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Introduction

1.1 Who Should Read This Book?

"Principles of forensic engineering applied to industrial accidents" is intended to be an introductory volume on the investigation of industrial accidents. Forensic engineering should be seen as a rigorous approach to the discovery of root causes that lead to an accident or a near-miss. The approach should be suitable to identify both the immediate causes as well as the underlying factors that affected, amplified or modified the events (regarding consequences, evolution, dynamics), and the contribute by an eventual "human error".

A number of books have already been published on similar topics. The idea behind this book is not to replace those important volumes but to obtain a single concise and introductory volume (also for students and authorities) to the forensic engineering discipline that helps understand the link among those critical but very functional aspects of the same problem in the global strategy of learning from accidents (or near-misses). The reader, in this sense, will benefit from a single point of access to this vast technical literature that can be only accessed with proficiency having the right terms, definitions, and links in mind. On the contrary, the reader could get lost in all the quoted literature that day by day increases due to the speed of the research in this complex field.

The intent of the book is:

- Presenting simple real cases as well as give an overview of more complex ones, each of them investigated with the same framework;
- giving the readers the bibliography to access more in-depth specific aspects;
- giving them an overview of the most and commonly used methodologies and techniques to investigate accidents;
- giving them a summary of the evidence, which should be collected to define the cause, dynamics, and responsibilities of an industrial accident;
- giving them an overview of the most appropriate methods to collect and to preserve evidence through an appropriate chain of custody; and
- giving an overview of the main mistakes that can lead to misjudgment or loss of proof.

The book is an introductory volume for readers in academia as well as professionals who want to know more about the forensic engineering methodologies to be applied to discover more about the causes of industrial accidents in order to derive lessons. Among those professionals, we can identify process and safety managers, risk managers,

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industrial risks consultants, attorneys, authorities having jurisdiction, judges and prosecutors, and so on.

It is particularly addressed to those who would like to approach the fundamentals of forensic engineering discipline without directly going to specialised already available volumes and handbooks that need a sound background to be read. Nonetheless, reading this book may help professionals (e.g. loss adjusters, risk engineers, safety professionals, safety management systems consultants.) and students who want to have a concise book as prompt reference towards the main important recognised resources available (e.g. CCPS©-AIChE© books also edited by Wiley, NFPA© 921 Standard, etc.) or as a bridge between risk assessment and accidents investigation (as a tool to learn from real accidents or near-misses in order to improve safety).

1.2 Going Beyond the Widget!

When investigating an industrial accident or a near miss, it should be well kept in mind that the primary goal to be reached is not to find a concise fault of a well-defined widget, confined to a distinct domain. A rigorous approach to the forensic discipline requires going much deeper in the investigation, not stopping at the main relevant evidence, even if properly gathered and analysed. It often happens that accident reports are one-dimensional [1]: in simple words, they identify only a single cause, usually corresponding to the outer layer of the complexity that surrounds the reconstruction of the incidental dynamics. Even when multiple causes are discovered, the investigator seldom looks beyond them.

In the industrial context, a complex system of relations, information, and people is present, with its peculiarity and hierarchy, creating a structured entity that needs to be considered when investigating an accident or a near miss. Thus, it becomes necessary to consider as an element of investigation the management systems as well, as some causes of the accident may be related to management failure, so to take the corrective actions and to prevent a further similar failure. A good investigator does not find culprits, does not blame. A good investigator collects evidence, analyses it and finds the root causes and the relations among them that lead to the accident, whilst also considering the managerial duties and, as usually happens, then provides suggestions about corrective actions to avoid the reoccurrence of the undesired event.

Focusing on the system, rather than the individual, represents the right way to face an investigation, at least for two reasons [2]. Firstly, if equipment and systems provided to persons reveal to be not effective, thus it is not the individual responsibility that has to be pointed out as the fault cause. Secondly, it is much easier to change a managerial choice rather than a person or his/her behavior, which is susceptible to vary daily. Third, human errors may often be the consequence of insufficient training, motivation or attention to safety, all being aspects that the management should promote and monitor. It is a matter of controllability and reliability, as they are the two most essential ingredients to ensure that the lesson learnt will guarantee an increasing, or a restoration at least, of the safety level accepted in the industry at the corporate, field and line levels. Metaphorically speaking, an accident investigation is like peeling an onion: this concept, cited in [3], gives us a live image of what we are called to solve (see Figure 1.1). Technical problems and mechanical failures are the outer layers of the onion: they are the immediate causes.

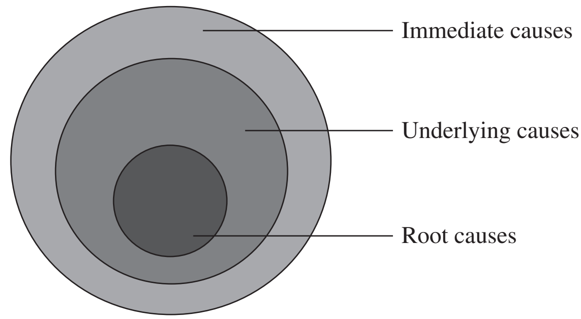

Figure 1.1 The onion-like structure between immediate causes and root causes.

Only once you peel them you can find the inner layers, thus the underlying causes like those involving the management weaknesses.

Going beyond the widget is what a professional investigator does. Let us consider a relief valve that fails, causing harm and loss (thus an accident) also involving some injuries to the line operators. A neophyte may conclude: "It was a fault in the relief valve. Case is closed, people". On the contrary, a good investigator may wonder: "Is it a consequence of an unexpected running condition, exceeding the operational limits? Was there an erroneous maintenance procedure? Was it installed correctly? Is it a result of an entire procurement of damaged relief valves?". The differences in the two extreme examples are clear: it is highly recommended to investigate spanning at least over the following three levels: line, field, and corporate levels. This good practice should suggest what a proper investigation requires: a project management and a variously skilled team of investigators.

Conducting an investigation means to plan the activities, to organise meetings, to schedule recognitions of the accident area, to inform and to be informed, to commission tests to external laboratories, to manage resources, mainly time and budget. But most of all conducting an investigation means to link the collected elements in a multidisciplinary network. To do this you need many different skills to work together. Many people get confused about how to conduct an investigation. The best way to face such a complex challenge is to consider it as an ordinary project: organisational and managerial skills, listening capacity in addition to a problem-solving attitude, are the desirable features of the investigator.

The recent approach in accident investigation reflects the simple concept discussed in this Paragraph. Indeed, over the past decade, a transition has occurred not only in the way accidents are investigated, but also in the way they are perceived [4]. One more time, the transition has shown an increasing focus on the organisational context rather than on the technical failures and human errors. This transition is also felt by the public opinion that forms after an industrial accident and is broadcasted by media. It is interesting to observe that such a transition can also be noted from the legal point of view, with an evolution of national laws and international technical standards and codes supporting a progressive shift of liability from the worker to the contractor and, more recently, to the top management of the company or, in some countries like Italy, to the Company itself. It is possible to claim that there is a sort of alignment among the technical aspects implicated in the forensic science, including the procedural way to conduct an investigation, and the legal issues. This transition has given rise to new methods to analyse an industrial accident, whose attention is primarily focused on the so-called “organisational network” and whose objective is to reconstruct empirically the real accidental phenomenon exploring the theoretical organisational structures. The goal is very ambitious and hard. It requires a multiplicity of transversal scientific skills, attitude, intuition and managerial capabilities. It requires ground competencies to find, gather and analyse that evidence that may be the trace of some precursor events, thus helping directly in the search for the root causes, or that may be weak signal, thus requiring a much more in-depth analysis to be referred into the organisational network and put in position, just like a puzzle piece, both in time and space.

The approach here described is also encouraged by some recent studies, like the one reported in [5], which analyses the phenomenon and the request for a different methodological approach taking inspiration from complexity theory. After having observed that single-factor explanations usually prevail and that also the language used in the accident reports reveals a historical trend in finding in individual human actions and failures the single leading cause of an accident, it is possible to identify the limits of the Cartesian-Newtonian worldview. According to these studies, the classical accident investigation is based on the Newtonian vision of the world, where a chain of causes–effects is the trace to identify everything since everything is deterministic and materialistic. Following this investigation methodology, the time becomes reversible. In other words, it is always possible to cross the time domain in both its directions, because of the bi-unique relationship between cause and effect. The knowledge is complete, and the perceived complexity is only apparent because of the human incapability in thoroughly reading this world. However, if you insert the idea of a failure in the theory of complexity, then conclusions change. The attention is now focused not only on the individual components of the system but also on their relationships. The rising complexity, which is an intrinsic feature of the whole system – not of its parts –, implicates the time irreversibility (thus the link between a cause and effect is not always bi-directional because of the sufficient or necessary nature of the condition that links the two). The Newtonian certainties collapse leaving the field to the uncertainty of knowledge and the foreseeability of probabilities, nothing more. These implications of complexity theory for safety investigations represent an interesting topic that needs to be further studied deeply, especially regarding the consequences it may have on the daily activities of the forensic engineers, the judges, the attorneys, and all the people called into the forensic path, whose need–primarily the legal need–might not accept such a loss of knowledge. What it can be doubtless taken into account is a broad look at the relations, thus to interactions at all levels including management. Facing complexity is a challenge requiring a strong capability to deal with sociotechnical systems, system safety, resilience engineering: these are the main ingredients of a more in-depth accident analysis [6]. According to what just said, the reader is asked to not confuse the attribute “complex” with “complicated” for the rest of the book.

However, in some cases “going beyond the widget” could not be necessary: these situations represent some (fortunately) rare uncontrollable events, because they are the consequences of deliberately malicious acts, dereliction of duty, working under the influence of drugs or alcohol and so on. If one of these events occurs, then blaming is legitimated. This is why these examples of industrial accidents or near misses are not considered in this book. Moreover, the analysis of Natural Hazard Triggering Technological Disasters (NaTech) is not treated here.

1.3 Forensic Engineering as a Discipline

The arising of forensic disciplines in the modern era can be considered as a consequence of several factors. The most important one is the constant needing of skilled professionals called upon to deal with judicial cases, thus providing a tangible help to the complex machinery of Justice, whichever it is the role they assume in the context of the judicial parties. What emerges concisely is the need for an expert and competent help to judges and attorneys: this is another reason that led to the necessity to regulate the field, not only from a legal standpoint but firstly from the methodological one. Indeed, the rights to prosecute and to defend when called to participate in the discussions of the Court can be exerted only if these rights are soundly based on facts. No ideas, no principles and no intuition: only facts. As a natural consequence, the gathering of evidence and its analysis – being the focal point of the entire judgment – are steps that need to be regulated. It is now that forensic engineering arises as a discipline, just like forensic psychology, criminology, and other related fields.

Forensic engineering becomes a discipline when it meets a method. In forensic engineering, the scientific method by Bacon and Galilei is the one followed to ensure comparability, shared methodologies and proven results. These are the basic conditions to trigger a favorable discussion when facts are cited in the Court, with the primary goal of presenting the Truth. A forensic engineer should well keep in mind its role: you find the Truth, not the Blame. Prosecuting is not in the tasks; you do not investigate to search the culprits, but to discover the facts and to reconstruct the dynamics of the event. A Forensic Engineer should also be capable to speak to and with the legal professionals, to ensure that all the technical facets of the accident will be properly considered in the judgment process. This may be one of the most challenging tasks for the Forensic Engineer.

Forensic science is a challenging mix of science, law, and management. What makes it in this way are the continuous changing legislation and legal decisions which push for constant research for new methods, protocols, and sciences [7]. In the previous Paragraph, it was briefly mentioned that an accident investigation requires the typical structure of multidisciplinary project management: this is because of the multidisciplinary approach usually adopted. After the first step is concluded, consisting in analysing the problem, the synthesis is then required. This path is typical of a problem-solving approach and a project management attitude is the only way to ensure a standard quality, in terms of a guaranteed chain of custody of the collected evidence, reproducibility of tests–when repeatable–soundly obtained results based on scientific method, logic, and cause-and-effect analysis. The final objective is to ensure an incontestable outcome capable of reconstructing the Truth. In simple words, a project management attitude is required because of the scientific complexity combined with the bureaucratic administrative path imposed by the legal context in which the accident investigation is conducted. The consequence is that very often the investigator assumes the role of leader of a multidisciplinary team that works following a holistic approach.

The basis of the rigorous method required is logic. Distinguishing between inductive methods and deductive methods is possible. The inductive method goes back to Aristotle, and it is based on the reconstruction of general principles starting from peculiar evidence. A mistake in generating the conclusion can be made when the collection of proof is not wide enough to ensure a robust logic sequence. There are some methods (described in Chapter 5) based on this logic path. However, ancient Greeks are also famous for the deductive method, whose frame of logical argumentation – the syllogism – represents one of its primary achievement. The interested reader can go deep into the historical background of the scientific method by consulting [7].

Nowadays the scientific method is worldly recognised as the core layer on which humanity has created its scientific – and then social – achievements. As well known, the scientific method is not the unique method on which humans relied. At the time of Bacon, the doctrine of *apriorism* was the only accepted: according to this doctrine, a selection of *a priori* assumptions was the only starting point – thus the only cause – of the entire Universe. It was not possible to overcome these assumptions since they were perceived as a religious dogma [8]. This brief passage is necessary to understand the power, as well the courage, of the revolution of Roger Bacon and Galileo Galilei (Figure 1.2). According to the scientific method, which refuses the *apriorism*, only a close observation and experimentation can ensure a complete knowledge of Nature. Centuries were necessary to guarantee a solid establishment of the scientific method.

Forensic engineering spans many fields. The necessity to share standard models and approaches has brought about the formation of international associations. Their purpose is to ensure an advantageous exchange of expertise, experience and capability about how to generally face an accident investigation and how to properly treat a peculiar case (like a bombing scene investigation – see [9] for details –, an industrial accident, a ship disaster, a fire investigation). When the accident implies severe injuries to humans, then the application of forensic pathology may be required [10]. Being a discipline, just like forensic engineering, the application of the scientific method is mandatory. This

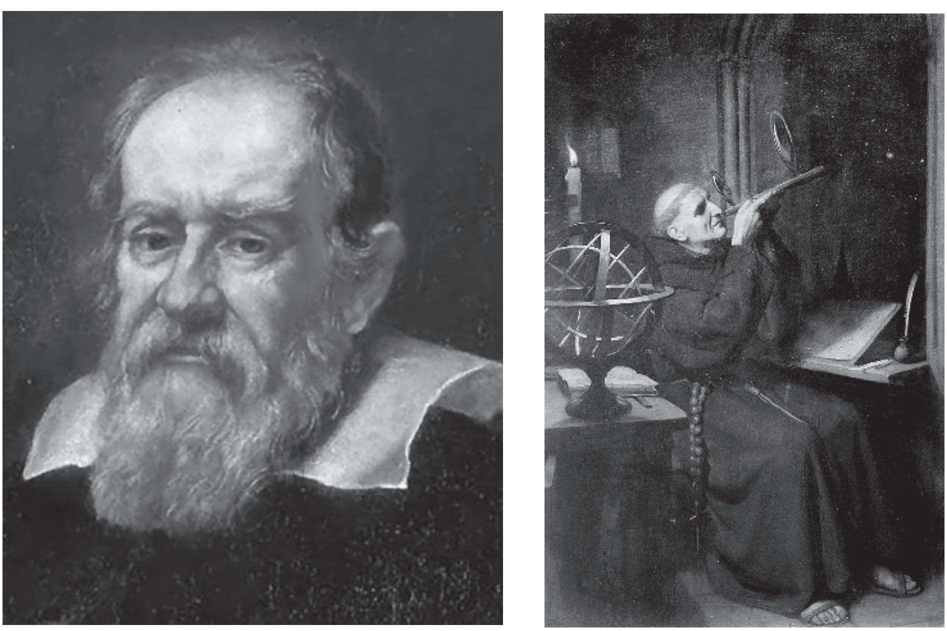

Figure 1.2 Galileo Galilei (left) and Roger Bacon (right): two of the brightest scientists of the world who supported the scientific method. Source: Attribution 4.0 International (CC BY 4.0) https://en.wikipedia.org/wiki/Wikipedia:Text_of_Creative_Commons_Attribution-ShareAlike_3.0_Unported_License.

feature allows the reconstruction of the accidental dynamics, starting from the study of the penetrating and perforating shrapnel, the dust tattooing, the burns from heat and so on: these are all elements, here taken as a mere example, necessary to the medico-legal opinion at autopsy.

Being a forensic engineer implies a multidisciplinary approach and therefore a sound proficiency in physics, chemistry, mechanics, metallurgy, computer science regardless of whether you decide to work in a team or not. The rigorously adopted approach, relying on the scientific method, is the unique assurance of doing this job in the right way.

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Further Reading

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