) for examples of how to determine each one of these parameters for the automobile industry, as well as calculating the RPN number.

5.14 Correlation and Risk Assessment

Correlation is a measure of the statistical association between two variables. For a detailed analysis see Garson (2013).

In analyzing risks, it is necessary to consider possible risks than can develop in relation to others; this is called 'correlation' in risk management parlance. Correlation, in essence, refers to variables that can vary consistently in the same or inverse sense, that is, when one increases or decreases, the same happens with another, or the inverse. For instance, when considering quality with price, there is a possible

Table 5.10 FMEA worksheet for equipment in service

						Failure mode and effects analysis (FMEA)							
						Equipment: Diesel electric generator in refrigerated trailer							
ID	Location	Statistic of failure	Probability of occurrence	Causes for failure	Failure mode	Reasons for failure	Effect	How does it affect service?	Direct consequences	Further consequences	End effect	Consequences	Risk
1209	Refrigerated trailer	Twice in 527 h 0.38 %	Low	Driving gears	Very strong noise and vibration	Excessive wear and ear because defective heat treatment of gears	Engine stops	Compressor stops	Cooling stops	Refrigerated cargo warms up	Perishable cargo rottens Client losses	90 % of cargo no apt for market	34.20 % loss of capital

correlation between these two variables, if price consistently increases when quality increases, or, in another example, the number of people using public transportation in a city increases when frequency of service also increases. It does not necessarily mean a cause-effect relationship, since the increment of users could have its origin in other causes, for instance, cost of fuel, traffic congestion, lack of places to park, etc., which encourage people to ride public transportation instead of using their cars.

Of course, it could also be that a variable increases when another decreases. An example is the Learning Curve used in manufacturing and construction if the same task is repeated many times. In that case, the time to perform the task, or its duration, decreases as the number of times the task is performed increases. To quantify correlation between two variables, use the correlation coefficient 'r', the values of which are:

- $r = 1$, meaning that two variables are totally correlated in a positive sense, that is, both increase or decrease; for instance, prices of airline tickets increase when greater travelling comfort is demanded.
- $r = -1$, meaning that two variables are totally correlated in the negative sense, that is, when one of them increases, the other decreases; for instance, production cost decreases when production volume increases.
- $r = 0$. Meaning that two variables are not correlated, that is, both are independent; for instance, production cost and weather.

A pair of variables can take any correlation value between these extremes, and thus, we can have a correlation of 0.67 between bus frequency and number of passengers, which means that 67 % of the traffic is explained by frequency.

When applying Monte Carlo, and because of the use of random values, it could be that a relationship such as prices increasing with quality does not hold, and instead, it could show that, in a particular scenario, price decreases when quality increases. Savvides (1994) exposes and exemplifies this circumstance very clearly, and this is explained by the very random nature of the model.

To compute correlation, it is necessary to have historic information on the two variables considered. The mathematical calculation of 'r', if not difficult, is cumbersome and error-prone. When the problem and the historic data are placed in a spreadsheet such as Excel, there is a function that allows for very easy computation of the correlation coefficient. If this coefficient has a value, say, for instance, below 0.3, it means that both variables are lowly correlated, or that only 30 % of one is explained by the other.

Why is correlation important? Because risk is more concentrated for higher correlations. Assume, for instance, a stock portfolio with stocks from the same economic area, say, computers, involving software developers, hardware manufacturers, and flat screen computer monitor (LCD, Liquid Crystal Display) manufacturers. These industries are strongly correlated, and therefore, a fall for whatever reasons in any of them will most probably be reflected in the others, multiplying the loss. Anke (2010) gives a very clear exemplified explanation of correlation applied to the Stock Market, the reading of which is recommended.

5.15 Expert Opinions

The opinion of experts in a matter under study is always welcome. However, consider that most opinions are of a subjective nature, based on experience and many times influenced by personal feelings, excessive caution, or exaggerated optimism, and, of course, there could be disagreements between experts regarding the probability level of a threat or the type of probability distribution to apply. On the other hand, past experience does not necessarily apply to a present scenario, because circumstances or projects are very seldom comparable.

Many times, and taking advantage of the easiness and speed of Monte Carlo calculations made by adequate software, it is possible to run data from experts independently and then compare results. One aspect to take into account is the formulation of the question in a sense that it is fully understood by the experts and the importance of their examining an issue under the same circumstances and subject to the same restrictions or variations.

5.16 Interviews

In many projects, it is crucial to interview people to hear their opinions, because they are going to live with its benefits and consequences. This is frequently done through surveys, polls and interviews. There is a distinction here, since there are qualitative and quantitative interviews with a definite objective and complementing each other. In a qualitative interview, there is no interest in extracting numbers, but only in hearing about what people say and feel about a project. Many times, after this kind of interview and the corresponding analysis, issues, circumstances and threats appear that the stakeholders or analysts did not even think about, let alone consider.

For instance, a project to build an urban landfill in a neighborhood will most certainly attract criticism, not regarding its usefulness, which, in all likelihood, nobody will query, but because of the consequences, mostly negative, for that neighborhood regarding land devaluation, odors, traffic, flies, noise, etc. A qualitative interview will most probably allow the interviewer to elaborate a theory as to what people are most opposed to, and detect signals of risk, such as strong opposition, political consequences, and even revolt against the project.

In a quantitative interview, data is collected about specific issues, such as support for or opposition to the projects, which normally reinforce findings from the qualitative interview.

5.17 Risk Identification – Qualitative Assessment

Once risk events are identified and listed in the risk register (Sect. 4.22), their probability of occurrence, as well as impacts, must be determined and prioritized as per their importance, naturally regarding the objective, as well as mitigation measures developed. This follows their prioritization, that is, the ranking of their importance regarding potential damage and significance concerning the objective.

As its name implies, this is a qualitative evaluation that consists of acquiring information about a threat and qualitatively evaluating its importance. It is useful, for this purpose, to use a risk matrix (see Sect. 5.10) in which it is possible, using probability and damage or impact, to define the risk. Qualitative evaluation also allows for examining different scenarios considering remediation, and a rational analysis of remediation costs versus consequence costs, as well as an appraisal of the magnitude of damage related to the size of the project.

Regarding the last issue, consider a 1,500,000 Euro project. An economic risk producing an impact valued at a 170,000 Euro loss is obviously important. However, the same impact in a 1,200 million Euro project is probably negligible.

By the same token, a delay of 1 month in the opening of a new restaurant will probably have no impact; however, if this delay affects the opening of a commercial mall, which has been already publicized, rentals paid, invitations sent, etc., it could be catastrophic.

Another point to consider is risks that depend on other/s occurring, and in this case, this also has to be examined. Section 5.5.1 proposes an example in which this type of conditional risk can happen, that is, risk B will materialize only when risk A occurs. The example analyzes a delay risk in transportation only if the risk of snowstorm materializes.

5.18 Risk Computation and Impacts – Quantitative Assessment

Quantitative assessment is more oriented toward assessing the value of risk and the way it can affect outputs.

There could be many threats and corresponding risks. The purpose of this assessment is quantifying them by means of determining the probability of them happening, as well as appraising the impact or damage they can produce, and the effectiveness of the preventive measures taken to avoid, decrease or transfer the risk.

What about impacts?

A risk may produce a single impact or several, and this has to be taken into account. Impacts, in turn, can be quantified using economic figures, such as damage in Euros produced by heavy hailstones in a city, or by using categories such as Negligible, Important, Serious, Very Serious, Catastrophic, etc. These categories can be based, for instance, on the size of hailstones, areas they can affect (for instance, in the parking lot of a car manufacturer full of brand new vehicles, ready for export), etc.

5.19 Timing the Risk

Consider the construction of a road tunnel 476 m long; some drilling tests show that there could be the risk of water filtration into the tunnel from aquifers. It is then convenient to ascertain the probable location where filtration might occur, that is, it could be at the beginning, some meters from the mouth, near the end, in various sites, etc. In this case, it could be convenient to breakdown the corresponding construction task according to the potential appearance of the risk, which will facilitate control.

5.20 Assessment of Risk Associated with Resources

There are many kinds of risks associated with resources, such as reliability of personnel related to personnel absence (for whatever reasons), sickness, accidents, etc., as well as risks related to equipment operation, quality of raw materials, etc. We examined these risks when dealing with labor (Sect. 5.7.1), materials (Sect. 5.8.2), quality (Sect. 2.9), etc.

5.21 Assessment of Risk Associated with Legal Issues

Legal external factors can seriously affect a project; this happens, for instance, when the project is to be developed in a non-clarified or ill-defined area. Examples abound, such as a hotel too close to the beach, a road passing near a native cemetery, a meat-packing plant and slaughterhouse installed in urban areas, a building in a protected forest, use of land with no clear titles, noise generated by a highway, etc. This is normally a delicate aspect that must be thoroughly studied and documented, considering potential future consequences (see example in Sect. 4.17.1).

5.22 Assessment of Risk Associated with Communications

Project communications may be affected by changes in the owner staff, suppliers still using conventional communication systems such as telex, fax or telephone instead of employing computer-assisted means, or installing the Enterprise Resource Planning (ERP), etc. Naturally, the problem is not simple, and its implementation sometimes brings more problems than solutions. See Venugopal and Rao (2011) regarding a failed ERP implement, and what its causal factors were.

5.23 Assessment of Risk Associated with External Factors

External factors affecting closing could be risky, such as overdue account receivables, contractor still working when the project is in operation owing to repairs or remediation, etc.

5.24 Activities Performed Before Commencing the Project

At this stage, all documentation is ready, since:

- Tasks or activities have been defined according to scope of work (WBS).
- Tasks or activities have been linked according to precedence and relationships, forming the project network (CPM).
- Monte Carlo model has been used to determine the most probable durations and costs.
- PERT, if needed, has be used to ascertain either the probability of completion in the allotted time, or to determine the total duration as per the desired probability of completion.
- Tasks or activities have been assigned buffers for time and cost (RBS, SWOT), that is, remediation measures have been implemented.
- Tasks and activities have been assigned resources (manpower, materials, equipment, funds) and the whole network scheduled (GANTT Chart).
- The baseline budget curve (BCWS) has been determined and payment schedule prepared.

5.25 Preparing the Best Strategy Regarding Remediation Costs

We have seen that probability of occurrence of a threat multiplied by impact or impacts that it can produce yields a value for risk or risks. Normally, for each one of them, a strategy is developed, a remediation course of action that normally means that some money has to be spent.

However, and since in a large project there could be a multiplicity of threats and impacts, there could be situations with a large probability of occurrence the mitigation measures of which imply low cost. As an example, assume a city built in a valley along a river. Because of heavy rains, the river swells and floods a low sector of the city, causing a severe impact; however, the remediation is relatively simple and inexpensive, and would consist of building a concrete barrier at critical areas along the river shore. Other measures that are more expensive could involve building a dam to store excess water, or constructing large reservoirs beneath certain streets.

There is an opportunity here, since the stored water can be used for city services, such as irrigation and street-cleaning.

At the other extreme, assume a modern office building. The threat of fire is small, however, the remediation measures taken, such as automatic sprinkler systems, could be very expensive.

Our goal, naturally, is to design a project, whatever its nature, in which the main risks are properly addressed; however, and because of costs, what we want is a project adequately protected and, at the same time, requiring as little money as possible. As can be understood, there could be hundreds of combinations for risk remediation, however, we need to select the best one, considering availability of funds.

This is a very well-known problem, called Multicriteria Decision Making (MCDM), and for which there exists many different mathematical approaches, as well as dedicated software. In reality, the problem consists of finding the most economical alternative that considers threat probability, impact severity and remediation costs. It is also necessary to remember that the entrepreneur or owner of a project usually has some risk management money for remediation measures, and that this amount, usually considerable, affects the cash flow and economic and financial feasibility of the project. See Gonen (2011) for a method for addressing this issue.

5.26 Assessment of Risk Associated with Closing the Project

A risk exists when the project is complete but the owner or client is not satisfied with the closing, because of the lack of mandatory and contractual documentation that has to be handed over to him at the end of the work. The risk relates to the probability that the client becomes unhappy owing to the delay or for the incompleteness of the documentation received from the contractor. For instance, the contractor did not prepare a set of *'As built'* drawings, or did not leave the site clean and without construction debris, or did not comply with the contractual provision of providing certain spare parts for the equipment.

These risks are somehow related to quality and may be easily avoided simply by foreseeing them, and of course, by taking adequate measures to solve the issue to the client's satisfaction.

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Chapter 6
Sensitivity Analysis

Abstract The chapter begins by defining sensitivity in projects, whatever their nature. The main word here is uncertainty, because no matter the kind of project, there is always uncertain data and predictions, vague information, unexpected people or stakeholder reactions, deviations in prices, labor performance different from estimated, etc. Sensitivity analysis is designed to examine the response or reaction of an output variable, such as the IRR, the NPV or the Payback Period, to variations of input variables, such as sales volume, price, etc. To this extent, this chapter starts by examining variations on task durations in a schedule, and introducing concepts such as the Tornado Diagram and the Criticality Index. It also refers to variations associated with the outcomes of the project's profitability linked with economic and financial issues, as well as those related to equipment and material costs. The chapter examines the sensitivity in even more realistic cases where variations from different variables acting simultaneously and in different scenarios. The chapter concludes by examining the Sensitivity Ratio or Elasticity, a very well-known and widely used tool in Economics.

Keywords Sensitivity • Financial statements • Input variable variation • Output variable variation • Sensitivity ratio

6.1 Sensitivity Analysis: Fundamentals

Most projects are usually economic entities, normally built to manufacture something and to obtain a profit out of it, be it automobiles, clothing, mining, petrochemicals, software, pharmaceuticals, hotels, etc. A project can also be designed to render a service, such as schools, hospitals or a warship, from which, albeit, the economic aspect is absent, but for which there are other objectives that must be fulfilled, such as benefits to the population, disease reduction, environmental protection, dissuasion potential, etc. But in all cases, there is performance to test in one sense or another.

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*, DOI 10.1007/978-3-319-05251-9_6,

But how can we test something that is not built yet? By examining its reaction when certain fundamental components have values that differ from those estimated changes, the occurrence and amplitude of which are, of course, unknown, in other words, uncertain.

Many components or inputs upon which a project is based are uncertain, such as production costs, price of materials and equipment, duration of tasks, sales volume, number of students in a course, probability of acceptance of a new drug, number of people buying certain types of houses, soil condition, etc. That is, the project analyst works with uncertainties, and because of those, and even using risk analysis, results are not very reliable, let alone accurate. Thus, the need to learn how variations or changes in certain project components (Inputs) will affect the result (Output) is understandable, because with that knowledge, the project team will be able to foresee consequences and concentrate its efforts on trying to improve or enhance the accuracy of input data the better to evaluate results.

Thus, the word 'Sensitivity' expresses very well how sensitive an output is to input variations, and, as FAO (2013) *says*, "*In general, if an acceptable NPV and/or IRR is obtained for a project, using the initial estimates of parameter values (the expected values), then the analyst will be interested in testing alternative value assumptions that are less favorable in terms of project outcome, i.e., higher cost assumptions and/or lower benefit assumptions. The results provide some indication of how large unexpected cost increases or benefit value reductions would have to be to have a critical effect on the chosen measure(s) of project worth (see previous definition of critical).*"

However, such complex an issue as a project tends to be will have different aspects upon which to appraise results. For instance, there are variations in execution time (unfortunately, very common) that produce delays. There are variations in economic and financial issues that produce significant economic problems, such as low demand, or serious financial problems, such as increases in interest rates or difficulties with cash flow, which can put a brake on the project's development or even shut it down.

There are variations with material prices and equipment quotations that, again, affect the economics of the project, and there could be quality variations that put the project in jeopardy.

The fact that a survey on hundreds of projects performed in the USA shows that only 27 % of them finished on schedule and under budget sends a clear message that uncertainty is the main culprit, and that a large number of projects face risks in one way or the other. A sensitivity analysis will most likely not solve the problem, however, there is no doubt that improving the information that we have by means of a sensitivity analysis will help in sharply increasing that percentage.

This book proposes different methodologies for performing a sensitivity analysis in accordance with the purpose.

1. *Related to schedule*. For variations in task durations, which will influence the project's total duration and completion date.
2. *Related to financial statements*. For aspects such as variations in demand, price, operating costs and working capital (inputs).

Where will these variations be reflected? They will influence the financial indicators (output) used to measure project performance, for instance, Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), Debt Coverage, Earnings per Share and others (see Sect. 5.6.1).

3. *Related to equipment and material costs.* Here, the emphasis is put on how much variation we can admit or consider regarding cost of equipment and materials. Customarily, these inputs vary according to many different causes the values of which are beyond the knowledge of the decision-maker. For instance, equipment acquired abroad may be contractually subject to inflation in the manufacturing country, or differences in insurance costs, custom duties, etc. However, it is always possible to make an appraisal of how much that variation could be, and this is the information that the sensitivity analysis needs.

Nonetheless, a standard problem or concern is determining which input variables are the ones that will affect the output. To that effect, some researchers have been able to track that information for specific types of projects. For instance, Khomenko and Poddubnaya (2011) give important information related to water projects, with output such as water demand, investment costs, financial revenues, etc., and relate each one to different inputs, like population growth, achieved coverage, household consumption, etc., for the 'Demand' output. Fortunately, in general, data is available either for outputs or inputs. In their paper, Khomenko and Poddubnaya (2011) say that their article "*…deals with the topic of how efficient sensitivity analysis is in different spheres of the economy.*"

6.2 Sensitivity Analysis Related to Schedule

This refers to the always-existing risk of delays in the project's completion date (and there usually is a delay). We have analyzed in Sect. 2.3 how to deal with uncertainties in the schedule using PERT, and described a more advanced tool, Monte Carlo, in Sects. 2.4 and 3.3.

We have also utilized the critical path for determining the output duration-wise, as well as examined the probabilities of compliance for a certain available time and, conversely, the time needed for an established level of confidence. Therefore, we know the tasks, their relationship and durations (input), and have the result (output) in the form of time and probability of compliance. We do know that a delay on any critical task will replicate at the end of the project; therefore, there is certainty here. However, what happens for changes or variations in non-critical tasks?

We cannot say that we do not care, because they have floats, however, not all non-critical tasks have the same importance considering their durations. It is reasonable to think that non-critical tasks that end in a node or gate pertaining to a critical task are more important than others, even with a smaller float but without any connection to the critical path. However, there is always the risk that a delay can consume its float, converting it into a new critical task and perhaps altering the result; therefore, it makes sense to determine how risky a task is. A method can be applied to determine this level of risk.

This method considers one task at a time, holding the others with their original values, that is, the *ceteris paribus* principle. Monte Carlo is applied and works with its optimistic and pessimistic durations that allow for computing the critical path for both dates. After 500 iterations or more, the result will show two finishing dates, one for the optimistic duration and another for the pessimistic duration, represented in a Gantt Chart. Once the procedure is complete for all tasks, there will be a ranking of tasks according to the magnitude of the differences between both final values; tasks with larger differences are more critical than those that present a smaller range. Why?

Because it indicates that the final date has a larger deviation, meaning values more spread out around the mean, increasing uncertainty, and thus, riskier than tasks with smaller differences. Conversely, a small deviation means that values are closer to its mean, and thus, it is less risky.

It looks as if, in a large network, this is an exhausting exercise, but fortunately, there exists dedicated software to do the job, although it is time-consuming. However, even with software, it would be a formidable task to draw new Gantt Charts with the two durations for each task, and to identify the riskiest. For this reason, there is a tool, called a 'Tornado Diagram' that helps (Fig. 6.1). This is also a Bar Chart, but instead of the abscissa marked with time, it is divided into percentages of risk impact on the output, or just Euros.

As can be seen, tasks are grouped top to bottom in accordance with the final duration variation they can produce. Thus, task 79 has the potential to produce a risk between −2 and 8 % of total duration.

Regarding resources – especially labour – sensitivity analysis can be applied using the Learning Curve (see Sect. 5.14), especially adaptable in the case of repetitive tasks, such as high-rise construction. If the duration of a task, say, for instance, 'flooring', has been calculated using standards, consultation of a learning curve for that activity can provide the expected duration of this activity that will reflect on its duration. Then, replacing the original values for these tasks with this average and running the CPM again, the result will show how sensitive the final date is to variations of this set of repeated tasks. This information can be important for those projects that are labor-intensive.

6.2.1 Criticality Index

There are also activities that are not on the critical path and that could have a large probability of becoming critical (this probability is easily computed by risk software); some authors call this the 'criticality index'. For these tasks, it is then important to check how it will affect the project if its total duration is increased by one unit of time, which naturally will depend on the amount of its float. When working with tasks that have a high probability of becoming critical, say, 70 or 75 %, try increasing duration by one unit of time, then run PERT, and see what happens with the project completion time.

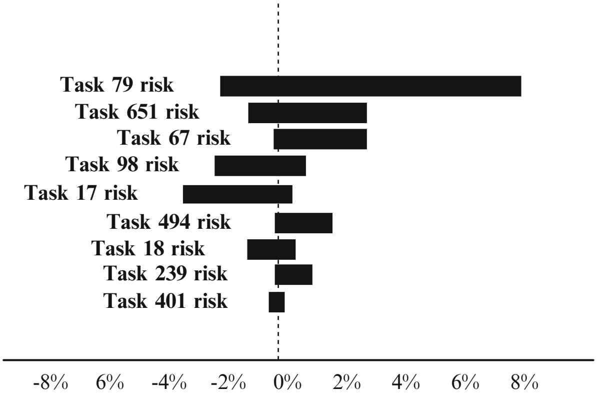


Fig. 6.1 Tornado diagram identifying tasks of greatest risk

6.3 Sensitivity Analysis Related to Economic and Financial Issues

This is one of the most important subjects in sensitivity analysis, because its importance refers to the way in which project performance is affected by changes or variations in aspects such as price, sales volume, demand, interest rates, cost of capital, software, etc.

There are different ways to compute this; however, in this book, we use a mathematical model in which all economic, accounting and financial aspects are considered and interrelated. This model is called *'Projected Financial Statements'*, and is normally prepared for large projects by the Accounting and Financing Departments, together with Engineering, beginning at the onset and computed for each year along the project's life; it starts with its construction and ends with its closing, final depreciation and residual value. It describes the potential performance of the project, and is used to show and persuade investors and lending institutions about its merits, (and is also, in many cases, a contractual document).

This document is, in reality, a complex mathematical model broken down in a set of different statements or 'modules' that are wholly linked. Consequently, any change in any module is automatically reflected in the others, that is, the model works as a series of dynamic tables.

In general, this model works as a 'black box' in which data is introduced and processed through a series of mathematical operations, with results obtained. Some of this data are independent entities, such as price, sales volume, operating costs, inflation, exchange rates, etc., which are usually uncertain values in the sense that we do not know if they will change in the future, and if so, at which level of magnitude. This is the type of data or 'Inputs' that we use to get outcomes or 'Outputs'. Figure 6.2 sketches the procedure.

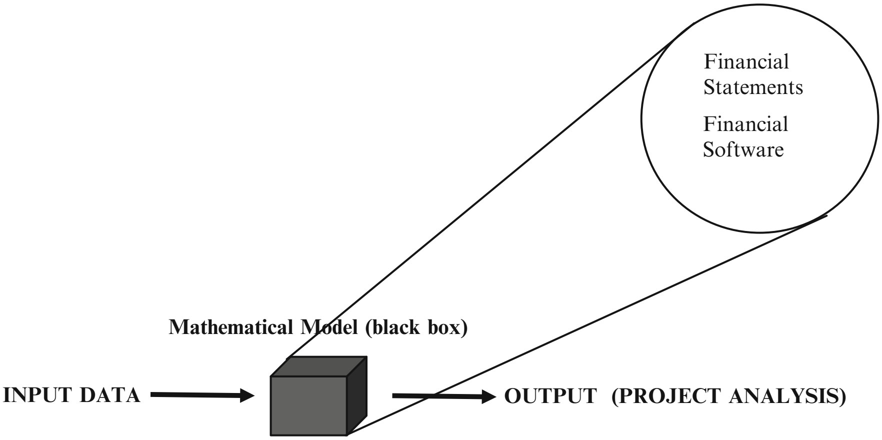


Fig. 6.2 Scheme of using financial statements as a mathematical model for sensitivity analysis

Outputs, in turn, are those parameters that measure project or business performance, such as the Net Present Value (NPV), the Internal Rate of Return (IRR), the Cash flow (CF) and others, the examination of which allows the company to decide to go ahead with the project, modify, or reject it. Both inputs and outputs for sensitivity analysis are selected by the project analyst or the project team.

The most usual modules or financial statements are:

- Project analysis
- Balance sheet
- Cash flow statement
- Statement of earnings
- Long term loan schedule
- Assets, depreciation and amortization schedule

6.3.1 Sensitivity Analysis Using Financial Statements

It is normally possible to test a variable, for instance, ‘Sales’, by increasing it by, say, 10 %, and then running a piece of financial software. When this new data is inserted into the ‘Statement of Earnings’, it will produce a new ‘Revenue from sales’ figure for each year, and this change will automatically be reflected in all the other financial statements along the life of the project. Naturally, the analyst can test other variables, such as ‘Loans’ or ‘Interests during construction’, in the Balance Sheet Statement. The influence of these variations will be reflected in the Project Analysis Statement in the final value of the NPV, IRR, Cash flow, etc., for each year of the project-planning horizon.

It is also possible to test all variables simultaneously, which is better, increasing, for example, 'Sales' by 10 %, reducing 'Price' by 5 % (or better still, establishing a variation between −5 % and, say, 5 %), increase 'Operating costs' by 7 %, and increasing 'working capital' by 10 %. The result of the run will show how these simultaneous variations affect the results. The following Section proposes an example for illustrating the method.

6.3.1.1 Case Study – Sensitivity Analysis for Financial Parameters (Outputs) – Metallurgical Project

Project: Construction of gold concentration plant

Characteristics:

The project calls for construction of a gold concentration plant located near an open pit mine.
Construction period: 3 years
Project horizon: 14 years (3 years construction 11 years operation)
Cost of capital: 9.75 %[1]
Documents to be used: Projected financial statements

The method works as follows:

1. Determine the outputs to be analyzed. In this case, outputs selected are:

   - Cash Flow (CF)
   - Internal Rate of Return (IRR) (must be greater than cost of capital)
   - Net Present Value (NPV)
   - Debt Coverage Ratio (DCR)

   Selected outputs depend upon characteristics of the project and on their uncertainty and importance.
2. Determine the inputs to be analyzed and assign a percentage of change in minus or plus, for each one as needed. In this case, it is considered (−10 %) for unit price and sales volume and a (10 %) for operating costs and process equipment. Selected inputs are:

   - Unit price of the product to be manufactured or produced by the project (in this case, gold)
   - Sales volume
   - Operating costs for mining and refining
   - Process equipment costs for mining and refining

   Selected inputs, depend upon characteristics of the product, the changes of which will be analyzed regarding their impacts on the output.

[1] The cost of capital is the rate of return that capital can be expected to earn in an alternative investment of equivalent risk (Wikipedia).

Table 6.1 Statement of project analysis (values in Euros x000)

Outputs	2014	2015	2016	2017	2027	2024	2026	2027
Cash flow					11,406	27,294	26,834	67,155
IRR					12.45	13.21	13.79	15.00
NPV					16,476	18,331	20,834	21,820
Debt coverage					21,02	23.90	25.40	27.26
Earnings per share					4.83	4.78	4.79	4.79
Gross profits/sales ratio					0.71	0.71	0.71	0.71

3. Run the financial software that was used to prepare the projected financial statement.
4. Look for results in the last column of the project analysis statement. An example of that statement is depicted in Table 6.1, showing the main outputs that have been selected together with others, such as the 'Earning per share' and the 'Gross profit/sales ratio'.

Table 6.2 was prepared using those statements and varying one input at a time without changing others – that is, *ceteris paribus* – with a 10 % variation for each input. It is some sort of worst-case scenario, since it assumes a 10 % decrease in Price and Sales Volume, as well as a 10 % increase in Operating Costs and Process Equipment. Let us analyze these results:

Cash flow

- For a −10 % **Price** change, Cash flow goes down from 67,155,000 to 62,454,000 Euros, that is, 7 %.
- For a – 10 % **Sales Volume** change, Cash flow goes down to 59,096,000 Euros, that is, −12 %.
- For a 10 % **Operating Costs** change, Cash flow goes down to 58,424,000 Euros, that is, −13 %.
- For a 10 % **Process Equipment** change, Cash flow goes down to 59,096,000 Euros, that is, −12 %.

Analysis: Cash flow denotes an appreciable decrease for all input variations. The company must make an appraisal regarding how these decreases impact its operations, for instance, in Working Capital.

IRR

- For a −10 % **Price** change, IRR goes down from 15 to 13.5 %, that is, −10 %.
- For a −10 % **Sales Volume** change, IRR goes down to 12.75 %, that is, −15 %.
- For a 10 % **Operating Costs** change, IRR goes down to 12.60 %, that is, −16 %.
- For a 10 % **Process Equipment** change, no variation is registered.

Considering these values, the company must decide if it can live with these reduced IRRs, related to the cost of capital, or if it is more convenient to reject this project and to invest its funds in more profitable ventures.

Table 6.2 Impacts on some output parameters produced by changes in some critical input components of the project

Output parameter	Target	Inputs components and impacts as differences with targets values							
		Unit price 10 % decrease	Difference with target (%)	Sales volume 10 % decrease	Difference with target (%)	Operating costs 10 % increase	Difference with target (%)	Process equipment 10 % increase	Difference with target (%)
Cash flow	67,155 (€x000)	62.454 (€x000)	–7	59,096 (€x000)	–12	58,424 (€x000)	–13	59,096 (€x000)	–12
IRR	15 %	13.5 %	–10	12.75 %	–15	12.6 %	–16	15 %	0
NPV	21,820 (€x000)	18,983 (€x000)	–13	18,329 (€x000)	–16	18,220 (€x000)	–16.5	20,249 (€x000)	7.2
Debt Coverage Ratio (DCR)	27.26	25.08	–8	24.53	–10	24,81	–9	23.63	–13.3

NPV

- For a −10 % **Price** change, NPV goes down from 21,820,000 to 18,983,000 Euros, that is, −13 %.
- For a −10 % **Sales Volume** change, NPV goes down to 18,983,000 Euros, that is, −13 %.
- For a 10 % **Operating Costs** change, NPV goes down to 18,220,000 Euros, that is, −16.5 %.
- For a 10 % **Process Equipment** change, NPV goes down to 20,249,000 Euros, that is, −7.2 %.

The analysis is the same for NPV. Remember that, while positive, these values mean a profit to the company, and so, naturally, it comes down to whether the firm is happy with these returns, or if it considers that there are other more profitable investments. Regarding investment under uncertainty and risk, see Jovanovic (1999).

Debt Coverage Ratio

- For a −10 % **Price** change, DCR goes down from 27.26 to 25.08, that is, −8 %.
- For a −10 % **Sales Volume** change, DCR goes down to 24.53, that is, −10 %.
- For a 10 % **Operating Costs** change, DCR goes down to 24.81, that is, −9 %.
- For a 10 % **Process Equipment** change, DCR goes down to 23.63, that is, −13.3 %.

The decrease in this ratio means that there could be a reduction in cash flow, which is necessary to cover interests and principal from banks and other lenders. This is not good news, since the lending institutions, if any, will wonder if, in case of a decrease in the price of gold, the company will be able to honour such debts and liabilities. The original ratio of 27.26 is very reasonable for this type of industry; however, its decrease is a signal that must be examined, especially when this decrease is maintained for changes in Sales Volume, Operating Costs and Process Equipment.

6.3.1.1.1 Conclusion of This Case

It is always possible to evaluate the probability of changes in selected inputs studying trends, the gold market, gold production at a global level, countries producing gold and their policies, etc., and from there, infer consequences. As a result, it is possible to compute risk in each case, and then compare each one with the risk that the company is willing to accept. Regarding this point, see the ‘Consequences matrix’ in Sect. 5.6.1. On the other hand, it is evident that not all inputs have the same weight; for instance, in this case, unit price and sales volume are probably more important than operation costs, because of their incidence in the outputs, and because they are external factors over which the company does not have any control.

However, this is not the case with process equipment, because the company has control over its own operations and has the capacity to negotiate prices with equipment suppliers (see example in Sect. 5.9.3). Nevertheless, if risk can be computed for each output, then it is possible to establish a ranking of inputs according to the importance of the risk they generate. Once this data is known, the company is able to dedicate efforts to mitigate the effect of those riskiest inputs.

6.3.1.2 Sensitivity Analysis Considering Several Inputs

As seen, using financial statements is an easy, straightforward and fast way to analyze the effects of changes; however, we proposed only one change for each input (10 %) just to compare the impacts that **different inputs** produce on **different outputs** for the **same** variation, although with different sign. In some cases, it is of interest to learn how impacts develop for **different changes from one input**. In other words, how does a change range from an input such as 'Price' affect an output, for instance, the NPV, or several outputs?

To answer this question, assign a minimum positive percentage change to price in the Statement of Earnings, say, 10 %, run the financial software, and look at the value obtained for each output. Now, increase the price input by another 10 %, run the software again, and save the result. Increase it by another 10 % and repeat the process until a maximum reasonable range for the input is obtained (see Table 6.3).

For instance, assume that the undertaking will produce an estimated 2,239,200 g of gold on year 2017, and that the spot price of gold in the Paris gold market is 31.27 Euros/g. at this time. Thus, total revenue is 2,239,200 × 31.27 = 70,019,784 Euros. Now, replace the price (31.27 Euros) with an increase of, say, 5 %. If production holds at 2,239,200 g/year, the revenue on year 2018 will be 2,239,200 × 31.27 × 1.0 5 = 73,520,773 Euros, and, of course, updated for the following years. When the software is run, the Project Analysis Statement of Table 6.1 will register the new values for the outputs considered.

This procedure can be repeated for other change intervals for the price of gold, however, it is believed that a better procedure would be to fix a lower and upper limit for the range with negative to positive values, for instance, between 8 and 10 % of the original spot price. Then, run Monte Carlo, specifying the probability distribution model to apply, and determine the mean value. This mean value can then be used in the Statement of Earnings (see Table 6.3). Naturally, those ranges will most likely change along the life of the project, and therefore should be considered. Thus, we are using two models here. The first one is Monte Carlo, used to select an average price for gold; the second is to introduce this quantity into the Statement of Earnings to analyze its influence in one or several selected outputs.

Notice that we can use different percentages and ranges for different inputs and different probability distributions.

6.3.1.2.1 Another Scenario

In another case, this time applied to manufacturing, assume that the project will produce a product already known in the market, with several brands, and the average price of which is 9.99 Euros with a low of 9.10 Euros and a high of 10.95 Euros. Our company wants to enter into this market, and for the first 2 years, that is

Table 6.3 Statement of earnings

	2014	2015	2016	2017		2027	2024	2026	2027
Revenue from sales (×000)				70,019		75,428	77,897	79,621	81,237
Operating costs				15,237		15,856	15,856	15,856	15,856
Gross profit				54,782		59,572	62,041	63,765	65,381
Revenue deductions	←		→						
Depreciation		Construction period							
Interest on debt									
Amortization of deferred charges									
Amortization of construction interest									
Income taxes									
Net earnings									

2015 and 2016, will offer it at 8 % less than the lower and 7 % less than the upper competitors' prices. Therefore, its range is 9.19 and 10.18 Euros. After 2 years, when it is considered that the product is consolidated and known, and with a certain share of the market, the lower and higher limits are raised. These values are placed in the Statement of Earnings in the corresponding years and using the β-Distribution (see Sect. 9.2.1).

Another input, such as 'Operating Costs', may have a range between 4 and 11 % during 2016, in accordance with a Normal Distribution (see Sect. 9.2.6). From then on, because personnel will be more acquainted with the new technology and/or because there is a learning process (see Sect. 5.14), the range will be −3 and 4 % for the year 2017, and between 3 and 3 % for 2018.

There are, of course, inputs that do not change, such as linear depreciation, or amortization, because even if they decrease or increase, they do that following a mathematical formula with no room for probabilities and established at the very beginning of the construction of financial statements.

Once the Monte Carlo process is over, we can use the mean values computed for each input in the financial statements.

6.3.1.2.2 Analyzing a Sole Input with a Range of Changes Affecting Multiple Outputs

Another scenario the company wants to consider is the individual testing of each input (Price, for instance) at a specific time, with a range of changes but simultaneously affecting a set of outputs. In this circumstance, only price is considered, and with a variation between 12 and 22 %, affecting six outputs. When this data is introduced into the Statement of Earnings and the financial software run for each percentage, the following results are obtained for a 10 % change (see Table 6.4).

Table 6.4 Output variation for a +10 % change in price

Input: PRICE		
Input change: +10 %	OUTPUT	Output variation
	Cash flow	8
	IRR	4
	NPV	6
	Debt coverage	2
	Sales volume	–3
	Market share	–6

Table 6.5 Output values for different PRICE input changes

	Change in Price input									
	-40	-30	-20	-10	0	10	20	30	40	50
Change in cash flow output	-12	-10	-9.5	-7	0	8	10.2	10.8	11.4	11.9
Change in IRR output	-18	-16	-15	-10	0	4	6	9	10.9	11
Change in NPV output	-23	-21	-16	-13	0	6	7.9	9.5	11	16
Change in debt coverage output	-9.5	-9	-9	-8	0	2	2.5	3.2	3.9	6
Change in sales volume	13	12	8	2	0	-3	-6	-7.5	-10	-11
Change in market share	11	10.9	8.2	5.8	0	-6	-7	-7.9	-8.1	-9.5

This process is repeated for each change percentage (seven times in this example, considering positive and negative changes), and tabulated as shown in Table 6.5. The '0' column corresponds to the original values, therefore, the percentages indicate values of deviation relative to the original values. If positive percentages are considered, notice that all the percentages are positive, which means an increment on the original value. However, notice that there are also negative values for positive changes, as in' Sales Volume' and 'Market Share', because logically, if the price increases, the sale will most probably go down, as will the share of the market. Naturally, the same happens on the left side of the Table that registers variation for negative input changes, but with the sign reversed.

One practical way to take advantage of this information is to put it in a graph, as shown in Fig. 6.3, called 'The Spider Diagram'; it has percentages of change input (price) as abscissa and variation for outputs as ordinates.

With this, it is possible to visualize the effect of a single change in the input and realize how many outputs it impacts and at which level. See, for instance, that a change of 20 % in price affects all outputs and indicates their variations, positive and negative. This diagram is easily done in Excel, starting with the values of Table 6.5.

Notice that a decrease of, say, 20 % in price produces negative percentages, that is, a decrease in the first four outputs, while the same negative percentage produces positive percentages for the last two outputs, because if the price goes down, either Sales Volume or Market Share will most probably increase.

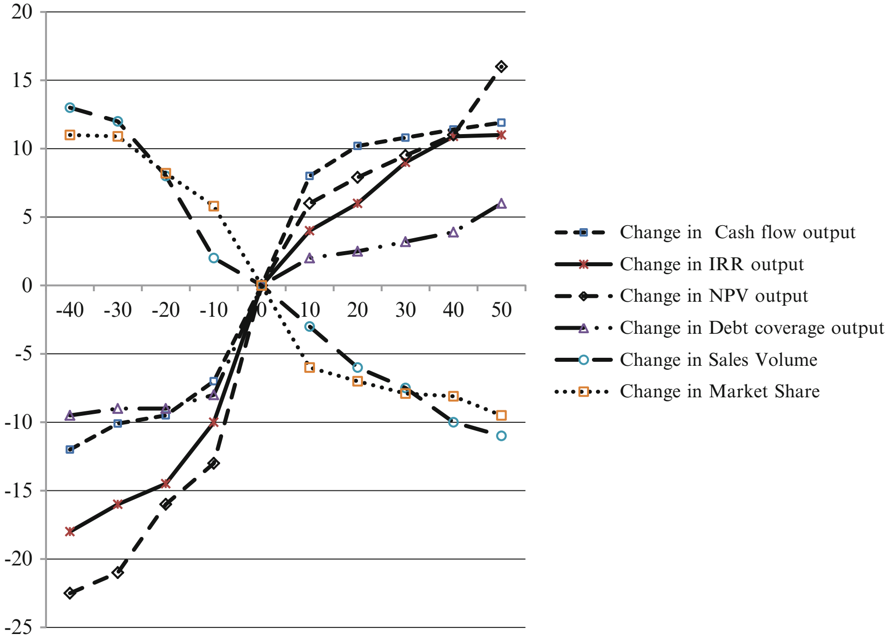


Fig. 6.3 Spider diagram for PRICE changes

6.3.1.2.3 Conclusion

It can be seen that projected Financial Statements, which are mandatory for medium and large projects, are a very powerful tool for examining sensitivity of certain outputs to certain inputs. It is possible to work with several input changes at the same time, however, one must be assured that data is not contradictory, such as assuming a percentage decrease in Price, a percentage decrease in Sales Volume and an increase in Cash flow. Besides, take into account that it is necessary to select the input change in the corresponding statement, that is, to look in which statement the input is raw data and not a processed figure. For instance, the value for 'Cash Surplus' in the 'Balance Sheet' comes from the 'Cash flow statement', therefore, if we are investigating this variable, we should start in the latter statement.

6.4 Sensitivity Analysis Related to Equipment and Material Costs

In this case, we are studying how the outputs, normally cost and time, vary when equipment and material prices change, mostly as a function of time or purchasing. Section 5.9.1 examines a brewery project in which the equipment is to be acquired in 2.5 years' time, and thus, the convenience of purchasing it up front is analyzed.

Table 6.6 Determining influence of each component on project's total cost

	1	2	3	4	5	6
	Cost negotiations	Monte Carlo costs at 95 %	Equipment weight	Percentage of cost increase	Sensitivity of each component to project	
Preparing specifications	2,100	2,100	0.0003			
Bid and proposals study	25,600	25,500	0.0037			
Equipment 1	1,234,750	1,390,700	0.20	12.63 %	15.16 %	(2)
Equipment 2	1,184,987	1,383,100	0.20	16.72 %	20.05 %	(1)
Equipment 3	1,658,278	1,815,814	0.26	9.50 %	11.99 %	(4)
Ancillary equipment	561,249	568,592	0.08	1.31 %	1.42 %	(5)
Equipments transportation	12,367	14,036	0.002	13.50 %	13.52 %	(3)
Equipments assembling	18,905	20,425	0.003	8.04 %	8.06 %	(6)
Equipments installation	583,614	583,614	0.08			
Equipments concrete foundations	1,123,402	1,125,788	0.16	0.21 %	0.25 %	(7)
Equipments testing	2,378	2,378	0.0003			
Totals	6,407,630	6,932,047	1.00			

That is, it takes into account the probability that the equipment price changes during that time and the advantage of its immediate purchase.

6.4.1 Sensitivity Related to Influence of Components

To determine the influence that each variable has on the final result, use the potential increase of costs, as well as the weight of each risk. An example will clarify this.

6.4.1.1 Case Study – Sensitivity Analysis of Components – Project Equipment

Project: Installation of process equipment

Assume that a project needs equipment manufactured overseas, which will take a year to manufacture. During said period, there will be increases in labor and materials, which are contemplated in the letter of intention between the entrepreneur and the manufacturer. Table 6.6 shows data for this scenario.

Table explanation

Column 1: The first column is the contractual cost for the entrepreneur.
Column 2: Assuming suitable probability distributions for each item and applying Monte Carlo gives the expected costs.
Column 3: The ratio between each Monte Carlo cost and the total gives the weight of each cost.
Column 4: Percentage of cost increase due to risk.
Column 5: Sensitivity of each item affecting the results is obtained by multiplying the percentage of cost by increase in weight.
Column 6: Ranking of components.

6.4.1.1.1 Conclusion

It can be seen that the project is most sensitive to ‘Equipment 2’, followed by ‘Equipment 1’, then ‘Equipment transportation’ and ‘Equipment 3’. Therefore, it makes sense to have a close look at these components, perhaps by renegotiating contracts, purchasing insurance, advancing transportation, etc.

6.5 Sensitivity Analysis Using Regression Analysis

Regression analysis is a statistical mathematical procedure for analyzing the relationship between two variables. For instance, two variables such as ‘price’ and ‘quality’ are normally related, and thus, it is possible, knowing the evolution of one of them, to ascertain the value of the other. The variable taken as reference is called the *‘independent variable’*, while the other variable, the value of which is determined as a function of the first, is called the *‘dependent variable’*. The method works with historical values of both variables, which are compared through adequate mathematical functions, such as those in Excel®.

The result is a formula that allows for computing the value of the dependent variable for a certain increase in the independent. The strength, and thus, the reliability, of the estimate between these two variables is numerically depicted by ‘**r**’, that is, the ‘correlation coefficient’, the values of which range from −1 to 1. Negative correlations indicate an inverse relationship, that is, one variable increases while the other decreases. Positive correlations indicate that both increase or decrease simultaneously. To understand the meaning, consider, for instance, $r = 0.9$; it indicates that 90 % of the dependent variable variation is explained for a unit variation of the independent value. In an example, considering ‘Sales Volume’ as the independent variable for a product manufactured by a project, with IRR being the dependent variable, then it is possible to determine the estimate variation in the predicted IRR for each unit variation in sales volume.

The relationship between variables may be linear or non-linear. The concept is similar for both, however, the Pearson correlation coefficient (see Garson 2013) is used for the first, while the Spearmen correlation coefficient is used for the second. A very important concept to bear in mind is that a correlation does not necessarily mean a cause-effect relationship, but that both variables move in the same direction.

6.6 Sensitivity Ratio

The sensitivity ratio (SR) is another technique that can be used for sensitivity analysis. It is the ratio between percentage change in an output divided by the percentage change in the input. It is a well-used concept in Economics, known as ‘Elasticity’, for investigating the robustness of the output for uncertain variations in an input.

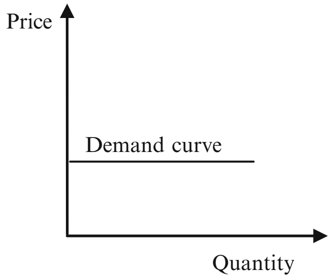


Fig. 6.4 Perfect elasticity

An example is the elasticity of demand to price in the automobile industry, that is, how the demand is affected by a variation in price.

$$\text{SR} = \frac{\textit{Percentage change in variable demand}}{\textit{Percentage change in varable price}}$$

As an example, assume that a car's demand has been 5,975 units per month at a price of 11,712 €. When the price is raised, for instance, to 12,600 €, the new demand is 5,017 units, thus SR, the price elasticity of demand, is

$$\text{SR} = \frac{\frac{5,017 - 5,975}{5,975}}{\frac{12,600 - 11,712}{11,712}} = \frac{-0.16}{0.076} - 2.10$$

Therefore, the absolute value for SR is 2.10 (considering absolute values for SR); thus, demand is elastic to price, since SR > 1, and it means that the demand change is greater than the price change.

If the SR < 1, demand is inelastic to price, and it means that the price change is greater than the demand change.

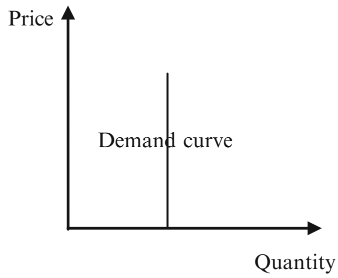
If SR = 1, demand is unit elastic to price. A decrease of, say, 10 % in price produces an increase of 10 % in demand, and vice versa.

For a perfect elastic demand, the curve between price and demand is a horizontal line that means that, for a fixed price, there is infinite demand (Fig. 6.4). It is difficult to find real situations where perfect elasticity exists, but suppose that a produce shop sells potatoes, as hundreds of others in the area do. If this produce shop increases its price even by one cent, buyers will buy the same product from another produce shop, that is, there is a large number of substitutes for this particular shop. That is, for a fixed price, buyers buy any quantity.

If there are no substitutes for a particular good, then the buyers will buy it whatever the price, as with, for instance, certain unique drugs (see Fig. 6.5).

Be careful in drawing the relationship between price and demand. Even if it is a linear relationship, and because its mathematical expression is similar to slope, they are different. The slope is constant along the line while elasticity changes along it, and there is a simple arithmetic explanation for this.

Fig. 6.5 Perfect inelasticity



6.7 Sensitive Score

This is a sensitivity ratio in which input variables are weighted. Obviously, it is of interest to know what the factors are and to what degree they influence the result. For instance, a car assembly plant produces different types of vehicles, however, they all have in common that their export accounts for more than 80 % of production. It transpires that any variation in the country purchasing these vehicles will have a very large impact on the outcome, therefore, the strength and economy of this country contributes the most to the risk.

6.8 Sensitivity Analysis and Risk

As has been said many times, risk is closely linked with uncertainty, thus, if we at least know the potential variation of an input, it is possible to ascertain the risk involved because of this variation. Section 5.6.1 in Chap. 5 gives an example, using the Z-Matrix, as to how risk can be computed and how to use it to decide if the project is a go or not.

Section 5.7.1 uses the same tool to examine the risk when aspects such as Society, Environment and Logistics are involved. As Makhani et al. (2010) say. "*In today's world, the fulfillment of project outcomes is extremely important. Once an idea is finalized, its outcomes are decided on the initial basis and they are highly impacted by the risk sensitivity analysis measures. If there were a change in a single factor of these measures, then it has an impact on the overall project, and especially the outcomes, which might not be achieved 100 percent.*"

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Chapter 7
Project During Execution – Strategy – Updating

Abstract This chapter fundamentally examines project performance during its execution period, however, risk must always be considered, especially at the very beginning of the project when the risk is normally maximum, and at each update. In the Project Monitoring stage, this chapter explores what happens with foreseen risks, that is, if they really happened or not and their consequences. In the Project Control stage, the chapter uses Earned Value Analysis and examines Performance Factors, which are used to predict completion regarding time and cost. However, because these calculations are based on past performance, there is always the risk that this performance will not be replicated in the future, and consequently, there is uncertainty about the completion time and cost. Risk Management can help in forecasting distribution of values by limiting this uncertainty, considering that it will probably follow a normal distribution probability curve and determine durations and cost values with a 95 % confidence, that is, assuming only a 5 % risk or whatever other value that stakeholders are willing to accept.

Keywords Earned value analysis • Performance factors • Estimates at completion • Forecasting • Normal distribution curve

7.1 Project Monitoring

Well, now the project is underway, and therefore, we are no longer concerned with risks…. Of course, not really, because risks could have materialized or not; in the first case, it is necessary to study the actual circumstances that led to the threat happening and to learn about it for future reference, since threats can repeat in future projects and even in the present one. If they did not materialize, there is also need to examine what led the Project Team at the beginning of the project to consider this potential threat. They can learn if they were pessimistic or else considered something that should not be taken into account. In addition, if the risk did not

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9_7, © Springer International Publishing Switzerland 2014

materialize in time, for instance, and if the task was on a critical path, the buffer was unused, and thus, it can be used for another task or to advance the completion date of the project.

Monitoring is the activity of learning what really happened, not only with risks, but also with other issues, that is, the action of observing, checking, supervising, or examining how the project performed regarding schedule, cost, and quality, and, of course, risk. The monitoring process also implies checking and auditing the master schedule, since alterations in a subcontract can, and most probably will, affect another subcontract.

At the very beginning of the project, the planning department produces the CPM or PERT network representing all interactions between tasks, assigns a time or duration to each task, and allocates resources, as well as the cost per task. This allows for defining the critical path, that is, the series of tasks the summation of which gives the total time for the project. With this data, it is possible to draft the accumulative curve that represents work to be done, valued in monetary units (or in man hours), which is called the '*Project Base Line*', the '*S-Curve*', or the '*Budget Cost of Work Scheduled*' (BCWS) (Sect. 5.9.2).

Because the Project Team already has a figure for the total duration of the project, it is possible to establish a starting date, and the expected completion date for the whole project will automatically be determined, as well as the earliest start and latest finishing for each task. This action is called '*Scheduling*', that is, placing tasks on a time interval, and it is done using the Gantt Chart, the tool that also builds, together with costs and resources, the BCWS curve, which details accumulated expenses as a function of time.

As the project advances, work is performed, and it can be on time and under cost or delayed and with overruns, or in other combinations of cost and time. That is, at a certain update, the advance could have reached the foreseen progress (measured as money spent) according to the BCWS (in monetary units), and thus, keep expenses under budget. If not, as most usually happens, the accumulated money spent does not match, in plus or in minus, what was foreseen. Thus, the BCWS acts as a benchmark to measure advance and cost in each successive update.

If the work actually done at actual costs does not match the BCWS, the set of actual values along time define another curve called the '*Actual Cost of Work Performed*' (ACWP), which may be below, above or crossover the BCWS curve.

However, work actually **completed** is one thing, and at **what cost** is another, since generally, there are differences in cost owing to inflation, labor agreements, higher prices for material, etc., with those having been estimated in the BCWS. That is, the advance of work could be fine and in agreement with the BCWS, however, if the work actually done is valued at budget – not actual – costs, there could be, at each update, another set of values which defines the '*Budget Cost of Work Performed*' (BCWP).

These three curves (BCWS) (solid line), (ACWP) (dashed line) and (BCWP) (double line), are shown in Fig. 7.1.

The BCWS is drawn at the beginning of the project, and is usually a contractual document. There are no other curves when work starts, since the other curves are

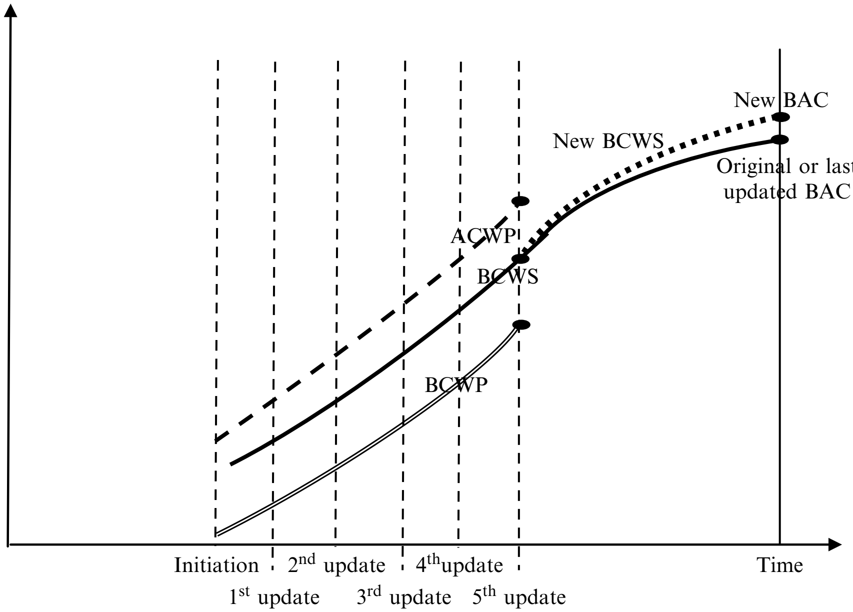

Fig. 7.1 Updated BCWS and projection

built as work progresses; consequently, at each update, values for ACWP and BCWP are determined, and their respective series of values as functions of time allow for construction of both curves. However, it gives the impression that the BCWS curve keeps its shape and values from start to finish; unfortunately, it is not so, since multiple causes, such as unexpected costs, change orders, weather, unforeseen circumstances, external factors, etc., can make it change, and thus, it has to be updated from time to time, as shown in Fig. 7.1.

This is indicated by a point curve (New BCWS) from the fifth update to completion. These curves, and the coefficients computed from them, are the tools that Earned Value Analysis (EVA) uses to control project performance and for forecasting. The clear distinction between planning and scheduling by CPM and PERT and performance measurement by EVA can be seen here, in the sense that the first two, using different approaches, try to plan the project from inception to completion; naturally, the more complex and lengthy the project, the larger the uncertainty that the plan and schedule will be honoured.

EVA, on the contrary, studies the past to determine the project's execution regarding time, cost, and quality, and, supported by this data, tries to forecast future performance. However, it does not take into account uncertainty, always present, and thus, it is necessary to use another tool to tackle this uncertainty: Risk Management. Consider, however, that CPM and PERT, as well as Risk Management, start from the very beginning, while EVA starts on the first update, but there is no doubt that there are close relationships between the three techniques and that they complement each other, albeit under the Risk Management umbrella, as shown in Fig. 1.1.

7.2 Project Control – Earned Value Analysis (EVA Management)

Every project needs to be updated periodically; in large projects, about once a month or even weekly, through monitoring and control. If it is true that EVA analyzes past performance, it also looks for risk occurrence or absence, and to what extent the risk was avoided or mitigated, or if, for whatever reasons, the risk nonetheless materialized. If the risk did not materialize and prevention measures were, in reality, unnecessary, there could possibly be a surplus in time, cost or both, which, in the case of time, can be subtracted at the end of the project, but will count as a loss in the case of cost, if it cannot be recovered.

In some manner, at each update, the project team will find itself in a situation similar to that at the beginning of the project, because of the need to forecast what can happen from then on.

However, it is not exactly the same position, because at each successive update, the project team has increased its prediction capacity, possessing more known elements upon which to base its forecast. Uncertainty decreases during the advancement of the project, as there are fewer aspects that can go wrong than before, and also because the project complication declines, measured by the interaction between different elements, amongst other things. On the other hand, the project team has a better knowledge of the performance of contractors, vendors, and suppliers, as well as relations with the owner, company staff working, weather, certain external factors, etc.

Specifically, there is a cumulative knowledge of which to take advantage, especially if repetitive work lies ahead that replicates what has already been done, as is usual in many large constructions. It is not the same, for instance, to schedule construction of formwork for the first floor of a 27-story residential tower as it is to schedule this same task for successive floors, and this is a process which can be quantified through the 'Learning curve' (see Sect. 5.14).

Besides the learning curve, the key element for forecasting the future of the project is past performance, that is, the way and the rate at which work was implemented, most especially by the main contractor. This is done using the three above-mentioned curves built by the monitoring team, based on visually checking and measuring the work done by the main contractor on the job site, as well as work and advances by vendors and suppliers on their premises. More information can be collected studying the main contractor, vendors and suppliers' 'look-ahead' schedules, that is, how they plan to perform the job in the next month, regarding manpower, materials, equipment, difficulties envisioned, etc.

At each update, new figures concerning cost and advance are obtained; they allow for the construction of the three curves.

The main characteristics of these curves are as follows:

BCWS. This curve corresponds to the scheduled work, **valued at budget costs**, or baseline budget, usually a contractual document, and consequently, the yardstick against which actual work is measured. However, very seldom does this curve remain unchanged; reasons abound, for instance, time elapsed since the budget estimate, which normally provokes cost increments due to inflation on material and equipment, cost of life affecting labor costs, union agreements also influencing labor costs, raises in transportation, increases in fuel costs, exchange rates, etc. On the other hand, there could be – and normally are – changes in the project scope, for instance, installing five water pumps instead of the seven originally estimated, which will reduce the original budget, or by additions to the project scope that will increase the original budget, or by increasing environmental control costs by hiring more personnel, etc. According to the above, new figures are obtained which will modify the original BCWS curve as mentioned and cause the need for a new estimate budget at completion (BAC).

ACWP. This curve corresponds to work actually done, **valued at actual costs**. Once the amount of work completed at an update is computed by the monitor, it is multiplied by the actual – not the budget – cost. The amount of work at an update may or may not match that from the schedule due to different reasons, such as:

- Incorrect definition of work
- Insufficient people for certain tasks
- Lack of availability of certain equipment when needed
- Necessity of rework owing to changes
- Different type of soil as initially considered
- Necessity of replacing underground piping not shown in original information
- Too many people in a small working space
- Price increase
- Quantities taken off do not agree with those placed
- Budget estimate too high or too low
- Variable contractor performance
- Unforeseen difficulties (see, for instance, Sect. 4.11)
- Personnel not well trained for a certain job
- Accidents delaying the job, etc.

There is also some fuzziness in this stage because it has to be agreed upon ahead of time when work (or a set of tasks) is considered ‘done’. Some PM support the criterion that it must have been decided upon after the task starts, others support the principle that it is done when it is finished, and finally, others maintain the criterion of measuring percentage of advance, which appears to be the most reasonable course, although not the easiest. It consists of measuring the volume of concrete poured, tons of steel placed, m^3 of excavated dirt, etc., or may be a percentage completed of a whole task, say, concrete columns, over a total, together with actual hours spent and funds used, including unexpected expenses.

The first criterion is practically useless in tasks with a long duration, perhaps months, because its initiation does not guarantee its finishing on time, and thus, produces inaccurate data. The second is the opposite; it penalizes the task for its long duration, and thus, does not represent the work advance during its development. For these reasons, the third option is considered the best.

BCWP. This curve corresponds to work actually done, **valued at budget costs**. Once the amount of work at an update is known or has been computed, it is multiplied by the budget – not the actual – cost. Again, these amounts may not coincide with the ACWP for the reasons commented upon above.

7.2.1 Analysis of Curves

It is interesting to note comparisons between the three curves.

The reason for the eventual difference at a certain date between the ACWP and BCWP is called '*Cost variance*' (CV), (see Fig. 7.2 which simulates a project update) which indicates to what extent these two costs differ and shows that the project is under-run or over-run. However, the CV only registers differences in money and says nothing about schedule.

A project can eventually have the same BCWS and BCWP, meaning that it is under budget; however, it can also be ahead or behind schedule. In the first case, the project is more advanced cost-wise than predicted at that update (because we have spent the predicted amount of money, but MORE work has been done).

In the second case, the project is less advanced cost-wise (because we have spent the predicted amount of money, but LESS work has been done).

To measure the project advance, compute the difference between BCWP and BCWS.

That difference is called the '*Schedule Variance*' (SV).

As a bottom line, the basic element by which performance is measured is the **amount of work done**. This work has an actual cost, but when it is valued at budget cost, there could be a difference or variance. This variance is the CV.

If the work done is valued at budget cost and is compared with the schedule cost, there could be a difference or variance. This variance is the SV.

These variances can be visualized in Fig. 7.2. Observe how it can be appreciated visually that the project is behind schedule by 14 days (TV), because the amount corresponding to BCWP (302,761 Euros) on July 31 should really have been spent 14 days before.

Notice also the geometry of the CV, which shows that, on July 31, there is an accumulated actual cost of 445,710 Euros, when the same work, valued at budget costs, should cost 302,761 Euros.

As can be appreciated, the Earned Value Analysis Management (EVA) combines costs incurred and work done, and thus, gives precise information about the project status and where it stands at a certain date. It is necessary to remember that RM plays a significant role here, because risks causing delays can be avoided or mitigated, the same as risks causing overruns.

Until now, EVA has analyzed what happened, and that is important, however, it is more important to be able to predict the future development of the project.

Once EVA furnishes the three curves corresponding to BCWS, BCWP and ACWP, is it possible to extrapolate them to the future? Yes, if it is assumed that the same conditions (risks, contractor's performance, prices, delays, etc.) present in the past will hold true in the future.

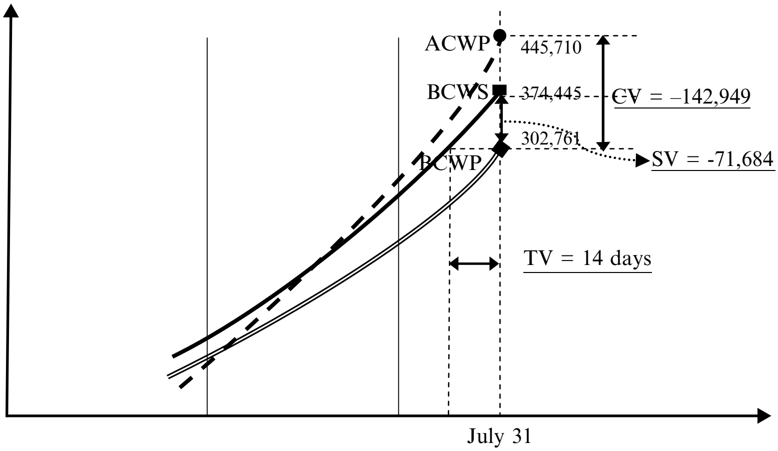

Fig. 7.2 Variances in a project

However, this is too much of a simplification, because conditions can – and usually do, change – and consequently, it is impossible to forecast that future accurately. This uncertainty is very large at the beginning of the project and usually decreases as the project develops. Therefore, it is necessary to use some methodology other than the simple extrapolation by drawing the curve shapes. One way calls for using mathematical forecasting formulas, which, while admittedly not guaranteeing the results, are helpful in approximating them.

A formula for forecasting the Estimated at Completion Cost (EAC) is as follows:

$$\text{EAC} = \text{ACWP} + (\text{BAC} - \text{BCWP}) \tag{7.1}$$

This formula assumes that the final cost will be the amount already invested (ACWP) plus the difference between the expected cost at completion at budget prices (BAC) and the work already done valued at budget prices (BCWP). This makes sense, if we know how much the definite BAC will be, but we do not know that.

However, if it is assumed that the past performance will somehow hold for the future, then there are more probabilities of making a correct guess. Consequently, the above formula is affected for something called the Cost Performance Index (CPI) (Sect. 7.3), which reflects the past (see formula 7.2).

$$\text{EAC} = \text{ACWP} + \frac{(BAC - BCWP)}{CPI} \tag{7.2}$$

This, in essence, means that, if work continues at the same rate as in the past, we can compute the final cost. In reality, this is not so, because we do not have the certainty that past performance will replicate in the future; however, we do not

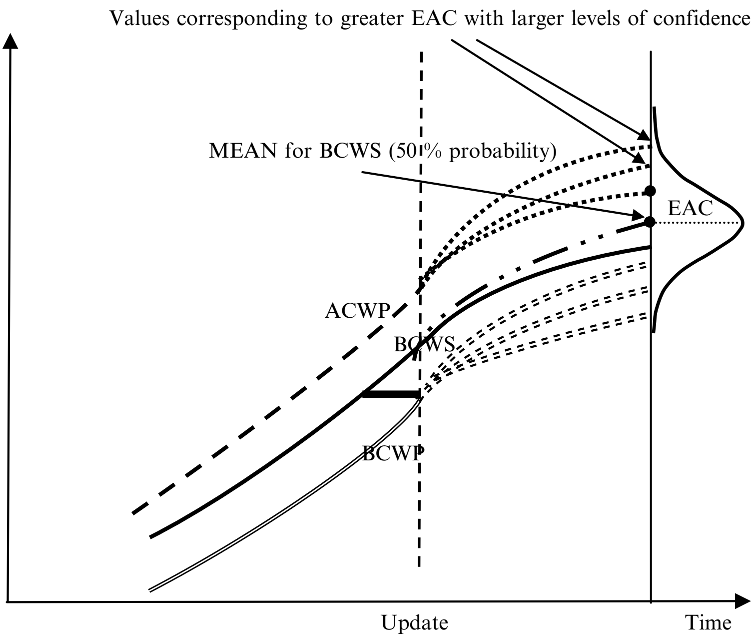

Fig. 7.3 The three curves and their projections

have any other choice but to use it. Interestingly enough, Christensen and Heise (1993) makes reference to a study on 165 government contracts in which it was found that past contractor performance CPI normally does replicate into the future. It is seen that if the CPI >1, meaning a performance improvement, the EAC will be lower than estimated, and vice versa. In reality, at each update, there is a range of values that could happen for each curve, which, translated to the final date, offers a cloud of uncertain values, with the value we are looking for being somewhere within the cloud (Fig. 7.3).

Risk management can help in forecasting a distribution of values for delays and costs with mean values, which is the information we are seeking.

7.3 Performance Factors

With this updated data, performance indexes can be built as follows:

The '*Cost Performance Index*' (CPI) relates work performed at *budget* values to work performed at *actual* values. Then:

$$\text{CPI} = \frac{BCWP}{ACWP} \tag{7.3}$$

Ideally, this ratio should be equal to 1.

If CPI > 1, it means that the project is running under budget.
If CPI < 1, it indicates that it is over budget.

Another index is the '*Schedule Performance Index*' (SPI), which relates work performed and work scheduled, *both valued at budget costs*. Thus:

$$SPI = \frac{BCWP}{BCWS} \tag{7.4}$$

Ideally, this ratio should be equal to 1.

If SPI > 1, it means that the project is running ahead of schedule.
If SPI < 1, it means that the project is running behind schedule.

One of the main purposes of doing this exercise is to be able to forecast two very important points of paramount interest to the project owner or stakeholders. These points are:

- How much will the final cost be?
- When will the project be finished?

To answer these two questions, use the formulas shown above.

Both CPI and SPI can be used to measure the effectiveness of RM; the larger the CPI and SPI values, the better, since it can indicate that risk is well controlled (Hillson 2004). Normally, the last CPI and SPI values are used, however, in this book, it is suggested that one use values resulting from the projection of their respective trends into the future. This can be easily done plotting values in Excel and finding the equation of the trend line.

One way to keep track of these indexes' values is to adopt the format widely used for quality control designed by Shewhart (1913).[1] In this chart, both CPI and SPI values are plotted when updating the advance of work, as shown in Fig. 7.4. Naturally, it is not expected that their ratio will be exactly '1', and thus, an allowable variation with which the PM is comfortable must be established, for instance, between 0.90 and 1.10 (thresholds), and with other thresholds if need arises, such as 0.80 and 1.20.

While the updated values are within the 0.90–1.10 range (shaded), it is considered that the work is going well and that risk measures are working fine.

When CPI points are above the 1.10 threshold, this means that the BCWP > ACWP (that is, the work done at budget cost is greater than the work effectively done at actual or real cost). For SPI points above the 1.10 threshold, the BCWP > BCWS (that is, the cost of work done at budget cost is greater than the cost of work scheduled), and this could be an excellent result.

However, for values exceeding 1.10, be careful, because if it is true than the higher, the better, very high values also indicate that the budget was probably poorly

[1] Walter Shewhart developed these charts in the 1920s while working for Bell Laboratories.

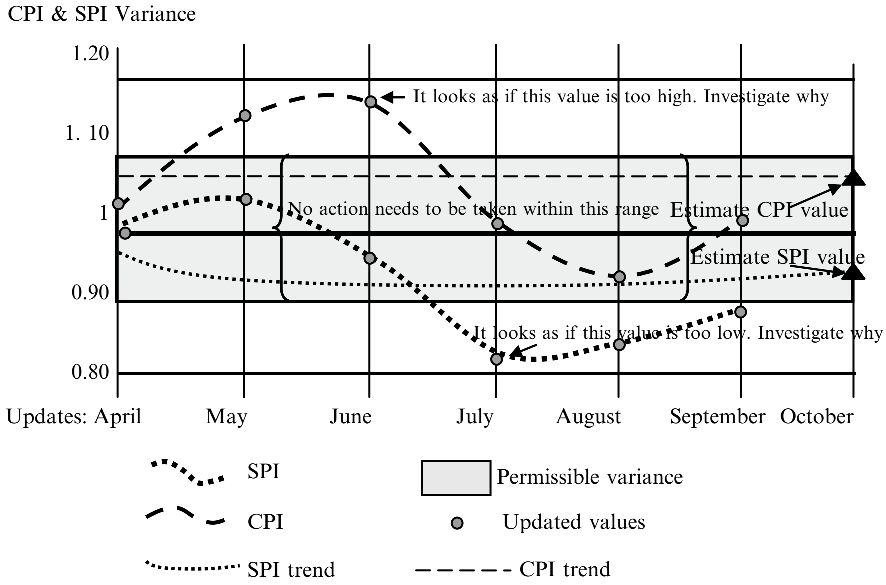

Fig. 7.4 Control chart for CPI and SPI

done through inflating prices unnecessarily. This is serious business, since it implies that more funding than needed was estimated, perhaps hurting other projects competing for these same funds, or to pay unnecessary interest on banking loans.

The opposite is also true, and when values are lower than 0.9, it could mean that the budget and durations were too conservative or errors led to lower estimates, thus risking the ability of the company to continuing developing the project.

In these circumstances, both cases denote a lack of quality.

When the schedule is updated, two techniques are considered simultaneously: EVA and Risk Management (RM). Why the two of them? Because they have different purposes.

EVA analyzes the present and forecasts the future based on past performance, that is, on something that is already done, and for which certainty exists. What has been built is in there, usually in a tangible format, be it a construction, a study, or software.

RM tries to predict the future up to the project's completion, trying to limit uncertainty. By using entropy (Sect. 5.9.3), it is possible to measure, to a certain extent, the level of existing uncertainty and adopt measures to reduce it.

However, is RM necessary when we know what happened in the past and that it will probably be replicated in the future? Absolutely.

Hillson (2004) uses a very clear analogy to explain EVA's role and the importance of limiting its use to predict the future when he says, "…. *it is not possible to drive a car by only looking in the rear-view mirror. A forward view is also required, and this is what RM offers.*"

7.3.1 CPI and SPI Variance

A complete description and analysis of this methodology, including Performance factors, can be found in DCMA (2012).

7.4 Introducing Risk Into the Future

At each monthly update, it is normal to run a new CPM to determine new floats, new tasks added or deleted, change orders, etc. If PERT is used, new three points estimates may be introduced for some tasks, considering greater knowledge or perhaps with the introduction of a risk buffer (see Sect. 2.5). The result will be a new completion date, as well as new EAC cost, with a certain probability, say, 90 %, established by the PM into the Monte Carlo model (see Sects. 3.3 and 5.3.1). As we know, the result of either the completion time or the final cost will have a 90 % probability of compliance, and a 10 % probability of non-compliance.

Thus, it is possible to estimate which impact or impacts will produce a delay or higher costs at the respective updates. Since we have both a probability of completion and several monetary values for different impacts, risks can be calculated for each outcome. If the risk is too high in certain outcomes, it would be wise to take measures to transfer, avoid or decrease the risk. This action will most probably translate into more expenses, and thus, the PM and the company must evaluate the convenience of spending that additional money or not, since it could be that remediation costs are higher than evaluated impacts.

7.5 A New Approach for Forecasting the EAC

A new approach is proposed here for forecasting the EAC more accurately. The method is based on the fact that what is really governing the development of the project cost-wise is the ACWP, because it depicts something that is tangible, irreversible, and quantitative. What is built is built and offers no room for guessing. Therefore, it is believed that if we want to know the final cost of the project, it has to be based forcefully on actual work performed by a certain date. This is not new, and, as a matter of fact, Formula (7.2) uses it. This formula is logical, however, it can scarcely determine the final cost accurately, because it is based on:

BAC: Which is guessed
CPI: Which is an average value.

Consequently, the EA C is an average value, and, as such, has only a 50 % probability of compliance. Nevertheless, Formula (7.2) is useful, because it establishes a coherent basis for a more accurate prediction.

As said, ACWP and BCWP seldom coincide, producing the CV. However, this CV is far from constant and varies along the life of the project. It thus makes sense to find these CVs and compute their trend. When this trend is extrapolated to the final date, either graphically or by its mathematical equation, very easily found through Excel, it is possible to have average values for these CVs at the final update. This value thus constitutes the mean on Normal Distribution for CV values. If this mean value is added to the previously found EAC, we will have the mean value for the ACWP.

Because of the Central Limit Theorem, we know that this final ACWP will follow a Normal Distribution. The Standard deviation of this distribution, that is, its shape, can be determined by giving values below and above this mean and using this formula:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x-\mu)^2} \tag{7.5}$$

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Chapter 8
Closing and Reporting

Abstract It often happens that closing and reporting do not deserve particular attention from the contractor or consultant Project Manager, however, they are important. This chapter analyzes diverse situations that imply risk specifically related to an owner being dissatisfied owing to a deficiency of documentation in quantity and quality handed over, or perhaps due to a lack of quality in finishing concrete work, or through failure to clean the site. The chapter analyzes these aspects, pointing out that closing-out a project is a process as important as the rest of the processes in the project's life cycle, and examines the need to produce a good Technical Memory that must incorporate a string of information not only related to the work done, but also to be used as a future reference. This chapter continues with the production of 'As built' drawings, a fundamental document that depicts the real condition of the project, which may differ from the original planning, as well as the need to produce a complete and trusty report.

Keywords Client satisfaction/dissatisfaction • Technical documentation • Environmental site condition • Technical memory • 'As built' drawings

8.1 Diverse Situations That Imply Risk

This chapter is not devoted to project completion delays or project overrun costs when completed; these subjects have been discussed in Sects. 5.5.1, 5.8 and 7.1. It is referred to here as a process for closing a project, and the obligations that a contractor has to the promoter or owner regarding quality of work, as well as information that has to be handed over.

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*, DOI 10.1007/978-3-319-05251-9_8,

At first sight, it appears that, when a project is closed, all risks have been addressed, and that nothing else can happen. Unfortunately, this is not so; there are different types of risks when closing a project, a few examples of which are:

1. Leaving an unsatisfied client because the quality is not as he/she expected.
2. Neglecting to hand over all documentation about the development of the project to the owner.
3. Neglecting to leave the job site in the same environmental condition as it was when the project began.

These risks can be addressed when considering their avoidance from the very beginning of the project, that is, in its planning stage. The first-mentioned risk is averted through a close watch of the quality of the work being done during the undertaking. It is necessary to consider that doing the right thing quality-wise during construction is normally much cheaper than trying to remediate shoddy work. Naturally, this control implies larger costs, because experienced people are needed to verify that concrete is poured properly and at the right temperature, that welding is executed correctly, a forest reforested adequately and with the right species, a building shows neat finishing details, etc., but it pays.

What is the risk of not doing quality work? Most probably, an annoyed owner who will think twice about giving another project to the same contractor or consulting firm or, even worse, may consider finishing in a court of law. Therefore, in the planning stage, a contractor must consider this circumstance.

The second risk refers to the contractor's obligation to hand over all the documents pertaining to a project to the owner or promoter, including, but not limited to, the documents enumerated in Sect. 8.3.

It is suggested to consult publication Ontario General Contractors Association (2007) for a comprehensive guide for implementation of project closeout process.

To avoid risky situations, it is necessary to take this last step in the project very seriously. A project is not made up of a series of isolated actions, and its documentation should not be a jumbled pile of papers thrown together in haste so as to leave the site as quickly as possible. As with every other aspect of the project, there is a series of activities to perform, because "*Project Closure is more than a milestone… it is a process, with deliverables, for successfully concluding your project.*" (Mastering-Project-Management.com 2009).

8.2 Technical Memory

This is a comprehensive report or Descriptive Memory, normally prepared by the Project Manager concerning the project, related to how it was developed, and inconveniences and problems encountered, such as:

- Change orders
- Certificate of final completion
- Contractor claims

- Environmental problems
- Equipment and raw material quality
- Equipment performance, as well as availability
- Lack of communication between contractor and stakeholders
- Lack of information
- Legal aspects encountered
- Lodging problems (when the jobsite is remote)
- Payment certificates
- Performance of installed equipment and services, etc.
- Personnel problems that could have affected the work
- Social disturbances
- Strikes
- Supplier delays
- Transportation problems
- Unforeseen circumstances
- Weather that influenced the normal development of the project

This information is normally very important for the contractor, consultant or owner, because it will be used to plan new developments, acknowledging and taking advantage of lessons learnt in the present project in order to avoid repetitions of past errors. From this point of view, it is convenient to perform a Post Implementation Evaluation Report (PIER), that is, a revision of the development of the history of the undertaking and its critical evaluation. Without a doubt, this exercise will provide information on errors (and successes), and will help to understand, for instance, if assumed threats really materialized, and if so, the seriousness of their impacts, or if there were no predicted risks that in hindsight should have been considered at the onset of the project development. Make a thorough reading of contractual documents and, most especially, the project charter to make sure that everything has been complied with, and all deliverables produced; maybe there is a fence that should have been erected, or the demolition of an old structure or lighting of a small yard that have been forgotten. Most probably, the owner will later call your attention to this lack of compliance, and thus, it will be necessary to have personnel and equipment sent back to the jobsite to remediate the problem, at considerable expense. If this problem is noticed during the closing process, this risk can be averted, and the work done at considerably less cost, because workers and equipment are still on the jobsite. See also State of Kansas (2008) for useful ideas and hints.

8.3 Documentation

The gathering of reliable documentation to be handed over to the owner is a vital part of the closing process. Naturally, in a large project, there are hundreds of documents pertaining to different areas of the project and addressing construction, personnel, unusual facts, contractor and supplier performance, weather, communications, etc., that need to be classified. The following list, far from complete, can serve as a beginning guide:

1. Furnish a complete set of '*As Built*' drawings depicting what was actually built, and not what was supposed to have been built according to the original drawings.

   These drawings are essential to any project, because they are the documents that the owner will consult if something happens in the future. Different circumstances may arise such as, for instance, the need to find actual routes of escape in case of fire, or the location of buried piping and valves in the event of flooding or broken pipes, or to look for survivors after an earthquake, just to mention a few potential uses of these documents.

   It would be frustrating if, in a case of need, one finds that the original drawings show an alley linking A and B that does not exist or that a concrete wall intercepts the path. Figure 8.1 shows an 'As built' drawing for the construction of concrete work for hydroelectric turbines. Observe in the manuscript the remarks of the surveyor checking the work done, with indication of the coding of the 'As built' drawings for each part of the structure.
2. Information about the state of the site. Detail and take pictures of the portion of the site where the construction offices and trailers for personnel lodging and kitchens (supposedly dismantled) were located, to show that they have been left tidy and clean, or that the existing environment has been restored as much as possible, for instance, if some trees were logged to make room for these premises. For another example, if, owing to the construction of a dam, a lake was formed behind it, with the possibility of this lake flooding a nearby forest, it is necessary to show compliance and perhaps the execution of a reforestation plan at another site to compensate for the loss of trees. The risk is that an environmental agency may fine the owner because of the destruction of existing trees. In the case of a construction camp, installations such as a sewage treatment plant built for kitchen discharges, as well as from trailers, must be decommissioned and the site restored to its original state. The risk is that the owner, besides being annoyed, could get the job done themselves and then charge the contractor, and probably at a higher cost.

   Large projects, such as a hydroelectric dam, located in remote and isolated areas need construction camps that can lodge several hundred workers. It is thus necessary to install a wastewater treatment plant (WWTP) for sanitary and kitchen discharges, as well as to build a landfill for solid wastes, with the WWTP being underground. In the closing process, the WWTP needs to be deactivated and the landfill covered with dirt. Naturally, the contractor has to perform these tasks, however, they also have to provide the owner with location drawings of these facilities. If this is not done, the owner could end up doing some work on top of these undertakings in the future that could produce certain problems.
3. Make sure to have documented information regarding the owner's personnel having suitable training to operate installed equipment. Failure to do this can lead to a lengthy and costly process in a Court of Law if accidents occur or if equipment is damaged owing to untrained personnel.

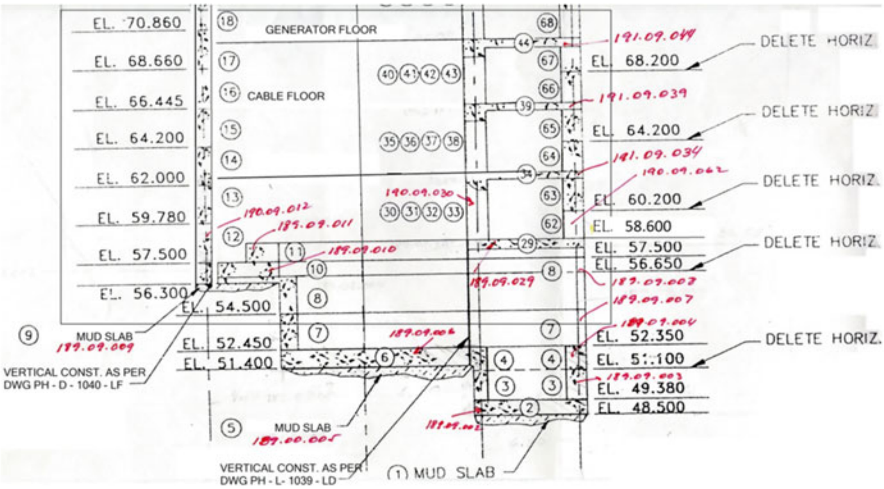

Fig. 8.1 Actual concrete work done for hydroelectric turbine installation

4. By the same token, the equipment manuals, as well as those for operation and maintenance, equipment guaranties, vendor's information, vendor's technical notices and procedures, memos, e-mails, testing reports from vendors and from owner's inspectors should all be handed over to the owner.
5. Facilitate documentation regarding visits to the vendor's premises to check equipment during the manufacturing process, etc.; these documents are produced during the construction phase of the project and must incorporate all data concerning tests, essays, and results. There is a great risk that, if for any reason, a piece of equipment fails, for instance, in producing the contracted output, the vendor can counter-claim that it is because the equipment has not been properly operated. Under this circumstance, documents must be available to show factory tests in which the equipment delivered the correct output, and consequently, the decrease in output could be chalked up to other reasons, including negligence by the owner or non-compliance in full with the manufacturer instructions regarding type of fuel to be used, electrical frequency adequate for equipment, low quality raw materials, etc.

Report everything related to the work, even if it is against the contractor or consultant's interest. It is not wise to conceal information on the grounds that it is too cumbersome to collect or because it does not put forth a good image of the contractor or consulting firm, under the belief that what is not known cannot harm you. To this notion, Jisc Infonet (2008) wisely states, "*It can be tempting to skimp on final documentation, particularly if the project is already late or overspent. However, projects that are late or overspent are prime examples of situations where you need to record exactly what did happen to inform the planning of future projects*". It is obvious that the owner will appreciate this honesty, and may even favor the contractor for future work. Therefore, there is a risk in pointing out one's own failures or mistakes, but also an opportunity if, in the future, the owner remembers that this contractor or consulting firm can be trusted.

There are templates and guides for the closing process. A good and detailed guide for project closing can be found in Young (2010).

When everything is checked, write a formal acceptance letter, which, after being signed by the owner, will mean that the contract is complete.

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Chapter 9
Brief Introduction to Probability Distributions

Abstract There is a great deal of uncertainty in any project. That is, data is seldom absolutely reliable and exact, since there is never certainty about duration of tasks, price variations, effect on the environment, etc., to say nothing about those aspects which are external to the project and for which the project developer has no control, such as weather conditions, demand, stock fluctuations, inflation, supplier's delays, etc. It is believed that many projects are not completed in time and finish with cost overrun, because in their preparation, data is taken as unquestionable, and then actual conditions show that it is not precisely the case. For this reason the uncertainty aspect has to be considered in projects preparation, and this is the objective of this chapter, by introducing statistic techniques.

Keywords Uncertainty • Probabilities • Probabilities distribution • Normal distribution • Monte Carlo analysis • z-score

9.1 Introduction

Risk management works with uncertainties, and thus, probabilities are the tool. Grossly defined, a probability is the relationship between a probable occurrence and the total number of possible events. For instance, tossing a die, the probable occurrence of each number is 1, but the possible numbers that can appear are 6, thus the probability of, say, a number 3 appearing will be 1/6. In this case, we have equal probabilities since all numbers from 1 to 6 have the same 1/6 probability of occurring. If we toss the die 1,200 times and register the results for each toss, it will most probably end up that all numbers have appeared with the same frequency, that is, about 200 times; in other words, all numbers have the same probability. Another example is the lottery, since all numbers considered have the same probability.

However, in most cases, this does not happen, for instance, in task durations; it is clear that the same probability does not exist that a task might be executed in 4 days or in 18. Specifically, durations have different probabilities of occurrence; the

N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*, DOI 10.1007/978-3-319-05251-9_9,

collection or set of these probabilistic values between extreme limits constitute what is called a 'Probability Distribution', which is 'contained' under a probability curve.

For instance, we assign a duration of 17 days for a task to be performed, but this is not certain, since it can perhaps be performed in 16, 15 or even 14 days. By the same token, there could be chances that the task will take 18, 19 or maybe 20 days or more. Obviously, we are assuming that the same resources apply to them all, but the risks or opportunities (if performed in lesser time) due to unforeseen circumstances must be calculated and preventive measures taken to avoid or decrease the risk.

Another example could be rain; assume that historical records in a region show that, on average, there are 29 rainy days in a year, thus the probability of rain occurrence will be 29/365 = 7.9 %.

On the other hand, not all risks have the same importance, and thus, it is necessary to rank them.

If an occurrence takes place, it will have an effect, known as an 'impact', the consequences of which should be considered, therefore, there could be a risk or an opportunity; rain may be beneficial, and thus, have a positive impact, however, excessive rain can cause floods with very negative impacts.

There are many probability distributions, and some are more suitable for representing certain events than others; in Project Management (as in PERT, for instance), a probability distribution that accepts lower and upper limits is mainly used, such as the triangular and the β-Pert distribution. PERT uses the β-Pert distribution for computing the most probable value for task duration; however, to find the total number of days for a project to be completed, it uses the normal or Gauss probability distributions, justified by the Central Limit Theorem.

A **probability distribution** indicates the range of values that a random variable can assume, as well as the probability of each value, given by the surface under the curve.

There are some important concepts that need to be addressed to understand the results:

Probability density function: Shows the relative probability for a given value.

Probability distribution shape: Shows the different shapes that a distribution curve can take, considering aspects such as 'kurtosis', a measure of the peakedness of the distribution curve, which indicates the concentration of probability values around the mode. Another important measure is 'skewness', which is a measure of the asymmetry of probability values regarding the mode or an indication that they are unevenly distributed around the mode.

Mean of a distribution (μ): Is the average value.

Mode of a distribution: Is the most frequent value.

In normal distribution, since it is symmetrical, mean and mode coincide.

Variance (σ^2): Is a measure of the squared differences between values around the mean and the mean.

Standard deviation (σ): Is a measure of the spread of values around the mean or the square root of the variance.

There are mathematical formulas that compute each of these characteristics, as well as many others.

9.2 Probability Distribution Types

There are many different probability distributions; however, some are more tuned toward certain types of problems than others, and they can be continuous or discrete. The main characteristics of probability distribution curves for our purposes are:

9.2.1 β-Distribution

This is a continuous distribution for values defined in the 0–1 interval, the form of which is defined by two parameters α and β (Fig. 9.1).

9.2.2 β-PERT Distribution

This is a continuous distribution, as shown in Fig. 9.2, with a central value (Most Likely value) and two extreme values (Optimistic and Pessimistic), normally used in Project Management. The model is strongly sensitive to the Most Likely value, since in its mean formula, it is multiplied by 4, while the other two are multiplied by 1. According to Vose Software (2007), PERT distribution will display 10 % less

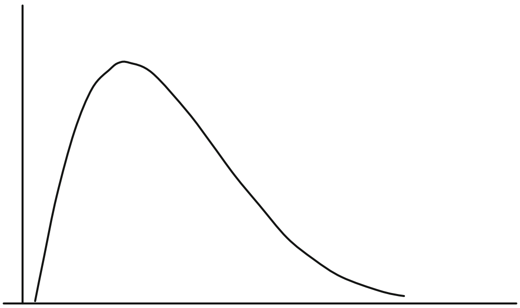


Fig. 9.1 β-distribution

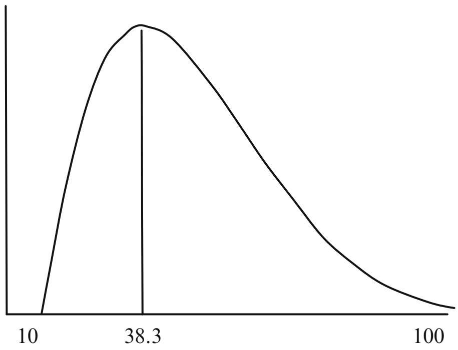


Fig. 9.2 β-PERT distribution

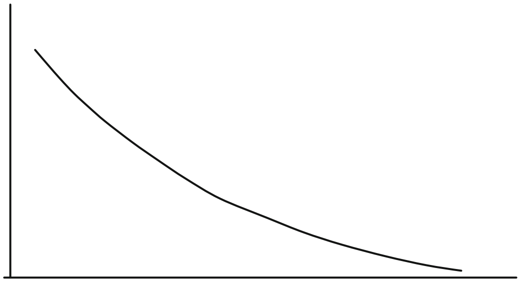


Fig. 9.3 Pareto distribution curve

uncertainty than the triangular distribution. Areas under the curve – as in any other continuous distribution – represent probability density and give the probability for each duration value. Notice that the curve is not symmetrical, but skewed, showing the sensitivity commented upon above.

9.2.3 Pareto Distribution

This is a continuous distribution, mainly used with empirical data and with extreme events such as distribution of wealth (the famous 20/80 Pareto Principle), size of cities in a region where a few cities account for a very large percentage of the total urban population in the region, hard drive errors, etc. In Project Management, it can be used to identify the 20 % of items or tasks in a project which are responsible for 80 % of the project total cost (Fig. 9.3).

9.2.4 Triangular Distribution

This is a continuous distribution with similar values of β-PERT distribution, that is, a lower value, a mode (the most probable), and a higher value. It is mainly used when data is scarce and there is not too much of an idea as to how the whole population is distributed, although extreme values are guessed.

Figure 9.4 shows a triangular probabilistic distribution with the three parameters indicated in abscises, and in which the probability is equally sensitive to each parameter, which means that the three of them have the same importance or weight, explaining its regular shape.

9.2.5 Poisson Distribution

This is a discrete distribution which allows for determining the number of times that an event can occur in a certain interval. In Project Management, the Poisson distribution can be used related to the number of workers in a project with respect to known limits. It is also used in reliability engineering (Fig. 9.5).

Fig. 9.4 Triangular distribution

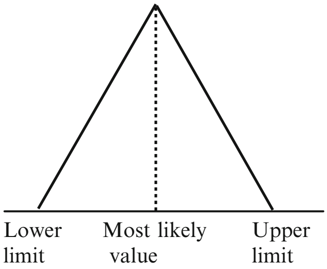
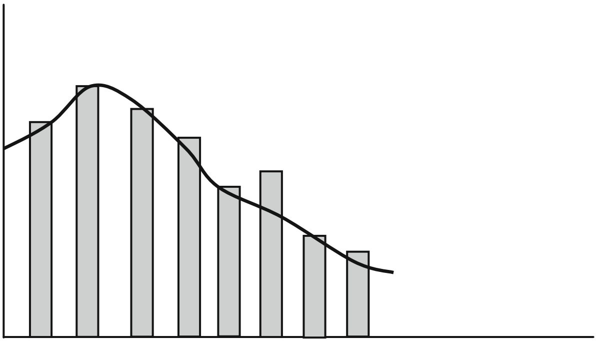


Fig. 9.5 Poisson distribution



9.2.6 Normal Distribution

The normal distribution, or ‘Bell curve’, is shown in Fig. 9.6.

It is a continuous distribution and the most important probability distribution in Statistics, because many practical problems and natural phenomena follow it. It works with uncertain variables, the performance of which are influenced by many factors, such as demand for a product, prices, many indexes, accidents, manufacturing defects (Quality Control), etc. It is also used in PERT to analyze the probability that a project may be completed in a previously established period, or for determining the duration needed for the project to have an established probability of success. Its use in PERT derives from the Central Limit Theorem, which establishes that, given many random variables (such as durations), the result, when considered jointly (as in PERT), follows a normal distribution the mean of which is the sum of the means of each variable and the variance of which is the sum of the variances from each variable.

This perfectly symmetrical curve, with a shaded area equal to 1, is plotted in an x-y coordinate system where the axis represents the z-score values in a standardized distribution (that is, a normal curve with mean $(\mu) = 0$) and standard deviation $(\sigma) = 1$, such as shown in Fig. 9.7 – Curve A, while the ordinates represent the frequency of z-scores. The z-score values are numbers used to measure the distance between a score and the mean, related to the standard deviation (or the value of this distance per unit of standard deviation).

The z-score is used as follows:

In our example, we employ PERT and have determined that the duration of the project is, say, $\mu = 34.8$ days, with a 50 % probability of completion (a value that

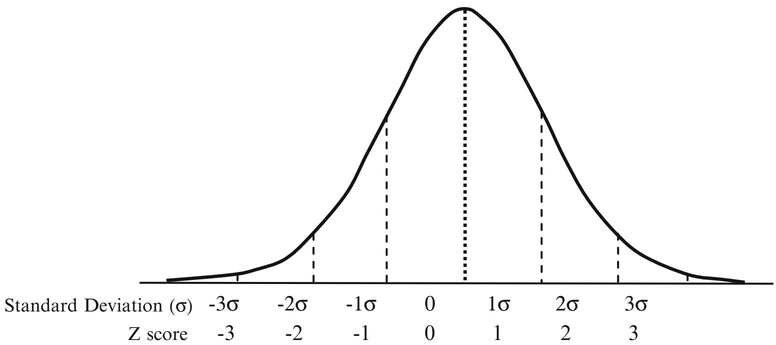


Fig. 9.6 Normal distribution

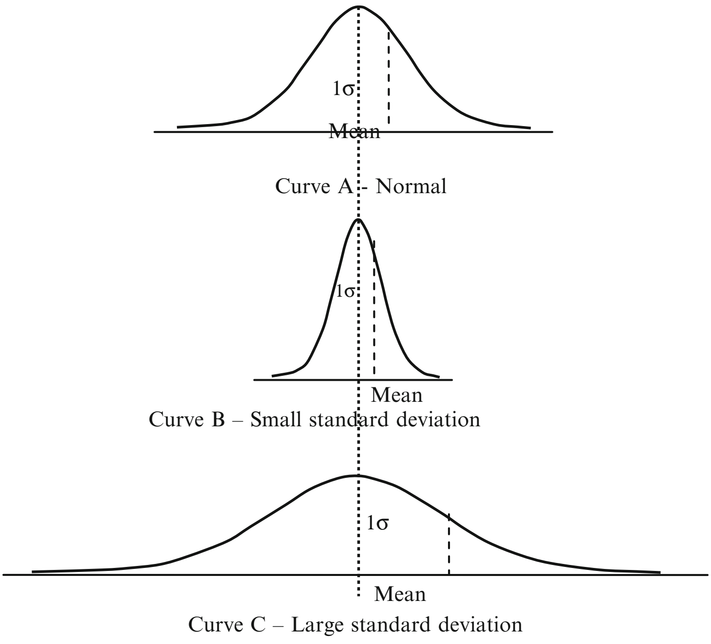


Fig. 9.7 Different kurtosis of the normal distribution curve according to standard deviations

also corresponds to the mean of the normal curve for that project), with a standard deviation of $\sigma = 4.70$. Assume that we only have 40 days to execute this project, and we want to know what the probability of completing it in these 40 days is. We compute the z-score:

$$z = \frac{(x - \mu)}{\sigma} \tag{9.1}$$

with x = the number of days we have in mind, in this case, 40. Then:

$$z = \frac{(40 - 34.8)}{4.70} = 1.106 \cong 1.11.$$

Entering this z value in a normal distribution table (Table 9.1), we will get a value of 0.8665, that is, 86.6 %, meaning that there is about 87 % probability that the project will be completed in 40 days.

Assume now that the standard deviation is greater than 4.70, say, 5.64, which indicates a larger distance or that the z-scores are more spread out with respect to the mean (Fig. 9.7 – Curve C). In this case, the curve, even when keeping its bell shape, will be flattened; consequently, it is assumed that, for a value of 40 days, the probability will be lower.

Let us see

$$Z = \frac{40 - 34.8}{5.64} = 0.92$$

and in this case, the normal distribution table says that the probability of completing the project in 40 days is 0.8212, that is, about 82 %.

If the standard deviation is small, probability values will be more concentrated around the mean, thus the area beneath the curve will be very thin (see Figure 9.7, Curve B), and consequently, the probability of completion in 40 days will be much larger. If the standard deviation is, say, 1.24, z will be 4.19, and the table says that it is practically a certainty that the project will be completed in 40 days because of its high probability.

At the limit, when the standard deviation is 0 – that is, all values coinciding – $z = \infty$ and there will be certainty.

Assume now that, instead of fixing a number of days (that could be the time we have available), we want to determine the number of days necessary for us to have a probability of, say, 95 %.

We again use formula (1) and isolate 'x', that is, our unknown. Then:

$$x = \sigma . z + \mu \tag{9.2}$$

Enter this into the normal distribution table and find that a value of z = 1.65 corresponds for 95 %.

Working with the same values as in the first example, that is, $\mu = 34.8$ and $\sigma = 5.64$

$$x = 5.64 \text{ x } 1.65 + 34.8 = 44.11 \text{ days.}$$

Note how the duration of the project has increased in consonance with a higher probability.

The shape of the distribution curve is defined by the mean and by the standard deviation, and consequently, the area may be very thin or very wide, albeit always

Table 9.1 Normal distribution table

Z	00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996					

with the value of 1, and to characterize its shape, the ‘kurtosis’ term is used. (From the Greek word κυρτός, kyrtos or kurtos, meaning curved, arching (Wikipedia)). This is a measure of how peaked a distribution is.

When the probability distribution shows a ‘lopsided’ look either to the right or to the left, it is called ‘skewed’.

9.3 Continuous and Discrete Risks

For continuous risks, the interval between two values can take any value, as, for instance, percentages, durations, costs, etc., and therefore, continuous distributions can show a large quantity of values with small increments/decrements. Discrete risks are linked to the fact that they can happen or not, and a discrete probability distribution will only have a few values, such as the number of workers labouring in a project, the number of accidents on a highway, the number of cars arriving at a toll station, etc. Thus, discrete distribution takes a discrete number of values. There are several discrete probability distributions, such as Bernoulli, Poisson, Binomial, Geometric and others.

Because of the large distribution family, it could be difficult or cumbersome to select one. However, some researchers report that examination of many Monte Carlo analysis shows that final results do not differ in a large measure. This can be verified in Sect. 5.5.2, where the same problem is tackled with four different probability distributions with similar results.

Table 9.1 depicts the Normal Distribution table that we have been using all along the book.

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N. Munier, *Risk Management for Engineering Projects: Procedures, Methods and Tools*,
DOI 10.1007/978-3-319-05251-9,