

Risk Measurement and Monitoring

THE FERMA-RIMAP[®] SERIES

The FERMA-rimap[®] Series serves as a proactive, continuous and dynamic learning and research platform to respond to risk managers' present and future educational and professional needs. The volumes set a flexible and dynamic measurable standard taxonomy for European Risk Managers and essential reading for students gaining their qualification. The scope of *The FERMA-rimap[®] Series* is to reach out to experienced or junior risk professionals, whatever their background is, and wherever their career is heading. All risk professionals have a duty to stay in contact with the evolution of the risk landscape.

Risk Measurement and Monitoring

EDITED BY

SIMON GRIMA

University of Malta, Malta

MARÍA ISABEL MARTÍNEZ TORRE-ENCISO

Universidad Autónoma de Madrid, Spain

AND

MAURIZIO CASTELLI

Augustas Risk Services SpA, Italy



United Kingdom – North America – Japan – India – Malaysia – China

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INVESTOR IN PEOPLE

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Preface

Risk measurement and monitoring are fundamental to modern risk management practices, enabling organisations to assess, quantify, and respond to uncertainties effectively. In today's complex and rapidly evolving risk landscape, financial institutions, corporations, and policymakers require sophisticated measurement techniques to make informed decisions and ensure resilience against unforeseen disruptions.

This volume, *Risk Measurement and Monitoring*, is a vital resource designed to equip risk professionals with the necessary knowledge, tools, and methodologies to measure, monitor, and mitigate risk effectively. It serves as a bridge between academic research and practical application, ensuring that risk managers can make informed decisions based on data-driven analysis and strategic foresight.

The book delves into both quantitative and qualitative risk assessment techniques, offering a multidimensional perspective on risk measurement. Covering essential topics such as uncertainty modelling, portfolio risk management, operational risk, corporate governance, supply chain risk, and cybersecurity, this volume provides a holistic view of the risk landscape. It also addresses contemporary challenges such as emerging risks, geopolitical threats, environmental risks, and the impact of artificial intelligence on risk management.

By integrating theoretical models with practical examples, the book offers valuable insights into modern risk management frameworks, emphasising regulatory compliance, decision-making under uncertainty, and enterprise risk management (ERM). Furthermore, the book highlights best practices in risk communication, reporting, and stakeholder engagement, reinforcing the importance of transparency and accountability in risk management.

As a part of the *FERMA-rimap® Series*, this book aligns with the European certification standards for risk professionals, ensuring that both experienced practitioners and newcomers in the field can benefit from its structured and forward-looking approach. Whether used as an educational tool or a professional reference, this book is an indispensable guide for navigating the complexities of risk measurement and monitoring in today's dynamic environment.

The book *Risk Measurement and Monitoring* specialises in enterprise risk management (ERM) and risk measurement methodologies, with a strong emphasis on quantitative techniques, strategic risk integration, and regulatory frameworks. It serves as a key educational and professional development resource for risk managers, financial analysts, auditors, and executives responsible for risk oversight.

The book is structured around core risk measurement topics, including:

- Uncertainty Modelling – Exploring historical data methods, expert-based analysis, and hybrid approaches for predicting and mitigating risk.
- Portfolio Risk and Efficient Frontier – Applying financial principles to optimise risk-taking in investment and corporate decision-making.
- Corporate Social Responsibility (CSR) and ESG Risk – Integrating environmental, social, and governance risks into enterprise risk management.
- Risk Communication and Governance – Understanding the role of corporate governance and effective communication in risk mitigation.
- Operational and Supply Chain Risk Management – Addressing systemic risks, compliance challenges, and third-party risk mitigation.
- Cybersecurity and Emerging Threats – Managing risks associated with cyber threats, data privacy, and artificial intelligence-driven vulnerabilities.
- Mergers, Acquisitions, and Financial Risk – Evaluating the risks involved in corporate restructuring, financial modelling, and regulatory compliance.
- Terrorism and Geopolitical Risks – Assessing the impact of terrorism, political instability, and macroeconomic disruptions on risk exposure.
- Reputational Risk and Crisis Management – Strategies to manage and recover from reputational crises and stakeholder challenges.

This book serves as an essential guide for professionals in risk management, finance, insurance, and corporate governance, offering both foundational knowledge and advanced methodologies to enhance risk resilience and decision-making.

We extend our sincere gratitude to the contributing authors, industry experts, and academic professionals who have shared their insights and expertise in shaping this publication. Their dedication ensures that this book remains a valuable resource for risk managers, corporate leaders, policymakers, and students alike. This book series is a testament of FERMA's (Federation of European Risk Management Associations) unwavering commitment to promoting excellence in risk management through education, research, and professional development.¹

¹To know more FERMA's commitment to risk management, please visit www.ferma.eu

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Instructional design and copy editing (FERMA materials)

Stephanie Heriot AE, ANZIIF (Allied), Grad Dip Editing & Publishing, Cert. IV TAE

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- **www.anziif.com and www.ferma.eu**
- **Industry experts (ANZIIF source modules)**

Simon R. Doherty
BAppSc (Tour Mgt), Grad Cert Bus (Dpl & Trade) and Grad Cert Emerg Hth

Deanne Keetelaar
CPRM

Kevin W Knight AM
CPRM, Hon FRMIA, FIRM (UK), LMRMIA, ANZIIF (Mem)

Kimberley Turner
CPRM

Mark Wheatley
CPRM

Lynda Fay
ANZIFF Admin

Mikaela Reynoldson
MBA, LLB, BComm, GAICM

Bob Anderson
ANZIFF Admin

Gordon Taylor
ANZIIF Fellow, CIP, Adv. Dip FS, Hon Life Member

Peter Moloney
ANZIFF Admin

Shaun Wilkinson
ANZIIF (Fellow), FCII, Dip Bus Studs (Ins Mgt), FIRM

Stuart Bassett
LLB, BComm, FICSM, ASA, AAI, AIRM

Gordon Young
BA, MSc, ARM, AFRMIA, CPRM

Harry Rosenthal
BA, MBA, ARM, CPCU

Ian Deayton
Dip RM, AII (Assoc), RMIA (Mem)

Vanessa Dallan
ANZIIF (Fellow) CIP, MRM

Tom Beer
DSc, PhD, FEIA

Gordon Young
BA, MSc, ARM, CPRM, AFRMIA

J. Peter Clarke
FCA, MBA

Roger Clarke
BCom, MCom, PhD, FACS

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Chapter 1

Uncertainty Modelling

Introduction

The Volkswagen emissions testing scandal that sent shock waves throughout the industry in Europe is a vivid reminder of how events that are hard to foresee can still disturb profitability and threaten an organisation's survival. Producers are not only subject to these kinds of random events but also to shocks due to shifting consumers' tastes, volatile exchange rates, business cycles and technological developments; these are just some of the factors that can alter an organisation's fortunes. Executives must make forward-looking decisions in the face of all these uncertainties – but how?

It requires a new expanded definition of risk. Therefore, the 'new' risk manager must think and look beyond the organisation's frontiers, more specifically to include all economic partners, indeed all stakeholders of the organisation. Special attention will have to be devoted to the procurement chain and the interdependences of all parties and this includes a solid understanding of modelling uncertainty.

As a matter of fact, risk management is maturing into a fully-fledged branch of managerial sciences dealing with the handling of uncertainty, both threats and opportunities, to which all organisations are confronted due to more or less predictable changes in the internal and external context in which they operate as well as evolutions in their ownership and stakeholders' expectations and their impacts on objectives.

Enterprise-wide risk management is involved both in the design and implementation of strategies that must include provisions for adaptations and/or anticipations of these changing conditions and put in place sentinel events to warn of possible ruptures as early as possible. This will deliver value by facilitating prompt reaction and pre-emptive actions to allow managers to reach their optimal objectives, goals, and missions under any circumstances while coping with surprises, even of cataclysmic proportions.

However, this organisational resilience can be achieved only through the implementation of a continuous process of risk management at all levels in the organisation stemming from a clearly defined risk management strategy approved by the board in which the risk appetite is defined and communicated. This process loops through the review and audit process of the risk management programme to ensure that the key objectives are the centre of all decision-making and are achieved through a proper implementation of the plans.

Judgement can be applied to decision-making in risk-related issues, but rational and transparent processes called for by good governance practices require that risks be quantified to all extents possible. When data are insufficient, unavailable or irrelevant, expertise must be called upon to quantify impacts as well as likelihoods. Therefore, the risk manager must understand and be able to guide the implementation of the appropriate quantification tools at all three steps of the risk management process: risk assessment (identification, analysis and evaluation), risk treatment (reduction and financing), and monitor and review to validate the results and improve the future direction of the major models and provide illustrations on how they could apply.

This chapter will provide a description of the major models and provide illustrations on how they could be applied.

Learning Outcomes

By the end of this chapter, you should be able to:

- define different approaches to modelling uncertainty;
- describe the major methods based on historical data;
- distinguish between simple, complex and matrix organisational structures;
- define data-based approaches to modelling uncertainty.

Modelling Methods

Forecasting models based on probabilities and trend analysis are part of the risk manager's fundamental tool kit, and the question of analytics should be at the top of any new risk manager's agenda.

The mass of data that flows through the organisation and that is relevant to risk management is such that computer-based systems are early in the game.

There are analytical tools available to risk management professionals to measure the degree of uncertainty and to predict how an organisation will fare depending on various influencing factors and strategies.

Organisations assess the impact of uncertainty – that is, risk – through the development and use of empirical models. These models assist decision-makers in simulating, testing, and predicting outcomes and learning from the information produced.

The information derived from models helps in making decisions at all levels: strategic, tactical, and operational.

The methods for modelling uncertainty are traditionally split into three broad categories:

- methods based on historical data
- methods based primarily on expert input
- hybrid methods based on a combination of historical data and expert input.

Beyond these three categories, the methods could be viewed as a continuum and they should be each analysed for their benefits and limitations depending on the context and needs of the organisation.

When it comes to using the different methods, it is unlikely that each organisation would use all of them.

Modelling Continuum

Historical Data Analysis	Hybrid Models	Expert Input
Empirical distribution		Bayesian networks
Fit parameters of theoretical probability density functions		
Stochastic differential equations		
Extreme value theory		

Methods Based on Historical Data

Traditionally, insurers approach uncertainty and predictive issues based on historical data and past patterns and this has been carried over to the risk management community.

The following are the major methods based on historical data:

- empirical distribution
- fit parameters of theoretical probability density functions
- stochastic differential equations (SDE)
- extreme value theory (EVT)
- regression analysis.

Empirical Distribution

An empirical distribution develops the theoretical probability distribution function of a set of many observations of a random variable (X_1, X_2, \dots, X_N) forming a sample of observations. The most straightforward approach to constructing an empirical distribution is to form the hypothesis that the future is a reflection of

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the past and that the sample is a precise extraction of the population. In such a situation, the analyst can infer a discrete probability distribution.

Therefore, an empirical distribution is often represented by a series of steps representing the cumulative distribution from which the sample is drawn. As an illustration, organisations can use such an approach to predict the future return of a portfolio provided the portfolio has generated enough data to offer complete, reliable and consistent data, i.e. credible inputs.

This requirement is the limitation of this approach; it assumes that the organisation has been able to gather complete, consistent and reliable data in a stable context, including extreme events.

Fit Parameters of Theoretical Probability Density Functions

One way to manage the limitations of empirical distribution is to assume that the uncertainty – the risk – lends itself to a continuous probability density function. In such a situation, the analyst will compute the parameters of the distribution that best fit the sample available. However, this implies that the analyst has reasons to select a form of distribution, not always the normal distribution already defined in a previous rimap Block. For instance, in the case of property-casualty losses, their frequency is often assumed to follow a Poisson or negative binomial distribution, both non-symmetrical and presenting a thick tail (risk of catastrophic frequency). When it comes to the severity, experience has proved that assuming a lognormal distribution or a Pareto distribution (or conditional, or tail) is a better fit.

Stochastic Differential Equations

SDE represent the change between the value of a variable (for instance an interest rate or the quote of a share in the portfolio of an investor) between instant t and $t+1$, one period later. The change is expressed as the combination of a predictable (certain) change and a random change during the time span considered. The random change is represented by a random variable following a specified probability distribution (typically, the normal distribution is chosen as it is simply defined by two factors: mean and standard deviation). Using an initial value, an SDE helps to roughly develop a scenario in which value changes over time can be produced this way. Thus, scenarios can be represented as probability distributions for each point in time over the forecast timeline and can be used by management to develop forecasts to assist in strategic decision-making.

Extreme Value Theory

EVT is a subset of the discipline of statistics. Rather than creating a model based on the assumption that values or returns are normally distributed, risk managers can use EVT to include extreme or rare deviations from the median of probability distributions. As an analytical and a statistical tool, it aims to analyse probability distributions generated by processes. In the realm of risk, these processes may be natural forces such as erratic weather, one-hundred-year floods or earthquakes. More recently, EVT events have included finance and banking organisations’

significant or ‘extreme’ exposure to poorly performing collateralised debt obligations. For this reason, EVT has utility in assessing risk from infrequently-occurring but high-severity types of losses.

Statistics and Trend Analysis

Establishing forecasts on the basis of past data, i.e. using probability or trend analysis, is founded on the hypothesis that the future will reflect the past. Starting on this hypothesis, forecasts can be developed:

- On probability analysis: the world is stable and the future is a strict reproduction of the past.
- On trend analysis: the evolution of the world is stable and the evolution schemes of the past will continue in the future.

Whatever the circumstances, one of the basic objectives of risk forecasting is to evaluate the costs of future claims of a given organisation (from the viewpoint of the insurer and the reinsurer), or the future cash flows associated with uncertain future outcomes (from the viewpoint of the risk manager).

However, forecasts for the future are not used only in risk management, and using what the past teaches us of the future is a key to any rational management decision for a future that is intrinsically uncertain.

Just as a reminder, forecasts in the economic world are always based on past data. Only empirical probabilities can be used, by opposition to mathematical probabilities that can be computed without any sample or past experience (throwing dice, playing cards, etc.). The economic phenomena or situations are far too complex to lend themselves to a priori mathematical modelling as opposed to experience-based modelling. Therefore, they rely heavily on the accuracy of past data and the appropriate hypotheses on the foreseeable evolution of the mathematical relationship between key variables.

The major difference between ‘management’ and ‘risk management’ is in the word risk, meaning the degree of uncertainty. When the law of large numbers applies and reasonably accurate forecasts can be developed, there is no risk and it is just efficient management of a cost or profit centre (see Frequency risks). The problem is that when a real uncertainty (a serious risk) is involved, the data available may be too short to constitute a reliable sample to develop a probability distribution or a credible trend analysis.

This knowledge of the past must be translated in numbers to be used in all these forecast models. Therefore, collecting data, or learning from past experience, is a key to any rational approach to managing risks. (Any reader interested in furthering their knowledge of the field will find easily a number of books on forecast for beginners.)

Any useful data must be:

- exhaustive
- coherent (and stable)

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- pertinent
- in order.

Exhaustivity

The risk manager relies on all the department heads to gather data, and all other information necessary to establish reserves and forecast future losses. Incident reports and quasi-accident information must be reported, otherwise the risk management process will be based on truncated information and therefore may lead to ill-informed decisions.

Consistency (and Stability)

In probability, consistency refers to the fact that the data in the sample are drawn from the same probability distribution. In practice, data must be collected and evaluated on the same basis.

To fix this idea, let us illustrate with an automobile fleet. If we want to use a five-year claim history, all claims must be expressed with the same monetary unit (adjusted for inflation). Also, the evolution of the park (model types and numbers) and drivers (retirement, resignations, new recruitments, etc.) will have to be accounted for as well as the modification of the environment (competition, laws, etc.).

Relevance

This is particularly difficult, as one makes sure that the data are related directly to the phenomena to be explained.

Let us illustrate by the same example. The climatic conditions at the site of a car accident can provide insights into the behaviour of drivers or cars under given conditions. On the other hand, the temperature in Tokyo on the day of an accident in Europe may be totally irrelevant.

Order

Data must be ordered in a way that makes sense with regard to the independent variables that will be the basis for the analysis. One of the most frequent is time, but it can be also turnover for product liability claims and salaries for workers compensation.

Statistics

Probability analysis can be used only provided the world is stable. This supposes that the world of the future is identical to the world of the past. Then, and only then, can a probability distribution be drawn from past data, the sample, to forecast the future.

What do we mean by probability? It is the relative frequency of an outcome; that is, the ratio of the number of occurrences of one of the outcomes to the totality of possible cases. It is represented by a number between 0 and 1, usually given as a per cent.

Let us summarise here the characteristics of a probability distribution.

Central Tendency

The most common measure is the mean. Most probability distributions are more or less clustered around the most probable value, called the mode. Finally, a value leaves the same probability for the outcome to be higher or lower, it is the median. The mean is estimated by the arithmetic average of the sample.

Dispersion

Most readers are likely to be familiar with the 'bell-shaped' curve, or normal distribution, also known as Gauss Law. Intuitively, one may understand that the bell may be wide open, spreading over a large interval, or narrowly pointed around its mean. It is easy to figure that a narrow curve will provide a more precise evaluation of the future than the broader one.

The measure of this dispersion is called the standard deviation. As a reminder, the standard deviation is the square root of the variance. The variance is the sum of the square of the distance of every possible outcome to the mean multiplied by its probability. The shape of the curve is really given by the dispersion index equal to the standard deviation divided by the mean.

Symmetry

Some probability distributions are symmetrical, others are asymmetrical (Poisson, or binomial, distribution). This means they have a tail on one side. A distribution that is not symmetrical is skewed to the right or to the left. Most distributions found in the risk management world tend to be skewed to the right. In the case of a severity distribution, this means that there is a non-negligible probability that a catastrophic loss may be suffered.

The law of large numbers states that the larger the sample drawn from a population, the more trustworthy are the conclusions drawn.

Going back to the simplified risk mapping in four quadrants, it is clear that only risks with high frequency and low frequency will lend themselves easily to probability analysis. It is where the impact of prevention instruments can be assessed with some degree of accuracy.

However, the severe restriction due to the 'world stability' hypothesis reduces the domain where probability analysis can be applied as most elements of any organisation and its environment are always changing. This hypothesis can be partially lifted through trend analysis.

Trend or Regression Analysis

Trend or regression analysis consists in acknowledging the evolution of the environment and the system. However, it poses the hypothesis that the evolution follows mathematical relations between better-known dimensions (independent variables) and other variables (dependent variables). It is always essential to make a judicious choice of parameters, the evolution of which must be better known to forecast how the dependent variable may move in the future.

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If linear regression is easier to use, it is not the only mathematical relation that may be used in modelling for forecasting the future. Furthermore, one dependent variable may require several independent variables to explain its future behaviour. The formidable advances in computing capacity have made possible multiple regression analysis and the processing of a large number of data, which was impossible by hand in the past.

Here are some illustrations of regression that might prove fruitful for the risk manager:

- number of vehicles in a fleet explaining the variation in yearly total losses from the fleet;
- annual turnover and total amount of product liability claims (with a possible lag time between the two);
- number of employees and frequency of workers compensation claims.

But also consider product liability claims related to ‘quality budget’.

Let us remember if that dealing with uncertainty is at the heart of any rational management process, it is even more essential than the management of risks, intended to handle situations of extreme uncertainty. Probability, trend analysis, and modelling (Monte-Carlo, etc.) all rely heavily on the quality of data collected first through the past history of the organisation but also on the experience of similar organisations or industry wide data.

However, the rapidly changing and somewhat erratic world that we have experienced over the last 10 or 20 years has made modelling based on probability and trend analysis at best unreliable, if not totally obsolete. It remains to evaluate the new breach in forecasting future states of systems that will bring new developments in the mathematical world like chaos theory and the transposition of existing concept physics like entropy and other laws of thermo-dynamics into the economic sphere.

Note: When using regression analysis, it is essential to validate the quality of the regression thanks to the determination of efficient R2. R2 is between 0 and 1; the closer to 1, the better (more reliable) the regression. c is the most probable (see graph below).

