- There are specific sets of circumstances that can predictably lead to severe injuries—nonproductive activities, certain construction conditions, high-energy sources, and abnormal nonroutine activities.
- The symptoms that indicate something is incorrect in the management system include accidents, unsafe actions, and unsafe conditions.
- Under most circumstances, normal human behavior is an unsafe behavior. Thus, it is the management team's responsibility as leaders to make appropriate changes to the environment that fosters unsafe behavior in order to encourage safe behavior.
- In developing a good safety system, the three main subsystems that must be considered with care are the behavioral, the managerial, and the physical subsystems.
- There is no single method to effectively achieve safety in an organization. But, for a safety system to be effective, it must meet certain criteria, such as: have the top management visibly showing its full support to safety, involve worker participation, be flexible, and so on.

3.8 Accident-Causation Theories

As per [5], there are many accident-causation theories. Two such theories are presented below.

3.8.1 The "Human Factors" Accident-Causation Theory

The "human factors" accident-causation theory is based on the assumption that accidents occur due to a chain of events directly or indirectly linked to human error. It consists of three main factors, shown in Figure 3.7, that lead to the occurrence of human error [5,20]. These three main factors are: inappropriate response/incompatibility; overload; and inappropriate activities.

The factor "inappropriate response/incompatibility" is an important factor for the occurrence of human error and some examples of inappropriate response by an individual are as follows [6,20]:

- A person completely disregards the specified safety procedures
- A person removes a safeguard from a machine for increasing output
- A person detects a hazardous condition, but takes no corrective action

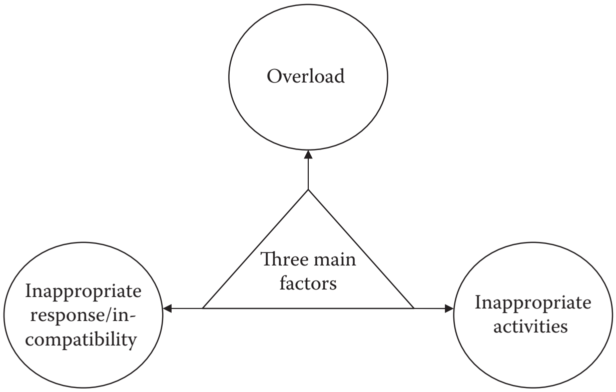

FIGURE 3.7
Three main factors that lead to the occurrence of human error.

The "overload" factor is concerned with an imbalance between the capacity of an individual at any time and the load he/she is carrying in a given state. The capacity of a person is the product of factors such as:

- The degree of training
- Fatigue
- Physical condition
- Stress
- State of mind
- Natural ability

The load carried by an individual is made up of tasks for which he/she has responsibility, along with additional burdens resulting from the situational factors (i.e., level of risk, unclear instructions, etc.), environmental factors (i.e., distractions, noise, etc.), and internal factors (i.e., personal problems, worry, emotional stress, etc.).

Finally, the factor of "inappropriate activities" is concerned with inappropriate activities undertaken due to human error, poor judgment about the degree of risk involved in a given task and subsequently acting on that misjudgment.

3.8.2 The "Domino" Accident-Causation Theory

This theory is encapsulated in 10 statements called the "Axioms of Industrial Safety" by H.W. Heinrick [21]. These 10 axioms are as follows [5,6,21]:

i. Most accidents are due to the unsafe acts of people.
ii. An unsafe act by a person or an unsafe condition does not always immediately lead to an accident/injury.

iii. Supervisors play a key role in the prevention of industrial accidents.
iv. The reasons why people commit unsafe acts can be useful in choosing appropriate corrective measures.
v. The severity of an injury is largely fortuitous, and the specific accident that caused it is generally preventable.
vi. There are two types of costs (i.e., direct and indirect) of an accident. Some examples of the direct costs are liability claims, hospital-related expenses, and compensation.
vii. The occurrence of injuries results from a completed sequence of numerous factors, the last one of which is the accident itself.
viii. Management should assume full responsibility for safety because it is in the best position for achieving the final results effectively.
ix. An accident can occur only when someone commits an unsafe act and/or there is a mechanical or physical hazard.
x. The most useful accident-prevention methods are analogous to the productivity and quality approaches.

According to Heinrich, the five specific factors in the sequence of events leading up to an accident are as follows [5,6]:

- *Ancestry and social environment.* In this factor, it is assumed that negative character traits such as recklessness, stubbornness, and avariciousness that might lead individuals to behave in an unsafe manner, can be acquired as a result of the social environment or surroundings or inherited through one's ancestry.
- *Fault of a person.* In this factor, it is assumed that negative character traits (whether inherited or acquired) such as ignorance of safety practices, excitability, recklessness, nervousness, and violent temper constitute proximate reasons for committing unsafe acts or for the existence of physical or mechanical hazards.
- *Unsafe act/physical or mechanical hazard.* In this factor, it is assumed that unsafe acts by people (i.e., starting equipment/machinery without warning, removing safeguards, standing under suspended loads) and physical or mechanical hazards (i.e., unguarded point of operation, unguarded gears, inadequate light, absence of guardrails) are the very direct causes for the occurrences of accidents.
- *Accident.* In this factor, it is assumed that events such as falls of humans and striking of humans by flying objects are the typical examples of accidents that cause injury.
- *Injury.* In this factor, it is assumed that the typical injuries that directly result from accidents include fractures and lacerations.

3.9 Problems

1. What are the three phases of a bathtub hazard rate curve? Discuss the causes of failures in each of these three phases.
2. Write down general equations for the following:
   i. Reliability function
   ii. Hazard-rate function
3. Prove Equation 3.11 by using Equation 3.6.
4. Write down formulas to obtain mean time to failure by using the reliability function.
5. Assume that a robot system is composed of three independent and identical subsystems and the constant failure rate of each subsystem is 0.0005 failures per hour. All three subsystems must operate normally for the robot system to work successfully. Calculate the robot system reliability for a 50-hour mission, mean time to failure, and failure rate.
6. A robot system has four active, identical, and independent units in parallel. At least three units must operate normally for the successful operation of the robot system. Calculate the robot system's mean time to failure if the unit's constant failure rate is 0.006 failures per hour.
7. Prove Equation 3.31 by using Equation 3.35.
8. Discuss the "human factors" accident-causation theory.
9. List at least 10 tasks of a product-related safety organization.
10. Discuss product-hazard classifications.

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