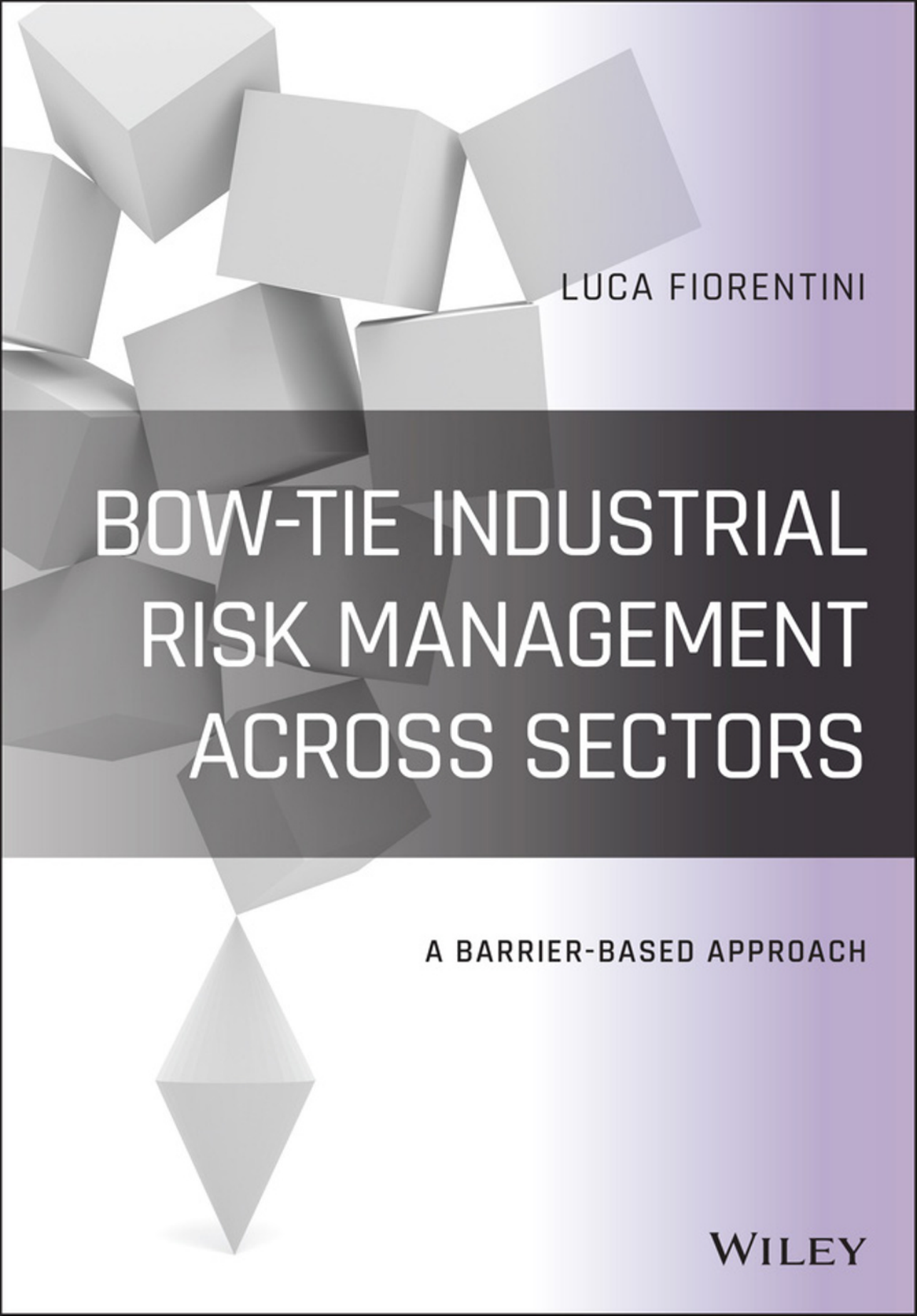

LUCA FIORENTINI

BOW-TIE INDUSTRIAL RISK MANAGEMENT ACROSS SECTORS

A BARRIER-BASED APPROACH

WILEY

Bow-Tie Industrial Risk Management Across Sectors

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Professor Luca Fiorentini

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To my wife Sonia, with whom, day by day and together, I always reach new important goals. Thank you for your support, patience and constant love, witnessed by the wonderful family we have.

Luca Fiorentini

Contents

List of Figures

List of Tables

List of Acronyms

AHJ	authority having jurisdiction
AIChE	American Institute of Chemical Engineers
ALARP	as low as reasonably practicable
BCM	business continuity management
BCMS	Business Continuity Management System
BFA	barrier failure analysis
BIA	business impact analysis
BPCS	basic process control system
BRF	basic risk factor
BSCAT	barrier-based systematic cause analysis technique
BT	Bow-Tie
CCD	cause-consequence diagram
CCPS	Centre for Chemical Process Safety
COSO	Committee of Sponsoring Organizations of the Treadway Commission
ERM	enterprise risk management
ETA	event tree analysis
FARSI	functionality, availability, reliability, survivability and interactions
FMEA	failure modes and effects analysis
FMECA	failure modes, effects, and criticality analysis
FMEDA	failure modes, effects, and diagnostic analysis
FSMS	fire safety management system
FTA	fault tree analysis
GAMAB	globally at least as good
GIGO	garbage in, garbage out
HAZID	hazard identification
HAZOP	hazard and operability analysis
HEART	human error assessment and reduction technique
HEMP	hazard and effects management process
HEP	human error probability
HFACS	human factors analysis and classification scheme
HLS	high-level system
HSE	health, safety, and environment
HSEQ	health, safety, environment, and quality
ICT	information and communications technology

IE	initial event
IEC	International Electrotechnical Commission
IEF	initial event frequency
IPL	individual protection layer
IRM	The Institute of Risk Management
IRPA	individual risk per annum
IRT	independent protection layer response time
ISO	International Organization for Standardization
IT	information technology
KPI	key performance indicator
LFE	learning from experience
LOPA	layer of protection analysis
LOPC	loss of primary containment
MEM	minimum endogenous mortality
MGS	at least the same level of safety
MOC	management of change
NFPA	National Fire Protection Association
NMAU	not more than unavoidable
PDCA	Plan-Do-Check-Act
P&ID	piping and instrumentation diagram
PFD	probability of failure on demand
PHA	preliminary hazard analysis
PIF	performance-influencing factor
PPE	personal protective equipment
PSM	process safety management
QIQO	quality in, quality out
QRA	quantitative risk assessment
RA	risk assessment
RAGAGEP	recognized and generally accepted good engineering practice
RBD	reliability block diagram
RCA	root cause analysis
RM	risk management
ROI	return on investment
RPN	risk priority number
RRF	risk-reducing factor
SCE	safety critical equipment
SHIPP	system hazard identification, prediction and prevention
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system
SLC	safety life cycle
SLIM	Success Likelihood Index Method
SMS	safety management system
SPAR-H	Standardized Plant Analysis Risk-Human Reliability Analysis
THERP	technique for human error-rate prediction
TR	technical report

Preface 1

Riccardo Ghini

Quality Head Italy & Malta and South Europe Cluster, Sanofi

Risk assessment is a basic concept that has always accompanied me throughout my work and professional experience, so being able to contribute, albeit marginally, to the drafting of this monumental work fills me with pride and happiness.

Since the time of Legislative Decree 626/94, the ability to evaluate the probability of occurrence and the possible consequences of accidents and injuries at work has been a fundamental skill for me to develop, through the study of ever-more-refined methods and techniques of investigation. Finding all these useful analysis tools grouped in this way, brilliantly described and accompanied by real application examples, represents for me, and for all professionals, a unique opportunity for enrichment and deepening.

In fact, as my career continued, I soon realized how the concepts underlying this book can be effectively applied, not only in the field of work safety, but also in all areas of business activity, where words like "risk," "scenario," "analysis of the causes," and "continuous improvement" have become commonly used, as they are based on the very structure of the management systems developed in accordance with the various reference standards, now completely standardized.

Furthermore, we mustn't fail to mention the importance assumed by the methods of analysis, assessment, and operational management of the risks associated with the predicate offenses of Legislative Decree 231/2001 (administrative liability of companies and entities), which constitute the essential element in the preparation of a Corporate Organization, Management, and Control Model that effectively prevents the occurrence of the types of offense and, at the same time, constitutes a valid exemption in the context of a possible criminal trial.

The real cultural transition, however, takes place when the concept of risk assessment is adopted and is also applied outside the professional sphere, elevating it to a rational criterion to guide our daily choices: "do I overtake or not overtake the car that's in front of me?, "do I subscribe to this insurance policy or not?," "do I vaccinate my children or not?" These are all questions and situations we face every day, and for which it is very useful to identify the possible "top event," the "consequences" that can be generated, and the "causes" that can originate it, as well as to know what "barriers" we can implement in our defence.

This book is therefore much more than a scientific text for a few super-technicians and experts; it is a concrete and useful reference to all, to bring order and reasoning into our decisions, whatever they may be, in a world increasingly dominated by superficiality and disinformation.

I would also like to underline another aspect, often not adequately communicated: the concept of risk not only with a negative meaning, as a threat or weighting of an unfavourable event, but also, from the perspective of ISO 31000, as a positive deviation from the result expected, therefore, as an opportunity, to be evaluated and seized for the development of the organization. A better understanding of this dimension of risk would certainly facilitate a wider and more extensive use of the methodologies illustrated in the book.

At this point, before diving into reading and studying, I just have to applaud the authors, who represent all-Italian excellence, similar to Ferrari and Parmigiano Reggiano, in this scientific field traditionally the prerogative of Anglo-Saxon and American schools, and of which we must all be proud.

Preface 2

Bernardino Chiaia

Head of SISCON (Safety of Infrastructures and Constructions), Politecnico di Torino

The number and the magnitude of accidents worldwide in the industrial sector and in the realm of civil and transportation infrastructures has risen since the 1970s and continues to grow both in frequency and socioeconomic impact. Several major accidents in the industrial sector (see, e.g., the Seveso chemical plant disaster in 1976, the Bhopal gas tragedy in 1984, the Chernobyl nuclear accident in 1986, the *Deepwater Horizon* oil spill in 2010, the explosion in Warehouse 12 at the Port of Beirut in 2020) have been under the lens of the United Nations Office for Disaster Risk Reduction (UNISDR), which puts great effort in developing safety guidelines within the Sendai Framework for Disaster Risk Reduction 2015–2030.

At the same time, the number of infrastructure failures in developed countries rose dramatically since the beginning of the new millennium. This is partly due to ageing and poor maintenance of bridges, viaducts, tunnels, and dams, which were constructed mainly in the first 35 years after World War II. Moreover, traffic loads and required performances have increased 20 times the original design conditions. On the other hand, in underdeveloped countries there is clear evidence that industrial regulations are less strict and that a general lack of a culture of safety generally results in looser applications of the rules, thus producing a physiological higher percentage of accidents.

In this evolving context, the barrier-based approach named *Bow-Tie* represents a successful methodology to approach risk analysis in a consistent and robust manner. The method allows a synthetic and powerful control of multiple hazard scenarios, clearly differentiating between proactive and reactive risk management.

In this book Dr Fiorentini clearly shows the applicability and the advantages of the methodology to various situations. He shows that, once all the hazard scenarios have been correctly identified and well defined, the definition of the most appropriate barriers represents the core of the methodology to ensure risk reduction. In the non-standard case of civil engineering, for example, the Bow-Tie method shows how inspections and maintenance operations represent *preventive* control barriers against the risk of structural collapse, whereas retrofitting, traffic limitations, and active monitoring represent *mitigating* or *recovery* barriers.

The wide experience of Dr Fiorentini, along with his clarity and scientific rigour, make the book a unique and comprehensive essay on the Bow-Tie methodology of risk assessment.

Preface 3

Luca Marmo

Professor of Safety of Industrial Processes, Politecnico di Torino Department of Applied Science and Technology

In over 30 years of mountaineering and ski touring (see an example in Figure 1), I have done thousands of risk analyses, probably more than I have ever done in my professional career. Each preparation for a climb includes risk analysis. Imagine, or remember, if you have the same passion as me, a classic of European ski mountaineering, the high street Chamonix Zermatt. Climbing it takes three days if you are a pro climber, four if you are super-trained—better five or six if you are merely human—between glaciers, crevasses, overhanging rocks, and descents hanging from a rope with skis on your shoulders. 6,300 m of positive altitude difference, all between 1,600 and 3,800 m of altitude. Risky? Yes. Accidents, even fatal ones, in these environments are not so rare. However, those who do not practice mountaineering tend to overestimate the risks because they do not have the cognitive tools to evaluate them.

Figure 1 Descent from Col du Chardonnet. Is it safe? *Source:* Luca Marmo archive photo.