Part I

Background

Part I lays the foundation for the entire book. Chapter 1 explains the multidisciplinary perspective used throughout—a perspective built on traditional occupational safety and health (OSH), enhanced by contributions from system safety, public health, and educational psychology. Chapter 2 delves into definitions of three terms used extensively in this book—hazard, risk, and risk reduction. Chapter 3 provides examples of common types of conceptual models and charting methods used in the book and the safety and health professions.

These background topics are fundamental building blocks for the four subsequent parts of the book that provide the content applicable to the practice of occupational safety and health. Part II explains several practical systematic methods for anticipating hazards, assessing risks, and analyzing systems encountered in occupational settings. Part III discusses programmatic and managerial methods for reducing risks. Part IV gets into the technical aspects of reducing risks associated with various forms of energy. Finally, part V addresses risk reduction for occupational hazards not directly linked to energy.

Chapter 1

Multidisciplinary Perspective

Throughout this book, the field of OSH is viewed broadly to include traditional occupational safety, industrial hygiene, occupational ergonomics, and, to a lesser extent, environmental pollution. To make the book internationally applicable, governmental regulations of the United States and other countries are rarely mentioned. All mathematics uses international units. In this and other chapters, italic font is used for titles of books and journals, and for the first use of technical terms defined at the end of the chapter.

Much of part I is based on information covered in traditional OSH books and journal articles. Concepts and methods from three other fields—system safety, public health, and education—are used to enrich and expand the basic OSH concepts and methods described in this book. Contributions from these three fields are provided in the following three sections.

1.1 SYSTEM SAFETY CONTRIBUTIONS

The specialty known as system safety developed in response to needs of the defense and aerospace industries to reduce the enormous costs from failed missile launches and crashed aircraft. After World War II, the United States and the Soviet Union engaged in a race to gain a military advantage. During this period of rapid technological advances, safety took a back seat, and numerous failures occurred during the testing and operational phases of these new systems.[1] Safety remained in the background during the 1950s and 1960s when a common practice was to design and build missiles and aircraft, fly them, investigate crashes, identify the apparent problems, fix those problems, and continue operations. This "fly–fix–fly" approach killed many pilots and destroyed many expensive missiles and aircraft.

The U.S. Air Force took the lead in changing the fly–fix–fly approach to one involving increased safety input during the design and testing phases of missiles, aircraft, and other major acquisitions. In particular, the Air Force published two sets of requirements: (1) *System Safety Engineering for the Development of Air Force*

Risk-Reduction Methods for Occupational Safety and Health, First Edition. Roger C. Jensen.

Ballistic Missiles, 1962; and (2) *General Requirements for Safety Engineering of Systems and Associated Subsystems and Equipment*, 1963.

The other branches of the U.S. Department of Defense (DoD) followed suit in 1966 with a broadly applicable standard for military acquisitions. A revised edition titled *System Safety Program Requirement (MIL-STD-882B)* came out in 1969 that has since been modified several times. These developments created a need for specialists to perform the required safety analyses. System safety career positions were available primarily in the DoD, the many defense contractors, and the National Aeronautics and Space Administration (NASA).

In 1973, some of those who pioneered the field formed an international professional society to support the new specialty known as system safety engineering. Now named the System Safety Society, it publishes the *Journal of System Safety* and annually conducts an international conference. More can be learned by visiting the organization's website (www.system-safety.org).

The annual International System Safety Conference provides opportunities to learn about diverse applications of safety analyses. Although many of the presentations focus on safety issues in the military and aerospace industries, applications in other domains continue to grow. One major area of growth is in the transportation domain, where the focus is on improving the safety of passenger trains, buses, ferryboats, harbor traffic, and commercial aviation. Another growth area has been consumer products, where risk assessment has become commonplace.

A diverse set of safety analysis tools has been developed since the early days of system safety.[1,2] This book addresses a few of the tools considered most appropriate for use by OSH professionals. But before jumping into the tools, readers need to learn what system safety is today. The following definition of *system safety* comes from a book by Roger Brauer: "System safety is the application of technical and managerial skills to the systematic, forward-looking identification, and control of hazards throughout the life cycle of a system, project, program, or activity."[3]

This definition contains several significant words and phrases deserving comment. System safety indicates a concern for a *system*, a word referring to a mix of equipment, property, and people interacting in an environment for some purpose. Table 1.1 may help clarify this vague description by pointing out different options for defining system levels, from the narrow to the very broad.[4] At the narrowest level, a system can consist of equipment functioning without humans. The next level adds an individual interacting with equipment. At a somewhat higher level, a system can be a group of employees interacting to accomplish the employer's objectives. At an even broader level, a system can be employees from multiple employers performing their respective functions to achieve broader objectives. The broadest level listed in Table 1.1 adds consideration of influences from applicable governmental regulators and societal values.

In the definition of system safety, the phrase "application of technical and managerial skills" indicates the practical orientation of the field. System safety developed as a technical field, but expanded to address the critical role of using managerial systems to implement safety-related practices and procedures.

Table 1.1 Examples of Systems at Different Complexity Levels

System level[a]	Occupational example
Equipment without human	A building heating system with thermostats, furnace, and air circulation ducts
Individual and equipment	A plumber repairing a leaking faucet. An OSH manager composing a memo on her personal computer
Workgroup level	An assembly line with interactions among employees and their workstations, supervisors, equipment, and materials
Multiple workgroups	A construction site with work being performed by employees of a general contractor and several subcontractors
Highest	All employers in a region or country operating under the same laws and regulatory processes

[a]These levels are adaptations of those described by Erik Hollnagel in Ref. 4.

The “forward-looking” phrase in the definition indicates attention on the future—necessarily involving anticipating problems that might occur. In contrast, a backward-looking focus attends more to investigating past incidents with the intent of assigning blame. A backward-looking focus is driven by the needs of politicians and parties to personal injury litigation, with system safety professionals seeing incident investigations as an opportunity to learn things potentially useful for the future. The core of the system safety community embraces the forward-looking focus by making use of systematic analyses, lessons learned from past incidents, and applicable standards. Another part of the forward-looking focus involves integrating controls into systems to mitigate damage during an incident. Familiar examples are occupant protection features of modern cars like seat belts, air bags, and safety glass in windows. Other examples are engineering devices and software used for monitoring and controlling the complex processes found in industrial systems such as nuclear power plants and chemical processing facilities.

The phrase “identification, and control of hazards” refers to the logical, interrelated steps of first identifying hazards within the system and then determining appropriate means to control those hazards. These steps are almost identical to those used in the practice of occupational safety, industrial hygiene, ergonomics, and pollution prevention. History has shown that hazards can easily be overlooked if systematic processes are not used.

“Throughout the life cycle” reflects the importance of thinking about the full life of a system during the development stage in order to head off future problems. For example, if a project involves hazardous materials, how will the materials be disposed of at the end of the project? How will ship bodies be dismantled and the materials recycled? What will become of outdated weapon systems? What will become of old respirators?

The phrase “system project, program, or activity” indicates that system safety tools and expertise apply to various projects, programs, and activities involving a broad range of systems. Examples of these references to systems are a new fleet of aircraft, a project to develop a prototype, a program for an ongoing organizational function, or an activity such as performing maintenance on equipment.

The OSH community has historically underutilized system safety tools. Those who practice system safety as professionals tend to advocate for greater use of their analysis tools by the OSH community. Two advantages of using system safety tools deserve mention. First, the forward-looking focus of these methods can help reduce the risk of harm to people and property. Second, professionals who develop skills using these methods will find that these tools are portable—they travel with the individual throughout the twists and turns of a career and can be easily adapted to OSH practice in different companies, different industries, and even different countries. This book emphasizes the system safety tools most practical for OSH practice: job hazard analysis, risk assessment, failure modes and effects analysis, and fault trees.

1.2 PUBLIC HEALTH CONTRIBUTIONS

The public health community took an interest in injury prevention during the same time the field of system safety was defining itself. Some of the concepts and tools developed in the early days of public health injury prevention remain viable today, and can be useful for risk reduction in the OSH field.

Although the public health community recognizes the burden of traumatic injuries as being a public health concern, the governmental bodies that fund public injury prevention have been reluctant to commit a lot of resources to these programs based on the seemingly persistent yet mistaken belief among the general public and legislatures that injuries are inevitable. That belief was the topic of a classic paper by Dr. William Haddon Jr. in the 1968 volume of the *American Journal of Public Health*.[5] Haddon advocated approaching roadway injury prevention with the perspective of public health and preventive medicine. He especially rejected the prevailing public opinion at the time that roadway "accidents" could be prevented by focusing funds on improving driver performance to the exclusion of any other preventive measures. His effective advocacy led to increased funding for measures addressing prevention of roadway incidents, better protection of vehicles and occupants during a crash event, and more effective post-crash response capabilities. All these types of measures reduce the risks of roadway transportation.

To sell his message, Haddon developed a tabular format for sorting out opportunities to reduce risks from roadway crashes.[6] Figure 1.1 is an example of the sort of table now known as a *Haddon Matrix*. The example has three rows for the phases of a crash and three columns for the factors involved, yielding nine cells for identifying phase-specific countermeasures. In other papers, Dr. Haddon showed how this basic matrix format can be adapted by adding more columns for other factors. It may also be applied in domains other than roadway transportation.

Today, the Haddon Matrix, in several forms, is highly regarded as a fundamental tool for guiding injury risk-reduction programs in many domains. It serves as one of the threads used to weave this book into a cohesive manuscript.

	FACTORS		
PHASE	Human	Vehicle and equipment	Environment
Pre-crash			
Crash			
Post-crash			

Figure 1.1 An example of a Haddon Matrix. Adapted from Ref. 6, Figure 13.

1.3 EDUCATIONAL THEORY CONTRIBUTIONS

In addition to incorporating contributions from system safety and public health, a third field contributed in subtle ways to this book. Known as *learning theory* in education circles, it provides a framework for structuring curriculum for young children through a university education. The reason for explaining this topic is to make the author's intentions transparent to readers. The OSH profession is in the midst of transitioning from rule-following field to a profession more dependent on effectively using higher level cognitive skills. Many of the Learning Exercises at the end of chapters were written to encourage students to use such skills. These experiences should help the next generation of OSH professionals become more skilled at analysis, adept at conceptual thinking, capable at evaluation, familiar with the science behind the practice, and appreciative of theory.

What is meant by higher level cognitive skills? In their often-referenced handbook, Professor Benjamin Bloom and his colleagues at the University of Chicago classified learning into three broad *learning domains*: cognitive, affective, and psychomotor. Within the cognitive domain, Bloom proposed the following six levels of development.[7]

1. Knowledge acquisition.
2. Comprehension.
3. Application.
4. Analysis.
5. Synthesis.
6. Evaluation.

These classifications remain highly respected by educational theorists in spite of various scholarly proposals for modifications and additions.[8,9] For purposes of writing Learning Exercises, the original Bloom levels are quite appropriate and satisfactory. The levels and their relationships are discussed in greater detail below.

Learning starts with basic knowledge acquisition. Preschool and elementary school learning experiences are structured to help the students gradually build a core knowledge, starting with the alphabets, numbers, and telling time. This knowledge provides a foundation for developing abilities for comprehending written words and arithmetic operations. Fostering the transition from the knowledge acquisition level to the comprehension level is integrated into the entire secondary education curriculum.

The third Bloom level, application, involves making a connection between classroom material and the world outside the classroom, especially with regard to connecting ideas and principles learned in books to everyday decisions and actions. For example, a student taking an introductory psychology course who learned the signs of depression in a book and subsequently recognizes those signs in a friend or relative has successfully applied in the real world what he or she has learned in the classroom. In OSH education, internship experiences after taking some OSH courses are extremely valuable for helping students connect what they learn in textbooks to everyday workplaces.

The original Bloom levels were presented as six progressive steps, like rungs on a ladder. Thus, the Bloom concept was that a person needs to develop, for example, levels 1 through 4 in order to develop level 5. Today, the Bloom list may be conceived as having three ordered lower levels (knowledge acquisition, comprehension, and application) with the higher three learning levels at the same level. Figure 1.2 depicts the relationship among these six levels as being shaped like the letter T.

The fourth level, analysis, involves the capability for examining a complex set of ideas to reach an end point. Often, the process of analysis involves breaking down the input information into components more suitable for analysis. For example, in a construction safety class, students may be assigned to write a short essay comparing and contrasting two different policies on employee drug testing. They may approach the assignment by creating a list of pros and cons for each alternative policy. This approach helps to organize the comparison and provide a basis for contrasting the policies.

The fifth level, synthesis, involves taking extensive input information and developing a model to explain how all the inputs form a logical whole. Some examples of models are provided throughout this book. This entire book is an attempt by the author to present a synthesized model of the OSH field.

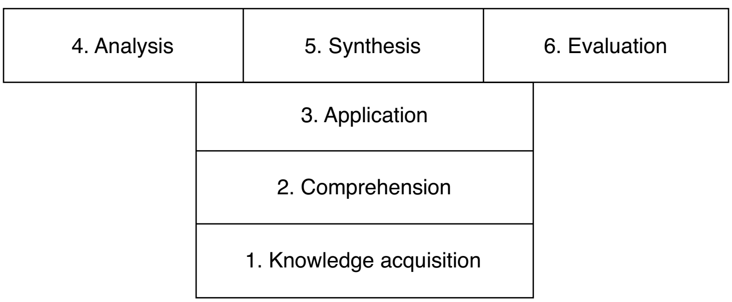

Figure 1.2 Relationship among Bloom's six levels of cognitive development.

Table 1.2 Bloom Level Skills for Topics in Later Chapters

Topic	Bloom level skills
Job hazard analysis	3: Application; 4: analysis
Risk assessment	3: Application; 4: analysis; 6: evaluation
Failure modes and effects	4: Analysis
Fault tree construction	3: Application; 5: synthesis
Fault tree analysis	4: Analysis
Incident investigation	1: Knowledge; 2: comprehension; 4: analysis
Human error	3: Application; 4: analysis

The sixth level, evaluation, involves comparing a specific something against a list of criteria. For example, a governmental agency seeking a contractor for a particular project will make public a description of the project and invite proposals. When proposals are in, agency personnel will review and rate each proposal using the applicable criteria. This skill is used extensively in OSH for periodic evaluations of progress on achieving program objectives.

The Learning Exercises at the end of each chapter contain items calling on a mix of lower and higher level skills. Table 1.2 provides a short list of topics included in parts II and III of this book and the primary types of cognitive skills used for each topic. Parts IV and V call for using the application level to understand how principles developed in earlier chapters apply to very diverse types of hazards.

LEARNING EXERCISES

1. Career paths vary. A person could, for example, be an industrial hygienist and spend an entire career in the mining industry. Or the person could work in various industries for a few years each. Which career path appears most fitting for you? Why?
2. Consider a student named Jane. Her father owned and operated a small roofing company, and Jane worked for him during the summers when she was 18 and 19 years old. As an undergraduate in OSH, Jane did two summer internships, one in building construction and the other in roadway construction. Upon graduating, she took a job in the safety department of a bridge construction company. Every year of her 20-year career, she attended a week-long professional development conference filled with seminars on all topics of safety, industrial hygiene, and environmental protection. She attended only the construction-specific seminars. When the construction industry slumped, she found herself in need of employment in a different industry. She knew her safety-related skills were effective in the construction industry, but all her applications for safety positions in other industries were unsuccessful. What lessons can be learned from Jane's story?

3. Consider another young OSH graduate named Robert. As an undergraduate, he did an internship in OSH with a petroleum company in the pipeline operations. After graduating, he worked for a chemical plant doing process safety analyses. After three years, he changed to a job with an aircraft manufacturer doing system safety analyses. When the aircraft contract ended, he interviewed for a product safety position with a manufacturer of washing machines, dryers, and refrigerators. During the interview, he was asked how his prior jobs prepared him for product safety work in the appliance industry. Imagine you are Robert. How could you use information from this chapter to shape an effective answer?
4. Compare and contrast the career paths of Jane and Robert.
5. Obtain the original article by Dr. Haddon in the *American Journal of Public Health* by following the steps below. After obtaining, read the Background section and write a summary of the main points he makes about (1) terms used when discussing trauma and (2) the etiologic approach used for diseases. The article may be obtained by visiting www.ajph.org, clicking Issues Past and Present, selecting from the grid 1968 and August.

TECHNICAL TERMS

Haddon Matrix	A two-dimensional table for identifying possible countermeasures for public injury problems. It has three rows for the incident phases and three or more columns for system components.
Learning domains	Broad categories for the diverse mental and physical skills humans learn. Bloom defined three categories: cognitive, affective, and psychomotor.
System	An integrated mix of equipment, property, and people interacting in an environment for some purpose.
System safety	A forward-looking and systematic approach to designing safety into a system, project, program, or activity.[3]

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