Risk Analysis for Large Projects

Models, Methods & Cases

Dale Cooper & Chris Chapman

Risk Analysis for Large Projects

Models, Methods and Cases

Dale F. Cooper

Spicer and Pegler Associates, London

and

C. B. Chapman

Department of Accounting and Management Science
University of Southampton

JOHN WILEY & SONS

Chichester · New York · Brisbane · Toronto · Singapore

Library of Congress Cataloging-in-Publication Data:

Cooper, Dale F.
Risk analysis for large projects.

Bibliography: p.
Includes index.
1. Reliability (Engineering) 2. Risk. I. Chapman,
C. B. II. Title.
TA169.C66 1986 658.4'03 86-15968
ISBN 0 471 91247 6

British Library Cataloguing in Publication Data:

Cooper, Dale F.
Risk analysis for large projects: models, methods and cases.
1. Risk management
I. Title II. Chapman, C. B.
658.4'03 HD61
ISBN 0 471 91247 6

Typeset by Paston Press, Norwich
Printed and bound in Great Britain

Risk Analysis for Large Projects
Models, Methods and Cases

Acknowledgements

The structure of this book was conceived while the first author was Visiting Fellow at the Australian Graduate School of Management (AGSM). Much of the material was presented at an Executive Seminar on 'Risk Analysis for Large Projects' at the AGSM. Significant contributions were made by John Stringer, Professor of Management at the AGSM, and Sandro Bignozzi, Managing Director of A. Bignozzi and Associates in Sydney.

A version of Chapter 1 has been published as

Cooper, D. F., and C. B. Chapman, (1985) Risk analysis for underground projects. *Underground Space* **9**(1), 35–40.

Chapters 2 and 12 are based on seminars in the series Modern Management Approaches, conducted for local businessmen and professional advisors by the Department of Accounting and Management Science at the University of Southampton.

Chapters 3, 7, 10 and 11 are concerned with models that have been described in different forms in a variety of publications.

Chapman, C. B. and D. F. Cooper, (1983) Risk engineering: basic controlled interval and memory models. *J. Operational Research Society* **34**(1), 51–60.

Chapman, C. B. and D. F. Cooper, (1985) Risk Analysis. In G. K. Rand and R. W. Eglese (eds). *Further Developments in Operational Research*, Pergamon, Oxford.

Chapter 4 describes work undertaken for a client of Acres International in Canada. Significant contributions were made by Gus Cammaert, the Acres project manager. The 'method' part of Chapter 4 has been published as

Chapman, C. B., D. F. Cooper and A. B. Cammaert, (1984) Model and situation specific OR methods: risk engineering reliability analysis of an LNG facility. *J. Operational Research Society* **35**(1), 27–35.

The President's Medal of the Operational Research Society was awarded to the authors for this paper.

The 'model' part of Chapter 4 has appeared in

> Cooper, D. F., C. B. Chapman, and A. B. Cammaert, (1983) Reliability analysis of an LNG facility. *Proceedings of the 6th National Conference, Australian Society for Operations Research, Brisbane*, 45–53.

Chapters 5 and 8 describe work undertaken for clients of Acres International in the USA. Significant contributions were made by Chuck Debelius and Tee Pecora, who both had project management responsibilities in Acres. A version of Chapter 5 has been published as

> Chapman, C. B., D. F. Cooper, C. A. Debelius, and A. G. Pecora, (1985) Problem-solving methodology design on the run. *J. Operational Research Society* **36**(9), 769–78.

Chapter 6 is based on work undertaken jointly with Will Cumberlidge as an undergraduate project when he was a student at the University of Southampton. An extended version of Chapter 6 was presented as

> Cumberlidge, W., (1983) Encoding Probability Assessments. Dissertation submitted in partial fulfilment of the degree of BSc (Social Sciences), University of Southampton.

Chapter 9 describes work undertaken for a client of Acres International in Canada. A significant contribution was made by Dave MacDonald, Head of Planning and Estimating in Acres. A version of Chapter 9 has been published as

> Cooper, D. F., D. H. Macdonald and C. B. Chapman, (1985) Risk analysis of a construction cost estimate. *International J. Project Management* **3**(3), 141–9.

A version of Chapter 13 has been published as

> Chapman, C. B. and D. F. Cooper, (1983) Risk analysis: testing some prejudices. *European J. Operational Research* **14**(3), 238–47.

Chapter 14 describes how risk analysis studies are conducted in BP International. A version of Chapter 14 has been published as:

> Chapman, C. B., E. D. Phillips, D. F. Cooper, and L. Lightfoot, (1985) Selecting an approach to project time and cost planning. *International J. Project Management* **3** (1), 19–26.

The authors are grateful for help, encouragement and inspiration provided by a number of colleagues not mentioned above. J. Gavin Warnock and Robin Charlewood of Acres were key instigators in many of the studies which are the basis of this book, and we have been supported by many other Acres staff who have been involved in individual studies. Members of the BP International Risk Analysis Group within the BP Engineering Planning and Costs division have played a central role in the development of many of the basic ideas over nearly a decade. More recently staff of Gulf Canada Resources Incorporated have contributed in a substantial manner. All the studies undertaken by the authors have provided important lessons, and in many cases our clients have been our mentors. It would be inappropriate to list all of them and their contributions, but the authors would like to express their gratitude. Only the errors and omissions are entirely our own.

Contents

Chapter 1

Introduction to risk analysis

Summary

This chapter introduces some of the main concepts to be used throughout the book. It considers what risk analysis is, the nature of the risk engineering approach to risk analysis, when risk analysis might be necessary, and some of the benefits which arise from its use. It also provides some general guidance for the reader.

THE NEED FOR RISK ANALYSIS

Recent decades have been chacterized by a vast proliferation of risk. The real scale of projects and investment programmes has expanded dramatically, increasingly intractable geographical areas have been developed, and economic instability in growth rates and prices has become endemic.

With this uncertain and volatile environment, the need for risk analysis of potential projects and investments has increased. The need for analysis is particularly apparent when projects involve

- Large capital outlays.
- Unbalanced cash flows, requiring a large proportion of the total investment before any returns are obtained.
- Significant new technology.
- Unusual legal, insurance or contractual arrangements.
- Important political, economic or financial parameters.
- Sensitive environmental or safety issues.
- Stringent regulatory or licensing requirements.

For many projects, the additional information needed to reduce risk and uncertainty to an acceptable level prior to commencing the development will not be available, and there may be large costs or delays in acquiring it. These factors increase the need for early assessment of the uncertainties and risks which affect the project before large sums of money are irrevocably committed.

Each major project may be viewed as unique. Some projects involve construction or operation in new or hazardous geographical and geological areas, some involve significant new or untried technology, and some involve risks with very large or potentially catastrophic consequences. Even where the individual risks may be known, their combined effects may not be obvious, as the synergy inherent in large projects frequently leads to quite unexpected consequences.

A DEFINITION OF RISK ANALYSIS

Risk is exposure to the possibility of economic or financial loss or gain, physical damage or injury, or delay, as a consequence of the uncertainty associated with pursuing a particular course of action.

Risk analysis can involve a number of approaches to dealing with the problems created by uncertainty, including the identification, evaluation, control and management of risk.

Risk engineering is an integrated approach to all aspects of risk analysis, used as the basis of discussion here. Its aim is to identify and measure uncertainty as appropriate, and to develop the insight necessary to change associated risks through effective and efficient decisions. Risk engineering uses risk analysis, defined in a very broad and flexible manner, for the purpose of better *risk management.*

RISK ENGINEERING APPLICATIONS

Risk analysis of this risk engineering form has many applications. They range from the evaluation of the risk from seismic hazards for a nuclear power station, through the optimization of a major offshore oil development programme, to the assessment of the risk of default on a bond offering. 'Engineering' is used in the sense of a 'synthesis of ends and means', with no intention of suggesting only technological aspects of large projects are relevant.

The risk engineering approach to risk analysis was first developed for and tested by BP International, for programme development for their North Sea projects, in the late 1970's. It is now applied to all major sensitive BP projects for project time and cost planning. Studies which formed the basis of this approach and its generalization to other application areas have involved a number of organizations in the UK, Canada and the USA, including Acres International Limited, Spicer and Pegler Associates, Gulf Canada Resources Incorporated, Petro-Canada, Alaska Power Authority, Alberta Utilities Consortium, Petroleum Directorate of the Government of

Newfoundland and Labrador, Northwest Alaska Pipelines, Fluor Engineers and Contractors Incorporated, Potomac Electric Power Company, US Department of Energy, Newfoundland and Labrador Hydro, Canadian International Project Managers Limited, Canadian Arctic Gas Study Group, and the Channel Tunnel Group.

Risk engineering is a synthesis of a number of other approaches to risk analysis, many of which can be treated as special cases. In particular, it draws upon key ideas from decision analysis, safety analysis of fault tree and event tree forms, generalizations of Program Evaluation and Review Technique (PERT) like Graphical Evaluation and Review Technique (GERT), Markov process modelling, reliability analysis, and 'futures' or 'scenario' modelling.

Risk engineering provides a structured means of looking ahead in the life of a project. It differs from many conventional approaches, such as sensitivity analysis, in three key areas:

It subdivides a project into a relatively small number of major elements, and then analyses the uncertainty associated with each in detail.

It identifies the causes of time delays, cost changes and other impacts, and it evaluates responses to associated potential problems, prior to assessing net effects.

It considers degrees of dependency between risks and between the project elements.

REQUIREMENTS FOR RISK ANALYSIS

There are five somewhat different circumstances in which uncertainty may be a major factor and in which suitable forms of risk analysis may be appropriate.

In the *pre-feasibility appraisal* of a proposed project or investment, a decision may have to be made, often on the basis of minimal information, to discard the project, to postpone it, or to proceed with more detailed feasibility studies.

A decision may be required concerning whether or not to undertake or become involved with a *marginal project*. This is the case when the rate of return calculated on the basis of the best estimates of capital requirements and cash flows is close to the opportunity cost of capital, or the net present value is close to zero.

When a project or investment involves *unusual risks or uncertainties*, which may lead to a wide range of possible rates of return, risk analysis may be appropriate.

Strategic decisions may be necessary when *choosing between alternative projects or investments*, for a project or investment concept which has already been justified at an earlier pre-feasibility or feasibility stage.

Risk analysis may be appropriate for *tactical decisions*, when developing a detailed plan or optimizing project specifications, for a project concept already given approval.

Within this broad framework, there may be formal requirements for risk analysis for many reasons:

Economic viability assessment, for high level strategic decision making within an organization or in relation to a government decision process.

Financial feasibility assessment, for the bond or debt market when a finance package is being assembled.

Insurance purposes, to assess premiums for unusual risks for which there may be little statistical or actuarial information.

Accountability, for major project managers to demonstrate that they have fully assessed all the material risks, that the measures taken to control risk are appropriate, and that the economic reward for taking on the risk that remains is adequate.

Contractual purposes, to assess alternative contractual and legal frameworks for the project, in the context of deciding who should bear what risks and determining an equitable allocation of risks and rewards between project owners, contractors and insurers.

Tendering, when deciding whether or not to bid for a proposed project, and at what level.

Regulatory purposes, for legislative, judicial or licensing agencies of government, or for public enquiries, to demonstrate accountability in a public or social context.

Communication purposes, to provide information for project owners, contractors or joint venture partners, or to demonstrate capability and competence in an area.

BENEFITS OF RISK ANALYSIS

Risk analysis may be required initially for a limited range of purposes. However, the experience of many organizations suggests a risk engineering approach provides other benefits which may prove far more important in the long term. These benefits include:

Better and more definite perceptions of risks, their effects on the project, and their interactions.

Better contingency planning and selection of responses to those risks which do occur, and more flexible assessment of the appropriate mix of ways of dealing with risk impacts.

Feedback into the design and planning process in terms of ways of preventing or avoiding risks.

Feedforward into the construction and operation of the project in terms

of ways of mitigating the impacts of those risks which do arise, in the form of response selection and contingency planning.
Following from these aspects, an overall reduction in project risk exposure.
Sensitivity testing of the assumptions in the project development scenario.
Documentation and integration of corporate knowledge which usually remains the preserve of individual minds.
Insight, knowledge and confidence for better decision making and improved risk management.

Of these benefits, *it is the reduction in project risk exposure which provides corporate management with the bottom-line justification for undertaking risk analysis studies.* At the project management level, better insight is one critical aspect, leading to better decision making and better risk management. Another is a control and reporting framework which avoids sudden surprises and losses of confidence. A third is a framework for the justification of prudent risk avoidance and mitigation measures which may involve early expenditure of substantial sums of money.

PERFORMING RISK ANALYSIS

Although risk analysis is usually thought of as quantitative, a risk engineering approach need not be about measuring risk, and it need not use probabilities. Risk analysis should be concerned with understanding what might happen and what should happen. As an aid in developing and communicating this understanding, structured verbal models can be extremely useful, especially when the nature of the risks and the associated responses may cause confusion or misunderstanding if an agreed definition is not provided.

Effective and efficient performance of risk analysis involves a number of contributing elements. These include models, methods and computer software, as well as less tangible skill-related elements such as methodology design, specialist expertise and study team management.

RISK ANALYSIS MODELS

Risk analysis is concerned with uncertainty and its consequences. Mathematically, risk analysis models manipulate probabilities and probability distributions, in order to assess the combined impact of risks on the project. The exact manner in which this is done depends on the purpose of the analysis.

A flexible set of verbal, graphical and mathematical risk engineering models has been developed for risk analysis tasks. They form a general family of models applicable in a wide range of specific risk analysis contexts. They are based on Controlled Interval and Memory (CIM) representations of probability distributions. The nature and use of CIM models is described in detail throughout this book, beginning in the next two chapters.

Risk analysis models other than CIM models are discussed briefly in the next chapter, to provide a simple basis for comparison. However, a detailed treatment of alternatives is beyond the scope of this book.

There is no single all-purpose risk analysis model. Some models are very simple, while others may be very complex, embodying not only uncertainty about events or activities, for example, but responses to that uncertainty and the consequences of the responses. In general it is advisable to start with simple models, and make them more complex only if doing so seems cost effective. CIM models allow a very wide range of levels of complexity, and a flexible structured approach to introducing complexity, as discussed in the final chapter, and demonstrated throughout the book.

RISK ANALYSIS METHODS

Risk analysis involves a method or a systematic series of steps. A detailed risk engineering method for project duration risk assessment is illustrated in Figure 1.1. Using this method involves an iterative approach, and the step sequence may not be strict. Such a method is necessary if the process of risk analysis is to be efficient and effective.

Phase	Step
Scope	Activity identification
	Primary risk identification
	Primary response identification
	Secondary risk identification
	Secondary response identification
Structure	Minor and major risk identification
	Specific and general response identification
	Simple and complex decision rule identification
	Risk/response diagramming
Parameter	Desired parameter identification
	Scenario identification and probability estimation
Manipulation and interpretation	Risk computation
	Risk efficiency decision rule assessment
	Risk balance decision rule assessment
	Budget contingency sum assessment

Figure 1.1 The phase and step structure of a risk analysis method for project duration assessment

Risk analysis methods must be designed to suit the model and the circumstances in which it is used. There is no single all-purpose method for risk analysis. Families of related risk engineering methods have been developed, involving similar concepts and characteristics. Like the method of Figure 1.1, they follow a systematic series of steps, but the steps are related to the specific risk analysis context. Different risk analysis methods are described in the case studies through this book, beginning in Chapter 4.

RISK ANALYSIS COMPUTER SOFTWARE

Some standardized risk analysis software packages are available. However, appropriate computer software must reflect the choice of model and method, and there is no one best approach for all forms of risk analysis.

Families of related programs have been developed for associated families of risk engineering models and methods. They are sophisticated, interactive program suites which provide a means of entering information in a wide range of different formats and synthesising it in any required manner. They are designed to take advantage of the general characteristics and terminology of the application area being addressed. More basic general risk engineering software is also available.

RISK ANALYSIS METHODOLOGY DESIGN

Methodology design involves choosing or developing an appropriate model/method/software combination for a particular kind of risk analysis in a particular context. The time and money available to perform the analysis, and the expected future use, are obviously important considerations, as well as the immediate task. Methodology design is a process which is necessarily dependent upon experience and intuition, but a comparison of the case studies in this book provides an introduction to some of the key issues, as does the final chapter.

RISK ANALYSIS AND SPECIALIST EXPERTISE

Risk analysis models, methods and software provide valuable tools for project planning and design, but obtaining the right answer still depends upon specialist expertise. Judgements must be made, in some cases based upon hard data, in some cases based on sound conventional guidelines, in some cases based on creative innovation and well schooled intuition rooted in a wide range of relevant experience. Expertise involving an effective and efficient blend of all these aspects is not made less important by adopting risk engineering methodology: it is simply made use of more effectively.

Risk analysis requires many forms of expertise. Economics, finance, environmental issues, contractual issues, and so on are clearly involved in most major projects. What is not always appreciated is that they may directly impact the way the design and planning is done, and they should be properly considered in a timely manner. Risk analysis helps to provide this integration.

RISK ANALYSIS STUDY TEAM MANAGEMENT

Risk analysis study team management requires special consideration. Like the model/method/software aspects of risk analysis methodology, it must be adapted to the circumstances. For example, one organization the authors have worked with uses an in-house Risk Analysis Group in an internal audit role most of the time. Analysts examine a project plan and project cost estimates in detail over a period of six to eight weeks. Their work then provides useful immediate feedback to the project staff, but they report to the project manager and the head of the planning and costing function group. Other organizations the authors have worked with used large teams over several months to perform a complete analysis, externally to the project team, and they used the analysis to make recommendations based upon fundamental judgements which went beyond the risk analysis itself. Very different kinds and styles of management are clearly necessary for such diverse operations. Proper treatment of these issues is beyond the scope of this book, although some insights are provided, in Chapter 5 especially.

SOME GUIDANCE FOR THE READER

This book is based upon a risk analysis special short course developed for an executive seminar in a business school. It draws upon a number of technical papers published and in progress, and a more technical text in progress, but it does not attempt a detailed technical treatment. Its concern is providing an understanding of key issues and concepts, for managers and clients who may want risk analysis performed for them, as well as for managers and their staff who may want to undertake risk analysis. It does not require a highly mathematical or technical background, but it does assume a degree of comfort with numbers, and familiarity with organizational decision processes and concerns. Further, it assumes readers who are familiar with other forms of risk analysis will suspend judgement of the risk engineering approach until they have finished this book and examined some of the more technical issues in the references provided. Finally, it assumes any reader who wishes to implement risk analysis studies based upon the suggested approaches will study the technical references provided or seek advice.

Chapter 2 provides an introductory overview of basic approaches to risk analysis, the only chapter which does not limit itself to a risk engineering perspective.

Chapter 3 introduces the controlled interval and memory (CIM) models which are central to a risk engineering approach. They are introduced in their simplest form, assuming the individual sources of risk that are of interest can be added assuming independence.

Chapter 4 provides a case study which sets these simple models in a realistic context, and introduces aspects of the risk engineering methodology. It concerns the reliability of an LNG facility.

Chapter 5 provides another case study which builds on the discussion of the risk engineering methodology, and introduces an important modelling complexity, concern for multiple criteria. It considers the best way to cross a river with a large diameter gas pipeline.

Chapter 6 deals with an issue which most readers will be concerned with by now: the elicitation of probabilities for risk analysis.

Chapter 7 introduces the treatment of dependence in a CIM modelling framework.

Chapters 8 and 9 provide case studies concerned with project costs and estimates of contingencies, extending the earlier discussion of the methodology and illustrating how some aspects of dependence can be handled in practice.

Chapters 10 and 11 consider more complex dependence modelling issues, concerned with structural dependence in a cost or duration estimation framework and dependence induced by a project planning network.

Chapter 12 considers project appraisal in terms of economic risk evaluation for large projects, building on all the previous material. Chapter 13 discusses related applications.

Chapter 14 provides an overview, considering the selection of an appropriate approach to project time and cost planning.

A glossary of terms, references and an index follow.

This material, and its sequence, has been selected to allow simple modelling concepts to be considered first and then gradually built upon, in parallel with the development of the key concepts of the risk engineering methodology, providing practical sources of motivation based on case studies throughout. The reader may find it useful to skim through the book before more careful reading, but sequential treatment of the material is important, and much of the later material will not be intelligible if earlier material has not been assimilated.