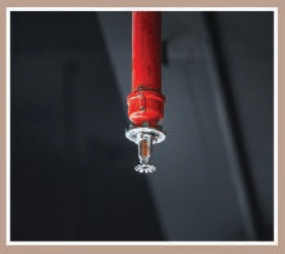

LUCA FIORENTINI • FABIO DATTILO

FIRE RISK MANAGEMENT

PRINCIPLES AND STRATEGIES FOR BUILDINGS AND INDUSTRIAL ASSETS

WILEY

Fire Risk Management

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Principles and Strategies for Buildings and Industrial Assets

Luca Fiorentini
Fabio Dattilo

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To my father, Carlo Fiorentini.

The memory of his passion for fire safety, his immeasurable expertise and above all his example at work with TECSA and with fire safety professional associations and also in our family accompanies me in my professional life every day, with the hope that I can always do my best and also leave a small contribution of my own to the world of fire-safety engineering and industrial risk assessment, which he made known to me and which I have always been close to, appreciating this whole world and developing a passion to be part of it.

Luca Fiorentini

To Carlo Fiorentini, father of Luca, pioneer and master in risk assessment and fire safety. His passion for his work, in-depth knowledge and love for his family mark our path like milestones.

Fabio Dattilo

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Foreword

"*Fire safety between prescription and performance*".

Fire safety, in deliberately general terms, is a discipline of extreme complex application. This is primarily because, although it presents itself as a specialised sector, it affects almost the entirety of the profiles in which the design of an activity is declined; if we think that the fire-safety strategy developed for a given commercial activity conditions the choice of furnishings and fittings, we immediately realise the breadth of the profiles and perspectives impacted by the discipline. Second, because fire safety runs through and affects all phases of the development of an activity, starting from design and ending with daily management, once implemented, the fire-safety strategy must be applied in the operation of the activity and cyclically measured in expected performances.

Considering therefore the breadth of the regulated profiles and the immanence of fire safety in management processes, it is easy to understand how the discipline cannot be relegated among the recurring fulfilments to be carried out once and for all, but must find an integrated place in the production cycle and constitute an opportunity to improve the overall management process of the activity.

A little further elaboration is needed on this point.

In fact, fire safety – particularly in its prevention portion – was perceived as a separate process that had to accompany, through fire-safety design, the technical development of a given project, and that ended with obtaining a favourable opinion from the competent authorities and obtaining certification once the project was implemented (where applicable).

Such an approach was undoubtedly favoured by a prescriptive regulatory approach that, by providing for predetermined standards, allowed for the certainty of compliance once they had been integrated.

In fact, this approach can certainly not be considered the most efficient; the inherent limitation of the prescriptive approach precisely lies in the general and abstract nature of the standardisation and thus in the rigid application of standards:

- on the one hand, they condition the possibility of developing innovative solutions in the case of new works;
- on the other hand, they do not allow the utilisation in the fire strategy of strengths that may be available in existing works and activities through compensation with other requirements that are not fully sufficient.

Granted, with all its limitations, but the prescriptive approach is somewhat reminiscent of the Platonic view of reality in which the project constitutes the ideality and its application represents its imperfect mirror.

The fact is that, probably also due to instances of severe and continuous innovation in architectural, engineering and supporting technological development, a more performance-oriented approach to fire-safety management has progressively established itself, the development of which has gone hand in hand with the affirmation of the centrality of risk assessment and the empowerment of the activity owner in this regard.

In short, the fire protection designer has been allowed to play a central role in constructing the fire protection strategy – as if he or she were the 'demiurge' that connects reality to bring it closer to its ideality – with the owner's guarantee and commitment to ensure that the assumptions underlying the design and expected performance are maintained over time.

Having said this, in such a largely established context, it would make no sense – in addition to being inconsistent with the obligations assumed by the owner with respect to the service – to manage fire prevention 'fulfilments' in a minimal and fractional manner in the context of the entire business cycle.

On the contrary, also thanks to the technological development of support tools, the integration of fire safety into the broader system of business process management constitutes an opportunity for overall improvement, both to strengthen safety and performance monitoring and to extend a participative and conscious approach of all actors involved.

This book, applicable to civil buildings as well as to industrial assets, enforces a holistic view of fire strategy design to be coupled with a conscious management of assets overtime to ensure the maintenance of the performances identified to achieve an acceptable level of fire risk from the earliest design stages and from the risk-based identification of fire scenarios by the competent application of sound approaches and methods.

Damiano Tranquilli
Head of Safety, Environment and Quality of Rete Ferroviaria Italiana, Direzione operativa stazioni. Head of Safety, GS Rail, Operations. Italian Ferrovie dello Stato Group

Foreword

According to its current technical definition, *risk* is the potential for realisation of unwanted, adverse consequences to human life, health, property or to the environment. Estimation of risk (for an event) is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event, given that it has occurred. In this context, fire risk management can be considered as the process of firstly understanding and characterising fire hazard in a building, unwanted outcomes that may result from a fire, and secondly developing optimal and robust fire strategies to reduce risk or, at least, control its occurrence.

Recent tragic fire events such as the fire of the Grenfell Tower in London (2017) and of the Torre dei Moro in Milano (2021) have shown the importance of integrating the fire risk analysis from the beginning of the building design process, in order to identify the best fire strategy to be implemented in the construction. In both cases, the composite facades heated up rapidly and allowed the fire to spread faster, pass through windows and advance from floor to floor up and down the building's facade.

In this book, the authors, thanks to their personal experience in fire-safety design and accident analysis, provide a comprehensive treatise of fire risk management. First, they describe recent fires, failed strategies and lessons learned. As a second step, they define the appropriate measures for fire risk assessment and the acceptable fire risk levels (according to national and international rules and performance-based codes) representing the first step in fire risk management. Then, the authors explain the state-of-the-art fire risk assessment and the fire-safety design leading to risk mitigation.

All the aspects of fire risk management are considered, including, for example, fault tree analysis, barrier performance, fire growth, fire spread and smoke movement, compartments, occupant response and evacuation models. Critical aspects of risk, such as the correct analysis of event consequences on people, environment, property and business continuity, are included. Finally, a note on explosions and appendices dedicated to railway stations, process industries and warehouse storage buildings are included.

The wide experience of the authors, both on civil buildings and industrial assets, along with their clarity and scientific rigor, make the book a unique and comprehensive essay on fire risk management.

Prof. Dr. Eng. Bernardino Chiaia
Head of the Center SISCON 'Safety of Infrastructures and Constructions', Politecnico di Torino (Italy)

Foreword

Fire risk management in contexts where the magnitude of damage is potentially very high is a particularly complex business. The history of major accidents teaches that they are typically determined by a variety of logically connected and antecedent causes to the facts, revealing that prevention is a multidisciplinary and multi-level theme, which is constituted on a stratification of decisions and controls, to be planned and supervised with the highest time priority.

Largest industrial organisations have long time ago understood that serious risks like this – which shake the foundations of entrepreneurial certainties linked to human, industrial, economic and reputational heritage – need to be matched, even before an adequately articulated architecture of measures, an iterative and very robust assessment system in order to properly understand accident phenomena in their possibilities, create organisational awareness and management competence among the professional figures involved, and reach a risk management plan capable of providing adequate strategies and responses.

Process control measures, as well as prevention and protection measures, while qualifying the organisation in terms of performance, activate investment procedures that are sometimes very demanding; therefore, the decisions connected to this must be carefully weighed, making use of all the available technologies and specific competencies to define the best actions to protect safety.

In this perspective, this editorial work is precious because, starting from a very broad and usable explication of the fundamental notions, it allows us to understand the importance of conducting weighted and customer-specific analyses and decisions. In fact, there are different methodologies and approaches for risk assessment, and it is now clear that the same performance result – in the design phase – can be achieved with a different dosage of technical-plant engineering solutions, organisational-managerial solutions and/or behavioural solutions, which turns into different costs and sustainability of the results for the operators or users of the assets. What are the most appropriate choices? What implications and charges do these choices entail on the operational management of processes? Since safety is the ultimate and common goal of all the involved actors, fire risk management is obviously not a theme that is affirmed only when the analysis is carried out, nor it is resolved in the effective completion of an authorisation process: the assessment process must accompany a project from its birth and continue throughout its life, consolidating its being as plural process in terms of ownership, temporal development and a variety of analytical and methodological focuses.

Risk assessment becomes a mindset to be used regularly. Appropriately fast and accurate methodologies must correspond to this; the use of resources must in fact be modular so that the efforts of calculation, representation, discussion and investment are diversified and concentrate where needed. Conversely, adopting inadequate methodologies necessarily involves a high risk on

detriment of the asset under consideration, for the simple fact that some risk scenarios may be unknown and therefore not well controlled.

Finally, a good risk assessment provides clear and accurate outputs. Based on this, an effective competence network can be established for the benefit of all components of the organisation concerned. It is no longer just a matter of fostering the ability to react at zero time; rather, the foundations are laid for a widespread governance culture causal elements as well as elements not directly conducive to, obtainable only through an adequate study that moves the centre of the time axis away from the moment of the accident.

Vito Carbonara
Sabo S.p.A. (Italy) –Technical Procurement and Logistics Director

Preface

Heraclitus, an ancient Greek philosopher, asserted that everything in the world flows ('Panta Rei') and that fire represents universal becoming better than anything else because fire itself is the 'arché', the principle from which all things are generated.

For the philosopher, this is becoming not random and chaotic but is regular and orderly, provided one knows the rules.

In this volume, we have tried to explain the complex rules governing fire in a simple way, using methods, from the simplest to the most refined, such as the engineering approach.

Studying the development of smoke and heat in fires, knowing the effects they have on people and buildings, helps a great deal in adopting the right strategies for preventing and containing fires.

But the approach taken in the book is deliberately holistic in the sense that each individual strategy can have a great influence on the others, and therefore fire prevention must be seen as a whole.

And as a whole, the success (or failure) of the strategies implemented also depends on the behaviour of the people involved, behaviour that must be framed within a safety management perspective.

A volume that purports to present the historical discipline of fire prevention but with a new methodological approach based on the performance to be achieved rather than on strongly prescriptive but often uncritical methods and requirements.

Happy reading.

Luca Fiorentini and Fabio Dattilo

Acknowledgments

First of all, we would like to express our sincere thanks to Riccardo Di Camillo (P.Eng.).

Riccardo Di Camillo is Head of Fire Safety and Emergency Planning at Grandi Stazioni Rail S.p.A. – Operations, where he deals with all safety issues including permitting activities for the major Italian railway stations. Given his expertise in dealing with very large and complex railway infrastructures as well as with their renovation and modification plans, Riccardo gave us an important and fundamental support in developing all the fire strategy elements in the chapter with the title 'fire strategies'. Fire risk mitigation should be based on a fire strategy conceived to be reliable over time, focused, auditable, and Riccardo, being a professional engineer specialised in fire-safety engineering, also offered us the practical experience in managing fire strategy elements on a daily basis in complex railway stations and infrastructure. This allowed us to highlight how the link between risk analysis, the basis of a performance approach, must necessarily find fulfilment in the implementation of an effective strategy over time as a commitment by organisations to ensure that an acceptable level of fire risk is maintained over time. Riccardo showed how the effective maintenance of the basic elements of the strategy must take into account the complications associated with the normal day-to-day management of the infrastructure for which he works, posed by the constant transformations during the necessary operational continuity, the presence of the public, the intersection with other infrastructure, and nonetheless the architectural complexity, the extension and the use of historical assets. By masterfully managing these aspects within the scope of his work, relating to all stakeholders, he enabled us to describe in a simple, clear and effective manner the problems and methods to seek their solution in the combination of actions aimed on the one hand at identifying and measuring the fire risk and on the other hand at managing the risk over time.

A heartfelt thank you people at TECSA S.r.l. (www.tecsasrl.it) who deal every day in fire risk assessment and industrial risk assessment consulting activities, overcoming the challenges posed by complexity and sharing the professional growth of the entire organisation that complexity itself poses to all those who are called upon to ensure safety over time. Through TECSA activities it is possible every day to measure oneself against important and unique experiences that impose the need to disseminate and share the lessons learnt so that we can increasingly not only speak a common language but also acquire a common understanding. TECSA gave us the material to prepare the case studies in this book summarising some experiences.

Finally, considering the fact that fire safety is an achievement of the organisations for themselves to protect their people, their contractors and third parties working there, the environment, their assets and their business continuity, it is most important to thank Dr. Germano Peverelli, President

and CEO of Sabo S.p.A. (www.sabo.com), a fine chemical company operating for more than 80 years and under the requirements of the Seveso major accident EU Directive. We appreciated the proactive attitude of the company in dealing with fire and industrial risks as issues to be conjugated with the business. We should thank those guys firstly not only for having allowed high-level risk identification and management activities to be carried out using modern methodologies, but also for having established a relationship over the years characterised by seriousness and a common will to assess and manage fire and industrial risks in the best way and without compromise as a fundamental value for the organisation and all the involved stakeholders including the authorities having jurisdiction. Some of their continuous investments for safety and their commitment widely transpire from several summarised case studies presented in this book for which we thank them.

List of Acronyms

AHJ	Authority Having Jurisdiction
AIChE	American Institute of Chemical Engineers
AIIA	Associazione Italiana di Ingegneria Antincendio (SFPE Italy)
ALARP	As Low as Reasonably Practicable
ANSI	American National Standards Institute
API	American Petroleum Institute
ASET	Available Safe Egress Time
ATEX	Explosive Atmosphere
BFA	Barrier Failure Analysis
BIA	Business Impact Analysis
BLEVE	Boiling Liquid Expanding Vapour Explosion
BS	British Standard
BSI	British Standard Institute
CEI	Comitato Elettrotecnico Italiano
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CFD	Computational Fluid Dynamics
CLP	Classification, Labelling and Packaging (EU Regulation)
COMAH	Control of Major Accident Hazards (Regulation)
DCS	Distributed Control System
DNV	Det Norske Veritas (now DNV-GL)
DOWF&EI	Dow Fire and Explosion Index
EIV	Emergency Isolation Valve
ETA	Event Tree Analysis
EVAC	Evacuation
EWS	Early Warning System
F&EI	Fire and Explosion Index
F&G	Fire and Gas
FARSI	Functionality, Availability, Reliability, Survivability and Interaction
FDS	Fire Dynamics Simulator
FEM	Finite-Element Method

FERA	Fire and Explosion Risk Assessment
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes and Effects Criticality Analysis
FMEDA	Failure Modes and Effects Diagnostics Analysis
F–N	Frequency–Number (of fatalities)
FPSO	Floating Production and Offloading
FRA	Fire Risk Assessment
FRM	Fire Risk Management
FSE	Fire-Safety Engineering
FSM	Fire-Safety Management
FSMS	Fire-Safety Management System
FTA	Fault Tree Analysis
GSA	Gestione Sicurezza Antincendio (Fire-Safety Management)
HAC	Hazardous Area Classification
HAZAN	Hazards Analysis
HAZID	Hazards Identification
HAZOP	Hazard and Operability
HEP	Human Error Probability
HMI	Human–Machine Interface
HRA	Human Reliability Analysis
HRR	Heat Release Rate
HS	Health and Safety
HSMS	Health and Safety Management System
HSE	Health, Safety, Environment
HVAC	Heating, Ventilation and Air Conditioning
ICI	Imperial Chemical Industries
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
IPL	Independent Protection Layer
ISO	International Standard Organisation
ISO-TR	ISO-Technical Report
ISO-TS	ISO-Technical Specification
LFL	Low Flammability Level
LGN	Liquid Natural Gas
LOC	Loss of Containment
LOPA	Layer of Protection Analysis
LPG	Liquified Petroleum Gas
MARS	Major Accidents Reporting System
MIL-STD	Military Standard (US)
MOC	Management of Change
NFPA	National Fire Protection Association (USA)
NIST	National Institute for Standards and Technology (USA)
OHSAS	Occupational Health and Safety Assessment Series
P&IDs	Process and Instrumentation Diagrams
PDCA	Plan Do Check Act
PED	Pressure Equipment Directive (EU)

PFD	Probability of Failure on Demand
PHA	Preliminary (Process) Hazards Analysis
PSV	Pressure Safety Valve
QRA	Quantitative Risk Assessment
RAGAGEPs	Recognised and General Accepted Good Engineering Practices
RAM	Reliability Availability Maintainability
RAMS	Reliability Availability Maintainability Safety
RBD	Reliability Block Diagram
RHR	Heat Release Rate
R_{env}	Risk for Environment
R_{life}	Risk for Occupants
R_{pro}	Risk for Assets and Business Continuity
RM	Risk Management
RSET	Required Safe Egress Time
SFPE	Society of Fire Protection Engineers
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIS	Safety Instrumented System
SMS	Safety Management System
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzo
TOR	Terms of Reference
UNI-VVF	Italian Specific Technical Regulation
UVCE	Unconfined Vapour Cloud Explosion
VCE	Vapour Cloud Explosion