CHAPTER 35

RISK MANAGEMENT AND ASSESSMENT

35-1 RISK AND LOSSES

In life there are events that result in gains or losses for people and organizations. Most people do not want losses, although they will take a chance at achieving a gain in the face of some potential loss. Risk involves avoidance of losses and unwanted consequences as well as probability and potential for losses.

Rowe[1] defines risk as the potential for realization of unwanted, negative consequences of an event. Risk aversion is action taken to control or reduce risk. There are many definitions for risk. For safety and health, a common definition of risk infers a quantitative concept. Risk is the product of frequency and severity of potential losses. Frequency is the probability of occurrence of an event, such as once per week or once per year or once every 100 years. Severity is the potential loss when an event occurs. The loss may be expressed in human terms, such as loss of life, serious injury, serious illness, number of cancer cases, and so forth. The loss may also be expressed in financial terms, like dollars lost, cost to replace lost equipment, cost of downtime, or cost to replace facilities. Loss may be expressed in legal terms, such as claims, lawsuits, and liability.

Out of these concepts have come formal methods for dealing with risks: formal risk assessment methods and risk management methods. Risk assessment and management applies to general operation of a business and business decisions. The losses and unwanted consequences for a business ultimately are financial. The idea of risk for a business has a broad meaning that implies any kind of detriment to a business. Companies apply risk to financial decisions, security of trade secrets and computer systems, and other potential losses. Risk also is used in dealing with losses associated with accidents, human error, and health exposures. It is the latter aspect of risk that this discussion addresses.

Closely related to risk and risk aversion is loss control, which is the controlling of conditions that can be responsible for a loss. As noted in the previous chapter, accidents and injuries affect the financial picture of a company or its departments. It can affect the financial picture of an individual. The term *loss control* often is associated with insurance. Loss control seeks to reduce the likelihood of an occurrence or reduce its severity.

35-2 RISK MANAGEMENT

The Process

Risk management involves five components:

Safety and Health for Engineers, Second Edition, by Roger L. Brauer

1. risk identification
2. risk analysis
3. eliminating or reducing risks
4. financing risks
5. administering the risk management process

The objectives of risk management can be divided into two groups; preloss and postloss objectives. Preloss objectives address those things that may happen. Postloss objectives involve application of resources to recover completely and quickly from a loss. Table 35-1 defines preloss and postloss objectives.

Risk Identification

Risk identification is not an easy task because it is easy to overlook something. It requires training and experience to see unsafe conditions and foresee unsafe acts. It is not easy to see how combinations of things and the complexity of operations, equipment, and facilities can lead to undesirable events.

The goal in risk identification is to reduce uncertainty in describing factors that contribute to accidents, injuries, illnesses, and death. Risk identification involves identification of hazards. It improves understanding of risks for particular situations or groups. Risk identification is conducted to determine whether and to what degree effects in one situation apply to another. It involves gathering facts and data. In risk identification, data are analyzed to determine what components contribute to a process that produces injury or

TABLE 35-1 Risk Management Objectives[a]

Preloss objectives	
Economy	Minimizing the economic expenditures consistent with postloss goals for safety programs, risk identification and analysis, insurance premiums, and so forth.
Reduction in anxiety	Reducing the fear and worry over potential losses.
Meeting externally imposed obligations	Satisfying safety, health, and environmental regulations; satisfying employee-benefit plans; acquiring required insurance.
Social responsibility	Meeting the demands for good citizenship to employees, customers, suppliers, and the community. Maintaining public image and social consciousness.
Postloss objectives	
Survival	Being able to resume some operations after a loss.
Continuity of operations	To return to or continue full operations following an interruptlon. There may be reduction in earnings. Keeping human and material resources available.
Earnings stability	Keeping earnings stable through continued operations with cost control or from funds to replace lost earnings.
Continued growth	Finding ways to expand growth by product development, market expansion, acquisition, and mergers.
Social responsibility	Taking care of employees, customers, suppliers, and the public. Maintaining public relations and public image.

[a] Derived from Mehr, R. I., and Hedges, R. A., *Risk Management: Concepts and Applications*, Richard D. Irwin, Homewood, IL, 1974.

illness and to establish if data from particular cases can be generalized to other situations or populations.

For example, can data from commercial airplane crashes in 1 year be used to characterize the risk of death from flying for all commercial passengers in the future? Is it more accurate to characterize the risk for passengers by aircraft model, by the time since an aircraft has undergone a major overhaul of an engine or airframe, or by the number of takeoffs and landings an aircraft has experienced? Similarly, in assessing the risks of chemicals, one must generalize data from animal and organism studies to humans, characterize the behavior of a chemical within the body, consider interactions with other substances in the body or interactions within cells and organs.

Risks change with time. The process of identifying risks requires a continual and systematic approach. Risk identification involves recognition of hazards and things that can go wrong. It may involve attaching values to potential losses. The values in this step help establish how certain a loss is for general situations.

There are many techniques for identifying risks. Hazard recognition is an important element. One approach is drawing on the past knowledge and history of accidents. Another approach is applying systematic techniques, such as system safety and other analytical methods (see Chapters 36 and 37). It may be necessary to use specialists to help identify risks, because the specialists have unique knowledge and experience and may recognize some important hazards that others may overlook. Checklists of hazards and conditions producing hazards can be developed and used for comparison with the proposed or actual operation, process, equipment, or system. Sometimes energy and energy release analysis are used to identify what failures in a system might occur and what the consequences might be. Sometimes analysis of human behavior and underlying motivating factors helps identify risks.

Frequency and severity data from accidents can help identify risks. A review of accident records and classification of accident data can help. Various statistical methods applied to accident data will help reveal trends in losses and what factors contribute to accidents and injuries. Analyzing claims, such as worker compensation claims[2] or customer claims against products, will help isolate factors associated with losses.

Risk Analysis

Risk analysis is applying qualitative or quantitative techniques to potential risks. It reduces the uncertainties in measuring risks and it usually involves frequency and severity. Frequency deals with the likelihood that an event will occur or that a hazard will be present. Severity is the effect of an event when it occurs. It is measured in deaths, injuries, disease or illnesses, or loss of equipment or property. Severity may also be expressed in financial terms.

Example 35-1 Risk identification may have noted that people traveling in automobiles to and from work face the risk of a vehicle accident. Suppose the data show that there are 29,800,000 automobile accidents per year in the United States, people travel 1.511 billion miles per year by automobile, and the average person travels 4,500 miles each year driving to and from work. Risk analysis would identify the probability of an accident, P, from

$$P = \frac{2.98 \times 10^7 (4{,}500)}{1.511 \times 10^{12}}$$
$$= 0.089 \text{ accidents per year per person.}$$

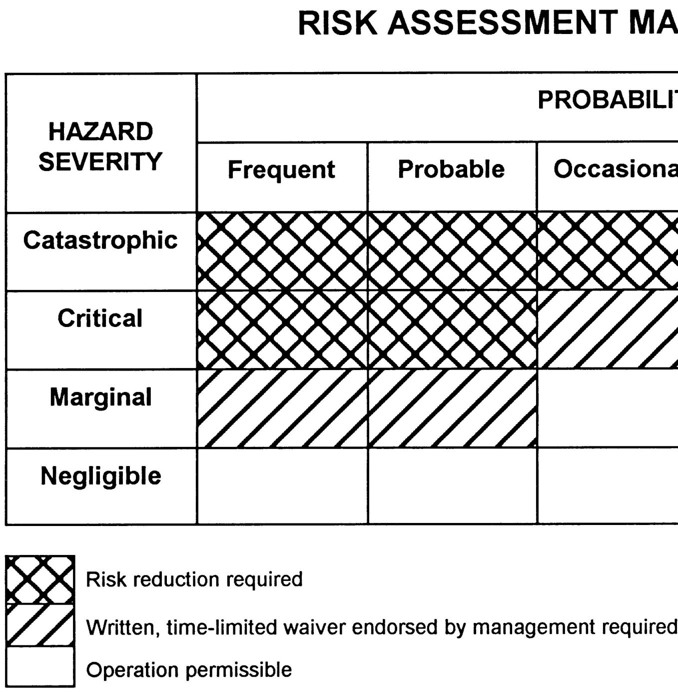

Figure 35-1. Risk reduction decision matrix.

TABLE 35-2 Hazard Severity Classification

Description	Category	Mishap Definition
Catastrophic	I	Death or system loss
Critical	II	Severe injury, severe occupational illness, or major system damage
Marginal	III	Minor injury, minor occupational illness, or minor system damage
Negligible	IV	Less than minor injury, occupational illness, or system damage

It is not possible to quantify all risks. There are many applications where a qualitative risk analysis is more feasible. The risks are classified according to relative frequency and relative severity. One scheme is depicted in Tables 35-2 and 35-3 and in Figure 35-1. The risk or hazard is assigned one of four severity categories from Table 35-2 and one of five probability categories from Table 35-3. These classifications leave out quantities completely. Considerable judgment is needed to apply the categories consistently.

Risk analysis is discussed further in the section on risk assessment.

Eliminating or Reducing Risks

If risks are known, one can attempt to eliminate them. However, it is not possible to eliminate all risks; some can only be reduced. When many risks exist at once or when resources are limited, the problem is what risks to tackle first. This problem requires setting priorities.

There are several methods for setting priorities. Cost-benefit analysis was considered in Chapter 34, and some other methods will be explored in the next two chapters.

TABLE 35-3 Hazard Probability Classification

Descrition[a]	Level	Specific Individual Item	Fleet[b] or Inventory
Frequent	A	Likely to occur frequently	Continuously experienced
Probable	B	Will occur several times in the life of an item	Will occur frequently
Occasional	C	Likely to occur sometime in the life of an item	Will occur several times
Remote	D	Unlikely but possible to occur in the life of an item	Unlikely but can reasonably be expected to occur
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

[a] Definitions of descriptive words may have to be modified based on quantity involved.
[b] The size of the fleet or inventory should be defined.

TABLE 35-4 Example Classification for Costs to Correct Risks

Category	Value
A	<$1,000
B	$1,000–10,000
C	$l0,000–100,000
D	>$100,000

Quantitative or qualitative methods can be applied to setting priorities. Alternate ways to achieve elimination or reduction in risks must be explored. Two key factors are the cost of implementing actions and the degree of reduction achieved for each.

The classification of risk severity and probability in Tables 35-2 and 35-3 is extended to a decision matrix in Figure 35-1. Risks or hazards are organized into three categories. Some require elimination or reduction, some are permissible and need no reduction, and others are left for management to wrestle with on an interim basis. Little judgement is necessary in applying the matrix. The greatest judgment involves how to eliminate or reduce catastrophic and critical hazards or finding alternatives when it is impossible or impractical to eliminate or reduce them.

Some methods add a classification table for grouping the correction costs. Table 35-4 gives an example of a cost-to-correct table.

Financing Risks

Managing risks requires decisions regarding how to pay for the risks. Money can be invested in directly eliminating or reducing risk, particularly the most effective reduction alternatives. Developing a cash reserve is one method to pay for risk reduction measures. A second option is to purchase insurance for each risk. The premiums may be lower than the cost to implement a risk-reducing alternative. A third option is to do nothing, which may be logical for events that are not likely to occur and those that have low severity.

Example 35-2 The data from Example 35-1 can be extended to financial aspects. Assume that the cost of vehicle accidents is $39.3 billion per year. The average cost per accident, C, is

$$C = \frac{\$39.3 \times 10^9}{2.98 \times 10^7}$$
$$= \$1,319 \text{ per accident.}$$

Similarly, the financial risk for each person per year, R, is

$$R = 0.089 \times \$1,319$$
$$= \$117.39 \text{ per person per year.}$$

From these data, a decision can be made whether it is better to buy insurance or create a fund to cover the cost of accidents. (In reality, most states require drivers to carry insurance.) In addition, other information may help in deciding if there is any way to reduce the likelihood of an accident or reduce severity if one occurs. Alternatives may reduce the risk if money is spent for driver training, driving a larger car that has lower cost per accident, or incorporating protective features to reduce severity.

Administering the Process

The final step in risk management is administering the process. Part of administration is setting acceptable levels of risk. A company or organization must decide what level of risk it will assume and what level it will transfer. Another aspect of administration is assigning resources to the process. The process may require specialists for risk identification and analysis and financial specialists to help determine the overall costs, benefits, and most economical way to finance risks. Administering the process necessitates monitoring and evaluating if reductions are achieved, if frequency and severity actually resulted as projected, and if expenditures achieve the benefits that were anticipated. Another aspect of administering the process is selecting methods to be used and tracking items analyzed, hazards identified, analysis applied, and decisions made.

Figure 35-2 is an example of a form for tracking risk identification, analysis, and actions taken. Data can also be tracked using computer records. Nomograms have been developed to analyze risks and justify costs. Figure 35-3 gives examples.

35-3 RISK ASSESSMENT

Terminology for risk, risk management, and risk assessment is not fully consistent across sources. In general, risk assessment is a portion of risk management. Risk assessment involves identification, analysis, and evaluation of risk. A diagrammatic representation of risk assessment is given in Figure 35-4, where risk assessment is divided into two components: risk determination and risk evaluation. Risk determination includes identifying risks and risk estimation. There are several approaches that help identify risks. Risk estimation is projecting frequency and severity. Probabilistic risk assessment (PRA) includes risk assessment techniques that evaluate the probability of events occurring and the probability of their severity.

Risk evaluation includes risk aversion and risk acceptance. Risk aversion is estimating how well risk can be reduced or avoided through various alternatives. Risk acceptance involves creating decision tables or standards for deciding what risks are acceptable for individuals, companies, or society. What is acceptable may differ for each group.

Risk assessment is not independent of the process or the personnel involved. The method being used, as well as the participants, can affect the risk assessment. Sometimes,

<table>
<tr><th colspan="2">RISK MANAGEMENT DATA SHEET</th></tr>
<tr><td colspan="2">Item or Event</td></tr>
<tr><td>Risk Identifier</td><td>Method(s) Used</td></tr>
<tr><td colspan="2">Risk Ratings Frequency: ________ Severity: _________</td></tr>
<tr><td colspan="2">Description and Contributing Factors</td></tr>
<tr><td colspan="2">Summary of Supporting Data</td></tr>
<tr><td colspan="2">Corrective Action(s) Proposed</td></tr>
<tr><td>Proposed Action</td><td>Effectiveness/Cost</td></tr>
</table>

Figure 35-2. Example of a risk management data sheet.

people who could be affected by a risk are not included as participants, which can create significant biases in the process.

The National Academy of Sciences[3] identified four steps in every complete chemical risk assessment:

1. hazard identification
2. dose-response assessment
3. exposure assessment
4. risk characterization

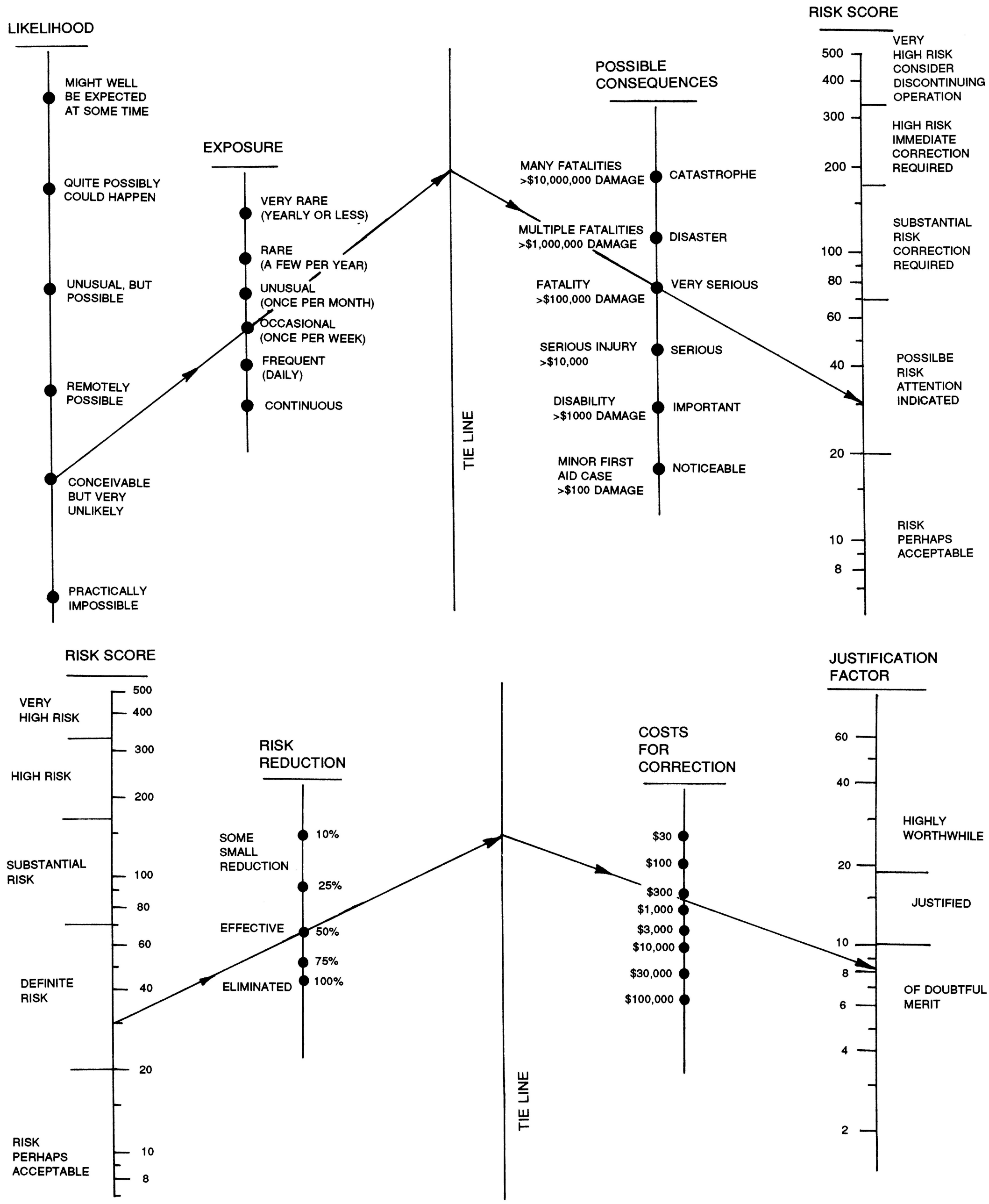

Figure 35-3. Nomographs for analyzing risk and cost justification. (From Kinney, G. F., and Wiruth, A. D., *Practical Risk Analysis for Safety Management*. NWC Technical Publication 5865, Naval Weapons Center, China Lake, CA, 1976.)

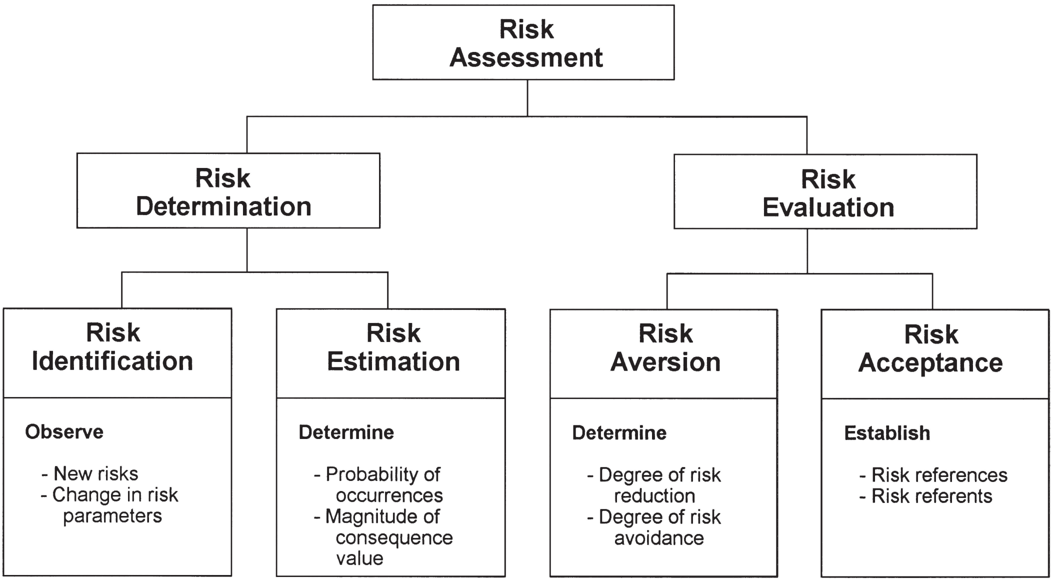

Figure 35-4. Risk assessment concept. (Derived from W. D. Rowe, *An Anatomy of Risk*, Wiley, New York, 1977.)

Hazard Identification

Hazard identification and some methods for it have already been discussed. Hazard identification may include engineering failure assessment, which consists of evaluating the reliability of specific segments of a plant operation and determining probabilistic results. Fault-tree analysis (see Chapter 36) is a common form of engineering failure assessment.

Dose-Response Assessment

For chemicals, dose-response assessment involves describing the quantitative relationship between the amount of exposure and the extent of toxic injury or disease. It requires that the hazard of a material be recognized before the effects are assessed. A dose-response assessment may provide linear equations relating exposure or dose to response or disease. The equations may be derived from regression analysis of dose-response data.

Exposure Assessment

Exposure assessment is describing the nature and size of populations exposed to an agent and the magnitude and duration of the exposures. Exposures include past, present, and future exposures. Exposure assessment may include analysis of toxicants in air, water, or food and it could apply to the prevalence of certain factors in automobile accidents.

Risk Characterization

Risk characterization is integration of data and analysis to determine if people will experience effects of exposure. Risk characterization includes estimating uncertainties associated with the entire process of risk assessment.

Application Issues

Risk assessment often must rely on inadequate scientific information or the lack of data. For example, repair data may not be useful in predicting failures accurately for newly designed equipment because there may be a lack of understanding of phenomena. For example, in toxicological assessment, assumptions must be made about the validity of using animal studies to predict effects for humans. Many people involved in risk assessment will take a conservative approach to avoid overestimating risk, whereas others will use comparison techniques on various options. Then the absolute risk values are not as important as the relative differences between options.

35-4 EXAMPLES OF METHODS

People have applied risk assessment and management in various ways. This section will take a closer look at several approaches.

William Fine

Fine[4] proposed a method for deciding if the cost to correct a hazard is justified and how quickly hazards should be corrected. His method involves the use of risk. A risk score, R, is computed from

$$R = C \times E \times P, \tag{35-1}$$

where

C is the consequence rating value,

E is the exposure value, and

P is the probability value.

The risk score can be used to decide how quickly to act to correct hazards. See Table 35-5 for decision guidance. One can compute a cost justification value, J, from

$$J = \frac{R}{(CF \times DC)}, \tag{35-2}$$

where

CF is a cost factor and

DC is a degree of correction value.

The values for Equations 35-1 and 35-2 are selected from tables (see Table 35-5). Fine suggests that if $J > 10$, the cost is justified and if $J < 10$, the cost is not justified. Fine emphasizes that his method should be used for *guidance* only. The values used in the process and for decision making are somewhat arbitrary. Other definitions could be substituted, other values assigned, and a different value used for J in decision making. However, the approach does provide a simple way to evaluate a variety of hazards and controls and present them to management for approval.

Logical Process Risk Analysis

Frank and Morgan[5] proposed a systematic method for helping managers allocate funds to achieve the greatest risk reduction across several departments within a plant. The method

TABLE 35-5 Values for Fine's Decision Process

Rating	Classification
Consequences, C (most probable result of potential accident)	
100	Catastrophe; numerous fatalities; damage over $1,000,000; major disruption of activities
50	Multiple fatalities; damage $400,000–1,000,000
25	Fatality; damage $100,000–400,000
15	Extremely serious injury (i.e., amputation, permanent disability; damage $1,000–100,000
5	Disabling injury; damage up to $1,000
1	Minor injury or damage
Exposure, E (frequency of occurrence of the hazard event)	
Hazard event occurs	
10	Continuously (or many times daily)
6	Frequently (about once daily)
3	Occasionally (once per week to once per month)
2	Unusually (once per month to once per year)
1	Rarely (it has been known to occur)
0.5	Remotely possible (not known to have occurred)
Probability, P (likelihood that accident sequence will follow to completion)	
Complete accident sequence	
10	Is the most likely and expected result if the hazard event takes place
6	Is quite possible, not unusual, has an even 50–50 chance
3	Would be an unusual sequence or coincidence
0.5	Has never happened after many years of exposure, but is conceivably possible
0.1	Practically impossible sequence(has never happened)
Cost factor, CF (estimated dollar cost of proposed corrective action)	
10	>$50,000
6	$25,000–50,000
4	$10,000–25,000
3	$l,000–10,000
2	$100–1,000
1	$25–100
0.5	Under $25
Degree of correction, DC (degree to which hazard will be reduced)	
1	Hazard positively eliminated 100%
2	Hazard reduced at least 75%
3	Hazard reduced by 50%–75%
4	Hazard reduced by W-50%
6	Slight effect on hazard (<25%)
Risk score summary and actions	
Score	Action
200–1,500	Immediate correction required; activity should be discontinued until hazard is reduced
90–199	Urgent; requires attention as soon as possible
0–89	Hazard should be eliminated without delay, but situation is not an emergency

also could be used to compare several plants and to allocate funds to each. The procedure applies risk concepts and was prepared for application to chemical processing plants. The method involves six steps:

1. Compute a risk index for each department.
2. Determine relative risk for each department.
3. Compute the percent risk index for each department.
4. Determine composite exposure dollars for each department.
5. Compute a composite risk for each department.
6. Rank all departments relative to each other based on composite score.

Risk Index A risk index is developed for a department by evaluating hazards and controls, establishing a hazard score and a control score, and subtracting the hazard score from the control score. The authors developed a hazard checklist (see Table 35-6) and a control checklist (see Table 35-7). The hazard checklist includes six groups of hazards, and there are points associated with each hazard within a group. The points are summed for those hazards that apply within a group, and the product of the sum and a hazard or weighting factor for the group of hazards yields a score for the group. The hazard score for a department is the sum of scores computed for each of the six groups.

The control scores are determined in a similar manner. After identifying what controls apply to a department for each of six groups of controls, the points for each applicable control are summed within a group and multiplied by a group control factor. The control score for a department is the sum of scores for each of the six groups.

The risk index is the control score minus the hazard score. A risk index may have a positive or negative value.

Relative Risk The goal is to rank departments, not individual hazards. Because the department with the highest risk index (highest positive value) is not likely to need much reduction in hazards (the high risk index value indicates that controls are very effective), it will need funds less than other departments. The authors use the best department risk score as the baseline for all others. All scores are adjusted relative to the score for the best department by subtracting the risk score for the best department from all risk scores. This adjustment makes the relative risk score for the best department zero.

Percent Risk Index The percent risk index for each department represents the relative contribution each makes toward the total risk of the plant. The relative risk for each department is converted to a percent of all risk by a simple procedure. The total risk for all departments is the sum of absolute values of all relative risk scores. Dividing the absolute value of the relative risk for each department by the total risk gives the percent risk index.

Composite Exposure Dollars Next, one needs to know what the total dollars-at-risk are for each department. The composite exposure dollars are the sum of the monetary value of three components: property value, business interruption, and personnel exposure. The property value is determined by estimating the replacement cost of all material and equipment at risk in a department. Business interruption is computed as the product of the (1) unit cost of goods produced, (2) the department production capacity per year, and (3) the expected percent of capacity. The personnel exposure is the product of the total number of people in the department during the most populated shift and the monetary value for each person. The authors set the monetary value somewhat high to reflect that loss of life is not acceptable.

TABLE 35-6 Hazard Checklist

Rating Points	Hazard Group and Hazard (Group Hazard Factor in Parentheses)
Fire/explosion potential (10)	
2	Large inventory of flammables
2	Flammables generally distributed in the department rather than localized
2	Flammables normally in vapor phase rather than liquid phase
2	Systems opened routinely, allowing flammable/air mix, versus a totally closed system
1	Flammables having low flash points and high sensitivities
1	Flammables heated and processed above flash point
Complexity of process (8)	
2	Need for precise reactant addition and control
2	Considerable instrumentation requiring special operator understanding
2	Troubleshooting by supervisor rather than operator
1	Large number of operations and/or equipment monitored by one operator
1	Complex layout of equipment and many control stations
1	Difficult to start up or shut down operations
1	Many critical operations to be maintained
Stability of process (7)	
3	Severity of uncontrolled situation
2	Materials that are sensitive to air, shock, heat, water, or other natural contaminants in the process
2	Potential exists for uncontrolled reactions
1	Raw materials and finished goods that require special storage attention
1	Intermediates that are thermally unstable
1	Obnoxious gases present or stored under pressure
Operating pressure involved (6)	
3[a]	Process pressure in excess of 110 lb/in^2 (gauge), or
2[a]	Process pressure above atmosphere but less than 110 lb/in^2 (gauge), or
1[a]	Process pressure ranges from vacuum to atmospheric
3	Pressures are process rather than utility related
2	High pressure situations are in operator frequented areas
1	Excessive sight glass application
1	Nonmetallic materials of construction in pressure service
Personnel/environmental hazard potential (4)	
3	Exposure to process materials pose high potential for severe burns or severe health risks
2	Process materials corrosive to equipment
2	Potential for excursion above threshold limit value (TLV)
1	Spills and/or fumes have high impact on equipment, people, or services
1	High noise levels make communication difficult
High temperatures (2)	
1[a]	Equipment temperatures exist in <100°C range (low), or
2[a]	Equipment temperatures exist in 100 <170°C range
3[a]	Equipment temperatures exist in 170 <230°C range (350 lb/in^2 [gauge] steam)
2	High temperature situations are m operator-frequented area
2	Overflows and/or leaks are fairly common
2	Heat stress possibilities from nature of work or ambient air

[a] Maximum of three points from this subgroup.

TABLE 35-7 Control Checklist

Rating Points	Control Group and Control (Group Control Factor in Parentheses)
Fire protection (10)	
4	Automatic sprinkler system capable of meeting demands
2	Supervisors and operators knowledgeable of installed fire protection systems and trained in proper response to fire
1	Adequate distribution of fire extinguishers
1	Fire protection system inspected and tested with regular frequency
1	Building and equipment provided with capability to isolate and control fire
1	Special fire detection and protection provided where indicated
Electrical integrity (8)	
3	Electrical equipment installed to meet National Electrical Code (NEC) area classification
1	Electrical switches labeled to identify equipment served
1	Integrity of installed electrical equipment maintained
1	Class I, division 2 installations provided with sealed devices. Explosion proof equipment provided or purged reliably and good electrical isolation between hazardous and nonhazardous areas.
1	All electrical equipment capable of being locked out
1	Disconnects provided, identified, inspected, and tested regularly
1	Lighting securely installed and facilities properly grounded
Safety devices (7)	
3	Relief devices provided and relieving is to a safe area
2	Confidence that interlocks and alarms are operable
2	Operating instructions are complete and current, and department has continuing training and/or retraining program
1	Safety devices are properly selected to match application
1	Critical safety devices identified and included in regular testing program
1	Fail-safe instrumentation provided
Inerting and dip piping (5)	
2	Vessels handling flammables provided with dip pipes
2	Vessels handling flammables provided with reliable “inerting” system
2	Effectiveness of inerting assured by regular inspection and testing
1	Inerting instruction provided and understood
1	Inerting system designed to cover routine and emergency startup
1	Equipment grounding visible and tested regularly
1	Friction hot spots identified and monitored
Ventilation/open construction (4)	
3	No flammables exist or open air construction is provided
2	Local ventilation provided to prevent unsafe levels of flammable, toxic, or obnoxious vapors
2	Provision made for containing and controlling large spills and leaks of hazardous materials
1	Building design provides for natural ventilation to prevent accumulation of dangerous vapors
1	Sumps, pits, etc., nonexistent or else properly ventilated or monitored
1	Equipment entry prohibited until safe atmosphere assured
Accessibility and/or separation (2)	
2	Critical shutdown devices and/or switches visible and accessible
2	Adjacent operations or services protected from exposure resulting from incident in concerned facility
2	Operating personnel protected from hazards by location
1	Orderly spacing of equipment and materials within the concerned facility
1	Adjacent operations offer no hazard or exposure
1	Hazardous operations within facility well isolated

Composite Risk The composite risk for a department is the product of the composite exposure dollars and the percent risk index. The composite risk represents the economic value of the relative risk for a department. Units for composite risk are dollars.

Final Ranking The final step in the process is to rank the departments based on composite risk. Because the goal is to help managers decide where to apply funds to achieve the greatest risk reduction, the departments should be ranked from highest composite score to lowest. The lowest will be zero for the reference department.

Example 35-3 Six departments in a plant are asking for money to improve process safety. The company elects to use logical process risk analysis as a guide for allocating funds. The goal is to reduce potential losses. Analysis is performed for each department to determine hazard scores, control scores, and exposure dollars. Data are presented in Table 35-8.

The data are used to rank departments. The results are presented in Table 35-9.

Risk Analysis with Return on Investment

Another example of risk analysis follows a process of computing risk and cost for controls. Results include return on investment. The items to be analyzed are processes, activities, or equipment. The first step is hazard identification, followed by estimates of

TABLE 35-8 Data for Example 35-3

					Composite	
Exposure Department	Hazard Score	Control Score	Property Value (×$1,000)	Business Interruption Cost (×$1,000)	Personnel Value (×$1,000)	Exposure Dollars (×$1,000)
A	257	304	2,900	1,400	900	5,200
B	71	239	890	1,200	653	2,743
C	181	180	1,700	720	1,610	4,030
D	152	156	290	418	642	1,350
E	156	142	520	890	460	1,870
F	113	336	2,910	3,100	1,860	7,870

TABLE 35-9 Results of Analysis for Example 35-3, Including Final Ranking for Departments

Dept.	Risk Index	Relative Risk	% Risk Index	Composite Exposure Dollars (×$1,000)	Composite Risk (×$1,000)	Rank
A	47	–176	–22.3	5,200	1,160	1
B	168	55	7.0	2,743	192	4
C	–1	–224	28.4	4,030	1,145	2
D	126	–97	12.3	1,350	166	5
E	–14	–237	30.0	1,870	561	3
F	223	0	0.0	7,870	0	6
		–789	100.0			

frequency, and severity of losses for each hazard. Associated with each hazard are one or more controls, the costs and effectiveness of which must be estimated. Effectiveness is reduction in frequency and severity of losses. Implementing a control will reduce risk from what it would be without the control. From this analysis, one can project benefits, return on investment, and payback period.

Example 35-4 A company wants to reduce the hazards of injury for a machine. There are two options that may help: installing a guard or using an interlock device. The goal is to compare each approach and express the solution as a return on investment. Table 35-10 compares the two alternatives.

Chemical Risk Analysis

Although the steps in the risk assessment process seem quite simple, the procedures for applying risk assessment to chemicals is complicated. There are many points in the process at which technical judgement must be applied. As a result, considerable knowledge and experience with the process are necessary to understand the many intricacies that must be accounted for.

Hazard recognition is a starting point in applying risk assessment to hazardous chemicals, and it depends on data from toxicological studies. The amount and type of data vary widely for different chemicals, and there are several difficulties in estimating chemical hazards. For example, animal studies may have considered single doses. As a result, there is little information for estimating chronic exposure problems. Also, animals may have had high dose rates that are not representative of human exposures. There are difficulties in extrapolating animal data to humans, and although most human carcinogens are also animal carcinogens, the converse is not necessarily true.

Additional difficulties arise when making dose-response assessments. First, one must select what measure of dose to use. A common measure is milligrams of chemical per kilogram of body weight per day. Then a scaling factor between species must be applied and an adjustment made for absorption rates, because they are affected by several factors. Extrapolation must be carried out from high to low doses because not all extrapolations are linear or linear over a range of dose rates. Adjustment may be needed for

TABLE 35-10 Risk Analysis for Example 35-4

Step	Option A	Option B
A. Hazard: Becoming caught in a machine		
B. Frequency of occurrence (events per year)	3	3
C. Severity (expected $ loss per event)	$10,000	$10,000
D. Risk, annual (B × C)	$30,000	$30,000
E. Control	Guard	Interlock
F. Control cost (initial, assume no annual recurring costs)	$2,000	$800
G. Control effectiveness (relative to B)	90%	70%
H. Control effectiveness (relative to C)	80%	80%
I. Risk after control is implemented (B × G)(C × H)	$21,600	$16,800
J. Benefit, annual (D − I − F)	$6,400	$12,400
K. Return on investment (100 × J/F)	320%	1,550%
L. Payback period, years (F/J)	4 months	3–4 weeks

threshold effects also. For some substances, there are no-observable-effect levels (NOELs) or lowest-observed-effect levels (LOELs).

The assessment of exposure also has complicating factors. First, the medium of exposure must be considered (air, diet, water, soil). Then the duration of exposure must be accounted for. An exposure may be chronic, covering a major portion of a person's lifetime, or acute, involving one contact or contact for one day or less. Exposures between acute and chronic are called subchronic. What concentration is in an environment must be known and what the intake rate is for a particular environment must be estimated. Some common units for doses in exposure assessment are maximum daily dose (MDD) and lifetime average daily dose (LADD), which is used frequently in carcinogenic risk assessment. LADD is estimated from the product of the average MDD and the fraction of the total lifespan that one is exposed (exposure days per days per lifetime). Furthermore, the individuals exposed need to be characterized because factors such as age, sex, health status, and other exposures (such as cigarette smoke, occupational agents, etc.) may contribute to the risk.

Finally, the risk is estimated from the other data and analysis. From the data, risk can be reported in various ways. One method is establishing allowable dose rates for humans. Typical units are acceptable daily intake (ADI), which are based on NOELs and apply a safety factor to protect sensitive people. If data are available from human studies, a smaller safety factor is applied compared with having data available from only animal studies.

Risk assessment for chemicals is a complicated process of generalizing risk from known, highly controlled situations to situations that were not included in studies. Regardless of its difficulties and uncertainties, risk assessment is a systematic way to organize, analyze, and present information on environmental chemicals and to decide when public protection is needed.

For chemical processes, readers should refer to detailed procedures[6] that go beyond the scope of this book.

EXERCISES

1. A company developed data on injuries resulting from becoming caught in machines. The data show that on the average, 15 workers in company machine shops receive a machine injury each year. The measured severity in financial terms found that the average cost per case is $9,750. lf there are 450 machine shop workers in the company, what is the risk (cost per year) for each worker?
2. A company is contemplating changing a process to reduce a hazard. The company has the following data about the change: if there is an accident, there will be multiple fatalities and more than $500,000 in damage. The hazard event occurs once per year. There is a small chance (coincidental) that an accident sequence will follow to completion. The cost to correct the hazard is $60,000. The correction will reduce the hazard by 80%. Use the William Fine method to determine
   (a) risk score and a recommended action to correct the hazard
   (b) cost justification and a decision to implement the change
3. Use the logical process risk analysis method to determine the ranking for applying funds to each of the five plants in a company. Data for the five plants (more were involved in the analysis) are in the following table.

Plant	Relative Risk (%)	Composite Exposure ($)
A	8	822,000
B	15	1,219,000
C	16	759,000
D	7	598,000
E	21	1,021,000

REVIEW QUESTIONS

1. Define the following:
  (a) risk
  (b) risk aversion
  (c) loss control
  (d) risk management
  (e) risk assessment

2. What are the five steps in risk management? Briefly explain each.

3. What are the four steps in risk assessment? Briefly explain each.

4. To what is Fine's risk method applied?

5. To what is logical process risk analysis applied?

6. Discuss some problems in each of the four steps of risk assessment when it is applied to chemical risks.

NOTES

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