RISK MANAGEMENT
IN CONSTRUCTION

José Cardoso Teixeira
Janusz Kulejewski
Michał Krzemiński
Jacek Zawistowski

Guimaraes, Warsaw, 2011

"This project has been funded with support from the European Commission under the Lifelong Learning Programme. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein."
These manuals were developed within the scope of the LdV program, project number: 2009-1-PL1-LEO05-05016 entitled “Common Learning Outcomes for European Managers in Construction” (“Model of certification and mutual recognition of qualifications of construction managers and engineers - development of manuals for post-graduate and supplementary studies”), Stage II. The project was promoted by the Department of Construction Engineering and Management, Faculty of Civil Engineering at the Warsaw University of Technology. Partners of the project were:
- Technische Universität Darmstadt (Germany)
- Universidade do Minho (Portugal)
- Chartered Institute of Building (Great Britain)
- Association of European Building Surveyors and Construction Experts (Belgium)
- Polish British Construction Partnership (Poland)

Within this part of the project the following manuals were developed:
M8: Risk Management (130)
M9: Process Management – Lean Construction (90)
M10: Computer Methods in Construction (80)
M11: PPP Projects in Construction (80)
M12: Value Management in Construction (130)
M13: Construction Projects – Good Practice (80)

The scope of knowledge presented in the manuals is necessary in activities of managers - construction engineers, managing undertakings in conditions of modern market economy. The manuals are approved by the European AEEBC association as a basis for recognizing manager qualifications. Modern knowledge in the field of management in construction, presented in the manuals, is one of prerequisites to obtain EurBE (European Building Expert) cards, a professional certificate documenting the qualification level of a construction manager in EU.

The manuals are designated for managers - construction engineers, students completing postgraduate studies “Management in construction” and students completing construction studies. Postgraduate studies are a recognized program, and graduates receive certificates recognized by 17 national organizations, members of AEEBC.

The manuals were translated by Lingua Nova translation office.
More information:
www.leonardo.il.pw.edu.pl
www.psmb.pl
www.aeebc.org
# TABLE OF CONTENTS:

## CHAPTER 1
**INTRODUCTION**
(J. C. TEIXEIRA)

1.1 RISK CONCEPT ........................................... 6
1.2 BASIC RISKS OF CONSTRUCTION PROJECTS ............... 8
1.3 RISK MANAGEMENT PROCESS OVERVIEW ................. 13
  1.3.1 PREPARATION ........................................ 16
  1.3.2 RISK IDENTIFICATION ................................ 16
  1.3.3 RISK ASSESSMENT .................................... 18
  1.3.4 RISK MITIGATION .................................... 22
  1.3.5 MONITORING & REVIEW ................................ 23
  1.3.6 INTERACTION BETWEEN THE RISK MANAGEMENT STEPS ..... 24

## CHAPTER 2
**CONSTRUCTION PROJECTS AND CONTRACTING**
(J. C. TEIXEIRA)

2.1 CONSTRUCTION PROJECTS .................................. 26
2.2 CONSTRUCTION PROCUREMENT AND CONTRACTING .... 28
  2.2.1 TRADITIONAL PROCUREMENT ...................... 30
  2.2.2 DESIGN & BUILD ..................................... 30
  2.2.3 MANAGEMENT FEE .................................... 34
  2.2.4 COMPARING PROCUREMENT SYSTEMS .............. 37

## CHAPTER 3
**RISKS AT THE TENDER STAGE**
(J. C. TEIXEIRA)

3.1 GENERAL CONCEPTS ..................................... 43
3.2 PRINCIPLES OF RISK MANAGEMENT AT THE TENDER STAGE .................................. 46
  3.2.1 PREPARING TENDER DOCUMENTS .................... 48
  3.2.2 PRE-QUALIFICATION OF BIDDERS ................. 49
  3.2.3 ANNOUNCING/ INVITING AND OPENING TENDERS .... 50
  3.2.4 TENDER EVALUATION AND CONTRACT AWARD .... 51
CHAPTER 4
RISK MANAGEMENT AT THE CONSTRUCTION STAGE.................54
(J. KULEJEWSKI, M. KRZEMIŃSKI, J. ZAWISTOWSKI)

4.1 RISK MANAGEMENT PROCESSES ........................................54
4.2 RISK MANAGEMENT PLANNING ........................................56
  4.2.1 PROCESS ESSENTIALS............................................56
  4.2.2 TOOLS AND TECHNIQUES.......................................57
  4.2.3 PROJECT RISK MANAGEMENT PLAN.............................57
4.3 RISK IDENTIFICATION ..................................................59
  4.3.1 PROCESS ESSENTIALS............................................59
  4.3.2 TOOLS AND TECHNIQUES.......................................61
  4.3.3 PROJECT RISK REGISTER .........................................67
  4.3.4 AN EXAMPLE OF CONSTRUCTION PROJECT RISK IDENTIFICATION .............................................68
4.4 QUALITATIVE RISK ANALYSIS AND ASSESSMENT...............74
  4.4.1 PROCESS ESSENTIALS............................................74
  4.4.2 TOOLS AND TECHNIQUES.......................................74
  4.4.3 AN EXAMPLE OF QUALITATIVE ANALYSIS AND ASSESSMENT OF A CONSTRUCTION PROJECT RISK .............................................74
4.5 QUANTITATIVE RISK ANALYSIS AND ASSESSMENT ............79
  4.5.1 PROCESS ESSENTIALS............................................81
  4.5.2 TOOLS AND TECHNIQUES.......................................99
  4.5.3 AN EXAMPLE OF PROJECT QUANTITATIVE RISK ANALYSIS AND ASSESSMENT .............................................99
4.6 RISK RESPONSE PLANNING ...........................................105
  4.6.1 PROCESS ESSENTIALS............................................105
  4.6.2 TOOLS AND TECHNIQUES.......................................108
  4.6.3 EXAMPLES OF THE PROJECT SCHEDULE BUFFERING .............................................114
4.7 RISK MONITORING AND CONTROL ...................................128
  4.7.1 PROCESS ESSENTIALS............................................128
  4.7.2 TOOLS AND TECHNIQUES.......................................130
  4.7.3 AN EXAMPLE OF APPLICATION OF THE EARNED VALUE METHOD .............................................132

CHAPTER 5
PROJECT CLOSURE AND GUARANTEE PERIOD RISKS ..............137
(J. C. TEIXEIRA)

5.1 COMMISSIONING ....................................................137
5.2 CONSTRUCTION DEFECTS ............................................138
5.3 DEFECTS LIABILITY PERIOD .................................................. 141
5.4 FINANCIAL RISKS .............................................................. 142
5.5 LITIGATION RISKS .............................................................. 143

BIBLIOGRAPHY ........................................................................... 145
CHAPTER 1

INTRODUCTION
(J. C. TEIXEIRA)

1.1 RISK CONCEPT

The development of building activities is carried out in several phases, all related to uncertainty, hazard and risk. These three concepts are different and should first be set up.

A hazard may be understood as a situation that sets some level of threat to life, health, property, environment, personal integrity, and so on. From the health and safety point of view, a hazard may be understood as a condition holding the potential of causing physical impairment or health consequences in people (or any other type of life). In a project environment, hazard is anything that may affect the success of project activities and the project as a whole. Similarly, companies, ventures, physical assets, the environment and society as a whole face hazards. Most hazards are potential or latent but when they become active or effective, they often generate emergency situations. A hazardous situation that has turned into effectiveness causes an incident, an accident or a disaster.

The term uncertainty cannot be considered identical to the risk. The two terms are distinct and have different meanings. The uncertainty refers to the occurrence of an event about which little is known, while a risk is the outcome of an event which is predicted on the basis of statistical probability. Uncertainty exists when there is more than one possible outcome and risk exists when a decision is expressed in terms of a range of possible outcomes.

The first step for risk assessment is to identify hazards because after this has been done, it is possible to make the adequate treatment of risks, thereby preventing them. However, an exact definition of risk is exclusive and its meas-
urement is still controversial - it is surprising how this question does not gather consensus given the ubiquity of risk in almost every human activity.

In literature, the word “risk” is used with many different meanings. The European Commission states that a risk is defined as any factor, event or influence that threatens the successful completion of a project in terms of time, cost and quality. However, there are many other definitions of risk presented in literature such as (Padiyar, Shankar, & Varma):

- “A situation where there exists no knowledge of its outcome”
- “The variation in possible outcomes that exist in nature in a given situation”
- “High probability of failure”
- “Lack of predictability about structure, outcome, or consequences in decision or planning situations”
- “The chance of something happening that will have an impact on objectives”

Looking at the various definitions of risk and their relationship with the previous concepts, it can be said that, although the risk concept has been defined in many ways, it is characterized by two main factors: the likelihood of a particular hazard actually taking place and the impact or consequences of that. Actually, many risk standards state that it is important to understand these two component elements for fully defining a risk. While some definitions of risk focus only on the probability of occurrence of an event that may possibly affect the achievement of a given process, more comprehensive definitions consider both the probability of the occurrence and its consequences.

![Risk definitions](Fig.1.1: Basic definitions from ISO /FDIS 31000:2009(ISO/IEC Guide 73))
According to the Project Management Institute, PMBOK – Fourth Edition (2008), a risk may have one or more causes and, if it occurs, it may have one or more impacts which in turn may have positive and negative effects on the project objective. A cause may be a requirement, assumption, constraint, or condition that creates the possibility of negative or positive outcomes. However, some definitions tend to focus only on the downside scenarios.

![Risk dimensions diagram]

**Fig. 1.2: Risk dimensions**

### 1.2 BASIC RISKS OF CONSTRUCTION PROJECTS

The construction industry is an economic activity with high rate of work accidents and has gained a very poor reputation in coping with adverse effects, with many projects failing to meet deadlines, cost and quality targets (Medeiros & Rodrigues). The risk of time and cost overruns can compromise, in extreme cases, the economic viability of the project, turning a potentially profitable investment into an expensive and untenable project. Compared to many other activities, construction is subject to more risks due to the unique features of the construction activities, such as long duration, complicated processes, unpredictable environment, financial intensity and dynamic organisation structures.
Pinsent Masons\(^1\) states that construction is undeniably a risky business and that risks are unavoidable in any project. For them, risks like tax risks, interface risks and local site risks are the most common and inevitable risks in construction projects. Other risks that may be less likely to occur are force majeure events or changes in law; but should these risks occur, they will have significant impact on the project. Ratz points out that delays, claims for increased costs, injuries to workers and so on are the most common risks in construction projects. The accumulation of all these risks or the combination of them can be termed “project risks”.

Construction project risks are interrelated and interdependent. The customary origins for project risks are the following (U.S. Department of Transportation, 2006):

- Performance, scope, quality, or technology issues;
- Environment, safety, and health concerns;
- Scope, cost, and schedule uncertainty;
- Political concerns

Risks in construction projects may be classified in a number of ways according to their source. Naturally, risk will be peculiar to each particular project and each project participant, meaning that each project will have its own unique set of risks. Notwithstanding, it is commonly accepted that all construction projects share common risks. Risks can be classified as following (Guerra & Teixeira):

- **CONSTRUCTION**
  - Changes in the work
  - Subsurface geological and geotechnical conditions
  - Site access
  - Level of detail design delivered by the owner
  - Late drawings and instructions
  - Availability of resources
  - Accidents (such as collision, fire and so on)
  - Damage to persons or property
  - Defective design
  - Cost of tests and samples
  - Actual quantities of work
  - Equipment commissioning

\(^1\)Pinsent Masons is an international law firm recognised as the leading provider of legal services to the construction and engineering, energy and infrastructure industries worldwide.
• **FINANCIAL AND ECONOMIC**
  o Inflation
  o Funding

• **PERFORMANCE**
  o Productivity of labour
  o Productivity of equipment
  o Suitability of materials
  o Defective work
  o Conduct hindering performance of the work
  o Labour disputes

• **SECURITY**
  o Vandalism
  o Terrorism
  o Corruption
  o Assaults
  o Negligence
  o Intrusion

• **CONTRACTUAL AND LEGAL**
  o Delayed dispute resolution
  o Delayed payment on contracts and extras
  o Change order negotiation
  o Insolvency of contractor or a subcontractor

• **PHYSICAL**
  o Subsurface geology geotechnical conditions
  o Conditions
  o Subsurface conditions and ground water
  o Topography
  o Natural catastrophes

• **POLITICAL AND SOCIETAL**
  o Soil availability for construction
  o Environmental pressures
  o Regulations (safety or labour laws)
  o Public disorder
  o Strike
The US Department of Transportation (2006) adopts the following risk organisation structure:

A. TECHNICAL RISKS
- Design process
  - Owner involvement in design
  - Inadequate and incomplete design
  - Change in seismic criteria
  - Errors or incompletion of structural/ geotechnical/ foundation
  - Wrong selection of materials
  - Take off data (traffic demand, water consumption demand, etc.)
  - Need for design exceptions
- Construction risks
  - Inaccurate contract time estimates
  - Construction procedures
  - Construction occupational safety
  - Work permissions
  - Utilities
  - Late surveys, incomplete or wrong
  - Delayed deliveries and disruptions
  - Worker and site safety
  - Innovative projects
  - Unsuitable equipment and materials
  - Environmental risks (such as projects close to a wild river, floodplain, coastal zone, high sensitivity for palaeontology area, and so on)
- Environmental factors
  - Environmental analysis incomplete or wrong
  - Offsite and onsite wetlands
  - Hazardous waste preliminary site investigation wrong
  - Lack of specialised staff (biology, anthropology archaeology, etc)
- Inaccurate assumptions on technical issues in the planning stage
- Fact sheet requirements (exception to standards)

B. EXTERNAL RISKS
- Contractual relations
  - Landowners unwilling to sell
Priorities change on existing program
- Funding changes for fiscal year
- Stakeholders request late changes
- New stakeholders
- Additional needs requested by stakeholders
- New information required for permits
- Inconsistent costs, time, scope, and quality objectives
- Permits and licences

• Force majeure factors
  - Political factors change (political interference)
  - Political climate
  - Economic instability
  - Market conditions
  - Exchange rate fluctuation
  - Public safety regulation

• Social factors
  - Local communities pose objections

• Environmental factors
  - Environmental regulations change (for example in water quality)
  - Water quality issues
  - New information required for permits
  - Environmental impact statement required
  - Historic site, endangered species, or wetlands present
  - Pressure to compress the environmental schedule

C. ORGANISATIONAL RISKS

• Inexperienced staff assigned
• Losing critical staff at crucial point of the project
• Insufficient time to plan
• Unanticipated project manager workload
• Not enough time to plan
• Priorities change on existing program
• Inconsistent cost, time, scope, and quality objectives Project Management Risks
• Project purpose definition, needs, objectives, costs, deliverables are poorly defined or understood
• No control over staff priorities
• Too many projects
• Consultant or contractor delays
| • Estimating and/or scheduling errors  
| • Communication breakdown with project team  
| • Lack of coordination/communication  
| • Inexperienced workforce/inadequate staff/resource availability |

The size of some projects, which reflect in long contracting periods involving a large number of workers, and the ambitious time schedules for design and construction, are just two examples of factors that incorporate considerable uncertainty in construction projects. Uncertainty however, needs to be considered, reducing and controlling identified risks (Guerra & Teixeira). Therefore, it is important to capture all potential risks in the project and undertake all necessary actions or make provisions for eliminating or preventing them from occurring. Alternatively, the solution for best dealing with risks may be reducing their effects and allocating them to the party best prepared for managing them. In order to achieve these aims, the literature suggests that a systematic approach should be followed in the scope of a risk management process.

### 1.3 RISK MANAGEMENT PROCESS OVERVIEW

Completely eliminating project risks is a complicated task and it actually proves impossible in most cases; therefore, risks must be managed. Risk management is a process whereby tools and techniques are applied to monitor and track the events with potential impacts on the outcomes of a project. Risk management is a central part of the strategic management of any modern organisation focusing on the identification and treatment of risks. According to the ISO 31000:2009 (ISO/IEC guide 73):

- Risk management is defined as a set of coordinated activities to direct and control an organisation with regard to risk;
- Risk management process is defined as a systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risks.

Essentially, risk management is a process which accompanies the project from the early beginning through its planning, execution till closure. Many of these
processes are updated throughout the project lifecycle and new risks can be identified at any time. Risk management adds value to the organisation and its stakeholders through supporting the organisation’s objectives. Principal aims and benefits are as follows (ISO/FDIS 31010:2009):

- Understand risks, increase the probability of success and reduce both the probability of failure and the uncertainty of achieving the overall objectives of the organisation;
- Provide information for decision makers about the policies and procedures that help to best understand risk and its potential impact upon objectives, in order to assist in the selection of the most appropriate risk treatment procedures;
- Identify the most relevant contributors to project risks;
- Assist by establishing priorities;
- Allow clarification, understanding and consideration of all issues related to the project success from the start;
- Continuously monitor the definition and structure of the project; and,
- Build up historical data to assist future risk management procedures.

The key outcomes of risk management are twofold: the organisation has a current, correct and comprehensive understanding of its risks; and the organisation risks are within its risk criteria.

An effective risk management approach can help understand not only what kinds of risks are faced, but also how to manage these risks in different project phases. Risk management models have been developed by various sources in order to attempt answering questions such as: What can happen and why? What are the consequences? What is the probability of their occurrence? Are there ways to mitigate or reduce risk?

A variety of risk assessment models with different numbers of stages can be found in the literature. Table 1.1 presents some risk management models issued by a set of respected international organisations and summarises the main steps for putting them into practice.
Table 1.1: Stages of risk management process

<table>
<thead>
<tr>
<th>Organisation/Standard</th>
<th>Risk Management Process Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC/FDIS 31010</td>
<td>1. Establishing the context</td>
</tr>
<tr>
<td></td>
<td>2. Risk Assessment</td>
</tr>
<tr>
<td></td>
<td>2.1 Risk identification</td>
</tr>
<tr>
<td></td>
<td>2.2 Risk identification</td>
</tr>
<tr>
<td></td>
<td>2.3 Risk evaluation</td>
</tr>
<tr>
<td></td>
<td>3. Risk treatment</td>
</tr>
<tr>
<td></td>
<td>4. Monitoring and review</td>
</tr>
<tr>
<td>UNCTAD(^2)</td>
<td>1. Establish the context</td>
</tr>
<tr>
<td></td>
<td>2. Identify the risks</td>
</tr>
<tr>
<td></td>
<td>3. Analyse the risks</td>
</tr>
<tr>
<td></td>
<td>4. Evaluate the risks</td>
</tr>
<tr>
<td></td>
<td>5. Treat the risks</td>
</tr>
<tr>
<td></td>
<td>6. Monitoring and review</td>
</tr>
<tr>
<td></td>
<td>7. Communication and consultation</td>
</tr>
<tr>
<td>OSI(^3)</td>
<td>1. Identify</td>
</tr>
<tr>
<td></td>
<td>2. Analysis</td>
</tr>
<tr>
<td></td>
<td>3. Plan</td>
</tr>
<tr>
<td></td>
<td>4. Track and control</td>
</tr>
<tr>
<td></td>
<td>5. Communicate</td>
</tr>
<tr>
<td>PMBOK(^\circ) - Fourth Edition</td>
<td>1. Plan risk management</td>
</tr>
<tr>
<td></td>
<td>2. Identify risks</td>
</tr>
<tr>
<td></td>
<td>3. Perform qualitative risk analysis</td>
</tr>
<tr>
<td></td>
<td>4. Perform quantitative risk analysis</td>
</tr>
<tr>
<td></td>
<td>5. Plan risk response</td>
</tr>
<tr>
<td></td>
<td>6. Monitor and control</td>
</tr>
</tbody>
</table>

It is interesting to note that, despite the variety of models, preparation, risk identification, assessment, mitigation and monitoring & review form the core of the project risk management process. Moreover, all models go essentially through the same steps; only the level of detail comprised therein may vary. Accordingly, the following paragraphs aim at explaining the tasks comprised within each step of the project risk management process and interactions between them.

\(^2\)UNCTAD – United Nations Conference on Trade and Development

\(^3\)OSI – Office of System Integration
1.3.1 PREPARATION

The first thing to do, before attempting to manage risks, is to establish the context of the study understanding the objectives of the project and how it fits the business overall, its scope and other characteristics (Dallas, 2006). According to the IEC/FDIS 31010, this step aims to establish and agree on the risk assessment objectives, risk criteria, and risk assessment programme. There should be particular emphasis on understanding the environment in which the organisation operates (some of the greatest risks may arise from outside such as cultural, political, legal, financial economic and so on), as well as the understanding of the structure and capabilities of the organisation (policies, processes, internal stakeholders, strategies and so on).

“During this stage, it should be established who needs to be consulted for the identification of risk and the most appropriate means of communication” (Dallas, 2006)

1.3.2 RISK IDENTIFICATION

Risk identification aims to find, recognise and record risks that might affect the achievement of the project objectives (Akintoye, Beck and Hardcastle, 2003). This is the key feature of a suitable risk management approach and involves a process where concerns about the project success are transformed into identified risks. It should be noted that risk management does not only deal with negative concerns but with opportunities, i.e. positive outcomes, as well.

The risk identification process begins with the compilation of the project risks by the project team. These risks are the result of issues and concerns (inputs) such as:

1) Project documents like work reports, assumptions and so on;
2) General checklists created for recurring risks;
3) Cost estimate i.e. likely cost of completion for activities scheduled;
4) Examination of the project description i.e. the features of the product or service requested by the client (generally in the early phases product details are scarce but increase as the project develops);
5) Design and construction schedule (risks related to time allowances for project activities, slacks, and so on);
6) Stakeholder records, background of organisations involved in the project, external factors (e.g. environmental factors), risk management approach, and so on.
Risk identification should address both internal and external risks. Internal risks are those that the project team can control or influence, such as staff assignments and cost estimates; external risks are those that cannot be controlled or influenced by the project team, like market shifts or government action.

A number of tools and techniques are available to support the risk identification process. Risk identification methods may include:

1) Examining artefacts and documentation (such as safety reviews, plans, assumptions, previous project files, contracts and so on). The revision of previous projects conducted by organisations involved allows for the identification of planning and execution pitfalls and helps find corrective and preventive actions for the project under consideration.

2) Monitoring project activities (through brainstorming sessions with focus groups and site visits). Brainstorming sessions in all project phases allows identifying and preventing the most enigmatic risks; site visits help find specific risks (like site accessibility, ground hazards, etc).

3) Interviewing/polling and participation in discussions and meetings (with various stakeholders) may help identify risks not detected during the normal planning activities. Personal and corporate experience and expert consultation may help spot the less perceptible risks, benefiting from the accumulated experience of those persons in similar previous projects (systematic errors, for example).

4) Analyse checklists (classified according to their impacts, origins or consequences) ensures that the all risks are checked. This is a technique that allows for setting up a list of typical risks that deserve consideration.

5) Diagramming techniques (such as cause and effect diagrams, flow charts, organisational charts and so on) helps the project team better understand the causes and effects of risks.

The risk identification step will vary, depending on the nature of the project and the risk management skills of the team members. It is important to emphasise that the persons and the risk culture of the organisation are the key to risk identification. The tools and techniques should only support these persons in the risk assessment process and never inhibit or replace the engineering judgment. Essentially this process identifies the risks which can affect the project and records their characteristics. Accordingly, the outcomes of the risk identification phase is a list of risks classified by the source, the potential risk events that may affect the project and the risk symptoms (indirect manifestations of risk events like cost overruns, time delays and so on).
1.3.3 RISK ASSESSMENT

Risk assessment or risk analysis or risk evaluation is the process of quantifying the risk events documented in the preceding stage. It is supported by persons familiar with the risk management approach and involves the classification and prioritisation of risks. Risk assessment mainly involves the quantification of the two following factors before deciding on whether further treatment is required for each specific risk detected:
   a) the likelihood of occurrence;
   b) the impact on the project if it actually materialises.

Risk assessment provides an understanding of risks, their causes, consequences and probability of appearing. Additionally, risk assessment is a tool for supporting decisions on whether a specific risk needs treatment (and on what is the best way to do it), and on new opportunities that may come up as the project proceeds (PMBOK Guide). Risk assessment is thus primarily concerned with determining which risks require response (either cancelling underlying hazards, if possible, or mitigating their consequences) in order to minimise their (direct or indirect) impact in the project outcomes (for example, cost or schedule overruns).

Estimation of risk costs is therefore an important step in risk assessment because risks are likely to have a direct impact on the project (delays, for example, have effect on costs). However, cost estimation of complex risks may not be an easy task because it is difficult to predict risk effects and measure their consequences (Dallas, 2006).

When the risk assessment process is completed, it becomes necessary to compare the risk estimated against risk criteria established by the organisations involved in the project (this may include costs and benefits, legal requirements, socio-economic and environmental factors, stakeholder concerns, etc).

The most widely used techniques for risk assessment can be qualitative or quantitative, as discussed below.

1) Qualitative risk analysis

Qualitative assessment is used to compile a list of principal sources of risks and to describe their most probable consequences. It is used when uncertainty is prevalent (Akintoye et al., 2003). It is a process for prioritising risks by assessing and combining the probability of occurrence and impact of each risk (PMBOK Guide, 2008). The assessment is essentially subjective (for example,
assigning “low, medium, high” or colour code to the risk factors under analysis) therefore requiring the perspective of an expert to perform it (AbouRizk, 2003, Creedy, 2006). Inputs for this process are diverse, namely, the organisational process assets, the project scope statement, the risk management plan and the risk records. The outputs of qualitative risk analysis should comprise the following information (OSI):

- **Risk classification** – risks identified should be classified into risk groups (categories); this enables the creation of risk checklists, risk registers, and databases for future projects.
- **Risk impact** – considers the consequences for the project if the risk materializes (table 1.2).
- **Risk probability** – involves considering the likelihood of the risk occurrence (table 1.2).
- **Risk timeframe** – the period of time within which the risk is expected to occur (for example, risks can be short-term, medium-term or long-term).
- **Risk exposure** – is derived from the risk attributes of impact and probability, and is used in conjunction with a timeframe for prioritising risk mitigation candidates.
- **Risk severity** – a measure of risk importance based on the risk potential impact, the probability of occurrence (likelihood) and the timeframe. In short, multiplying the likelihood and the impact gives the risk severity rating.
- **Mitigations / Contingencies** – developed actions to mitigate the risk.

On the chart of Fig. 1.3, the x-axis represents the level of consequence of risks on schedule and/or cost and the y-axis represents the likelihood of occurrence.
2) Quantitative risk analysis
Quantitative risk analysis is used for numerically measuring the effects of identified risks in the overall objectives of project. However, quantitative assessment of construction risks is hard to perform because methods used for this rely on construction data that is often difficult to obtain because each project is unique (Creedy, 2006). It starts out from the same inputs mentioned above and utilises a set of deterministic, probabilistic and modelling techniques for getting results. In other words, the aim of quantitative techniques is to represent the probability and impact of risk in terms of money and time. This cannot always be fully achieved, because risk problems may not allow for it. Akintoye et al. (2003) state that quantitative assessment may only be used when the impact of risks can be established fairly accurately and when information is available.
<table>
<thead>
<tr>
<th>QUALIFICATION</th>
<th>DESCRIPTION</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Almost certain</td>
<td>Probability of occurrence over 80%. It is almost certain or very likely that the risk will occur. It is estimated to occur at least once in the project lifecycle. It happens several times in similar works.</td>
</tr>
<tr>
<td>4</td>
<td>High likely</td>
<td>Probability of occurrence between 50% and 80%. Likely to occur once in the project lifecycle. Likely to occur in similar works.</td>
</tr>
<tr>
<td>3</td>
<td>Likely</td>
<td>Probability of occurrence between 10% and 50%. May occur once in the project lifecycle.</td>
</tr>
<tr>
<td>2</td>
<td>Not likely</td>
<td>Probability of occurrence between 1% and 10%. Seldom occurs in the project lifecycle.</td>
</tr>
<tr>
<td>1</td>
<td>Low probability</td>
<td>Probability of occurrence below 1%. Unlikely to occur in the project lifecycle.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUALIFICATION</th>
<th>DESCRIPTION</th>
<th>COST</th>
<th>SCHEDULE</th>
<th>REPUTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>High</td>
<td>Project budget increase over 30%</td>
<td>Key project milestone delayed</td>
<td>Adverse national/international media coverage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of Money</td>
<td></td>
<td>Government intrusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Great concern to the public</td>
</tr>
<tr>
<td>4</td>
<td>Significant</td>
<td>Project budget increase between 20-30%</td>
<td>Several months delay</td>
<td>Adverse national media coverage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of production</td>
<td></td>
<td>Government intervention</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Statement of Administration</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Increases between 10-20% of the project budget</td>
<td>3 to 7 month delay</td>
<td>Adverse regional media cover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of production</td>
<td></td>
<td>Statement of the Board</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Increases between 5-10% of the project</td>
<td>Few months delay</td>
<td>Adverse local media cover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of production</td>
<td></td>
<td>Report to the Directorate</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>Insignificant increase</td>
<td>Marginal delay</td>
<td>Not drawing media attention</td>
</tr>
</tbody>
</table>

Table 1.2: Probability and consequence of risks (Guerra & Teixeira)
1.3.4 RISK MITIGATION

Risk mitigation (risk plan or risk treatment) is also called risk response development or response planning (PMBOK Guide). It involves searching options for increasing opportunities and giving response to threats, and translating mitigation into action plans. In most cases, it is unlikely that a given risk will be entirely eliminated through this process, but the risk exposure can be reduced to a more acceptable level. Low and very low risk levels can normally be accepted, although subject to on-going monitoring, while other risks must be included in the management plan.

Organisations like building companies should endeavour to mitigate the risk of their own projects especially those with more relevance, in order to avoid the consequences of hazards. Even if consequences are not dramatic (for example, serious incidents) companies normally strive for limiting risks of their activities, because if these risks are to materialize they may result in a bad publicity jeopardizing credibility and consequently the loss of future projects.

Mitigation strategy should be supported by mitigation plans (“to-do lists”) devised early in the project life, thereby ensuring that the project may carry on smoothly. The most current strategies used to mitigate risks are as follows (Akintoye et al., 2003):

1) Risk elimination – through means such as a partial or complete redesign, different project strategy or method (change the project to avoid the risk); a risk may be completely eliminated but this may imply the adoption of rather drastic actions that may be very costly.
2) Risk reduction – reduce uncertainty by obtaining more information; this generally leads to re-evaluation of the likelihood or impact.
3) Risk transfer – transfer the risk element by contracting out affected work so that risks are allocated optimally, i.e. to the party that can manage them conveniently and inexpensively; this is not risk elimination, simply shifting responsibility.
4) Risk retention – risk keeping or risk sharing means the retention of risks (at least, partially) that have not been eliminated or transferred.
5) Insurance – risk can be minimised through contracting insurances. This is only one of the mechanisms available to manage and transfer project risks (for many project participants, the concept of risk management is roughly equivalent to insurance but this is not right because only some project risks are insurable).
The most effective mechanisms to reduce/avoid risks are always the utilisation of proper pre-construction planning, proven construction means and methods, use of experienced personnel and application of stringent safety programmes.

Each risk category has its own mitigation strategy and follows a specific mitigation approach. Activities undertaken for risk mitigation should be documented in the risk register, and reviewed on a regular basis. The main outcomes of the mitigation step of the risk management process are the actions that should be taken for reducing the probability and/or the impact of each risk identified and the creation of a contingency plan to deal with residual risks. However, if an intolerable risk remains after trying all possible means to mitigate it, project abortion would possibly be the best option.

1.3.5 MONITORING & REVIEW

Monitoring and reviewing risks is the process of implementing risk mitigation strategies (risk response plans) tracking and reviewing risks previously identified, monitoring residual risks, and identifying possible new risks. Additionally, this step must allow for recognising the events that are likely to trigger the occurrence of hazards previously identified and for following the same previous steps for emerging risks (either because they were not detected before or because they are new). Moreover, because risks are susceptible to change as the project progresses, claims are almost inevitable. Therefore it is essential to ensure that risks will be regularly monitored and reviewed (Leidel & Alfen, 2009).

The above actions should continue throughout the project lifecycle for ensuring adequate risk treatment. Risk managers must monitor activities and processes to determine the accuracy of planning assumptions and the effectiveness of the measures taken to treat risks. Methods can include:

- Auditing policy and standard compliance to identify improvement opportunities
- Auditing risk
- Reassessment of risks
- Progress meetings

The monitoring process should assure that there are appropriate controls in place and that the procedures are understood and followed. Results from this step are an updated risk management plan with new risks identified, measured and treated.
1.3.6 INTERACTION BETWEEN THE RISK MANAGEMENT STEPS

All steps in the risk management process interact with each other. Therefore, risk management should be approached as an iterative process and not in discrete phases of identification, evaluation, mitigation and control (Akintoye et al. 2003). Each process may involve effort from one or more individuals or a group of individuals based on the project needs and generally occurs at least once in every project phase. The risk management process iteration continues until a satisfactory position is reached.

Successful risk management is dependent on effective communication and consultation with stakeholders thereby ensuring that the project interests are understood and considered. Some outputs from the process are possible. Among the most common are the following:

- Sensitivity analysis for individual risks
- The likelihood of potential impact of each risk identified
- Risk prevention measures
- Risk allocation decisions (to whom the risk is allocated or shared)
- Which risks can be insured against
- The likely cost if risks occur
- Risk management mitigations plans and strategies
- The relevant clause references in the contract

Most of this information may be placed in a risk matrix. In complex projects this document is important to the project team because it helps to get a broad picture of risks, thereby facilitating the communication to senior management on critical risks (Table 1.3).
Table 1.3.: Risk management process flow diagram (short example)

<table>
<thead>
<tr>
<th>Flow diagram</th>
<th>COMMUNICATE AND REFER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Identification</td>
<td>Risk Assessment (*)</td>
</tr>
</tbody>
</table>

**Inputs**

1. Risk management plan
2. Project description
3. Cost estimate
4. Design and construction schedule
5. Project documents
6. Stakeholder register
7. Previous checklists

**Tools and techniques**

1. Examining documentation
2. Monitoring project activities
3. Interviewing and consulting experts
4. Analysing checklists
5. Diagramming techniques

**Outputs**

1. List of risks (classified by source and category)
2. Risk events
3. Inputs to other processes

1. All information resulting from risk identification step
2. Potential risk events
3. Documented risks and your source

1. All information resulting from previous steps
2. Threats that require attention
3. List of opportunities
4. Risk data

1. Risk elimination
2. Risk reduction
3. Risk transfer
4. Risk retention
5. Insurances

1. Audits of policy and standard compliance
2. Audit risk
3. Reassessment of risks
4. Progress meetings

1. Mitigation
2. Risk ownership
3. Measurement
4. Action plans
5. Secondary risks
6. Inputs to other processes

1. Mitigation progress status
2. New risks identified
3. Risk management plan (actualized)

(*) if the risk is acceptable then it must be monitored and reviewed (there is not a risk mitigation step), otherwise it must be treated before being monitored and controlled.
CHAPTER 2

CONSTRUCTION PROJECTS AND CONTRACTING
(J. C. TEIXEIRA)

2.1 CONSTRUCTION PROJECTS

“Construction” is defined as a process consisting of erecting or assembling a building or infrastructure facilities while a “Construction Project” is the process of achieving it through a set of inter-related activities (such as site preparation, foundations, mechanical installations, and so on) employing resources (labour, materials, equipment and tools and so on). The aims of construction projects are to allow built facilities to be used and to provide services. Construction can be characterised as a specific feature concerning production, such as temporality, bounded location and one-off products.

According to the type of facilities aimed at by construction projects, various types of construction projects may be identified with each type requiring a specific project team to plan, design, build, operate and maintain it. A broad division mostly used for statistical purposes classifies construction projects under the headings of “building” and “civil engineering” projects. A further division often found in the same type of sources is “refurbishment projects” (normally associated with buildings). Further detailing the most popular types of construction projects, the following division may be used:

1) **Building construction:** This is perhaps the most popular type of construction project. It is the process of erecting a facility for human use on a real property. Buildings are extremely diverse in function, size and complexity; building projects extend from small renovations to com-
plete large buildings for a variety of uses and including numerous installations and equipment.

1.1) **Residential construction** is a type of building construction encompassing houses, townhouses, apartments, single-family houses, multi-family dwellings and so on. The design is done by architects and engineers and the construction is executed by builders and special purpose subcontractors. A great number of building companies of various sizes are attracted to residential projects because construction processes used for current residential projects are quite methodical and relatively standard. The residential construction market is conditioned by demand and is highly competitive, with potentially high risks as well as high rewards.

1.2) **Institutional and commercial construction** covers a great variety of projects such as hospitals, schools and universities, sports facilities, shopping centres, skyscrapers for offices, hotels and so on. For these kinds of projects, specialised architects and engineers are required for design and construction. This market has few competitors when compared to residential construction projects because of high specialisation required and large project value.

2) **Industrial Construction:** These projects are generally owned by large for-profit industrial corporations such as manufacturing, power generation, medicine, and petroleum companies. Very large scale projects with a high degree of technological complexity may be included under this heading, such as nuclear power plants, steel mills and so on. These kinds of projects can be heavily influenced by environmental protection institutions or by other sector agencies. Because of their size, these projects require highly specialised expertise both at the planning stage and at the stages of construction and maintenance.

3) **Highway construction:** Involves the construction, alteration and repair of roads, highways, streets, parking areas etc.

4) **Heavy construction:** Examples of this type of projects would be water and sewer line projects, dams, sewage treatment plants and facilities, flood control projects etc.

It is worth mentioning that construction has a sustainable focus and therefore all possible choices must be appreciated and evaluated before deciding for the best possible solution for a specific client’s problem. Actually, both in sustainable terms and in economic terms, erecting a new facility instead of adapting or refurbishing an existing one can possibly be revealed as the worst solution for the
client. Moreover, leasing or renting an existing facility may be a better solution for the client than erecting a new one. Irrespective of the client’s choice, construction is a complex endeavour nowadays (for example, a refurbishment project may be far more complex than building a new facility). Most clients (particularly those with less experience in this field) need support for adequately conducting a construction project because they face natural difficulties in defining the project brief, understanding the schedule, anticipating contract problems and so on. Unless for very small or simple projects, clients therefore need an advisor belonging to their internal team for overcoming natural problems arising from the project development as well as for providing professional support for other aspects exogenous to the project (tax and legal aspects, market research, for example). The project advisor should fully understand the client’s objectives and requirements and relate to the project structure external to the client’s internal team (e.g. the project manager and the design team leader) but have no other participation in the project execution, in order to avoid conflicts of interests (The Chartered Institute of Building, 2002).

2.2 CONSTRUCTION PROCUREMENT AND CONTRACTING

Construction procurement and contracting is a key issue in the construction process. Several methods currently exist for procurement and contracting professional services and construction work. Methods may be quite different between each other but generally they can be classified under the following three main types:

- Traditional Procurement or Design-Bid-Build;
- Design & Build;
- Management Fee.

All methods involve that the client appoints, either directly or indirectly, designers and other professional service providers as well as constructors, material suppliers, and a myriad of construction service providers in some point of the construction process. It is essential for the client to weigh up the strengths and
weaknesses of each method before deciding on the most suitable in view of its interests. The choice will be largely determined after assessing, namely:

- Level of involvement required for each project participant (e.g., what roles will the client, designer, and contractor play during the construction process?);
- Project complexity;
- Time available for design and construction;
- Budgetary constraints;
- Level of expertise of the client’s in-house staff;
- Method of project finance;
- How much risk the client is willing to take in the process.

In view of the above, risk evaluation is an important component of the client’s reasoning because different procurement and contracting approaches will correspond to distinct modes of risk sharing between the client and other project participants. Many construction clients are not regular purchasers of construction work therefore they will tend to select a solution that satisfies their interests and needs, at affordable costs. Accordingly, typical construction clients tend to be conservative and this is one of the reasons for the success of the traditional method.

Irrespective of that, some methods may be unsuitable for certain types of projects and certain types of clients; selecting the right one is often vital to the project success. Having a clear understanding of the project objectives as well as defining the roles of the various project stakeholders (allocation of risks and obligations) are the issues that should be properly managed if the project is to meet its objectives (e.g., time, cost and quality) and to avoid claims, disputes, additional costs, delays in completion and so on (AbouRizk, 2003).

A project that does not meet the client’s needs (quality, functionality and performance), or overruns the time or the cost limits imposed by the client, may affect the client’s business. The procurement approach adopted by the client may have a clear contribution towards achieving the project goals. However, following a procurement approach that focuses on only one of the above risk factors (for example, costs) may have negative effects on the others and cause serious inconveniences to the client. Therefore, the procurement and contracting approach should adequately balance risks against project goals and this ought to be decided at an early stage of project development. In other words, the procurement and contracting process provides the vehicle for each party to negotiate, define and limit each other’s rights (and risks) in accordance with the goals to accomplish.
In order to decide which procurement approach should be followed, the client may seek advice from the project manager, the design team, building contractors or building service companies, that can help find the potentially strong and weak points of each approach for the project under consideration.

2.2.1 TRADITIONAL PROCUREMENT

Traditional procurement (also called design-bid-build) remains the most popular method by far, nowadays. It is based on a separated and sequential process of design and construction contracting. It basically comprises the production of documents making explicit the client’s requirements for the process output (e.g., a building), a bidding process for selecting the most suitable purchaser (either professional or construction service provider), the contract award and the execution of the work contracted (the building design, on the first process phase and the building construction, on the second).

Traditional procurement implies two separate contracts, at least – one between the client and the design team and the other one between the client and the constructor. This initial simple form has greatly evolved during the last decades mainly because of the ever increasing complexity of projects and relationships among the project team. Accordingly, because clients have felt the need to better support their decisions in the project’s complex environment, traditional procurement nowadays involves other actors beyond the initial three (i.e., the client or owner, the design team and the contractor), namely (Fig. 2.1):

- The project manager, for managing the whole process
- The contract administrator, for monitoring and controlling contracts between parties involved in the project stages
- The project coordinator for dealing with the pre-construction stage
- The project director for taking care of contract relationships between sub-contractors, independent professionals and specialists acting on the owner’s behalf (this may be performed by the contract administrator, as well).
The main characteristic of the traditional procurement model is that design is separated from construction. In mainstream contracting procedures, the client appoints a team of consultants to prepare design, comprising the following three sets of documents:

- General and detailed design documents produced on an agreed design brief supplied by the client;
- Documents required for project approval and certification;
- Documents needed for construction tender purposes.

The design team is fully responsible for the preparation of all documents above according to the contract with the client. However, the ownership of the design documents delivered by the design team to the client after completion makes the client liable for those documents from the construction contractors’ standpoint. The design documents are then presented by the client to construction contractors for tendering. Obviously, the client depends on the design team for the
quality of the tender procedure and for avoiding bidder claims on the documents provided (design errors or lack of clarification, unsuitable design solutions, inaccuracy of the bill of quantities, and so forth). Furthermore, the client depends on the quality of the design documents for the quality of the final product and for avoiding claims during design implementation. This means that under the traditional procurement arrangement the main contractor takes responsibility for construction and the design risk remains with the client.

The obligation of the construction company selected to perform the work (implementing the design solution provided by the client) normally comprises:

- Organising the works programme in accordance with design;
- Preparing and managing the construction site;
- Carrying out the work by the completion date and for agreed price agreed with the client.

Contractors are normally responsible for providing all labour, specialist consultants, materials and equipment needed for construction, according to the design provided by the client. However, the client may secure the supply of certain equipment, especially those to be incorporated in buildings (e.g. a sophisticated chiller) that will then be excluded from the contractor’s obligations.

The traditional procurement approach is suitable for many construction clients including those lacking experience in construction project contracting:

- Firstly because the client may retain control over the whole process by selecting all project participants (the client acts may be supported by specialist consultants of various types, as depicted in Fig. 2.1).
- Secondly, the client may be directly involved in the design phase options and in the construction phase decisions, and control the level of interaction between the design team and the contractor, whilst retaining control over the project evolution (although acting through specialist consultants, as above).
- Thirdly, for very small projects, traditional procurement may be more appropriate than other approaches because the process is essentially simpler (the roles of the parties involved are clearly defined) but it may also be helpful for technically complex projects because it facilitates the breakdown of large-scale works.
- Fourthly, traditional procurement provides extensive architectural and engineering support that may be translated into accurate work specifications thereby enabling low risk project implementation (contractors are asked for cost and time certainty before starting works, unless redesign is needed to make the project buildable).
Finally, traditional procurement appears to be a low-risk option to inexperienced clients, therefore proving ideal for those who wish to minimise their exposure to the risks of overspend delays or design failure (Gokhale, 2005).

In most cases, a single contractor will be appointed for each phase but that is not compulsory in most European legislation. Accordingly, more than a design team may be appointed for developing design (e.g., architect and engineering teams or independent professionals appointed by the client will merge in the design) and more than a contractor may be appointed for constructing (as opposed to the prime contractor model). Additionally, each entity contracted may possibly set up further contracts with other companies and service providers. This may be limited by specific client contract clauses or by general regulations, most notably in public contract arrangements. Moreover, although some works are subcontracted to specialist firms or independent professionals, the prime contractor remains liable to the client.

There are several types of tendering procedures under the traditional procurement approach. Private clients may use the tender procedure that best fits their requirements ranging from open tender to invitation; public clients must comply with the Public Contract forms. But in most cases, the tender procedure will pass through a bidding process. The use of a bidding system increases the competition with regards to project cost and scheduling, allowing for the design team and contractor to increase efficiency and quality of the project for the client. Typically, the lowest-bid contractor that is aligned with the project requirements of the contract documents will be selected.

In view of the above, the following risks are associated with the traditional procurement approach:

1. Delays caused by the process extension, as each work segment must be completed prior to beginning the next, and by mounting sequential work delays;
2. Adversarial relationships between the project team members (e.g., designers and contractors);
3. Inappropriate design solutions due to the lack of involvement of construction professionals during the design process;
4. Impractical design options (e.g., requiring unavailable materials or dangerous works);
5. Lack of quality of tender documents;
6. Claims of various types (including contractor manufactured claims, particularly when the lowest price bidding system is used);
7) Poor construction innovation due to the late engagement of construction professionals in the project;
8) Reluctance of designers to accept alternative design solutions suggested by contractors (possibly cheaper, faster or easier to implement);
9) Design changes (e.g., due to inappropriate design) likely to entail extra time or cost;
10) Extra costs (e.g. reworking) and safety problems due to dated design documents or changes;
11) Design inaccuracy due to short contracting time; and,
12) Lack of quality due to contractor inefficiency or to setting unreasonable construction duration targets.

Separating responsibilities for design and construction has been seen as the primary reason for the move to alternative contractual arrangements. But this option has not proved very popular as other forms of procurement, taken as a whole, only form a small percentage of construction transactions.

### 2.2.2 DESIGN & BUILD

Over the last decades, the Design & Build (DB) approach has gained substantial support from private and public clients but is still just the second most common procurement method. Basically, DB is a contractual arrangement whereby the contractor offers to design and build the project for a sum which is inclusive of both the design and the construction costs. The contract typically includes managing the project as well. The design and building team is often a joint venture of a general contractor (usually leading) and a design specialist.

In its basic form, DB procurement requires a single contract arrangement between the client and the contractor who takes the responsibility to design, build and manage the whole process. However, the client normally feels the need for technical support for conducting the project thus a project manager is often designated and several consultants appointed. Additionally, the client may wish to hold some intervention in project design, therefore a design team, acting on the client’s behalf, may be appointed for developing the initial conceptual phases, prior to embarking in the DB arrangement. The client may also wish that a design specialist or the design team leader will be further involved in the detailed design process, integrating the design team proposed by the contractor. If the client chooses not to designate a project manager, a quantity surveyor may be directly appointed for helping in the tender stage, monitoring project time cost
and quality and supporting the client’s decisions concerning these issues (Fig. 2.2).

The first step of the DB procurement approach is the client (or owner) designating the project manager (or performing its duties directly or with the support of a quantity surveyor, if it is the case). The first job of the project manager is to produce the project brief. This document defines the client’s requirements that the project must comply with and should be included in the tender documents (either for the client design team or for the contractor’s). Additionally, the project manager will prepare a document describing the works comprised in the DB contract (and in the design contract, if this is the case) and the duties assigned to the contractor’s team. Both documents are essential for preventing future claims.
Costs and time certainty are normally established before design and build contracts are signed, but this depends on there being no subsequent changes by the client.

The second step is DB procuring and contracting. The contractor can be selected through a bidding process or through negotiation (there are limitations for this in the public tender regulations, however). Each contractor invited to tender is carefully selected not only for its financial standing and construction record but also for its design capability and management structure for the work. The contractor will be responsible for the production and approval of the detailed design by the client consultants and by the authorities. The contractor may also use its own specialist consultants as well as subcontractors for performing design and construction.

The DB approach is an attractive option for many construction clients:

- Firstly because it is less risky as there is just one single point of responsibility for both design and construction, therefore minimizing contractor claims on damages for inappropriate design (as in the traditional approach); once the contract has been set up, the DB team is responsible for all design and/or construction issues and must resolve them at no cost to the client.
- Secondly because it is a quicker path for project delivery when compared to the traditional approach as it allows for design and construction phase overlapping, leading to early completion on-site and cost savings.
- Thirdly, design solutions are more credible and likely to lead to good project outcomes.
- Fourthly, contract prices tend to anticipate the final project costs closer than in the traditional approach.
- Finally, the DB approach is expected to lead to savings in both construction time and costs because the design developed by the contractor is more likely to suit its own organisation and construction methods (it is possible to reconcile the ideas of design and construction methods).

However, the client commits to the design cost and to the construction cost much earlier than in the traditional approach. Furthermore, prices for DB contracts are often higher than the sum of separate design and construction work, because the contractor obviously adds a premium for taking the integrated risk of design and construction.

In view of the above the DB may not be the best procurement approach for every situation. It is not appropriate for projects that cannot be adequately speci-
fied in the brief or requiring substantial client input during detailed design or holding significant potential for change. Actually, interfering in design after awarding the contract may cause important damages as this may possibly affect not only the design team but also impact in the whole cost structure of the contractor. This will certainly cause claims from the contractor which may prove very expensive to the client. On the other hand, client claims may arise on the basis of:

- Low quality of the design produced by the contractor or not adequately performing the functions described in the design brief;
- The facility designed by the contractor cannot be built as it is or cannot be built for the budget agreed.

If these design claims occur, the DB team should be responsible for fixing the problems detected at no cost for the client.

In short, the key points to successful DB contracts are as follows:

- Get the requirements right – Design & Build begins to lose some of its advantages when changes occur during the contract period.
- Maintain good communication – the owner and design-builder must have clear response communications internally and between themselves to keep the project moving.
- Maintain good relationship – verify if designers and constructors are really a team.
- Stay involved – design and construct is not a “hands-off” method, it requires continual owner involvement.

### 2.2.3 MANAGEMENT FEE

Under this approach, the design is procured separately from construction, the management of which is contracted for a separate fee. Essentially, the client/owner appoints consultants for development design and a set of work-package contractors to implement design. The duties of construction phase managers are to develop a programme for the works, divide the works in appropriate work-packages, issue tender documents and assist the client in tender phase. The key issues of management fee procurement are:

- The contractor brings practical build ability advice during design;
- The contractor is reckoned to be more client oriented than in the traditional approach;
- Construction work is carried out by work-package contractors;
- Design and construction on site often overlap;
- Lower price certainty (the management role of the prime contractor is contracted by the client to a consultant professional).

Management fee procurement is suitable for experienced clients, fast track projects and complex building projects. However it is unsuitable for inexperienced clients and for those wishing to pass most risks to the contractor. There are several variants to this approach but probably the best known are Construction Management and Management Contracting.

1) **Construction Management**

Construction Management is a fast track procurement method which enables work to begin on the early stages of construction while the design and documentation of later work packages are being finalised (*i.e.* the elements of project are let before the design of later work packages or elements have been completed). The client makes a contract for design to a design team, and appoints a Construction Manager to organise, let and supervise work-packages covering the whole construction works (Fig. 2.3).

![Diagram of Construction Management model](image)

**Fig. 2.3: Construction Management model**
Although working under the authority of the Design Team Leader for design issues, the construction manager has no contractual links with the design team but directly with the client, and gets a separate fee for performing the work. The duties of the construction manager are participating in the design team (specially bringing insights of the construction process) and managing work-package subcontractors. But construction contracts are placed directly between the client and the work-package subcontractors.

Accordingly, the construction manager usually oversees and monitors the whole construction project, from the design phase to construction tendering and construction. Construction managers will not perform any type of construction work, restricting their action to a consulting relationship with the client (and avoiding possible conflicts of interests) but they must thoroughly programme the works to ensure continuity and avoid possible delays. The conditions, responsibilities and risks may vary significantly between construction manager contracts. But typically they do not accept liability for delays, cost overruns or quality except when these issues are directly caused by their own negligence.

Construction management is useful in volatile economic and industrial climates by helping reduce the time and costs of project delivery. It requires constant involvement by the clients so it is only suitable for experienced clients. But by doing so, the client has the opportunity to closely control the budget.

2) Management Contracting
Management Contracting involves the client entering into an agreement with a management contractor who, in turn, contracts with individual trade or work-package contractors. This is a fast track approach which overlaps the design and construction stages and allows commencing the construction process before design has been completed. The client pays the cost of the work contracts as well as a fee for the management services.

As in construction management system, the management contractor is engaged to manage the whole contract in return for a fee but does not carry out construction work whatsoever. The management contractor is appointed early in the design stage for advising the client on build ability and programming, assisting the client on putting together work-packages for tendering and managing the works on site (Fig. 2.4).
Contrary to the construction management model, the client awards the whole contract to the management contractor that then lets all sections of work to work-package contractors through a competitive tender process. The management contractor acts independent of the client in this process but remains the connecting point between the client and the work-package contractors during construction. However, the management contractor cannot give extensions of time under a works contract without consulting with the client (or the client representative, e.g., the project manager) about the proposed decision, nor can it certify the completion of a works contract without the client’s consent.

During the construction phase, a cost plan is utilised for cost control (a cost plan is agreed between the client and the management contractor at the commencement of the project) although actual costs cannot be obtained until the final
work package has been awarded - so the final cost of the works is only known when the work-packages have all been let.

2.2.4 COMPARING PROCUREMENT SYSTEMS

Selecting the suitable procurement model is a key element for sound project implementation. Procurement models differ from each other in terms of allocation of responsibilities, activity sequencing, process and procedures, and organisational approach in project delivery. The characteristics of the various procurement models available should be considered before opting for the most appropriate. Table 2.1 shows a comparison among the most current models as described in the previous paragraphs according to a set of criteria.

Table 2.1: Comparison of procurement models (based on CIOB, 2002)

<table>
<thead>
<tr>
<th></th>
<th>Traditional Procurement</th>
<th>Design &amp; Build</th>
<th>Management Contracting</th>
<th>Construction Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early completion (time)</td>
<td>Inappropriate</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Timing of price certainty</td>
<td>Moderate</td>
<td>Early</td>
<td>Late</td>
<td>Late</td>
</tr>
<tr>
<td>Degree of quality certainty</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Complexity of project</td>
<td>Inappropriate</td>
<td>Inappropriate</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Complies with state statutes</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Limited</td>
</tr>
<tr>
<td>Responsibility</td>
<td>Moderate</td>
<td>Limited</td>
<td>Large</td>
<td>Large</td>
</tr>
</tbody>
</table>

4 This topic means the availability of recognised standard documentation of each system.
In view of the above, the various procurement models reflect fundamental differences in the risk strategy of each project stakeholder, and this directly reflects in their risk management approach for the tender stage. From the standpoint of the risk attitude, the selection of the procurement method should take the following steps into consideration (Johannsen, 2009):

- Identify general procurement requirements for project stakeholders (specific, regulatory, invitation, pre-qualification, contracting, and so on);
- Select the pricing model that best balances risk sharing for stakeholders (for example stipulated price, unit price and fixed price).

---

5 Facility to recover costs direct from contractor
CHAPTER 3

RISKS AT THE TENDER STAGE
(J. C. TEIXEIRA)

3.1 GENERAL CONCEPTS

Tendering is a specific procedure for conducting procurement and contracting in construction. Public clients must follow the tendering conditions of public contract regulations whereas private clients may adopt their own, provided they comply with the general law. The majority of work in construction industry is now awarded to contractors through a bidding process. The alternative to bidding is direct awarding but this is strongly limited for public contracting (e.g., by the contract nature and value) and is seldom used in private contracting (unless for very small projects). Tendering may be open (i.e., all candidates are accepted provided they match the tender requirements imposed by the client) or limited (i.e., only prequalified or invited candidates will be accepted). Most European regulations stipulate a minimum number of invited candidates in public procurement.

A tendering process typically engages a number of parties and involves considerable investment of time and money both from the promoter (preparation of tender documents, announcing, advertising and invitation, pre-qualifying candidates, analysing proposals, selecting, and so on) and from the candidate in the course of the bidding process (Berezowskyj, 2009). Tendering is actually a highly technical activity therefore requiring the participation of experts, specialised companies and qualified personnel from both parties, namely holding:

- Strong knowledge of law (to implement state guidelines, policies, ensure compliance of national laws, and so on);
- Knowledge and practical experience in similar projects (for observing and analysing problems that may arise and take the appropriate measures);
• Actual capacity to perform the work on time; and,
• Social skills (to participate actively in meetings and social activities).

Additionally, each candidate will develop a specific bidding strategy, considering a number of factors, namely (Cooke & Williams, 2004):
• Previous experience of working with the client team;
• Client financial stability;
• Market conditions and the level of competition for the contract;
• Inflation;
• Risk balance in the contract;

Determining which risks are likely to affect the project objectives (especially time, cost and quality) and documenting the attributes of each risk factor are fundamental steps in the project risk management processes during the tender stage (Mbachu & Vinasithamby, 2005). Essentially, all projects are a balance between cost (total cost) and value (value of the end product) for all project stakeholders. The client, for example, expects project value (tangible and intangible) to exceed costs (money and other costs) and defines the variance required between them (or profit for commercial projects) from the initial phase of project development. Therefore, the client is deeply interested in studying risk sources affecting project results, particularly in the tender phase.

Risk sources at the tender phase may be internal or external to the project environment with both generating implications to stakeholders (Fig. 3.1). More specifically, for commercial projects, for example, external sources may also include market conditions, interest rate changes, potential impact of schedule delay, and so on.
Fig. 3.1: Sources of risks in the tender phase of construction projects and implications to stakeholders (adapted from Mbachu & Vinasithamby, 2005)

The procedures for risk assessment normally appear in the Project Execution Plan (PEP) which is the core document for project management after design completion. The PEP states the policies and contains the procedures defined by the client (owner, sponsor, etc.) or by the project manager for conducting the project during the construction stage. Essential contents of the PEP are: project general definition, project business plan, market survey, financial procedures,
development strategy and procurement route, schedule and phasing for the remaining project phases, detailed design package, tendering, construction, operation, safety and environmental issues and so on.

The performance of project participants during the construction phase is dependent on the quality of the PEP; reciprocally, construction cost overruns and delays mostly derive from the lack of quality of PEP. Unfortunately, PEP is often poorly written and assembled from information of other identical documents which may not suit the requirements of the project for which it should be specifically tailored. (e.g., different local and contract conditions or different work programmes).

3.2 PRINCIPLES OF RISK MANAGEMENT AT THE TENDER STAGE

From the client’s perspective, the efficiency of risk management at the tender stage strongly depends on how it was prepared beforehand, i.e., at the pre-tender stage. Johannsen, (2009) indicates some general risk management principles suitable to the pre-tender stage, namely:

- Address risks related to the general project development (land, finance and regulatory approval issues), risks associated to the procurement process (pre-qualification, call for tenders, tendering and awarding procedures) and risks dependent on the construction performance.
- Be cautious while using risk matrices (they are often used as the only tool for identifying risks instead of going through a detailed analysis process).
- Understand that every project is different from another in size, complexity, construction technology, schedule, budget, and so on.
- Allocate each risk to the party best prepared to manage it (depending on the type of contractual relationship, market conditions and acceptance, and so on).
- Recognise that risk analysis may substantially differ depending on the standpoints of each project stakeholder.
• All risks and risk scenarios should be reported in the Project Risk Register that must be constantly reviewed and updated.

From the contractor’s perspective, the key point for effective risk management at the tender stage is access to as much information as possible on the project, on the project environment, on the client, on the other stakeholders, etc. Most contractors try to access to relevant information even before the tender is launched by the client because they are informed of the client’s intentions (e.g., being aware of the client’s investment plan). Nevertheless, under the traditional contracting approach, information is essentially provided by the client (such as the design, site surveying, health and safety risks and so on) within the tender documents. The risk management process conducted by the contractor should take into account all risks specified in the tender documents as well as other risks determined by investigation during the tendering phase. However, the short time usually given for tendering and the intensity of competition tend to make the contractor ignore or underestimate risks at this phase. Therefore, if some unpredicted risks would arise during construction, the contractor would certainly not be prepared to adequately deal with them. In order to prevent this, the contractor usually provides a risk allowance in the offer, normally calculated as a percentage of costs.

The client’s role for risk prevention during tendering may be summarised as follows:

• Ensure that tender documents and contract terms are clearly understandable.
• Clarify queries placed by candidates.
• Release clarifications to all candidates in appropriate time.

The contractor’s role for risk prevention during tendering may be summarised as follows:

• Understand bidding risks and construction risks.
• Be familiar with all contract documents and contract terms.
• Clarify all doubts before submitting the offer.
• Be aware that some risks not documented can possibly occur.

The tender stage can be divided into the following sub-phases which are further discussed in the following paragraphs:

1) Preparing tender documents
2) Pre-qualification of bidders
3) Announcing/inviting and opening tenders
4) Tender evaluation and contract award

### 3.2.1 PREPARING TENDER DOCUMENTS

The client consultants may be asked to prepare the tender documents, which will typically include Instructions to Bidders, a Tender Form or Schedules, a Form of Construction Contract and other materials, such as risk management policies, acceptance criteria of proposals and the classification system (Berezowskyj, 2009).

Managing risks in this stage from the client’s perspective mostly consists on checking that the various tender documents are produced at appropriate times, including those for enabling work performance (e.g. demolition, site clearance, access and boarding) and ensuring that those documents contain all special terms required by the client (The Chartered Institute of Building, 2002). Unfortunately however, tender documents are often put together from previous tenders without checking their conformity to the particular project to which they are intended; on other occasions, tender documents seem to have been produced by different people and were not adequately integrated in a single meaningful document. These may lead to interpretation problems and cause future disputes which are inconvenient to the project success.

Following sound procedures in preparing tender documents is a very important step for getting appropriate offers from contractors and for selecting the best contractor for the project.
An interesting topic in this sub-phase is setting up a pre-tender construction cost estimate. This is an important piece of information when making decisions at the project planning and design stage and is usually included in the tender documents for information of those interested in submitting a tender. In public procurement, this information is also used for setting up the likely contract value which is a guidance value (and also a restriction for public tendering, according to the law of some European countries where construction permits are organized into class values) or the maximum contract value that the client is interested to pay (as in public procurement in some European Countries).

However, most cost estimates are built up using estimated quantities and rates based on experience. Therefore, significant differences can occur between tender costs estimates and actual costs. A wide variety of factors influence construction costs either project specific (e.g., material costs are actually higher than calculated in the pre-tender stage), construction organisation specific (e.g., contractor equipment is more efficient than forecasted in the pre-tender stage) or external (e.g., modifications in the project scope, economic, legal and technological changes).

Positive cost differences have negative consequences for contractors who may suffer loses (may even collapse, leaving unfinished products) and decrease reputation, and for clients who may have to pay for cost overruns through opportunistic payments of variations or contractor re-engagement (COBRA, 2004).

3.2.2 PRE-QUALIFICATION OF BIDDERS

The success of a construction project largely depends on the capability of the contractor (and sub-contractors). Accordingly, pre-qualification may be an interesting tool for some projects because it allows setting up a list of contractors best prepared to carry them out properly. Obviously, this calls for a robust evaluation procedure and involves some risk for the client. The benefits of prequalification may be summarised as follows (ADB Standard Prequalification Document, 2006):

- Avoids bidding costs for the less qualified contractors (that have not been pre-qualified) and simplifies the evaluation procedure (because the number of offers is limited to the selected set).
• Contractors selected know that they are competing against other qualified companies that will probably submit realistic offers (this is important for the bidding strategy of competitors).
• It reduces significantly, or even eliminates, problems of rejection associated with low-priced bids submitted by bidders of doubtful capacity.
• Helps identify possible conflicts of interest between parties involved in the tender (e.g., between the contractor and a client officer or consultant).
• Incentivises contractor joint-ventures (thereby increasing their positioning).

But, on the other hand, there are risks associated to the prequalification stage (ADB Standard Prequalification Document, 2006).
• Makes the tender process longer than open tender
• Requires careful evaluation of all prequalification applications whereas under post qualification the review of the qualifications can be reduced to the lowest evaluated bidder.
• Raises the risk of secret agreements between pre-qualified contractors.

Note that prequalification for public contracts compulsorily follows an open competition procedure in most European countries. This contrasts with the invitation procedure that enables the client to pre-select contractors without going through a competitive procedure. Therefore, the invitation procedure may raise claims for inhibiting competition and its use is limited to special conditions (including the maximum contract value). However, competitive prequalification is restricted to large complex projects and it is seldom used for current projects.

3.2.3 ANNOUNCING/INVITING AND OPENING TENDERS

In this phase, the client supported by his/her consultants should disseminate information about the tender (announcing in official journals, as for public tenders and/or advertising in media, in the case of open tenders\(^6\)) or prepare lists of

\(^6\)The award of public contract through open tender is to ensure transparency in public procurement, maximise economy and efficiency, promote healthy competition among tenders, provide for fair and equal treatment to all the bidders and eliminate irregularities, interference and corrupt practices by authorities concerned.
firms to be invited to tender (in the case of invitation tenders or following a prequalification procedure).

The date and time for receipt of offers from candidates should be precisely specified; in public procurement, the date for tender evaluation should also be precisely indicated. In some European countries, the offers from contractors are kept closed until the public opening session. But in other countries (e.g., Portugal) all the process now runs through an electronic platform (access to tender documents, queries and clarifications, release of any type of information from the client, submission of the offers from contractors, tender evaluation, posting of results, claims, and so forth).

An interesting topic in this sub-phase is checking for conflicts of interest. A conflict of interest arises where a participant in the tender process has an interest or an affiliation that may be seen to prejudice his or her impartiality (MALCOE, 2005). However, if conflicts of interest are identified early and dealt with effectively, they need not involve misconduct. For example, client staff members or client consultants should disclose any conflicts of interest arising during the procurement process; potential service providers should also be required to divulge all potential conflicts of interest with bidders.

Note that conflicts of interest may also arise among bidders, for example, if one of the bidders or member of a joint-venture has some agreement with another bidder or joint member. Therefore, bidders should state their possible conflicts of interest in their offers in order to prevent future problems.

3.2.4 TENDER EVALUATION AND CONTRACT AWARD

Tender evaluation should consider value for money as the key evaluation criterion. This includes factors such as price, quality assurance (of the project team and project outputs), lifecycle costs, alternative project solutions, and so on. This may result in the lowest tender not being recommended for acceptance.

Accordingly, contractors should strive to submit ambitious and innovative tenders, matching the client’s requirements at the lowest possible costs. This is not an easy task however, because an attractive tender for the client may bear little interest for the contractor (high risks or small profit, for example). Additionally, resources involved in the project must be adequate for conducting the project and staff must have enough experience in projects of the same type. This con-
tributes to assuring the client that the project will be developed according to the proposal; on the contrary, the lack of this may endanger the positive appraisal by the client therefore putting at risk the tendering effort (in terms of time and money spent).

However, many clients excessively focus on the lowest bid as the only selection criterion and contractors organize their bids correspondingly. But this may be a risky option for the client because it may bring project delivery problems (e.g., cost overruns, delays, poor project quality etc) as contractors having shortage of work are tempted to submit a low bid simply as a strategy to gain the contract (Creedy, 2006). Accordingly, selection should be based on balancing quality and price. This will force bidders to understand their specific resources for generating competitive advantage and to develop strategies to win contracts based on the output performance taking into account costs and quality of the output (Tan, Shen, & Langston, 2010).

Tender evaluation on the basis of the lowest bid should be restricted to cases where all other factors are similarly accomplished by all bidders which is only possible by using a pre-qualification procedure (e.g., in invitation tenders where competitors are pre-qualified and it is possible to establish strict contract conditions concerning other relevant selection issues). But invitation may bias competition unless it follows an open prequalification procedure, as mentioned above. Competitive bidding, on the other hand, enables transparency in tender evaluation, especially if evaluation factors are known by all candidates before submitting their bids and tenders are evaluated exactly as the per-notified criteria.

Tender evaluation is a risky activity for clients and their agents and consultants and should include (Eskesen, 2009):

- Risk assessment between all tenders submitted.
- Contractor's risk management expertise.
- Contractor's ability to control risks through the adoption of adequate technical solutions.

Once the best offer is selected, a letter of intent to the approved bidder should be immediately issued (notifications for unsuccessful bidders should be issued likewise). This letter means final contractor selection and is the end of the tender stage.

After the client’s selection of the contractor which will perform the works, they should both cooperate in a risk management procedure in order to ascertain the
best way of mitigating risks previously identified, specially the most sensitive for project success. The risk management process of the successful tender may have identified some previously undetected areas of risk or special concern and additional risks may be included (for example, sub-contracting risks related to their technical qualifications, timeliness, readability and financial stability). By the end of the risk management process, all risks should be catered for in the contract agreement between the client and the contractor (additional risk mitigation clauses may be introduced in the contract, if necessary) which should include a detailed risk management system to be implemented during project execution (Eskesen, 2009).
CHAPTER 4

RISK MANAGEMENT AT THE CONSTRUCTION STAGE
(J. KULEJEWSKI, M. KRZEMIŃSKI, J. ZAWISTOWSKI)

4.1 RISK MANAGEMENT PROCESSES

When deciding to tender for a construction project, the Contractor takes into account his ability to meet the Client’s requirements with regard to:

- the scope of the works;
- the quality of the works;
- the entire construction project duration.

If the Contractor’s bid is accepted by the Client and the construction contract is concluded, there is still a requirement with regard to the cost limit of the works. However, each construction project is unique. Therefore, the Contractor forecasts that during the execution of the works, some events or circumstances may occur that may pose a threat to the fulfilment of at least one of the above requirements. Such a threat is referred to by the Contractor as the Construction project risk. Events or circumstances, foreseen as the probable causes of such a threat, are referred to as risk factors. The actual occurrence of such an event or a circumstance during the execution of the works is referred to as the materialisation of a given risk factor. The result or the effect of the materialisation of a given risk factor may include limiting of the scope of the works actually executed, the lowering of their quality, the extension of their duration or the increase of their cost over the prescribed limit. However, at the tender stage of the unique construction project, the Contractor can only foresee the more or less
probable threats, which may result from the materialisation of a given risk factor. So, if the appropriate risk management activities are not undertaken already during the bid preparation, the materialisation of a given risk factor during the execution of the works can become a **problem**.

Actively identifying and analysing the risk factors for the construction project and responding to them accordingly, it is possible to reasonably plan the project execution and reach its successful completion. For this purpose, construction project risk management should include the following processes (see Table 4.1):

1) **Risk management planning**: determining what, when, how and by whom it is necessary to perform within the framework of the individual risk management processes;

2) **Risk identification**: determining which risk factors may emerge, what is the cause of a given risk factor and which project objectives may be influenced by a given risk factor

3) Qualitative risk analysis and assessment: an approximate assessment of probability and impact of individual risk factors on the project objectives in order to determine which risk factors may be accepted and which of them require suitable preventive actions;

4) Quantitative risk analysis and assessment: a detailed numerical assessment of probability and impact of individual risk factors on the project objectives;

5) **Risk response planning**: determining how to reduce the probability of materialisation of a given risk factor, how to reduce the effects of its materialisation and what to do if the preventive actions turn out to be insufficient;

6) **Risk monitoring and control**: examination of the effectiveness of the preventive actions.

Table 4.1: Risk management processes and their objectives

<table>
<thead>
<tr>
<th>Processes</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk management planning</td>
<td>Making decisions on the main issues of the risk management of the particular construction project</td>
</tr>
<tr>
<td>Risk identification</td>
<td>Determining which risk factors may influence the achievement of the project objectives and describing their characteristics</td>
</tr>
</tbody>
</table>
Risk analysis and qualitative assessment  | An approximate assessment of the severity of the risk factors identified and ordering them in accordance with priority when planning and implementing the response to risk
---|---
Risk analysis and quantitative assessment  | Numerical assessment of the probability of meeting the project duration and cost limit and clarification of the qualitative assessment of the severity of the project risk factors
Planning of response to risk  | Specification of activities that reduce the potential threats to the project objectives
Risk monitoring and control  | Observation of the risk factors identified, the identification of new risk factors, implementation of responses to risk and assessment of their efficiency throughout the entire project execution period

### 4.2 RISK MANAGEMENT PLANNING

#### 4.2.1 PROCESS ESSENTIALS

Risk management planning is a process of making decisions on the organisation and of the mode of implementation of the remaining five risk management processes.

The decisions made must be appropriate to:

- the significance of the individual project objectives for the ordering party;
- the general policy of the executing company in terms of risk management;
- the significance of a given project for the executing company.

The general risk management planning process diagram has been presented in Fig. 4.1.
Fig. 4.1: General diagram of the risk management planning process

Input data for risk management planning include:

- Data concerning the project and conditions of its implementation, based on the project documentation (facility type, scope of works, the required level of quality of performance of works, organisational structure of the project, local conditions on site, time and cost limitations with regard to completion of works),
- Historic data concerning the scope of practice of the executing company with regard to risk management and appropriateness of these practices for achievement of the established goals for similar projects in the past.

The most important output of risk management planning is the *Project risk management plan*.

### 4.2.2 TOOLS AND TECHNIQUES

The basic risk management planning tool is the analysis of data on the project and the external conditions of its implementation, in association with historic data. As a result of such analysis, it is necessary to establish:

- The risk management methodology, taking into account the general risk management strategy of the executing company and the specific project traits;
- The breakdown of responsibilities for the project risk management;
- Resources (employees, hardware, software, financial resources) necessary to manage the project risk.
An auxiliary tool for risk management planning are meetings, organized by the Project Manager with participation of the Project Management Team and other persons representing the executing company, responsible for the project planning and implementation activities. Meetings can also be attended by representatives of suppliers and subcontractors, as well as external specialists, having at their disposal the appropriate legal, technical, market and other knowledge, adapted to the specific traits and scope of the project.

### 4.2.3 PROJECT RISK MANAGEMENT PLAN

To document the arrangements made, a Project risk management plan should be established. However, there is no universal template of such a document. Some construction companies prepare their own, specific Risk management plan templates, taking into account:

- recommendations presented in the recognized standards of project management, such as the Project Management Body of Knowledge (PMBOK),
- risk management plan templates, published by educational organisations or consulting companies,
- individual practices, resulting from the skills and experience of the personnel responsible for the project risk management.

On the basis of the recommendations presented and the templates published, it is possible to present the following framework scope of a Project Risk management plan:

1. A description of the division of responsibilities (manages/participates/is informed/approves) of the Project manager and the project management team members for activities associated with risk identification, analysis and assessment, planning of responses to risk and monitoring and control of risk;

2. A description of methodology and implementation of activities associated with individual risk management processes, including the requirements pertaining to:
   a) Creation, maintenance and updating of the Risk factors register, providing the document template to be used in a given project,
   b) The mode of project risks identification, referring to a standard list of construction project risk factors or a standard construction project risk factors breakdown,
c) The mode of: conducting of a qualitative analysis of the project risks identified, presenting the scheme of the assessment of probability and effects of the materialisation of a given risk factor and of the assessment of the result of risk qualitative analysis,

d) The mode of conducting of the quantitative assessment and analysis of the project risk, pointing out:
   - the rules of qualification of risk factors for the quantitative assessment,
   - sources of the quantitative data on the probability of materialisation of a given risk factor and on the probability distribution of its effects,
   - the required tools and techniques for a quantitative risk analysis and assessment,

e) Risk acceptance thresholds and rules of planning of response to risk;

3. Guidelines for organisation of meetings for planning of the project risk management and for assessment of results of implementation of risk management processes;

4. Arrangements concerning the budget designated for management of the project risk;

5. Guidelines for selection of responses to project risk;

6. Guidelines for the rules of communication to internal and external stakeholders of the results of implementation of project risk management processes.

4.3 RISK IDENTIFICATION

4.3.1 PROCESS ESSENTIALS

Risk identification is a process of determining and describing the risk factors – events, situations or circumstances that may constitute threats to achievement of the project goals established.
Risk identification includes the following activities:

- To put the risk factors identified in order, risk categories are introduced, equivalent to typical sources of risk;
- Within the framework of each risk category, risk causes are identified, which may cause events qualified as risk factors;
- Individual risk factors are determined, resulting from a common risk cause;
- The nature and area of threats expected that emerge as a result of materialisation of a given risk factor is determined.

For example:

<table>
<thead>
<tr>
<th>Risk category:</th>
<th>External risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk cause:</td>
<td>Weather conditions</td>
</tr>
<tr>
<td>Risk factor:</td>
<td>Periodical heavy rains</td>
</tr>
<tr>
<td>Threat foreseen:</td>
<td>Reduction of performance of work teams, resulting in extension of the duration of earthworks</td>
</tr>
</tbody>
</table>

The general project risk identification process diagram has been presented in Fig. 4.2. This process is implemented until completion of construction, because during the execution of works, new risk factors may emerge that were not identified when the decision was made to place the bid.

![Fig. 4.2: A general diagram of the risk identification process](image)
Input data for risk identification include:

- Output data from the risk management planning process, including the guidelines for the method of identification of the project risk factors and the Risk register model;
- Data on the project and conditions of its implementation, based on the project documentation (facility type, scope of the works, the required quality of the works, organisational structure of the project, conditions on the construction site, project duration and cost limitations), on the existing legislation, on the general economic condition and on the market conditions;
- Typical risk categories, systematizing the basic sources of threats for construction projects;
- Historic data, containing information on advantageous and disadvantageous circumstances occurring during the execution of similar projects in the past;
- The status of implementation of the construction project as an objectively existing situation (during the project execution, new risk factors may be identified).

The output data of the risk identification process should include:

- The risk breakdown structure in a given project,
- The basic information on each of the risk factors identified, which should be provided in the Risk register.

4.3.2 TOOLS AND TECHNIQUES

The tools and techniques of the risk identification process include:

- Reviews of the project documentation (Drawings, Technical Specifications and Conditions of Contract), data on conditions of implementation of the project and data on the construction planning results;
- Techniques of gathering information on the project risk factors,
- A checklist for the project risk factors,
- Cause and effect diagrams.

Having the knowledge on the typical risk categories for construction undertakings and historic data, it is possible to determine in detail the sources of potential threats to construction tasks undertaken by a given executing
company. As a result, it is possible to establish a model **risk breakdown structure** – a multi-level hierarchical structure of typical risks that threaten the successful execution of the entire project or of a specific construction work.

The general diagram of **risk breakdown** structure is presented in Fig. 4.3.

![Fig. 4.3: The general diagram of risk breakdown structure](image)

Fig. 4.3 presents a sample risk breakdown structure for a construction project. The risk for the entire project or for a given construction work results from the emergence of specific risk categories (level 1), grouping risk factors of a similar source of origin. Individual risk factors (level 3) with the same causes (level 2) are events, which may threaten the project or the works.
Fig. 4.4: A sample risk breakdown structure for a construction project.

The model structure of risk division is complemented by a risk factor checklist, explaining the nature of typical construction project threats, listed according to their source of origin. Table 4.2 presents a typical checklist of risk factors according to their source of origin. In each risk category, typical risk causes have been specified and marked with symbols, as well as exemplary risk factors with common causes.
Table 4.2: An exemplary checklist of risk factors for a construction project

<table>
<thead>
<tr>
<th>Risk categories</th>
<th>Risk causes</th>
<th>Exemplary risk factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Risk (GR)</td>
<td>Building law legislation (GR1)</td>
<td>Rigorous legal requirements concerning the construction (GR1.1)</td>
</tr>
<tr>
<td></td>
<td>Environmental legislation (GR2)</td>
<td>Rigorous legal requirements concerning environmental protection (GR2.1)</td>
</tr>
<tr>
<td></td>
<td>Market conditions (GR3)</td>
<td>Unstable prices of means of production (GR3.1)</td>
</tr>
<tr>
<td>Ordering Party (SRO1)</td>
<td></td>
<td>Unrealistic project objectives (SRO1.1)</td>
</tr>
<tr>
<td>Contractor (SRO2)</td>
<td>Lack of cooperation in performance of works, found on the basis of experience of the Contractor (SRO1.2)</td>
<td>Frequent and unjustified interference with the course of the construction, found on the basis of the statements of the Contractor (SRO1.3)</td>
</tr>
<tr>
<td></td>
<td>Lack of sufficient experience of the project management personnel with regard to selection of methods of performance of works for compliance with the requirements provided in the technical specifications (SRO2.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of sufficient experience of the supervision personnel in the field of management of human resources (SRO2.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of stability of the project management team (SRO2.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bad interpersonal relations, hindering communication between key personnel representatives (SRO2.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difficult financial situation, limiting the possibility of financing the construction in the time intervals between subsequent invoices (SRO2.5)</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Subcontractor (SRO3)</strong></td>
<td>Low availability of subcontractors of the appropriate production experience</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(SRO3.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient knowledge on technical conditions of performance and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>acceptance of subcontracted works (SRO3.2)</td>
<td></td>
</tr>
<tr>
<td><strong>Project organisation (SRO4)</strong></td>
<td>Unclear division of tasks among the project participants (SRO4.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unclear project management procedures (SRO4.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Management procedures not adapted to the character and scope of the project</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(SRO4.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Contract conditions (SRO5)</strong></td>
<td>Unclear and inconsistent contract conditions (SRO5.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incomplete drawings and technical specifications (SRO5.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of clarity, discrepancies and errors in drawings and technical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>specifications (SRO5.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Construction site (SRO6)</strong></td>
<td>Uncertain conditions of obtaining land for the construction of temporary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>plant &amp; facilities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient area of land for the construction of temporary plant &amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>facilities (SRO6.1)</td>
<td></td>
</tr>
<tr>
<td><strong>Weather conditions (SRT1)</strong></td>
<td>Periodical heavy rains (SRT1.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Periodical low temperatures (SRT1.2)</td>
<td></td>
</tr>
<tr>
<td><strong>Construction site (SRT2)</strong></td>
<td>Unpredictable subsurface and hydro geological conditions (SRT2.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incomplete data on the existing underground facilities (SRT2.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Susceptibility of the surrounding area to damage due to the performance of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>works (SRT2.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Contractor’s employees (SRT3)</strong></td>
<td>Low availability of work force with the qualifications required (SRT3.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient employee motivation (SRT3.2)</td>
<td></td>
</tr>
</tbody>
</table>
Hindered communication between work teams (SRT3.3)

Low availability of materials of required quality (SRT4.1)

Low capability of suppliers to ensure a regular supply of materials to the construction site (SRT4.2)

Susceptibility of materials to damage during transport and storage (SRT4.3)

Low availability of equipment of required technical parameters (SRT5.1)

Susceptibility of equipment to failure and damage (SRT5.2)

The checklist of risk factors is an internal document of the construction company, to be used many times. Performing a review of documentation and data for a specific project, it should be determined which of the risk factors included on the checklist may pose a threat to the project objectives.

To gather information on risk factors for a specific construction project, it is possible to use the Delphi method and the brainstorming technique. The Delphi method is based on hypotheses being formulated by independent experts on the sources of potential threats to the project. Each of the experts works in private, using their knowledge and experience. Brainstorming is carried out by the management team members during their meetings to review the project documentation and data on the conditions of its implementation. On the basis of the results of the review and experience from implementation of similar projects, the managing team members present their hypotheses on the sources and causes of the project risk. Afterwards, analysing the planning assumptions made to estimate the time and cost of implementation of the undertaking, they verify their completeness, integrity and certainty. As a result of arrangements made during presentation of opinions of individual members of the management team, the descriptive characteristics of a given risk factor are prepared in accordance with the general scheme:

cause --- risk factor --- an effect for a given project objective

Every construction project is unique with regard to its subject and conditions of implementation. Therefore, as an auxiliary tool for identification of risk factors, during brainstorming, it is possible to consider using the cause and effect diagram (Ishikawa diagram), which is a widely used tool for quality management). A diagram of this type (see Fig. 4.5) allows for a graphic
representation of correlations between risk factors, which cause a specific effect in relation to the quality, time and cost of performance of a given construction work. Due to its shape, Ishikawa diagram is often referred to as the fishbone diagram:

- **the fish head** symbolizes the effect of materialisation of a certain number of risk factors,
- **the bones** symbolize causes and risk factors.

![Fishbone Diagram](image)

**Fig. 4.5: An exemplary fishbone diagram for identification of construction work risk factors**

### 4.3.3 PROJECT RISK REGISTER

A framework scope of the Risk register can be presented as follows:

1. Basic information on every risk factor identified, including:
   a) unique marking (symbol, number) of each risk factor, facilitating its monitoring and control;
   b) date of entry in the Risk register;
   c) name and characteristics of each risk factor (what are the causes, what it is about, which project objective may it influence and what effects it may have – usually with reference to the project duration and cost);
d) identification of the owner of a given risk factor (person or group of persons, responsible for further activities associated with risk management).

2. Information on assessment of each of the risk factors identified; to ensure the clarity of the Risk register, qualitative risk assessment results are usually presented, including:
   a) The approximate assessment of probability of materialisation of a given risk factor;
   b) The approximate assessment of effects of materialisation of a given risk factor;
   c) Assessment of weight of a given risk factor (estimated impact of a given risk factor on achievement of individual project objectives).

3. Information on response to risk, including:
   a) Activities planned and implemented to minimize the probability of materialisation of a given risk factor;
   b) Activities planned and implemented to limit the effects of materialisation of a given risk factor;
   c) Status of a given risk factor: open (threat still existing and subject to review) or closed (threat not subject to review).

4.3.4 AN EXAMPLE OF CONSTRUCTION PROJECT RISK IDENTIFICATION

To illustrate the construction project risk identification, consider the following example.

The organisational unit responsible for risk management in construction undertakings is obliged to identify the risk factors in the newly prepared project. The project consists of construction of a building. The project includes construction and installation works. A network of correlations and a schedule has been prepared for the project. These have been illustrated by Fig. 4.6 and Fig. 4.7. The risk identification results have been presented in Table 4.3. The first column of the table is an ordinal number, specifying the identified risk factor number. The second column provides the risk factor identification date. The third column contains the risk characteristics, as expected by the contractor. The fourth column contains the project task, which may be influenced by a given risk factor. The fifth column describes the potential effects of
materialisation of the risk factor. In the sixth column, the identified risk category is provided. The seventh column contains the expected moment of time for the emergence of adverse effects of the risk factor materialisation. The eighth column presents persons responsible for activities aimed at counteracting a given risk. Abbreviation "CM" represents the Construction Manager, and abbreviation “PM” – the Project Manager. The ninth column provides the date of the last update. The last column contains the risk status information.
Fig. 4.6: The correlation network for the construction undertaking planned

Fig. 4.7: The schedule of the construction undertaking planned
<table>
<thead>
<tr>
<th>ID</th>
<th>DATE</th>
<th>RISK FACTOR</th>
<th>ACTIVITY</th>
<th>RISK EFFECT</th>
<th>RISK CATEGORY</th>
<th>TIME REMAINING</th>
<th>RISK OWNER</th>
<th>UPDATED</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.11.2010</td>
<td>Incomplete data on the existing underground facilities</td>
<td>Preparatory works</td>
<td>Necessity to perform unplanned additional protective works, can influence duration and cost of preparatory works</td>
<td>SRT</td>
<td>5 weeks</td>
<td>CM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td>2</td>
<td>24.11.2010</td>
<td>Rigorous legal requirements concerning environmental protection</td>
<td>Preparatory works</td>
<td>Delays of commencement of works caused by the need to obtain permission to remove of existing plants, can influence duration and cost of preparatory works</td>
<td>GR</td>
<td>5 weeks</td>
<td>PM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td>3</td>
<td>25.11.2010</td>
<td>Unfavourable weather conditions, heavy rain</td>
<td>Excavations</td>
<td>Reduction of the working team performance, can influence duration and cost of excavation</td>
<td>SRT</td>
<td>6 weeks</td>
<td>CM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>25.11.2010</td>
<td>Protests of the local population against the use of the existing local road for the movement of Contractor equipment</td>
<td>Excavations</td>
<td>Temporary suspension of works, can influence duration and cost of excavation</td>
<td>GR</td>
<td>6 weeks</td>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25.11.2010</td>
<td>Incomplete drawings and technical specifications for brick works</td>
<td>Brickworks</td>
<td>Changes of the scope of works, can influence duration and cost of brick works</td>
<td>SRO</td>
<td>9 weeks</td>
<td>PM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>25.11.2010</td>
<td>Unfavourable weather conditions, heavy rain, strong wind</td>
<td>Roofing</td>
<td>Temporary suspension of works, can influence duration and cost of roofing</td>
<td>SRT</td>
<td>11 weeks</td>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>26.11.2010</td>
<td>The limited availability of paints and varnishes of quality in accordance with the requirements of technical specifications</td>
<td>Painting</td>
<td>The need to identify the supplier of coatings of a quality consistent with the requirements, can influence duration and cost of painting</td>
<td>SRT</td>
<td>12 weeks</td>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>26.11.2010</td>
<td>Unfavourable weather conditions: heavy rain</td>
<td>External finishing</td>
<td>Temporary suspension of works, can influence duration and cost of external finishing</td>
<td>SRT</td>
<td>8 weeks</td>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>26.11.2010</td>
<td>Susceptibility of materials to damage during transport and storage</td>
<td>Need to replace the damaged materials, can influence duration and cost of external finishing</td>
<td>SRT</td>
<td>8 weeks</td>
<td>PM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>------------</td>
<td>---------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-----</td>
<td>--------</td>
<td>----</td>
<td>-------------</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>27.11.2010</td>
<td>The limited availability of fittings quality in accordance with the requirements of technical specifications</td>
<td>The need to identify the supplier of fittings of a quality consistent with the requirements, can influence duration and cost of water supply and sewage system</td>
<td>SRT</td>
<td>10 weeks</td>
<td>CM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>28.11.2010</td>
<td>Insufficient workers qualifications</td>
<td>Reduction of the working team performance and the need to perform corrective work, can influence duration and cost of water supply and sewage system</td>
<td>SRT</td>
<td>10 weeks</td>
<td>CM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>28.11.2010</td>
<td>Incomplete drawings and technical specifications for the external works (small architecture)</td>
<td>Changes in drawings and specifications, can influence duration and cost of external works</td>
<td>SRO</td>
<td>10 weeks</td>
<td>PM</td>
<td>04.12.2010</td>
<td>Reviewed</td>
</tr>
</tbody>
</table>
4.4 QUALITATIVE RISK ANALYSIS AND ASSESSMENT

4.4.1 PROCESS ESSENTIALS

The risk factors identified should be analyzed to assess which of them:
- may be accepted without any further actions;
- require monitoring, with the temporary suspension of any further actions;
- should be subjected to further analysis and planning of the risk response.

To determine the proper course of action, it is reasonable to rank the risk factors due to threats to project objectives, which may cause their materialisation. To do this, the weight $WR$ of a given risk factor is assessed as the product of the probability $P$ and of the impact (foreseen effect) $I$ of its materialisation. If such an assessment is based upon a scale of scores, the weight of a given risk factor is:

$$WR = P \times I.$$  \hspace{1cm} (4.1)

Based on the assessment of their weights, the risk factors are then ranked with regard to the order of planning an implementation of responses to the project risks. The diagram of the process is presented in Fig. 4.8.
Fig. 4.8: General diagram of the process of qualitative risk assessment and analysis

The input data for qualitative analysis include:

- Output data from the project risk factor identification process – characteristics of the risk factors identified, provided in the Risk factor register;
- Assumptions made for the work performance time and cost;
- Historic data, containing information on problems encountered during implementation of similar projects,
- The status of implementation of the project as an objectively existing situation (advancement of the project implementation allows for verification of the previous assessment of probability and effects of materialisation of a given risk factor).

The results of qualitative risk analysis and assessment should allow for:

- An approximate assessment of probability of materialisation of the risk factors identified;
- An approximate assessment of effects
- An approximate assessment of significance of the risk factors identified;
- Ordering the risk factors identified according to priority in the area of planning and implementation of responses to risks.

Risk factors, which are assessed as being at least of medium weight, are then subjected to the quantitative analysis and assessment.
4.4.2 TOOLS AND TECHNIQUES

The tools and techniques used for the qualitative risk analysis include:

- Reviews of documentation and data, carried out to assess the completeness, integrity and certainty of assumptions made for the work performance, cost and time planning;
- Reviews of historic data to support – in association with results of the planning assumptions assessment – the approximate assessment of probability and effects of materialisation of a given risk factor;
- The scale of approximate assessment of probability of emergence of risk factors,
- The scale of approximate assessment of effects of materialisation of risk factors;
- A matrix of risk weight assessment on the basis of approximate assessment of probability of emergence of a given risk factor and an approximate assessment of effects of materialisation of a given risk factor.

Tables 4.4 and 4.5 present the exemplary scales of assessment of probability and effects of materialisation of risk factors for qualitative analysis of risk. In the examples presented, the score assessment of probabilities was carried out using a linear scale, while the score assessment of effects of materialisation of risk factors was carried out with a non-linear (progressive) scale. Use of a progressive scale allows for emphasizing of the risk factors of very painful effects. Tables 4.6 and 4.7 present examples of matrices for assessment of weight of a given risk factor on the basis of assessment of probability and effects of its emergence.

### Table 4.4: Exemplary scales of assessment for probability of materialisation of risk factors

<table>
<thead>
<tr>
<th>Approximate probability</th>
<th>Probability description</th>
<th>Descriptive scale assessment</th>
<th>Score scale assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – 9%</td>
<td>Slight possible</td>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>10 – 19%</td>
<td>Practically impossible</td>
<td>B</td>
<td>0.30</td>
</tr>
<tr>
<td>20 – 39%</td>
<td>Medium</td>
<td>C</td>
<td>0.50</td>
</tr>
<tr>
<td>40 – 59%</td>
<td>High</td>
<td>D</td>
<td>0.70</td>
</tr>
<tr>
<td>60 – 99%</td>
<td>Very high</td>
<td>E</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Table 4.5: Exemplary scales of assessment of effects of risk factor materialisation

<table>
<thead>
<tr>
<th>Description</th>
<th>Score scale assessment</th>
<th>Impact of risk factor materialization on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Project scope</td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>Invisible limitation of the scope of works planned</td>
</tr>
<tr>
<td>Moderate - marginal</td>
<td>0.20</td>
<td>Impact on scope of more significant works</td>
</tr>
<tr>
<td>Very harsh - disastrous</td>
<td>0.80</td>
<td>Scope of works implemented practically useless</td>
</tr>
</tbody>
</table>

17 percentage indicators are exemplary
Table 4.6: Exemplary matrix for assessment of risk factor weight in the case of a descriptive assessment of probability and effects of materialisation

<table>
<thead>
<tr>
<th>Probability</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>6</td>
<td>12</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>8</td>
<td>16</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>10</td>
<td>21</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk weight assessment</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5</td>
<td>Risk low; planning and implementation of response to risk to be put aside until increasing of the risk factor weight assessment upon subsequent review of the project threats</td>
</tr>
<tr>
<td>6 - 10</td>
<td>Moderate risk; plan and implement a risk response in the case of emergence of symptoms of a given risk factor</td>
</tr>
<tr>
<td>11 - 25</td>
<td>High risk; plan and implement a risk response immediately</td>
</tr>
</tbody>
</table>

Table 4.7: Exemplary matrix of assessment of risk factor weight for a score-based assessment of its probability and effects

<table>
<thead>
<tr>
<th>Probability</th>
<th>0,05</th>
<th>0,10</th>
<th>0,20</th>
<th>0,40</th>
<th>0,80</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00</td>
<td>0,05</td>
<td>0,06</td>
<td>0,19</td>
<td>0,36</td>
<td>0,72</td>
</tr>
<tr>
<td>0,70</td>
<td>0,04</td>
<td>0,07</td>
<td>0,14</td>
<td>0,28</td>
<td>0,56</td>
</tr>
<tr>
<td>0,30</td>
<td>0,02</td>
<td>0,05</td>
<td>0,06</td>
<td>0,17</td>
<td>0,48</td>
</tr>
<tr>
<td>0,10</td>
<td>0,01</td>
<td>0,01</td>
<td>0,02</td>
<td>0,04</td>
<td>0,08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk factor weight assessment</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0,040</td>
<td>Risk low; planning and implementation of response to risk to be put aside until increasing of the risk factor weight assessment upon subsequent review of the project threats</td>
</tr>
<tr>
<td>0,041 - 0,170</td>
<td>Moderate risk; plan and implement a risk response in the case of emergence of symptoms of a given risk factor</td>
</tr>
<tr>
<td>&gt;0,170</td>
<td>High risk; plan and implement a risk response immediately</td>
</tr>
</tbody>
</table>
4.4.3 AN EXAMPLE OF A CONSTRUCTION PROJECT QUALITATIVE RISK ANALYSIS AND ASSESSMENT

To illustrate the construction project qualitative risk analysis and assessment, consider the following example.

On the basis of the data contained in Table 4.3 and additional analyses, Table A.1 was prepared (see Appendix 1), containing the results of qualitative assessment of the risk identified. The assessment was conducted using the assessment scale, used to examine the probability of materialisation of risk factors, provided in Table 4.4, and the assessment scale applicable to effects of materialisation of risk factors, provided in Table 4.5. As a result of qualitative analysis, risk factors subject to quantitative analysis and preventive measures for negative effects of their materialisation were identified. These factors were highlighted by shading the appropriate rows of Table A.1.

4.5 QUANTITATIVE RISK ANALYSIS AND ASSESSMENT

4.5.1 PROCESS ESSENTIALS

Quantitative risk analysis is based on numerical determination of the approximate probability and estimated effects of materialisation of individual risk factors to:

- Assess numerically the probability of implementation of the project within the time specified and/or within the framework of the cost specified.
- Numerical assessment of the share of risk factors specified in the general project risk.
A diagram of the process of quantitative risk analysis and assessment has been presented in Fig. 4.9.

**Fig. 4.9: General diagram of the process of quantitative analysis and assessment of risk**

The input data for the quantitative risk analysis process are:

- Output data from the qualitative analysis and risk assessment process – a list of risk factors for qualitative analysis and assessment of impact on the project goals;
- Assumptions made for planning of durations and costs of works;
- Results of planning of duration and costs of works;
- Historic data on the problems encountered during the execution of similar projects;
- The project status as an objective situation (*observing the project progress, we can verify our assessment of probability and effects of materialisation of a given risk factor*).

The decision to conduct the risk quantitative analysis and assessment may result in a necessity to prepare an additional Risk register for quantitative analysis and assessment, containing the following information:

- The risk factor unique symbol or number, assigned during the project risk identification,
- The risk factor name, assigned during the project risk identification (characteristics of the risk factor are provided in the Risk register),
- The numerical value of the approximate probability of emergence (materialisation) of a given risk factor,
- Project objective, influenced by materialisation of a given risk factor (usually: project duration and cost),
- Name of the project activity or construction work, influenced by a given risk factor (individual risk factors may influence the entire project or only some of the works),
- Estimated effects of materialisation of a given risk factor (if the risk factor impacts only some of the works, estimated effects of its materialisation are provided with reference to the time and/or cost of a given work).

4.5.2 TOOLS AND TECHNIQUES

Tools and techniques of the risk quantitative analysis process include:
- Reviews of documentation and data, carried out to assess the completeness, integrity and certainty of the assumptions upon the estimated duration and costs of the project activities;
- Reviews of historic data for the assessment of the uncertainty of duration and costs of the project activities;
- Surveys of experts on the probability distributions of duration and costs of the project activities;
- Monte Carlo simulation, allowing generation of various scenarios of the duration and costs of the project activities and to determine the resulting distribution of the entire project duration and cost;
- Statistical techniques, enabling the analysis of the results of Monte Carlo simulation;
- Sensitivity analysis, enabling the assessment of the influence of the variations of duration and costs of individual activities on the entire project duration and cost;
- Computer software to support the use of Monte Carlo simulation, statistical techniques and Sensitivity analysis.

The existence of various risk factors assigned to a specific project activity results in the uncertainty of the actual duration and cost of this activity. The quantitative expression of this uncertainty is usually done using the probability distribution – discrete or continuous.
The discrete probability distribution is used if it is assumed that the uncertain result or effect of the materialisation of risk factors may be expressed by a number of hypothetical percentage or numerical values, and each of these values has a specific probability of its emergence. Of course, the total probability of emergence of optional results of materialisation of a given risk factor must be equal to 1.00 (or to 100%). For example, we assume, that if rainfall will occur, then the duration of the earthworks will be 10 days with the probability 70% or 12 days with the probability 30%. We can also assume, that compared to the baseline estimation, the duration of the earthworks will be extended by 3 days with the probability 70% or by 5 days with the probability 30%.

A continuous probability distribution is used when it is possible to estimate only the approximate scope of percentage or numerical values of the uncertain result or effect of the materialisation of risk factors. If there are no suitable statistical data, the decision to use a specific continuous probability distribution is made on the basis of an expert opinion. Most often, the following two types of continuous probability distribution are applicable:

- The uniform distribution, if it is possible to estimate only the lower and the upper duration and cost of a given work (we assume that all of the intermediate values are equally probable),
- The triangular distribution, if it is possible to estimate the optimistic, the pessimistic and the most probable duration and cost of a given work – see Fig. 4.10.

Fig. 4.10: The triangular probability distribution

A specialist computer software allows for the simulation of the project duration and cost according to the randomness of duration and costs of individual project activities. However, first we have to develop a computational model, allowing the determination of the duration and the cost of the entire project (output vari-
ables) upon duration and costs of individual activities (input variables) in each simulation. Based on the techniques of the project network model analysis like Critical Path Method – CPM, we can use the following formulas:

For the earliest start dates \( es_j \) and for the earliest finish dates \( ef_j \) of individual activities \( j = 1, 2, \ldots, J \):

\[
es_j = \begin{cases} 0 & \text{if } \{\text{Prec}(j)\} = \{\emptyset\}, \\ \max_{i \in \{\text{Prec}(j)\}} \{es_i + t_i\} & \text{if } \{\text{Prec}(j)\} \neq \{\emptyset\}, \end{cases}
\]

\[
ef_j = es_j + t_j
\]

where: \( \{\text{Prec}(j)\} \) – a set of direct predecessors of an activity \( j \) in the network model, \( t_j \) – duration of activity \( j \) in the network model.

For the latest start dates \( ls_i \) and for the latest finish dates \( lf_i \) of individual activities \( i = 1, 2, \ldots, J \):

\[
lf_i = \begin{cases} 0 & \text{if } \{\text{Succ}(i)\} = \{\emptyset\}, \\ \min_{j \in \{\text{Succ}(i)\}} \{lf_j - t_j\} & \text{if } \{\text{Succ}(i)\} \neq \{\emptyset\}, \end{cases}
\]

\[
ls_i = lf_i - t_i
\]

where \( \{\text{Succ}(i)\} \) is a set of direct successors of an activity \( i \) in the network model.

On the basis of results of analysis of the network model, the following outputs can be determined in each simulation:

- For the entire project duration or completion date:
  \[ t = ef_j; \]

- For the entire project cost:
  \[ k = tk_p + \sum_{j=1}^{N} k_j, \]

where: \( k_p \) – the project overheads rate, related to the time unit, \( k_j \) – the direct cost of the \( j \)-th project activity.
Having the computational model, we can use the *Monte Carlo* simulation to determine the distribution of project duration and the distribution of project cost, taking into account the uncertainty of duration and costs of the individual activities.

In general, the *Monte Carlo* simulation is based on the random drawing of input variable values, subject to the established probability distributions, and then – on the calculation of the value of the output variable. Repeating of this procedure many times, hereinafter referred to as a *trial*, leads to a set of data, hereinafter referred to as a *sample*, presenting the distribution of values of the output variable. In our case, the input variables are duration or costs of execution of individual project activities, while the output variable is the duration or the cost of the entire project.

Using the *statistical techniques*, we can determine the most significant numerical characteristics of the given output variable distribution, as presented in Table 4.8.

**Table 4.8: The most significant numerical characteristics of the output variable distribution**

<table>
<thead>
<tr>
<th>Numerical characteristics</th>
<th>Basic measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central values of the distribution of the output variable</td>
<td>( \bar{x} ): average value from trial</td>
</tr>
<tr>
<td>Diversification of the value of the output variable</td>
<td>( x^p ): modal (most probable) value from trial</td>
</tr>
<tr>
<td>Asymmetry of the distribution of the output variable</td>
<td>( x^m ): median from trial (central value)</td>
</tr>
<tr>
<td></td>
<td>( R ): range from trial</td>
</tr>
<tr>
<td></td>
<td>( s^2 ): variance from trial</td>
</tr>
<tr>
<td></td>
<td>( s ): standard deviation from trial</td>
</tr>
<tr>
<td></td>
<td>( CV ): variability index from trial</td>
</tr>
<tr>
<td></td>
<td>( A_2 ): skewness index from trial</td>
</tr>
</tbody>
</table>

The sample *average value* (mean) \( \bar{x} \) is the arithmetic average of numbers constituting a set of values of the output variable obtained:

\[
\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}.
\]

(4.10)

where: \( n \) – the size of the sample (the obtained number of values of the output variable).

The sample *modal* (most probable) value is the value of the output variable, which occurs most often in the data set.
The sample median (central value) is the number, which divides the set of values of the output variable, put in non-ascending (or non-descending) order into two parts, both equal in the number of values.

The difference between the greatest and the smallest value in the sample is a sample range width:
\[ R = x_{\text{max}} - x_{\text{min}} \]  

(4.11)

The sample variance is called the arithmetic average of the squares of differences between individual results and the average value of these results:
\[ s^2 = \frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}{n}. \]  

(4.12)

The sample standard deviation is the quadratic mean of deviations from the arithmetic average. The standard deviation is equal to square root of the variance:
\[ s = \sqrt{s^2}. \]  

(4.13)

The more scattered are the observed values of the output variable, the greater is the value of the sample standard deviation.

The coefficient of variation is the number equal to the product of standard deviation and the average value:
\[ CV = \frac{s}{\bar{x}}. \]  

(4.14)

The sample skewness is the number \( A_s \), calculated as follows:
\[ A_s = \frac{(x_1 - \bar{x})^3 + (x_2 - \bar{x})^3 + \ldots + (x_n - \bar{x})^3}{(n-1)s^3}. \]  

(4.15)

If \( A_s < 0 \), the output variable value distribution is characterized by positive skewness (it is right skewed). Such distribution has an average value greater than the median.
If $A_s > 0$, distribution of the value of the output variable is characterized by negative skewness (it is left skewed). Such distribution has an average value lower than the median.

If $A_s = 0$, the distribution is symmetrical. The average of such distribution is equal to the median and the modal value.

To establish the sample modal value and median, two charts are prepared. The first chart presents the histogram, while the second chart presents the empirical cumulative distribution function - CDF of the output variable.

The starting point for the preparation of the two charts is to divide the set of values of the output variable into $k$ class intervals (usually right bounded) with the lower limits $x_{1i}$ and the upper limits $x_{2i}$, where $i$ stands for the subsequent class interval. The sum of sizes of individual class intervals must be equivalent to the size of the entire sample:

$$\sum_{i=1}^{k} n_i = n. \quad (4.16)$$

Then, the empirical frequencies $w_i$ are determined:

$$w_i = \frac{n_i}{n}, \quad (4.17)$$

where: $n_i$ - the number of values of an output variable in the individual class intervals.

Empirical frequencies inform us how often the values of the output variable occur in the individual class intervals. Any of these frequencies may be treated as the approximation of the probability that the output variable will take value from the individual class interval. An example is presented in Table 4.9.
Table 4.9: The determination of the empirical frequencies of the output variable

<table>
<thead>
<tr>
<th>i</th>
<th>$X_{i1}$</th>
<th>$X_{i2}$</th>
<th>$n_i$</th>
<th>$w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>145</td>
<td>150</td>
<td>1000</td>
<td>0.100</td>
</tr>
<tr>
<td>2</td>
<td>155</td>
<td>155</td>
<td>5000</td>
<td>0.160</td>
</tr>
<tr>
<td>3</td>
<td>160</td>
<td>160</td>
<td>8000</td>
<td>0.120</td>
</tr>
<tr>
<td>4</td>
<td>165</td>
<td>165</td>
<td>15000</td>
<td>0.300</td>
</tr>
<tr>
<td>5</td>
<td>165</td>
<td>170</td>
<td>6000</td>
<td>0.120</td>
</tr>
<tr>
<td>b</td>
<td>1/4</td>
<td>1/5</td>
<td>5000</td>
<td>0.080</td>
</tr>
<tr>
<td>7</td>
<td>175</td>
<td>180</td>
<td>4000</td>
<td>0.060</td>
</tr>
<tr>
<td>8</td>
<td>180</td>
<td>185</td>
<td>3000</td>
<td>0.040</td>
</tr>
<tr>
<td>9</td>
<td>185</td>
<td>190</td>
<td>2000</td>
<td>0.020</td>
</tr>
<tr>
<td>10</td>
<td>190</td>
<td>195</td>
<td>1000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The histogram is the graphical representation of results given in Table 4.9 – see Fig. 4.11. Drawing the lines connecting the centres of the adjacent histogram columns, we get the empirical probability density function - PDF of the output variable. Based on the highest value of this function, we can specify the value, taken most often by the output variable. This is the theoretical modal value of the output variable – we assume that this value is repeated most often in the trial, but it is not equivalent to any of the values resulting from the simulation.
Fig. 4.11: The histogram based on the empirical frequencies of the output variable

In order to prepare a chart of the empirical cumulative distribution function, it is necessary to establish the accumulated frequencies \( G(x_i) \), incrementally totalizing the empirical frequency values \( w_i \) – see Table 4.10.

Table 4.10: The accumulated frequencies of the output variable

<table>
<thead>
<tr>
<th>( i )</th>
<th>( x_{(i)} )</th>
<th>( x_{(i+1)} )</th>
<th>( n_i )</th>
<th>( w_i )</th>
<th>( G(x_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>145</td>
<td>150</td>
<td>1000</td>
<td>0,020</td>
<td>0,020</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>155</td>
<td>5000</td>
<td>0,100</td>
<td>0,120</td>
</tr>
<tr>
<td>3</td>
<td>155</td>
<td>160</td>
<td>8000</td>
<td>0,160</td>
<td>0,280</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
<td>165</td>
<td>15000</td>
<td>0,300</td>
<td>0,580</td>
</tr>
<tr>
<td>5</td>
<td>165</td>
<td>170</td>
<td>6000</td>
<td>0,120</td>
<td>0,700</td>
</tr>
<tr>
<td>6</td>
<td>170</td>
<td>175</td>
<td>5000</td>
<td>0,100</td>
<td>0,600</td>
</tr>
<tr>
<td>7</td>
<td>175</td>
<td>180</td>
<td>4000</td>
<td>0,080</td>
<td>0,880</td>
</tr>
<tr>
<td>8</td>
<td>180</td>
<td>185</td>
<td>3000</td>
<td>0,060</td>
<td>0,940</td>
</tr>
<tr>
<td>9</td>
<td>185</td>
<td>190</td>
<td>2000</td>
<td>0,040</td>
<td>0,980</td>
</tr>
<tr>
<td>10</td>
<td>190</td>
<td>195</td>
<td>1000</td>
<td>0,020</td>
<td>1,000</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td></td>
<td>50000</td>
<td></td>
<td>1,000</td>
</tr>
</tbody>
</table>

The bar chart of the accumulated frequencies of the output variable is given in Fig. 4.12. Drawing the lines connecting the upper boundaries of the adjacent bars, we get the empirical cumulative distribution function of the output variable. On its basis, we can determine the median as the value separating the higher half of a sample from the lower half. The median is also theoretical - it is not equivalent to any of the values resulting from the simulation.
As a result of the use of Monte Carlo simulation and statistical techniques, we can get:
- the histogram and the empirical cumulative distribution function of the project duration random variable \( T \), and
- the histogram and the empirical cumulative distribution function of the project cost random variable \( K \), due to the randomness of the duration and costs of the project activities.

Furthermore, we can determine:

1) For the random variable \( T \) of the project duration:
- the optimistic value \( t^a \) and pessimistic value \( t^b \); these values are often referred to the empirical cumulative distribution function \( G(t^a) = 0,10 \) and to the empirical cumulative distribution function \( G(t^b) = 0,90 \);
- the average value \( t \);
- the modal (most probable) value \( t^d \);
- the median \( t^m \), for which \( G(t^m) = 0,50 \);
- the probability \( P(T \leq t_d) = G(t_d) \) that the project will be executed within the prescribed time limit \( t_d \).
2) For the random variable $K$ of the project cost:
- the optimistic value $k^a$ and pessimistic value $k^b$; these values are often referred to the empirical cumulative distribution function $G(k^a) = 0.10$ and to the empirical cumulative distribution function $G(k^b) = 0.90$;
- the average value $\bar{k}$;
- the most probable value $k^d$;
- the median $k^m$, for which $G(k^m) = 0.50$;
- the probability $P(K \leq k_d) = G(k_d)$, that the project will be executed within the prescribed cost limit $k_d$.

Based upon the calculation of the total time float of an individual activity in each simulation:
$$tf_j = ls_j - es_j,$$
we can also determine the criticality of this activity. This can help for the planning the appropriate preventive actions.

However, for the proper risk management it would be more reasonable to identify the most critical risk factors, i.e. the factors that most threaten the achievement of the project objectives. For this, the following alternative procedure of risk analysis may be used:

1. Identify project activities with uncertain duration and direct costs.
   Refer to the Register of risk for quantitative analysis and assessment.

2. Determine risk factors causing the uncertainty of duration and direct cost of a given activity.
   Refer to the Register of risk for quantitative analysis and assessment.

3. Determine the probability of the materialisation of a given risk factor.
   Refer to the Register of risk for quantitative analysis and assessment. It is rare (however, not excluded) that a given risk factor will surely materialize. Therefore, assume the Bernoulli probability distribution of the probability of the materialisation of a given risk factor. This is the discrete probability distribution with only two realizations of the random variable $X$: $X = 1$ or $X = 0$. The probability of realization of a random variable with the Bernoulli distribution is:
\[ P(x_i) = p \quad \text{if} \quad X = 1 \quad \text{(4.19)} \]

or

\[ P(x_i) = q = 1 - p \quad \text{if} \quad X = 0, \quad \text{(4.20)} \]

Where \( i = 1 \) or 2. You can get the Bernoulli probability distribution on the basis of the binomial distribution, assuming the number of trials to be equal to 1 and taking the probability of success in one trial as equal to the estimated probability of the materialisation of a given risk factor.

4. Determine the probability distribution of the effects of materialisation of a given risk factor, separately for each of the project activities under consideration. Refer to the Register of risk for quantitative analysis and assessment.

5. Determine all of the possible scenarios of the materialisation of risk factors, assigned to a given project activity under consideration. If \( n \) risk factors have been assigned to a given project activity under consideration, the number of possible scenarios of materialisation of the risk factors for this task is equal to \( 2^n \).

For example, for three risk factors \( R_1, R_2 \) and \( R_3 \), we have to take into account the eight of the following scenarios of their simultaneous materialisation (1 stands for the materialisation, 0 – for the lack of the materialisation of a given risk factor):

<table>
<thead>
<tr>
<th>Scenario number</th>
<th>( R_1 )</th>
<th>( R_2 )</th>
<th>( R_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

6. Determine, for each of the scenarios of materialisation of risk factors, the probability distributions of the resulting duration and of the resulting direct cost of given project activity.

The effect of the simultaneous materialisation of two or more risk factors is usually greater than the algebraic sum of effects of materialisation of these factors, examined separately.
We can take this into account in the following way:
- let us assume that the duration of the $j$-th activity, disregarding all risk factors, has been estimated as $t_j = 100\%$;
- it is expected that during the execution of this activity, risk factors $R_1$ and $R_2$ may materialize,
- the shortening or the extension of the duration of this activity under the materialisation of factor $R_1$ or of factor $R_2$ is expressed using the triangular probability distribution, with the optimistic value $t_j^{(a)}$, the most probable value $t_j^{(d)}$ and the pessimistic value $t_j^{(b)}$, $k = 1$ or $2$, like below:

<table>
<thead>
<tr>
<th>Risk</th>
<th>$t_j^{(a)}$</th>
<th>$t_j^{(d)}$</th>
<th>$t_j^{(b)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>-10%</td>
<td>20%</td>
<td>90%</td>
</tr>
<tr>
<td>$R_2$</td>
<td>-15%</td>
<td>15%</td>
<td>25%</td>
</tr>
</tbody>
</table>

- the hypothetical result of the simultaneous materialisation of factor $R_1$ and factor $R_2$ may be expressed using the triangular probability distribution, with parameters $t_j^{(a)}$, $t_j^{(d)}$ and $t_j^{(b)}$, determined as below:

\[
\begin{align*}
    t_j^{(a)} &= (0.90 \times 0.85) \times 100\% = 76\%; \\
    t_j^{(d)} &= (1.20 \times 1.15) \times 100\% = 138\%; \\
    t_j^{(b)} &= (1.30 \times 1.25) \times 100\% = 163\%.
\end{align*}
\]

7. **Develop the simulation model**

We can use the following spreadsheet:
- select randomly the value 1 or 0 from the Bernoulli probability distribution of materialisation of each of the risk factors assigned to a given activity; for example, the result may be:
  \[P(R_1) = 1, P(R_2) = 0, P(R_3) = 1\] (refer to step 4);
- identify the scenario of materialisation of risk factors, assigned to a given activity; for the example given above, it is the scenario No 5 (refer to step 6);
- select randomly the value from the hypothetical triangular probability distribution of the duration and of the direct cost of a given project activity for the given scenario of the materialisation of risk factors, assigned to this activity (refer to step 7);
- calculate the resulting project duration and cost, using the formulae of the computational model for the project network analysis.
8. Run the simulation.
Use the specialist computer software, cooperating with the spreadsheet given above.

9. Analyse the result of the simulation.
Use the specialist computer software, cooperating with the spreadsheet given above.

In addition to the numerical characteristics of the given output variable distribution, the significant information for the further risk management processes is the precise assessment of impact of individual risk factors on the project duration and cost. This information results from:
1) the Tornado analysis;
2) the sensitivity analysis using Spearman’s rank correlation coefficients.

The Tornado analysis is carried out to assess the sensitivity of the project makespan and cost to the effects of materialisation of a given risk factor, assuming that the remaining risk factors are not materialized.

An exemplary result of the Tornado analysis has been presented in Fig. 4.13. It is a bar chart with the following characteristics:
- the lengths of the bars are proportional to the sensitivity of the project duration or cost to the effects of the materialisation of individual risk factors, examined separately;
- the bars are laid in the order of the decreasing impact of individual risk factors on variability of the project duration or cost;
- the cut-off ends of individual bars determine the minimum and the maximum duration or cost of the project in the case of the materialisation of a given risk factor.
The sensitivity analysis using the rank correlation coefficients is carried out to examine the strength of the monotonic correlation, positive or negative, between the effects of materialisation of individual risk factors and the resulting change of the project duration or cost in relation to the values estimated without the risk. In general, the positive monotonic correlation is observed, when an increase in the input variable value results in increasing of the value of the output variable. On the other hand, a negative monotonic correlation is observed, when an increase in the value of the output variable results in a decrease in the value of the output variable.

For a statistical sample, a rank correlation estimator for variables $X$ and $Y$ is determined as follows:

1. For each variable compared, independent ranking is carried out:
   - the observed values of a given variable (on a numerical or interval scale) are arranged in the ascending order,
   - to each value $x_k$ of variable $X$, rank $R_x$ is assigned, equal to the position of a given value of this variable in the ascending order (the lowest value gets rank 1, the next value – rank 2, etc.)
   - similarly, to each value $y_k$ of variable $Y$, rank $R_y$ is assigned.

2. After returning to the previous arrangement of variable values, a rank correlation estimator is determined:

$$r = \text{corr}(R_X, R_Y),$$  \hspace{1cm} (4.21)

where: \text{corr} - the classical Pearson correlation coefficient,
RX - rank of variable X in the sample,
RY - rank of variable Y in the sample.

In the case of a small sample and the lack of tied ranks (values do not repeat within the sample for any of the variables separately), the following formula can be used:

\[ r = 1 - \frac{\sum d_k^2}{n(n^2 - 1)} \]  

(4.22)

Where \( d_k = R_{X_k} - R_{Y_k} \) is the difference between ranks of variables X and Y for \( k \) – th observation, while \( n \) is the size of \( d_k \).

For example:

<table>
<thead>
<tr>
<th>Observation number, ( k )</th>
<th>( x_k )</th>
<th>( y_k )</th>
<th>Rank ( R_{X_k} )</th>
<th>Rank ( R_{Y_k} )</th>
<th>( d_k^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>2.4</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1.6</td>
<td>2.5</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2.7</td>
<td>3.1</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
<td>2.3</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>2.2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>3.1</td>
<td>3.9</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ \sum d_k^2 = 2 \]

\[ r = 0.94 \]

If a given variable value appears many times, each of its appearances is assigned the same rank, equal to the arithmetic average of the position in the ascending order (it is a tied rank). Therefore, fractional ranks may appear, such as rank 4.5.

In the case of the emergence of tied ranks, it is also possible to use Pearson’s formula:

\[ r = \frac{\sum_k (x_k - \bar{x})(y_k - \bar{y})}{\sqrt{\sum_k (x_k - \bar{x})^2 \sum_k (y_k - \bar{y})^2}} \]  

(4.23)
For example:

\[
\sum_k (x_k - \bar{x})^2 \sum_k (y_k - \bar{y})^2 = 3.21;
\]

\[
\sqrt{\sum_k (x_k - \bar{x})^2 \sum_k (y_k - \bar{y})^2} = 2.99;
\]

\[
r = 0.93.
\]

The specialist computer software to assist project risk management uses also other techniques to determine the rank correlation estimators of variables, such as the Iman – Conover algorithm.

The rank correlation coefficients take values from the interval \([-1; 1]\). The positive value of the rank correlation coefficient means that there is a directly proportional correlation between the effect of the materialisation of a given risk factor and the project duration or cost. Thus, the materialisation of a given risk factor will be a threat to the execution of the project within the prescribed time or cost limit. On the other hand, the negative value of the rank correlation value means that the materialisation of a given risk factor may increase the chance for the execution of the project within the prescribed time or cost limit. The null value of a rank correlation coefficient means that a given risk factor does not influence the project duration or cost.

Sensitivity analysis using rank correlation coefficient enables the arrangement of risk factors according to their impact on the project execution in the case of their simultaneous materialisation.
An exemplary result of a sensitivity analysis using the rank correlation coefficients has been presented in Fig. 4.6. It is a bar chart with the following characteristics:

- the lengths of the bars are proportional to the values of the rank correlation coefficients, specifying the strength of the correlation between the effects of the materialisation of individual risk factors and the variability of the project duration;
- the bars are arranged in the order equivalent to the decreasing impact of individual risk factors on the variability of the project duration;
- positive values of the rank correlation coefficients show that the materialisation of each of the risk factors will result in the extension of the project duration in relation to the duration estimated with neglecting the project risk.

Values of rank correlation coefficients can be normalized using the formula:

\[
    r_{i,sb} = \frac{r_i^2}{\sum_{i=1}^{n} r_i^2} \times 100\% \tag{4.24}
\]

where \( r_i \) is the value of the given rank correlation coefficient.

As a result, we obtain a bar chart as in Fig. 4.14. This diagram informs us about the percentage share of the effects of the materialisation of individual risk factors in the change of the project duration or cost.

![Fig. 4.14: An exemplary result of the analysis of sensitivity using the rank correlation coefficients](image).
Fig. 4.15: An exemplary result of the sensitivity analysis after normalization of the rank correlation coefficients

The results of the Tornado analysis and the sensitivity analysis with the use of rank correlation coefficients can then be used to course the risk response activities. On the basis of the results presented in Fig. 4.15, it can be stated that the risk factor marked as R6 does not require any further action.
4.5.3 AN EXAMPLE OF PROJECT QUANTITATIVE RISK ANALYSIS AND ASSESSMENT

To illustrate the construction project quantitative risk analysis and assessment, consider the following example.

Moving on with the example examined in Chapters 3 and 4, we conducted an analysis and quantitative assessment of risk for a construction project. In the case of disregarding of the effects of materialisation of the risk factors, the nominal project completion time is 75 working days, while the nominal cost of the project completion is € 890.000.

Individual risk factors, subjected to analysis of quantitative impact on the time and cost of the project implementation, have been assigned symbols from R1 to R7. Then the following were determined:

- the probability of materialisation of each of the risk factors,
- possible scenarios of materialisation of risk factors with reference to individual project tasks,
- probability distributions of effects of individual scenarios of risk factor materialisation with reference to individual project tasks.

It was assumed that:
- the required time of the project implementation was 85 working days from the construction commencement date,
- due to financial difficulties, the contractor could undertake implementation of a project with the performance cost not exceeding the amount of € 1.000.000,
- the probability of materialisation of risk factor R1 associated with site availability for organisation of the temporary plant and facilities is 60%,
- the probability of materialisation of risk factor R2 associated with obtaining of permits for removal of the existing plants is 80%,
- the probability of materialisation of risk factor R3 associated with changing availability of materials for performance of construction works is 50%,
- the probability of materialisation of risk factor R4 associated with changing availability of materials for performance of installation works is 20%,
- the probability of materialisation of risk factor R5 associated with qualifications of workers performing various types of works is 50%,
- the probability of materialisation of risk factor R6 associated with changeability of weather conditions is 50%,
- the probability of materialisation of risk factor R7 associated with the possible amendments of the scope of works is 50%.
The possible scenarios of materialisation of risk factors and probability distributions of effects of such materialisation have been presented in Table 4.11. It was assumed that the uncertainty of effects of various scenarios of materialisation of risk factors can be described using triangular probability distributions.

**Table 4.11: A breakdown of possible scenarios of materialisation of risk factors and probability distributions of effects of their materialisation**

<table>
<thead>
<tr>
<th>No.</th>
<th>Task name</th>
<th>Risk factor materialisation scenario</th>
<th>Nominal time or cost of task performance</th>
<th>In the case of risk materialisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Minimum value of time or cost of task performance</td>
</tr>
<tr>
<td>1</td>
<td>Preparatory works</td>
<td>R1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1 i R2</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Excavation</td>
<td>R6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Roofing</td>
<td>R6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Painting</td>
<td>R3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Finishing</td>
<td>R6</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>Water supply &amp; sewage</td>
<td>R4</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R5</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R4 i R5</td>
<td>12</td>
<td>17</td>
</tr>
</tbody>
</table>

**Part I – impact of individual risk factor materialisation scenarios on the task performance time**

| No. | Preparatory works          | R1                                  | 6                                      | 6                                 | 8                                 | 11                                 |
|     |                            | R2                                  | 6                                      | 7                                 | 8                                 | 10                                 |
|     |                            | R1 i R2                             | 6                                      | 7                                 | 11                                | 17                                 |
| 2   | Excavation                | R6                                  | 5                                      | 6                                 | 8                                 | 10                                 |
| 3   | Roofing                   | R6                                  | 6                                      | 7                                 | 8                                 | 10                                 |
| 4   | Painting                  | R3                                  | 7                                      | 7                                 | 10                                | 11                                 |
| 5   | Finishing                 | R6                                  | 13                                     | 15                                | 18                                | 24                                 |
| 6   | Water supply & sewage     | R4                                  | 12                                     | 15                                | 18                                | 21                                 |
|     |                            | R5                                  | 12                                     | 13                                | 14                                | 16                                 |
|     |                            | R4 i R5                             | 12                                     | 17                                | 22                                | 27                                 |

**Part II – impact of individual risk factor materialisation scenarios on the task performance cost**

| No. | Preparatory works          | R1                                  | 1200                                  | 1500                                | 1900                                | 2300                                |
|     |                            | R2                                  | 1200                                  | 1700                                | 2300                                | 2500                                |
|     |                            | R1 i R2                             | 1200                                  | 1900                                | 2600                                | 2900                                |
| 8   | Excavation                | R6                                  | 3500                                  | 4500                                | 5400                                | 5500                                |
| 9   | Roofing                   | R6                                  | 1800                                  | 2800                                | 3800                                | 4100                                |
The quantitative risk analysis was performed using the Excel spreadsheet and the Crystal Ball software (education licence). The analysis results have been presented below.

1. Analysis and quantitative assessment of the impact of individual risk factor materialisation scenarios on the project performance time

On the basis of Fig. 4.16 and Fig. 4.17 it can be stated that:
- as a result of possible emergence of various risk factor materialisation scenarios associated with individual project tasks, the project implementation time is a random variable ranging from 75 to 96 working days,
- the expected value of the project implementation time random variable is 84 working days, and the median of the project implementation time variable is 83 working days,
- in the example presented, the most probable value of the project completion time random variable is equal to the median of this variable,
- the probability of completion of the project within the required deadline is 66.4 %.

On the other hand, Fig. 4.18 shows that the most significant impact on variability of the project completion time is exerted by risk factor R4, characterized by the lowest materialisation probability. On the other hand, R2 risk factor of the highest materialisation probability exerts the least significant impact on changeability of the project completion time.
Fig. 4.16: A histogram of the project completion time random variable for the example presented

Fig. 4.17: A bar chart of cumulative parts (empirical distribution function) for the project completion time random variable
2. Quantitative assessment and analysis of the impact of individual risk factor materialisation scenarios on the project completion cost

On the basis of Fig. 4.19 and Fig. 4.20, it can be stated that:

- as a result of the possible emergence of various risk factor materialisation scenarios that exert impact on individual project tasks, the project implementation cost is a random variable assuming values of €890000,0 to €1272000,
- the expected value of the project completion cost random variable is €1025791, and the median of this random variable is €1021861,
- the most probable value of this variable is €1010871,
- the probability that the project implementation cost will not exceed €1000000, is 71.6%.

On the other hand, Fig. 4.21 indicates that the most significant impact on changeability of the project completion cost is exerted by risk factor R1 of materialisation probability equal to 60%. On the other hand, risk factor R2, characterized by the highest materialisation probability, is the least significant for change ability of the project implementation cost.
Fig. 4.19: A histogram of the project cost random variable for the example presented

Fig. 4.20: A bar chart of cumulative parts (empirical distribution function) for the project cost random variable for the example presented
4.6 RISK RESPONSE PLANNING

4.6.1 PROCESS ESSENTIALS

The objective of the process of planning of the response to risk is to specify and determine the actions that reduce the threats to achievement of the project goals as a result of materialisation of risk factors. In the case of acceptance of the possibility of materialisation of a given risk factor, reserves for the duration and cost of the project are established, which may become necessary to compensate for the effects of its materialisation.

The risk response planning process diagram has been presented in Fig. 4.22.
The input data for planning of the risk response include:
- Output data from the process of analysis and assessment of the project risk – a histogram and an empirical cumulative distribution function from the process of analysis and assessment of the project risk – a histogram and an empirical cumulative distribution function of the duration and cost of the project and a list of risk factors, arranged in accordance with their impact on achievement of the project goals;
- The risk acceptance thresholds – the required levels of reliability of keeping the planned duration and cost of the project;
- Historic data, containing information on effectiveness of individual responses to project risks.

Selection of a specific response to risk depends on the strategy of responding to risk factors, established at the company, depending on the assessment of their probability and effects of their materialisation. In general, the following types of responses to risk can be listed:
- Avoiding of risk;
- Acceptance of risk;
- Transfer of risk;
- Mitigation of risk.

Avoiding of risk is based on withdrawal from placement of bid for performance of the project or on placement of a bid for performance of only a part of the project (if the ordering party allows for such bid placement). Avoiding of risk may also be based on making of pessimistic assumptions with regard to estima-
tion of the duration or cost of the works. Such response is usually applied to risk factors, for which the probability is at least high and the effects of materialisation are at least painful.

**Acceptance of risk** is based on takeover of risk without undertaking any action. Such response is usually applicable to risk factors characterized by no more than moderate probability and effects of materialisation.

**Transfer of risk** to another participant in the undertaking or the insurer is an alternative to avoiding of risk, if the expected effects of materialisation of risk factors are assessed to be at least painful, regardless of the probability of materialisation of the risk factors.

**Mitigation of risk** is based on undertaking preventive action to reduce the probability or effects of materialisation of a given risk. Such response is usually applicable, when it is impossible to avoid or transfer the risk. In this case, apart from providing – in the Risk register – a description of the activities to mitigate the risk, an Emergency plan is also established to be used in the case of lack of effectiveness of the preventive measures.

Deciding to transfer the risk or to apply activities to reduce risk, it is necessary to consider:

- **Residual risk**, which remains present despite planning of the response to the original project risk. For example, if one of the threats to the project performance cost has been identified to constitute the possible necessity to eliminate the negative impact of the construction project on the environment, and only replacement of polluted soil around the warehouse of chemicals has been planned, there is still a possibility of emergence of the problem of elimination of environmental damage effects, among other things, due to harmful waste that remains after the works performed.

- **Secondary risk**, caused by implementation of the response to the original project risk. For example, if we plan to hire a subcontractor in response to a risk of making a mistake in the case of performance of a certain activity using own workforce, insufficient technical knowledge concerning the technical conditions of performance and acceptance of the works subcontracted may result in a dispute with the subcontractor, resulting in a delay in completion of the subcontracted works.
Activities that reduce the probability of materialisation of a given risk factor include:

- Verification of the project documentation and data on the construction site, received from the Client;
- Obtaining of additional explanations concerning the design solutions, technical requirements and contract conditions;
- Conducting of additional surveys on the site;
- Amendment of the assumptions with regard to the mode of performance of specific activities;
- Hiring only of reliable suppliers or subcontractors;
- Planning of appropriately early deadlines for delivery of materials to the construction site;
- Increasing of the scope and frequency of inspections and tests of materials and works;
- Improvement of communication between the supervision personnel and the work teams.

Activities that reduce the effects of materialisation of a given risk include:

- Allocation of additional workforces or equipment for performance of works susceptible to effects of materialisation of risk factors;
- Provision of means of protection of the construction site and its surround against the harmful impact of the execution of works;
- Provision of means of protection of the materials and works against low temperatures, rain and similar risk factors.

4.6.2 TOOLS AND TECHNIQUES

The tools and techniques for planning of a risk response include:

- Reviews of documentation and data, supporting the selection of a specific response to the possibility and effects of materialisation of risk factors for the project;
- A probabilistic analysis, supporting the determination of the necessary time and cost reserves (contingencies) for the project.

A traditional method of risk mitigation is to use the simulation results to establish the “safe” duration and costs of works for the planning purposes, i.e. the duration and costs of works which ensure the required reliability of compliance. The scheme for determination of the safe duration of \( a_i \)-th work on the basis of the simulation results is presented in Fig. 4.23.
According to this scheme, the “safe” duration of the $i$-th work is:

$$ t_i' = t_i'' + r_i' $$

(4.25)

where:

- $t_i'$ – duration of $i$-th work, estimated with taking into account the required risk acceptance threshold (RAT),
- $t_i''$ – duration of $i$-th work, estimated with neglecting project risks (or opportunities);
- $r_i'$ – time contingency (reserve) for $i$-th work.

Using the scheme similar to presented in Fig. 4.23, one can establish a “safe” cost estimate of $i$-th work. However, the presented above mode of responding to risk seems to be not rational, because the accumulation of contingencies may result in an unnecessary increase of the planned duration and cost of the project. It is more advantageous to:

- move the risk from the activity level to the entire project level;
- plan and perform the appropriate preventive actions, reducing the probability or effects of materialisation of a given risk factor.
This can be done by:

• inserting time buffers in the project schedule, ensuring the protection only of the planned completion date of the entire project against the disturbances caused by the materialisation of various risk factors.
• establishing a project reserve (contingency), containing the funds to be used to reduce the effects of materialisation of the project risk factors in the case of preventive actions turning out to be insufficient;

To move the risk from the activity level to the project level, the Critical Chain method (Goldratt, 1997; Leach, 2005) is recommended by some researchers and practitioners.

The Critical Chain (CC) is the set of activities, the duration of which determine the duration of the entire project, taking into account the technological and the additional resource relations between the project activities. Note, that the project critical path is determined only for the technologically dependent activities. Using the Critical Chain method, we aim on the protection only of the planned completion date of the entire project against the disturbances caused by the materialisation of various risk factors. The basic idea here is to:

a) use the “aggressive” estimation of activities’ duration instead of “safe” estimations,
b) identify the project Critical Chain,
c) insert:
   – at the end of the project Critical Chain: a Project Buffer (PB) to protect the planned completion date of the entire project,
   – where the project sub-paths merge with the Critical Chain: Feeding Buffers (FB) to protect the Critical Chain against the propagation of disturbances caused by delays in performance of activities from the outside of this chain.

The difference between the “safe” estimate and the “aggressive” estimate equals to the time reserve for the duration of a given work. Those reserves are aggregated in the Project Buffer and in the Feeding Buffers.

The size of the Project Buffer is determined analytically, according to the length of the Critical Chain, to the number of activities in this chain and to the uncertainties of their duration. The same applies to the Feeding Buffers sizing.

The Critical Chain method introduces also Resource Buffers, serving as a mechanism of ensuring that resources are ready for an activity which predecessors are completed. Resource Buffers do not occupy any time.

The scheduling with the use of the CC method is carried out in two stages. In the first stage, a preliminary schedule is established, which takes into account the limitations in availability of renewable resources – the workforce and the
equipment for performance of the works. In the preliminary schedule, a Critical Chain is determined, which contains the activities influencing the completion date of the entire project. During the second stage, the preliminary schedule is rearranged by inserting time buffers, which protect the scheduled project completion date against propagation of the disturbances caused by the materialisation of risk factors.

For the preparation of a preliminary schedule, “safe” duration of works are applied. Basically, the pessimistic estimate $t_i^b$ of a duration of a given work is considered as “safe”, but sometimes a safe estimate is determined at the probability level equal to 90%.

Using the results of a project critical path analysis, a preliminary schedule is determined for the latest possible start and finish dates of individual works. Then, the resource conflicts between activities are resolved. This results in introducing additional, resource relations (or dependencies) between some activities in an original project network model. Taking into account the technological order of works and the additional resource relations, the Critical Chain is selected. In the second stage, the planned duration of works are reduced from “safe” to “aggressive” estimations. This can be done simply by taking the one half of a given “safe” estimation. However, if we want to use simulation for the further check-out of the protection of project completion date, it would be reasonable to take a modal value $t_i^m$ as an “aggressive” estimate. The modal value ensures the safety of planned duration of an activity $i$ at the probability level of 50%.

After the reduction of planned duration of works, a buffered schedule is prepared. Originally, length of the Project Buffer is sized as the one half of the total of time reserves of activities in the Critical Chain (cut and paste method). Other formulae are also used to determine the size of the project buffer, such as root square error method:

$$ PB = \sqrt{\sum_{j \in CC} (t_{j}^{\text{des}} - t_{j}^{m})^2}. $$

(4.26)

The sizes of the Feeding Buffers are determined in a similar manner.

It should be noted that the baseline schedule for the contractual purposes does not contain any buffers. The data on project buffer and on feeding buffers should be known only to the construction management. Disclosure of this data may result in an occurrence of a “student syndrome” – putting off of the start
dates of works with regard to the time reserves. Individual works in the Critical Chain should be started immediately after the completion of their predecessors (the *road runner policy*). This means that for the managerial purposes, there are no prescribed start and finishing dates of works in the Critical Chain. However, the start of the any given Feeding Chain may be delayed as soon as possible. Work teams should be notified only of the approaching of the start dates of the works assigned to them and they should execute these works as quickly as possible.

The idea of the *CC* method is focused on the protection only of the planned completion date of the entire project. We can aim also at the additional protection of the planned start dates of individual project activities. For this purpose, we can adopt the **predictive scheduling method**, introduced by Herroelen and Leus (2004) and Van de Vonder et al. (2005, 2006). Simplifying this idea, we can stabilize the project schedule by inserting buffers which minimize the total expected cost of the deviations between the actual start times of activities, predicted (on the basis of the simulation) during project execution and their start dates given in the baseline schedule. It is assumed, that during the execution of the project, the following policies are used:

- the not buffered activities shall start as soon as possible (the *road runner policy*);
- the buffered activities shall start not ahead of their scheduled dates (the *railway policy*).

We can formulate the problem of the schedule stabilization as follows:

\[
\min \mathbb{E}(K_{\text{ins}}) = \sum_{j=1}^{J} k_j \mathbb{E}(S_j - s_j),
\]

where: 
- \(s_j\) – the planned start date of activity \(j\), fixed in the buffered schedule,
- \(S_j\) – the random variable of the predicted start date of activity \(j\),
- \(k_j\) – the unit cost of delaying the start of activity \(j\) in relation to its scheduled start date,
- \(K_{\text{ins}}\) –the random variable of the schedule instability cost,
- \(\mathbb{E}(X)\) – the expected value of the random variable \(X\).

The solution of the schedule stabilization problem must meet the following conditions:

- no activity may not begin until its predecessors are completed:
  \[
  s_j - b_j \geq s_i + t_i, \quad i \in \{\text{Prec}(j)\},
  \]

- the project starts at the zero moment of time:
Due to the high computational effort, it is impractical to search for the analytical method, which guarantees the exact solution of the given above problem. It seems more reasonable to develop the computational model in a spreadsheet and then to use the specialist computer software, automatically searching for and finding optimal solutions to the model via combination of simulation and optimization.

4.6.3 EXAMPLES OF THE PROJECT SCHEDULE BUFFERING
1) THE CRITICAL CHAIN METHOD

To illustrate the use of the Critical Chain method (CC) for the project schedule buffering, consider the following example. An original network model of a simple construction project is presented in Fig. 4.24. Symbols $S$ and $F$ stand for the start and for the completion of the entire project, respectively. The data for the network model analysis are given in Table 4.12. Symbols $W_1$, $W_2$, $W_3$, and $W_4$ stand for the names of the specialised work teams for the execution of individual works. The duration of activities are random variables of the triangular probability distribution. The time unit is a work day, and employees work 5 days a week.

The Client requires that the taking over of the completed construction should take place not later than on 01.10.2012. The Contractor is able to start the works not earlier than on 16.08.2012. Due to the holidays, to meet the taking over date defined by the Client, the construction must be completed no later than by 28.09.2012.

\[
\begin{align*}
\text{Fig. 4.24: The network model of a simple construction project} \\

table4.12: The data for the network model of a simple construction project
\end{align*}
\]

\[
\text{THE FIRST STAGE} \\
1. The preliminary schedule
\]
The results of the network model analysis with works durations \( t_i^{\text{pes}} \) are presented in Table 4.13. We assume that the project starts in the zero point of time. Therefore, the planned finish time of an activity \( F \) corresponds to the planned duration of the entire project: 25 work days. The critical path in the network model consists of activities: \( S-2-3-4-7-F \).

**Table 4.13: The Critical Chain method – the results of analysis of the network model for the pessimistic durations of works**

<table>
<thead>
<tr>
<th></th>
<th>Prec(i)</th>
<th>Succ(i)</th>
<th>( t_i^{\text{pes}} )</th>
<th>( es_i )</th>
<th>( ef_i )</th>
<th>( ls_i )</th>
<th>( lf_i )</th>
<th>( tr_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>2,5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>8</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>14</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>15</td>
<td>9</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>9</td>
<td>15</td>
<td>15</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>4,6</td>
<td>8</td>
<td>4</td>
<td>21</td>
<td>25</td>
<td>21</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>0</td>
</tr>
</tbody>
</table>

Assuming that works not belonging to the critical path can start and finish at the latest possible dates, we obtain the schedule presented in Fig. 4.25. Works could be started on 27.08.2012 and completed on 28.09.2012. Due to the application of the pessimistic estimations of duration of the works, the required project completion date is fully secured. However, the implementation of this schedule requires simultaneous performance of work \( i = 3 \) and work \( i = 5 \) by the work team \( W_2 \). The Contractor has at its disposal only one team with the work specialization \( W_2 \). Therefore, this schedule is not feasible.

**Fig. 4.25: The Critical Chain method – the Preliminary schedule**

2. The elimination of the resource conflict

To eliminate the resource conflict, it was decided that the execution of work \( i = 5 \) should precede the execution of work \( i = 3 \). This decision preserves the tech-
nological relations between the works. However, it results in the modification of the original project network, caused by the provision of additional resource relations between project activities (Fig. 4.26 and Table 4.15).

The results of analysis of the modified network model are presented in Table 20. In this case, the planned project makespan is 34 work days. The Critical Chain in the network model consists of activities $S\rightarrow 2 \rightarrow 5 \rightarrow 3 \rightarrow 4 \rightarrow 7 \rightarrow F$. The resulting construction schedule for the latest start and finish dates of works with durations $t_i^{pes}$ is presented in Fig. 4.27. To ensure the full protection of the required project completion time, the Contractor should start the works on 14.08.2012. In the case examined, however, this is not possible.

**Fig. 4.26: The Critical Chain method - the network model after the elimination of the resource conflict**

**Table 4.14: The Critical Chain method - the data for the network model after the elimination of the resource conflict (The additional resource relations between works are marked with italics)**

<table>
<thead>
<tr>
<th>Work, $i$</th>
<th>Prec($i$)</th>
<th>Succ($i$)</th>
<th>Work team symbols</th>
<th>Available number of work teams</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 1$</td>
<td>-</td>
<td>2, 5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3, 5</td>
<td>$W_1$</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2, 5</td>
<td>4</td>
<td>$W_2$</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>7</td>
<td>$W_3$</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1, 2</td>
<td>3, 6</td>
<td>$W_2^*$</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>7</td>
<td>$W_4$</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>4, 6</td>
<td>8</td>
<td>$W_1$</td>
<td>1</td>
</tr>
<tr>
<td>$F = 8$</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 4.15: The Critical Chain method – the results of analysis of the network model after the elimination of the resource conflict**
THE SECOND STAGE

3. The reduction of the duration of works

Table 4.16 presents the results of analysis of the modified network model after reduction of the duration of works from $t_{\text{ris}}$ to $t_{\text{im}}$. The construction schedule is presented in Fig. 4.28. Each of the works in the Critical Chain starts immediately after the completion of the preceding work. On the other hand, works not belonging to the Critical Chain (in this case, work $i = 6$) may be started at the latest times $ls_i$. The planned construction makespan is 25 work days. Assuming that works should be completed no later than on 28.09.2012, the execution of the project could be started on 27.08.2012. However, due to the random character of the duration of individual works, the probability of completion of the construction on 28.09.2012 is only 50%.

Table 4.16: The Critical Chain method – the results of analysis of the network model after the elimination of the resource conflict and after the reduction of durations of works
Determine the size of the project buffer as the one half of the total time reserve of the critical activities, we obtain:

\[ PB^I = 0.5 \cdot [(t_{6}^{\text{pes}} - t_{2}^{\text{m}}) + (t_{3}^{\text{pes}} - t_{1}^{\text{m}}) + (t_{4}^{\text{pes}} - t_{0}^{\text{m}}) + (t_{2}^{\text{pes}} - t_{5}^{\text{m}}) + (t_{7}^{\text{pes}} - t_{7}^{\text{m}})] = \\
= 0.5 \cdot [(8 - 6) + (6 - 4) + (7 - 5) + (9 - 7) + (4 - 3)] = \\
= 4.5 \equiv 5. \]

On the other hand, determining the size of the project buffer on the basis of the formula,

\[ PB = \sqrt{\sum_{j \in \text{CC}} (t_j^{\text{pes}} - t_j^{\text{m}})^2}, \]

we obtain:

\[ PB^I = [(t_{6}^{\text{pes}} - t_{2}^{\text{m}})^2 + (t_{3}^{\text{pes}} - t_{1}^{\text{m}})^2 + (t_{4}^{\text{pes}} - t_{0}^{\text{m}})^2 + (t_{2}^{\text{pes}} - t_{5}^{\text{m}})^2 + (t_{7}^{\text{pes}} - t_{7}^{\text{m}})^2]^{1/2} = \\
= 4.12 \equiv 5. \]

Similarly, for the feeding buffer, we obtain:

\[ FB_6^I = 0.5 \cdot (t_{6}^{\text{pes}} - t_{6}^{\text{m}}) = 0.5 \cdot (6 - 5) = 0.5 \equiv 1, \]

118
or:

$$\text{FB}_6^{II} = \left[(t_{6}^{\text{res}} - t_{6}^{m}) \right]^2 = 1.$$ 

It should be noted that the accuracy of the results obtained here for both formulas is coincidental.

5. Buffering the project schedule.

Fig. 4.29 presents the project schedule after inserting buffers \( PB^1 \) and \( FB^1_6 \) into the schedule depicted in Fig. 4.28. Each of the works in the Critical Chain starts as soon as possible, i.e. immediately upon the completion of the preceding work. On the other hand, each of the works not belonging to the critical path may start as late as possible, i.e. not earlier than on time \( ls_i^{fb} \), determined as a result of shifting “to the left” of time \( ls_i \) (given in Table 4.11) by the feeding buffer value. In this case, \( i = 6 \) and \( ls_6^{fb} = 17 - 1 = 16 \). The planned project make span including the project buffer, is \( t_{CC} = 30 \) work days. Assuming that construction should be completed no later than on 28.09.2012, the works should start on 20.08.2012.

![Fig. 4.29: The Critical Chain method - the schedule after inserting the Project Buffer and the Feeding Buffer](image)

6. The baseline project schedule

Fig. 4.30 presents the baseline project schedule after the removal of buffers.
Fig. 4.30: The Critical Chain method - the baseline schedule

To examine the quality of the baseline schedule, 10,000 simulations were carried out. The scheme for calculation of start and finish dates of project activities in each simulation are presented in Table 4.17. Symbols $t_j$, $s_j$ and $f_j$ stand for the output of the random variable of duration, of start date and of finish date of a given activity. The empirical distribution of the project duration is presented in Fig. 4.31. The random variable $T$ of the project duration takes value within the range of [22; 30] working days, with the mean value of 25 working days.

Table 4.17: The Critical Chain method - the scheme for calculation start and finish dates of activities in the baseline schedule simulation
Fig. 4.31: The Critical Chain method - the empirical distribution of the project duration

Based on the results of the simulation, one could conclude that if the project will start on 20.08.2012, the analytically determined buffers ensure the full protection of the required project completion on 28.09.2012. It should be underlined however, that this result does not constitute the proof of the effectiveness of the Critical Chain method. For example, if we increase the number of simulations up to 50000, the random variable of the project duration takes value within the range of \([22; 31]\) working days, still with the mean value of 25 working days. Of course, the Contractor could state in this case, that construction should start about one working day earlier. However, such a “hand-made” correction is not what we expect and there is still the need for more accurate analytical methods for determining the buffers in the CC method.

2) THE PREDICTIVE SCHEDULING METHOD

Now, we will illustrate the predictive scheduling method with the criterion of the minimization of the expected cost of schedule instability. Let us go back to Fig. 4.26 and let us make the following assumptions:
- the predefined deterministic duration of the project is \(t_c = 31\) working days,
- not keeping to the scheduled start days of activities \(j = 3, j = 5\) and \(j = 8\) results in penalties,
- the unit costs (the penalties) of delaying the start dates of given above activities in relation to their scheduled start dates are: \(k_3 = 7, k_5 = 5, k_8 = 15\).
As before, we develop the computational model based on the Critical Path Method and we determine the earliest start and finish dates of project activities, based on their expected duration $E(T_j)$ – see Table 4.18:

**Table 4.18: The predictive scheduling method - the earliest start and finish dates of activities in the not buffered schedule**

<table>
<thead>
<tr>
<th>$j$</th>
<th>$Prec(j)$</th>
<th>$Succ(j)$</th>
<th>$E(T_j)$</th>
<th>$es_j$</th>
<th>$ef_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 1$</td>
<td>-</td>
<td>2,5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3.5</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>4</td>
<td>4</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>1,2</td>
<td>3,6</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>4,6</td>
<td>8</td>
<td>3</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>$F = 8$</td>
<td>7</td>
<td>-</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

At first, we do not insert any buffers, but we assume, that activities $j = 3$, $j = 5$ and $j = 8$ will start according to the railway policy. Then, we simulate the not buffered project schedule. The model for calculation of start and finish date of each project activity is presented in Table 4.19. Symbols $t_j$, $s_j$ and $f_j$ stand for the output of the random variable of duration, start and finish date of a given activity.

**Table 4.19: The predictive scheduling method - the computational model for calculation of start and finish date of activities in the simulation of the not buffered schedule**

<table>
<thead>
<tr>
<th>$j$</th>
<th>$t_j$</th>
<th>$s_j$</th>
<th>$f_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 1$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>$t_2$ (random)</td>
<td>$s_2$</td>
<td>$s_2 + t_2$</td>
</tr>
<tr>
<td>3</td>
<td>$t_3$ (random)</td>
<td>$s_3$</td>
<td>$s_3 + t_3$</td>
</tr>
<tr>
<td>4</td>
<td>$t_4$ (random)</td>
<td>$f_3$</td>
<td>$s_4 + t_4$</td>
</tr>
<tr>
<td>5</td>
<td>$t_5$ (random)</td>
<td>$s_5$</td>
<td>$s_5 + t_5$</td>
</tr>
<tr>
<td>6</td>
<td>$t_6$ (random)</td>
<td>$f_6$</td>
<td>$s_6 + t_6$</td>
</tr>
<tr>
<td>7</td>
<td>$t_7$ (random)</td>
<td>$s_7$</td>
<td>$s_7 + t_7$</td>
</tr>
<tr>
<td>$F = 8$</td>
<td>0</td>
<td>max($s_8 = 25$, $f_f$)</td>
<td>$s_8$</td>
</tr>
</tbody>
</table>

In this example, 50,000 simulations of the unit buffered schedule were carried out. The empirical distribution of the project duration is presented in Fig. 4.32. The random variable $T$ of the project duration takes value within the range of [25; 31] working days, with the mean value of 26 working days. The random variable of start date of the not buffered activity $j = 3$ takes value within the
range [13, 17] and the random variable of start date of the not buffered activity \( j = 5 \) takes value within the range [6, 8].

Moreover, Fig 4.33 presents the empirical distribution of schedule instability cost. The random variable \( K_{\text{ins}} \) of the schedule instability cost takes value within the range of [0; 121.3] monetary units with the mean value of 18.9 monetary units. Based on the simulation results we conclude that 28% of this value is due to the instability of the start date of activity \( j = 3 \), 17% due to the instability of the start date of activity \( j = 5 \) and 55% due to the instability of the start date of activity \( j = 8 \) (i.e., the instability of the entire project duration). One can assume that the buffer size should be determined in proportion to the mean share of the cost of instability of the start date of a given activity in the mean cost of the project instability. However, here we will not explore this problem analytically, due to its computational complexity.
Instead, we will use the meta – heuristic optimization algorithm built in the Cristal Ball software (an educational licence). Using the optimization algorithm requires the determination of the lower and of the upper limits of the decision parameters $b_j$. We assume that the minimum size of a buffer $b_j$ is 0 and that the maximum size of a buffer $b_j$ equals to the range width of the simulated start date of activity $j$. Based on this assumption, we run the simultaneous simulation and optimization procedure. Our goal is to determine the sizes of buffers $b_3$, $b_5$ and $b_8$ that minimize the expected value $E(K_{ins})$ of schedule instability cost, provided that the maximum value of the random variable of the project make span should not exceed $t_c = 31$ working days. Optimization is performed according to the following scheme:

1. generate sample values of buffers $b_3$, $b_5$ and $b_8$,
2. determine, on the basis of the adopted computational model, the planned start and finish dates of activities in the buffered schedule,
3. run simulation and examine the fulfilment of the condition regarding to the maximum allowable project duration,
4. if the condition regarding to the maximum allowable project duration is fulfilled, determine the expected value $E(K_{ins})$ of schedule instability cost and go to step (5); otherwise, return to step (1),
5. check whether there is a reduction of $E(K_{ins})$ compared to the result obtained in previous simulation and decide to continue or to stop the procedure.
For the buffered schedule, we use the computational model given in Table 4.20. For the schedule simulation, we use the computational model given in Table 4.21.

The solution given by the optimization algorithm is $b_3 = 2$, $b_5 = 0$, $b_8 = 4$. The resulting start and finish dates of activities in the baseline schedule (buffered) are given in Table 4.22. The project baseline schedule (buffered) is given in Fig. 4.27.

Table 4.20: The predictive scheduling method – the computational model for calculation of activities start and finish dates in the buffered schedule

<table>
<thead>
<tr>
<th>$j$</th>
<th>$\text{Prec}(j)$</th>
<th>$\text{Succ}(j)$</th>
<th>$E(T_j)$</th>
<th>$b_j$</th>
<th>$s_j$</th>
<th>$f_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 1$</td>
<td>-</td>
<td>2, 5</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3, 5</td>
<td>6</td>
<td>-</td>
<td>0</td>
<td>$s_2 + E(T_2)$</td>
</tr>
<tr>
<td>3</td>
<td>2, 5</td>
<td>4</td>
<td>4</td>
<td>$b_3$</td>
<td>$b_3 + \max{f_2, f_3}$</td>
<td>$s_3 + E(T_3)$</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>-</td>
<td>$f_4$</td>
<td>$s_4 + E(T_4)$</td>
</tr>
<tr>
<td>5</td>
<td>1, 2</td>
<td>3, 6</td>
<td>7</td>
<td>$b_5$</td>
<td>$b_5 + f_2$</td>
<td>$s_5 + E(T_5)$</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>-</td>
<td>$f_6$</td>
<td>$s_6 + E(T_6)$</td>
</tr>
<tr>
<td>7</td>
<td>4, 6</td>
<td>8</td>
<td>3</td>
<td>-</td>
<td>$\max{f_4, f_5}$</td>
<td>$s_7 + E(T_7)$</td>
</tr>
<tr>
<td>$F = 8$</td>
<td>7</td>
<td>-</td>
<td>0</td>
<td>$b_8$</td>
<td>$b_8 + f_7$</td>
<td>$s_8$</td>
</tr>
</tbody>
</table>

Table 4.21: The predictive scheduling method – the computational model for calculation of the actual start and finish dates of activities, predicted on the basis of simulation of the buffered schedule

<table>
<thead>
<tr>
<th>$j$</th>
<th>$t_j$</th>
<th>$b_j$</th>
<th>$s_j$</th>
<th>$f_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 1$</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>$t_2$ (random)</td>
<td>-</td>
<td>0</td>
<td>$s_2 + t_2$</td>
</tr>
<tr>
<td>3</td>
<td>$t_3$ (random)</td>
<td>$b_3$</td>
<td>$\max{s_3, f_2, f_3}$</td>
<td>$s_3 + t_3$</td>
</tr>
<tr>
<td>4</td>
<td>$t_4$ (random)</td>
<td>-</td>
<td>$f_4$</td>
<td>$s_4 + t_4$</td>
</tr>
<tr>
<td>5</td>
<td>$t_5$ (random)</td>
<td>$b_5$</td>
<td>$\max{s_5, f_2}$</td>
<td>$s_5 + t_5$</td>
</tr>
<tr>
<td>6</td>
<td>$t_6$ (random)</td>
<td>-</td>
<td>$f_6$</td>
<td>$s_6 + t_6$</td>
</tr>
<tr>
<td>7</td>
<td>$t_7$ (random)</td>
<td>-</td>
<td>$\max{f_4, f_5}$</td>
<td>$s_7 + t_7$</td>
</tr>
<tr>
<td>$F = 8$</td>
<td>0</td>
<td>$b_8$</td>
<td>$\max{s_8, f_7}$</td>
<td>$s_8$</td>
</tr>
</tbody>
</table>
Table 4.22: The predictive scheduling method – the planned start and finish dates of activities in the baseline schedule (buffered)

<table>
<thead>
<tr>
<th>j</th>
<th>Prec(j)</th>
<th>Succ(j)</th>
<th>E(Tj)</th>
<th>bj</th>
<th>sj</th>
<th>fj</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2.5</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>3.5</td>
<td>6</td>
<td>-</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>-</td>
<td>19</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>1.2</td>
<td>3.6</td>
<td>7</td>
<td>0</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>-</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>4.6</td>
<td>8</td>
<td>3</td>
<td>-</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>F</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>4</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

Fig. 4.34: The predictive scheduling method – the baseline schedule (buffered)

To examine the quality of this solution (i.e., the schedule robustness), 50000 simulations of the buffered baseline schedule were carried out. The empirical distribution of the project completion time is presented in Fig. 4.35. The constant value of the simulated project duration is 31 working days. Therefore, it can be concluded that buffers determined by the simultaneous simulation and optimisation procedure ensure the full protection of the predefined project duration $t_c$. 

126
Fig 4.35: The predictive scheduling method – the empirical distribution of the project duration as the result of simulation of the project baseline schedule (buffered)

The empirical distribution of the schedule instability cost is presented in Fig. 4.36. The random variable of the schedule instability cost takes value within the range of [0; 22.11] monetary units with the mean value of 1.77 monetary units. Based on the simulation results we conclude that 2% of this value is due to the instability of the start date of buffered activity $j = 3$ and 98% due to the instability of the start date of non-buffered activity $j = 5$.

Fig. 4.36: The predictive scheduling method – the empirical distribution of the schedule instability cost as the result of simulation of the project baseline schedule (buffered)
4.7 RISK MONITORING AND CONTROL

4.7.1 PROCESS ESSENTIALS

The process of monitoring and control of risk is undertaken to:

- Observe the risks identified (including residual and secondary risks);
- Determine whether symptoms of materialisation of the risk factors identified have occurred;
- Make decisions on implementation of the risk responses planned;
- Assess whether the preventive actions undertaken in response to the risk bring the expected results;
- Determine whether new, unidentified risk factors that require a response, have emerged;
- Determine whether the assumptions made for planning of the project duration and cost are still valid or should be changed.

The diagram of the process of monitoring and control of risks has been presented in Fig. 4.37.

![Diagram of the process of monitoring and control of risk](image)

Fig. 4.37: A general diagram of the process of monitoring and control of risk
The input data for the risk monitoring and control are:

- Output data from all previous risk management processes;
- The project progress as an objectively existing situation (observing the progress of the project allows verification of whether risk factors have been fully identified, their impact has been correctly assessed and the proper risk responses has been planned).

Deviations of the actual progress of works from the project budget and schedule show that:

- Materialisation of an identified risk factor has taken place and the planned risk response (including preventive measures) has not been implemented or it has been implemented incorrectly (e.g. omitting some procedures or recommendations) or has turned out to be inefficient;
- Materialisation of risk factors not identified earlier.

Such situations require corrective actions, which – depending on the specific circumstances and their impact on the time and cost of the project implementation – may include:

- Updating of response to risk, which may require another analysis and quantitative assessment of risk,
- Implementation of Emergency plans;
- Devising, approval and implementation of plans improvised for the new project risk factors.

An assessment of the project risk management methodology should be subject to internal audits, carried out by authorized employees of the company not belonging to the Project management team. The objective of such audits is to verify whether the project risk management methodology applied is consistent with the general policy of the company with regard to risk management, including:

- Whether the risk identification frequency ensures the constant validity of data on threats to the project;
- Whether responsibility for each of the risk factors identified is entrusted to persons having the right knowledge, able to use the appropriate techniques and tools to assess risk and to prepare a risk response;
- Whether the probability and effects of materialisation of each of the risk factors identified are subject to assessment;
- Whether risk factors that exert substantial impact on the quality, time and cost of the project implementation are identified;
− Whether responses (including emergency plans) to risk are devised, which would influence substantially the quality, time and cost of the project implementation;
− Whether the results of implementation of the risk responses devised are assessed and the appropriate corrective measures are applied;
− Whether the status of each of the risk factors identified is updated;
− Whether a Risk register is maintained to document the results of the subsequent risk management processes implemented;
− Whether the Risk register is maintained in a manner enabling use of the information gathered as input data for planning of risk management in other projects.

The audit results should be used to assess the efficiency and effectiveness of the project risk management methodology applied and to draw conclusions with regard to any amendments to this methodology.

4.7.2 TOOLS AND TECHNIQUES

The tools and techniques of risk control and monitoring include:

− Periodical data reviews, concerning the status of implementation of the project, allowing for assessment of results of implementation of the risk responses;
− The Earned Value analysis;
− Formal assessments (internal audits) of the project risk management methodology applied.

The basic tool for monitoring and control of risk are periodical data reviews, concerning the project completion status. These reviews should be carried out periodically by the Project Manager and the Project Management Team.

If the Critical Chain method has been use to schedule the project, we can observe the amount of Feeding Buffers and Project Buffer consumption. We can use the scheme similar to given in Fig. 4.38 as a tool for the decision whether there is a need for an intervention. Here, the green zone indicates safety, the yellow zone indicates the problems ahead and the red zone indicates the existence of the serious danger. For example, let us assume that 60 % of the
Feeding Chain is still to be done. If only 10% of the Feeding Buffer is consumed, probably no intervention is required. If 40% of the Feeding Buffer is consumed, we should better plan the buffer recovery actions. If more than 50% of the Project Buffer is consumed, we should immediately implement the Buffer Recovery Plan. However, this scheme requires the proper calibration, according to the risk attitude of an individual Contractor.

![Fig. 4.38: Exemplary scheme, indicating the need for an intervention](image)

A complex assessment of the impact of deviations that emerge on the time and total cost of implementation is usually carried out using the Earned Value analysis. This analysis is based on assessment of deviations from costs of construction works that emerge in a given time period on the basis of value of three independent parameters:

- The planned value of a given work – PV (that is, the part of the work costs budgeted, which has been planned to be spent on implementation of work in a given time)
- The actual cost – AC (that is, the real cost of the really performed work in a given time) and
- Earned value - EV (that is, the cost of work really performed in a specified time, established on the basis of indicators assumed for the needs of planning of these costs).

The difference between EV and PV constitutes a deviation from schedule SV, and the difference between EV and AC constitutes a cost deviation CV for the undertaking. On this basis, we calculate the cost performance index CPI = EV/AC and the schedule performance index SPI = EV/PV.
4.7.3 AN EXAMPLE OF APPLICATION OF THE EARNED VALUE METHOD

The objective of analysis of the project using the Earned Value Method is to verify the stage of implementation of the investment project in relation to the baseline schedule and the investment budget. The input data for analysis is planning data (project schedule, cost estimate and budget), as well as the current reports obtained on the progress of works and the actual costs incurred. Table 4.23 presents a typical breakdown of planning data needed to conduct the Earned Value analysis – a schedule of works with the planned monthly expenditures. In the example, the analysis is conducted after the third month of the project implementation. This moment has been marked in Table 4.22 using a vertical break line. Fig. 4.39 presents the work completion schedule. Like in a Gantt chart, bars in Fig. 4.39 represent the planned work completion time. The dark shade represents the actual progress of works until the end of the third month of construction. On the other hand, Table 4.24 contains data on the actual work (task) completion costs until the end of the third month of the works.

Table 4.23: Breakdown of work (task) costs in individual months.

<table>
<thead>
<tr>
<th>Work</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1500</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>1500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1000</td>
<td></td>
<td>1000</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>4000</td>
<td></td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1000</td>
<td>2000</td>
<td>2000</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>3000</td>
<td>6000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>Total</td>
<td>6500</td>
<td>8000</td>
<td>9000</td>
<td>11000</td>
<td>10500</td>
<td>2000</td>
<td>3500</td>
</tr>
<tr>
<td>Σ</td>
<td>6500</td>
<td>14500</td>
<td>23500</td>
<td>34500</td>
<td>45000</td>
<td>47000</td>
<td>50500</td>
</tr>
</tbody>
</table>
Fig. 4.39: Schedule of works (tasks) with the marked estimated work progress and the planned total cost of works.

Table 4.24: A breakdown of actual costs of work performed (ACWP) along with the estimated work progress

<table>
<thead>
<tr>
<th>Task</th>
<th>ACWP</th>
<th>% performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9500</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>9800</td>
<td>45%</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>10%</td>
</tr>
<tr>
<td>4</td>
<td>1700</td>
<td>15%</td>
</tr>
<tr>
<td>5</td>
<td>2100</td>
<td>20%</td>
</tr>
<tr>
<td>Total ACWP</td>
<td>24300</td>
<td>49%</td>
</tr>
</tbody>
</table>
Table 4.24 takes into account works 1 – 5, which were to be implemented within the first three months of construction. The second column contains information on the actual cost of work performance. Comparing the planned and actual material and financial progress of the construction works, it can be stated that:

- task 1 was expected to cost 10000 Euro, and it reality it cost 9500 Euro and it has been completed
- task 2 was expected to cost 7500 Euro until the end of the third month, and it cost 9800 euro and it has not been completed (45% performance),
- task 3 was expected to cost 1000 Euro, and so far it has cost 1200 Euro and it has been completed in 10%,
- task 4 was expected to cost 4000 Euro, and it has cost 1700 Euro and it has been performed in 15%,
- task 5 was expected to cost 1000 Euro, and so far it has cost 2100 and it has been completed in 20%.

It is visible that completion of Tasks 2-5 has been delayed. Only Task 1 has been performed in time and cheaper than expected. A short analysis of the data obtained indicates that the project is being completed below the expectations.

A classical approach towards the project analysis would be based on comparison of the schedule deviations, that is, comparison of the baseline plan with the actual schedule and, on the other hand, on comparison of the planned and actual costs. Such analysis would provide the following results:

- task 1 was completed in time at a cost lower than expected,
- completion of tasks 2 – 5 has been delayed,
- the planned cost of tasks until the end of the 3rd month was 23500 Euro, while in reality, the expenditures amounted to 24300 Euro; thus, the cost estimate was exceeded only by 800 Euro.

Analysing these results, it would only be possible to get a general overview of the project status. The actual progress of works, however, can be examined more thoroughly using the Earned Value Method as presented below:

1. Basic indicators

1.1 Budgeted Cost of Work Scheduled BCWS (PV) = 17750 (see Fig. 4.39):

<table>
<thead>
<tr>
<th>Task</th>
<th>BCWS</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>10000</td>
<td>100%</td>
</tr>
<tr>
<td>Task 2</td>
<td>12000</td>
<td>45%</td>
</tr>
<tr>
<td>Task 3</td>
<td>2500</td>
<td>10%</td>
</tr>
<tr>
<td>Task 4</td>
<td>6000</td>
<td>15%</td>
</tr>
<tr>
<td>Task 5</td>
<td>6000</td>
<td>20%</td>
</tr>
<tr>
<td>Total (BCWS)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.2 Budgeted Cost of Work Performed: BCWP (EV) = 23500 (from Table 4.23)
1.3 Actual Cost of Work Performed: $ACWP (AC) = 24300$ (from Table 4.24)

2. Variances

2.1 Cost variance (CV):
$CV = BCWP - ACWP = 17750 - 24300 = -6550$

2.2 Schedule variances (SV):
$SV = BCWP - BCWS = 17750 - 23500 = -5750$

3. Performance indicators

3.1 Cost performance indicator (CPI):
$CPI = \frac{BCWP}{ACWP} = \frac{17750}{24300} = 0.730$

3.2 Schedule performance indicator (SPI):
$SPI = \frac{BCWP}{BCWS} = \frac{17750}{23500} = 0.755$

4. Project completion estimation

4.1 Estimate at Completion (EAC):
$EAC = ACWP + \frac{BAC - BCWP}{CPI} = 24300 + \frac{50500 - 17750}{0.730} = 69163$

4.2 Estimated Time to Complete (ETTC) in months from the project commencement date
$ETTC = ATE + \frac{OD - ATE \times SPI}{SPI} = 3 + \frac{7 - 3 \times 0.755}{0.755} = 9.2$

5. Summary
According to calculations performed for the first three months of performance of works, the following conclusions can be drawn:
- the costs planned were exceeded by 6550 Euro,
- less works were performed than planned, the difference being worth the amount of 5750 Euro
- the project cost performance amounts only to 73%  
- the schedule completion performance amounts only to 75.5%  
- the estimated final project cost is 69163 Euro, that is, 18663 Euro more than planned,  
- the estimated project duration time is more than 9 months, that is, two months longer than planned.

Such data is of great importance from the perspective of the investor or the general contractor, who can timely secure the additional funds to cover the increased expenditures associated with individual tasks, as well as attempt to shorten the project completion time by hiring additional employees or lengthening the daily work period.

The example shows that application of the Earned Value Method allows for a much more thorough analysis of an investment project in comparison with classical techniques. Thanks to calculation of the basic indicators and project variances, it is possible to examine the actual status of the project with regard to the schedule and cost performance at the time of analysis. On the basis of these calculations, it is also possible to estimate the future indicators of the project performance, such as the modified estimated cost of works and the planned project completion.
CHAPTER 5

PROJECT CLOSURE AND GUARANTEE PERIOD RISKS
(J. C. TEIXEIRA)

5.1 COMMISSIONING

The increasing complexity and sophistication of modern construction undertakings calls for verification and testing actions to take place after finishing construction and before utilisation starts. These actions obviously require some time but are essential for assuring the full operation and safety of the facility built. Actually, the commissioning of large building facilities (such as shopping malls, hospitals and schools) is a complex construction activity requiring various skills for performing tests and correcting possible flaws of installations and systems and preventing failures in service provision for end users. Essentially, building commissioning comprehends all the activities needed for assuring that all building engineering services are designed, installed and tested in accordance with design specifications and that they can be operated and maintained according to the client needs and operational requirements.

Actually, commissioning activities may take place in all phases of the project development including the pre-construction, construction and post-construction phases. Those activities aim at checking if installations and systems incorporated in the facility are functioning according to project specifications. The post-construction commissioning phase is preliminary to the project completion and handover to the client or final user.
5.2 CONSTRUCTION DEFECTS

The term “defect” tends not be defined in construction contracts but defects are almost inevitable in construction projects and are usually contentious between the client and the contractor. Generally, the physical works must conform to the contract requirements, any failure being considered a defect.

Causes of construction defects can be defined as acts of omissions or the combination of both that led to defects occurring (Oyedele, 2010). Glover (2008) points out that construction defects are different from a nuisance claim (for example squeaking floor) resulting from lack of maintenance or normal wear and tear. Some defects may threaten the building structural integrity (such as foundation problems, defects on floors or roof, etc.) while others only spoil the building aesthetics. Construction defects may be classified into the following main categories (Glover, 2008):

1) Design deficiencies
2) Material deficiencies
3) Specification problems
4) Execution deficiencies

Neighbour (2006) classifies the material defects into two categories with distinct consequences for contractors:
- Defects due to material/labour flaws not accomplishing the contract requirements: In this case the contractor should repair defects at no cost for the client.
- Defects occurring although material and their application respect contract conditions: In this case repairs are paid by the client.

Oyedele (2010) suggests that construction defects may be caused by:

- Poor design
- Inefficiency of the project manager
- Lack of skilful manpower
- Oversights of the contractors or sub-contractors
- Inadequate or inexplicit job descriptions
- Usage of poor or defective materials
- Lack of time leading to poor project planning and scheduling
- Inexperience of contractors or sub-contractors
However, the same author stresses that construction defects are not easy to define because of the multiplicity of project participants (for example, defects according to the client may not be viewed as defects by contractors or subcontractors).

Defects may occur or be detected in different stages of the project lifecycle, namely, during the construction phase, during commissioning and during the utilization phase. Because defects emerging during the utilization phase may fall into the contractor responsibility, a defects liability period is commonly established in construction contracts. The liability period (or guarantee period) is the time period after construction completion (after commissioning) during which the contractor is obliged to repair at its own costs any defects of its responsibility that might emerge in the built facility. Additionally, the contractor may also be liable for some defects appearing after this period (e.g., construction defects causing serious damage, premature loss of functionality of construction components, early decay of construction materials, and so on). Obviously, the later defects are detected the most difficult will be to prove liabilities. Moreover, the regulations of some European countries impose that the contractor should only be liable for defects claimed within a specified time after detection (e.g. Portugal).

In view of the above, the contractor’s responsibility to address defects is defined differently for different stages of the project lifecycle (Fig. 5.1). Additionally to compelling the contractor to rectify defects, the owner of the facility may also claim for further damages caused by those defects (e.g. temporary lack of use) or to third parties’ (e.g. flooding a neighbouring property). Accordingly, further to requiring the contractor to rectify defects, the owner may ask for damage compensation on the basis of disorders caused by the effects of those defects. However, in order to get compensation for disorders subsequent to defects, the owner must take the case to the Courts.

But the client’s claim (or owner’s claim, depending on the project phase when the claim takes place) for any defect may not have immediate remedy if the contractor does not accept responsibility. The contractor may not recognise the defect or may argue that it was not caused by its actions (e.g., wrong design options or misuse). If this is the case, a legal argument will often follow which may take some time to settle. Therefore, construction defects may introduce considerable risks for the client/owner and the contractor and involve substantial costs and time to overcome.
Irrespective of the responsibility of the contractor, in some European countries, the client/owner is entitled to disregard the contractor for repairing damages and recover the financial cost of remedial works for defects carried out either directly or through another contractor (Oyedele, 2010). But this is only possible in most countries if the contractor fails to perform repairs during the defect liability period within a reasonable time after receiving the claim form the client.

**Construction Period**

- During this period the contractor will be required to carry out remedial works, and may not be paid for defective works
- In order to achieve this, the contractor maybe required (or else do it voluntarily) to remove defective materials and substitute them for good ones and re-execute defective works

**Defects Liability Period**

- The contractor may be required to return to the built facility for remedying defects and has the legal right to do it.

**Post-Defects Liability Period**

- The contractor may be liable for defects emerging in the built facility but no longer has the right to remedy them without the client’s authorization.

**Fig. 5.1: Contractor's liability for construction defects**

All in all, there should be an effort from all project participants in order to avoid major defects and to manage residual defects appropriately. This can be
achieved by analysing the undesirable outcomes from previous projects, putting in place adequate contractual requirements and managing defect issues thereby reducing the potential financial and risk liability of project participants in all stages of the project lifecycle.

5.3 DEFECTS LIABILITY PERIOD

As soon as construction works are finished, the contractor informs the client representative who sets a meeting on site for inspecting the built facility and organising the post-construction commissioning phase. Should any defect be detected the contractor will be required to correct it within an agreed schedule. Similarly, if any malfunctions of engineering systems are detected during commissioning, the contractor will be asked to provide the remedy for them. After all rectifications are done, the client representative issues the Preliminary Completion Certificate stating the date on which all defects were cleared. This document means that the facility is considered completed by the client representative and may be handed over to the client (owner or end user).

The defects liability period starts after handover and lasts for the time specified in the contract conditions, although conforming to the minimum established in the general law or construction regulations of most European Countries. During the defects liability period, the owner’s consultants follow inspections at regular intervals and may require the contractor to rectify defects that they have possibly detected in the facility. It is worth noticing that requiring the contractor to rectify defects is for the benefit of both the client/owner and the contractor: The contractor can usually rectify defects more efficiently than can a third party (another contractor engaged by client to fix the problem), generally being able to mobilise more quickly given its familiarity with the job.

Before the expiry of the defects liability period, the owner’s representative should inspect the works and draw up a schedule setting out, in some detail, any defects which are still apparent. Upon completion of all rectifications, the owner’s representative issues the Final Completion Certificate on that basis,
stating the date on which all defects were cleared at the end of defects liability period.

But the Final Completion Certificate does not preclude the contractor’s responsibility for defects detected thereafter. Actually, possible defects identified after the issue of the Final Certificate still amount to a breach of contract and in some cases the court may compel the contractor to rectify the works under an order for specific performance (Robertson, Haggie, & Wilshire, 2010).

Therefore, the contractor is responsible for defects raised before, during and after the defects liability period ends (even in the case of defects that should have been raised during that period). Neither the defects liability certificate nor any other certificate will generally release the contractor from liability for any defects arising subsequently.

5.4 FINANCIAL RISKS

During the construction phase, defects may arise due to poor design, inadequate materials or inefficient workmanship (particularly when supervision is questionable). These defects are often identified and rectified as the work progresses. However, of greater concern are defects revealing after the Final Completion Certificate is issued, because this points out the end of the defects liability period. These defects may result in substantial economic loss to the facility owner or user, especially if the responsibility for defects cannot be allocated to the contractor (Ikpo, 2005).

The cost of repairing defects depends on the negotiation power of the client and the contractors that handled the project. Actually, the cost of rectifying construction defects has been one of the long contentious issues between contractors and clients. Generally, it is better to ask the initial contractor to rectify defects than involving a new contractor, for the reasons mentioned above. Additionally, involving a new contractor tends to be less cost effective and this cancels the responsibility of the initial contractor in future defects emerging from the repairs performed.
5.5 LITIGATION RISKS

Construction defects (appearing at any phase of the project lifecycle) tend to generate litigation risks. Generally speaking, construction litigation is caused by a variety of factors in different project times and some of them are not easily controlled by the project participants. Katz (-) points out the following factors:

- Regulatory requirements imposed by states and governments such as environmental legal requirements (e.g., hazardous waste disposal), non-discriminatory sexual hiring policies, and other social regulatory schemes;
- Lack of contract specification on a variety of operation and maintenance issues;
- Third-party tort actions often supported in indemnification clauses (injured worker injury or decease);
- Unmanageable risks and risk-shifting contract language;
- Personality of project participants which often reveal aggressiveness, greed and conflict of interests;
- Construction price system and the bidding process; and,
- Non-payment issues.

Construction defects are the major causes of litigation in construction project delivery (Ensbey, 2010). There is often disagreement when it comes to identifying what a construction defect is and who is responsible for it, due to different viewpoints and interests of project participants (about what is average quality, for example), to the quality of materials and efficiency of workmanship, or to a combination of various factors.

Under the traditional contracting model, the contractor is required to implement the design produced by the client’s design team. In this case, the contractor has no responsibility for design options unless for changes agreed with the client, particularly if those changes were the cause of some operational flaw of the facility. Defects appearing after the defect liability period tend to generate major litigation problems because the contractor seldom accepts liability after the Final Completion Certificate is issued. DBO contracts may introduce further conflicts between the owner and the contractor because of the level of operation or the maintenance efficiency achieved in the facility. In most cases, the owner is liable by the users for any operational flaw; therefore, the owner will try to pass liability to the contractor on sensitive issues.
Litigation is expensive for the parties involved. Firstly because various degrees of expertise with law, building technology and practice are required. And secondly because it takes much time to understand the intricacy of most construction problems.
ABBREVIATIONS


Guerra, J. R., & Teixeira, F. J. (n.a.): Risk Management applied to design, tendering/awarding and construction in EDP hydroelectric power plants.


MALCOE. (2005): Tender and Selection Policy. Retrieved in March 2011 from Macquarie University – Sidney:


Medeiros, J. A., & Rodrigues, C. L. (n.a.): A existência de riscos na indústria da construção civil e a suarelação com o saber operário.

http://findarticles.com/p/articles/mi_m0NSX/is_8_50/ai_n15377665/


http://www.scitopics.com/Managing_Construction_Defects.html

Padiyar, V., Shankar, T., & Varma, A. (n.a.). Risk Management in PPP. Retrieved in October 2010 from


http://cedb.asce.org/cgi/WWWdisplay.cgi?268903


Zour, P. X., Zhang, G., & Wang, J.-Y. (n.a.): *Identifying Key Risks in Construction Project: Life Cycle and Stakeholder Perspectives*
FURTHER READING


APPENDIX 1

Table A.1: Analysis and qualitative assessment of risk for an exemplary construction project

<table>
<thead>
<tr>
<th>RISK FACTOR</th>
<th>ACTIVITY</th>
<th>RISK EFFECT</th>
<th>PROBABILITY</th>
<th>IMPACT</th>
<th>CATEGORY</th>
<th>RESPONSE TO RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incomplete design and drawing</td>
<td>Preparatory works</td>
<td>Necessary to provide additional protection, can influence duration and cost of project works</td>
<td>3</td>
<td>Medium</td>
<td>High</td>
<td>Check site conditions prior to commencement of works, reanalyse required</td>
</tr>
<tr>
<td>24/11/2010</td>
<td>24/11/2010</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>DATE</th>
<th>ACTIVITY</th>
<th>RISK EFFECT</th>
<th>PROBABILITY</th>
<th>IMPACT</th>
<th>CATEGORY</th>
<th>RESPONSE TO RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24/11/2010</td>
<td>Preparatory works</td>
<td>Necessary to provide additional protection, can influence duration and cost of project works</td>
<td>3</td>
<td>Medium</td>
<td>High</td>
<td>Check site conditions prior to commencement of works, reanalyse required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>DATE</th>
<th>ACTIVITY</th>
<th>RISK EFFECT</th>
<th>PROBABILITY</th>
<th>IMPACT</th>
<th>CATEGORY</th>
<th>RESPONSE TO RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>24/11/2010</td>
<td>Preparatory works</td>
<td>Necessary to provide additional protection, can influence duration and cost of project works</td>
<td>3</td>
<td>Medium</td>
<td>High</td>
<td>Check site conditions prior to commencement of works, reanalyse required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>DATE</th>
<th>ACTIVITY</th>
<th>RISK EFFECT</th>
<th>PROBABILITY</th>
<th>IMPACT</th>
<th>CATEGORY</th>
<th>RESPONSE TO RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>24/11/2010</td>
<td>Preparatory works</td>
<td>Necessary to provide additional protection, can influence duration and cost of project works</td>
<td>3</td>
<td>Medium</td>
<td>High</td>
<td>Check site conditions prior to commencement of works, reanalyse required</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>24/11/2010</td>
<td>M.K.</td>
<td>Rigorous legal requirements concerning environmental protection</td>
<td>Preparatory works</td>
<td>Delays of commencement of works caused by the need to obtain of permission to remove of existing plants, can influence duration and cost of preparatory works</td>
<td>GR</td>
<td>Minor - Acceptable</td>
</tr>
<tr>
<td>3</td>
<td>25/11/2010</td>
<td>M.K.</td>
<td>Unfavourable weather conditions, heavy rain</td>
<td>Excavations</td>
<td>Reduction of the working team performance can influence duration and cost of excavation</td>
<td>SKT</td>
<td>Moderate - marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>25.11.2010</td>
<td>M.K.</td>
<td>Protests of the local population against the use of the existing local road for the movement of Contractor equipment</td>
<td>Excavations</td>
<td>Temporary suspension of works can influence duration and cost of excavation</td>
<td>Negligible</td>
<td>Law</td>
</tr>
<tr>
<td>5</td>
<td>25.11.2010</td>
<td>M.K.</td>
<td>Incomplete drawings and technical specifications for brick works</td>
<td>Brick works</td>
<td>Changes of the scope of works, can influence duration and cost of brick works</td>
<td>Acceptable</td>
<td>Negligible</td>
</tr>
<tr>
<td>ARMATURE</td>
<td>ARMATURE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01.12.2010</td>
<td>01.12.2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CM**
- 11 weeks
- 12 weeks

**Medline**

**Sheet - mm**

**SKT**

**Rooing**

**Planting**

**U.S.**
- 26.11.2010
- 25.11.2010

**NC**
<table>
<thead>
<tr>
<th>Activity</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>04.12.2010</td>
<td>PEM</td>
</tr>
<tr>
<td>8 weeks</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Provide scaffoldings, quantitative analysis required</td>
<td>Consider a schedule and budget review, quantitative analysis required</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Molecula - main</td>
<td>Molecula - main</td>
</tr>
<tr>
<td>Steel</td>
<td>Steel</td>
</tr>
<tr>
<td>Temporary site. Can influence duration and cost of external finishing</td>
<td>Need to replace damaged materials, can influence duration and cost of external finishing</td>
</tr>
<tr>
<td>External classification</td>
<td>External classification</td>
</tr>
<tr>
<td>Unfavourable weather conditions: heavy rain</td>
<td>Susceptibility of materials to damage during transport and storage</td>
</tr>
<tr>
<td>26.11.2010</td>
<td>26.11.2010</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>27/11/2010</td>
</tr>
<tr>
<td>11</td>
<td>28/11/2010</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>12</td>
<td>28.11.2010</td>
</tr>
<tr>
<td>13</td>
<td>28.11.2010</td>
</tr>
</tbody>
</table>