QUANTITATIVE RISK ASSESSMENT

Quantitative risk assessments cannot eliminate risk, nor can they resolve trade-offs. They can, however, guide principled risk management and reduction – if the quality of assessment is high and decision-makers understand how to use it.

This book builds a unifying scientific framework for discussing and evaluating the quality of risk assessments and whether they are fit for purpose. Uncertainty is a central topic. In practice, uncertainties about inputs are rarely reflected in assessments, with the result that many safety measures are considered unjustified. Other topics include the meaning of a probability, the use of probability models, model uncertainty, how to understand and describe risk, the use of Bayesian ideas and techniques and the use of risk assessment in a practical decision-making context.

Written for professionals, as well as graduate students and researchers, the book assumes basic probability, statistics and risk assessment methods. Examples make concepts concrete, and three extended case studies show the scientific framework in action.

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The Scientific Platform

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CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Tokyo, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521760577

First published 2011

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing-in-Publication Data

Aven, T. (Terje)
Quantitative risk assessment : the scientific platform / Terje Aven.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-521-76057-7 (Hardback)
1. Probabilities. 2. Risk assessment–Statistical methods.
3. Decision making–Statistical methods. I. Title.
QA273.A93 2011
519.2′87–dc22

2010037661

ISBN 978-0-521-76057-7 Hardback

Contents

Preface

Risk assessment is in many respects acknowledged as a scientific discipline per se: there are many master and PhD programmes worldwide covering this field, and many scientific journals and conferences highlighting the area. However, there are few books addressing the scientific basis of this discipline, which is unfortunate as the area of risk assessment is growing rapidly and there is an enormous drive and enthusiasm to implement risk assessment methods in organisations. Without a proper basis, risk assessment would fail as a scientific method or activity. Consider the following example, a statement from an experienced risk assessment team about uncertainty in quantitative risk assessments (Aven, 2008a):

> The assessments are based on the "best estimates" obtained by using the company's standards for models and data. It is acknowledged that there are uncertainties associated with all elements in the assessment, from the hazard identification to the models and probability calculations. It is concluded that the precision of the assessment is limited, and that one must take this into consideration when comparing the results with the risk acceptance criteria and tolerability limits.

Based on such a statement, one may question what the scientific basis of the risk assessment is. Everything is uncertain, but is not risk assessment performed to assess the uncertainties? From the cited statement it looks like the risk assessment generates uncertainty. In any event, does this acknowledgment – that a considerable amount of uncertainty exists – affect the analyses and the conclusions? Only very rarely! My impression is that one writes such statements just to meet a requirement, and then they are put aside. This says a lot about the scientific quality of the assessments.

I strongly believe that the scientific platform of risk assessment – and quantitative risk assessment in particular – needs to be strengthened. The aim of this book is to contribute to this end. For many years I have been engaged in research trying to improve the scientific basis of risk assessment; I have written many books and papers related to the topic, and believe that the time has come to publish a fundamental exposition on the topic *quantitative risk assessment – the scientific platform*. The basic idea is to provide a framework for analysing and discussing the quality of the assessments using the scientific requirements of reliability and validity. The reliability requirement is concerned with the consistency of the "measuring instrument" (analysts, experts, methods, procedures), whereas validity is concerned with the assessment's success at "measuring" what one set out to "measure". This gives a new and original approach to the analysis and discussion.

The quality of risk assessment relates to the scientific building blocks of the assessments but also to the role of the assessments in the decision-making process. On an overall level one can say that the purpose of risk assessment is to support the decision-making – to adequately inform the decision-makers – but what type of decision support (knowledge, judgements) should the assessments provide? Are the objectives (expectations) accurate risk estimates and/or uncertainty characterisations (representations/expressions of the knowledge and lack of knowledge available)? The scientific quality of the assessments obviously needs to be seen in relation to these objectives. Also the requirements of reliability and validity depend on these objectives. Using these criteria, we can evaluate the quality of the assessments for different objectives of the assessments.

Uncertainty is a key topic when discussing the scientific platform of risk assessment. Other important issues are the meaning of a probability, the use of Bayesian ideas and concepts, the meaning of risk, how risk should be described, the meaning and use of models, model uncertainty, the meaning and use of probability models and parameters, and the value of information.

The book is general and is relevant for all types of applications, but safety engineering has the main focus.

For many years there has been a lively discussion about the scientific platform of statistical analysis in general: the Bayesian/non-Bayesian controversy; see e.g. Lindley (2000). However, there has not been much work on establishing a proper scientific basis for risk assessments. A number of papers address foundational issues of risk assessment; see e.g. Apostolakis (1988, 1990), Kaplan and Garrick (1981), Singpurwalla (1988, 2006) and Cooke (1991), but I am not aware of much work where fundamental scientific quality requirements such as reliability and validity are discussed in the context of a risk assessment (Aven and Heide, 2009).

Of the few contributions found in the literature I would like to draw attention to the first issue of the international scientific journal *Risk Analysis* in 1981, and in particular Weinberg (1981) and Cumming (1981). These authors describe some of the problems of risk assessments, and express a large degree of scepticism about the scientific reliability and validity of risk assessments. Weinberg notes that "one of the most powerful methods of science – experimental observations – is inapplicable to the estimation of overall risk". Graham (1995) writes that the discipline "should (and will) always entail an element of craft-like judgment that is not definable by the norms of verifiable scientific fact", and that "any determination that a risk has been 'verified' is itself a judgment that is made on the basis of standards of proof that are to some extent arbitrary, disputable, and subjective" (Aven and Heide, 2009).

I share many of the same views on the scientific basis of risk assessment. However, in order to gain more insight into this subject and be able to make guidance on how to ensure and strengthen the scientific quality of risk assessments, we need to clarify the scientific pillars of the risk assessment and tailor the assessments to the decision-making context. As mentioned above, this is exactly what the present book does.

Small illustrating examples are included in the book for making concepts concrete and to illustrate ideas and principles. Three extended examples (case studies) will be presented early in the book (Chapter 4) and are pursued through the rest of the book. The first of these examples is related to the analysis of accident data, the second relates to the siting of a Liquefied Natural Gas (LNG) plant and the third discusses the design of a safety system. The idea is not that every concept or step of a risk assessment would be illustrated in each case study, but that these cases would recur often enough that the readers get a feel for the overall scope and shape of a real risk assessment and its use and are able to relate the scientific requirements to these concepts and steps. The cases are simplified so that the intellectual lessons are clarified, but they are nevertheless realistic.

The three cases illustrate different types of risk assessments. The first case covers a statistical data analysis, whereas the second shows an example of a system analysis which is strongly based on modelling of the phenomena studied. In Case 2 a large number of unknown quantities (model parameters) on the subsystem/component level need to be assessed. The third case presents an example of a reliability analysis of a specific system. The results of such analyses constitute important input to risk assessments.

Before we present and analyse the three main cases, we first review basic concepts and perspectives on how to define, understand and describe risk (Section 2). The aim is to give the reader an overview of the many different ways one can look at risk and to provide a structure for the coming analysis. We also discuss some fundamental issues related to science in a risk assessment context (Chapter 3): what are the basic features of risk assessment as a scientific method and how is risk assessment related to other scientific disciplines? This chapter also summarises the reliability and validity requirements mentioned above. Then in Chapters 5 and 6 we examine the three cases with respect to these scientific requirements: Chapter 5 looks at the situation when the objective of the risk assessment is accurate risk estimation, whereas Chapter 6 restricts attention to situations where the objective of the risk assessment is uncertainty characterisations. In Chapter 7 we discuss the implications of the findings in Chapters 5 and 6 for risk management and communication. Key issues addressed are the use of risk acceptance criteria, risk reduction processes, and the cautionary and precautionary principles.

From this analysis we are led to Chapter 8 which discusses and provides guidance on how risk should be approached, i.e. how we should define, understand and describe risk, as well as use risk assessments in a decision-making context. Chapter 9 provides some conclusions from the previous chapters.

The book allows for scientific analysis of different types of risk assessments, in particular assessments which in a detailed way reflect human and organisational factors. The book includes examples of assessments which reflect such factors, but it is beyond the scope of the book to provide a detailed account of these types of assessments. Well-selected references are presented for readers who do want to delve deeper in this area. See Section 1.1.

The book is for professionals in the field, as well as for graduate students and researchers. It should also be of interest to many policy makers and business people. The book would make it possible for them to better understand the boundaries of risk assessments and how they should be used for decision-making. The book is advanced (conceptually) but at the same time rather simple and easy to read. It has been a goal to avoid too many technicalities, but without diminishing the requirement for precision and accuracy. The main ideas and principles are highlighted. Readers would benefit from a basic knowledge in probability calculus and statistics as well as in risk assessment methods. It has, however, been a goal to reduce the dependency on extensive prior knowledge. The key statistical and risk concepts will be introduced and discussed thoroughly in the book. Thus the readers do not need to be experts on, for example, regression analysis. The focus will be on the basic ideas – "advanced statistical analysis" is not required. Appendix A provides a summary of basic theory (e.g. probability, Bayesian analysis). Appendix B includes a listing of some key definitions.

Acknowledgments

Many people have provided helpful comments and suggestions for this book. In particular, I would like to acknowledge Eirik B. Abrahamsen and Roger Flage for the great deal of time and effort they spent on reading and preparing comments on earlier versions of the book. I would also acknowledge Jan Terje Kvaløy for his kind help in producing the probability distribution shown in Figure 6.2. I am also grateful to two anonymous reviewers for valuable comments and suggestions on the plans for the book.

This work has been funded by The Research Council of Norway through the SAMRISK and PETROMAKS research programmes. The financial support is gratefully acknowledged.

I also acknowledge the editing and production staff at Cambridge University Press for their careful and effective work.