Chapter 5
Human, Nature, and Artificial Products

Mamoru Ozawa

Abstract Nature and societies that surround us are full of hazards. Depending on their intensities and surroundings, they develop into incidents. What artificial facilities are around, what actions people involved take, and states of societies or nature can further turn them into accidents or disasters. Risk management is ever more important for controlling such development and minimizing damages. This chapter overviews how hazards develop into accidents and damages and discusses several topics in risk management.

Keywords Hazard · Heinrich's law · Incident · Risk evaluation · Risk space

5.1 Environment That Surrounds Human and Societies

We, humans, since our first existence on the earth, have formed societies under certain sets of rules in the natural environment. The industrial revolution at the end of the eighteenth century triggered development of large-scale factory production systems, as well as power generation systems, systems for electricity generation and distribution, and so on. Once the transportation networks formed with steam-powered ships and railways, the human societies turned into somethings fundamentally different from what they used to be. The spread of factory production systems caused problems with health management and safety measures for factory workers, and in the mid-nineteenth century, England passed the Factory Act. Also as marine transportation turned active, people came up with ship inspection systems and marine insurance systems in case of marine accidents. Further for power generation systems, as people aimed at developing higher efficiency boilers, many of the efforts resulted in explosion accidents leading to boiler inspection systems by third parties.

M. Ozawa (✉)
Faculty of Societal Safety Sciences, Kansai University, Takatsuki, Osaka, Japan
e-mail: ozawa@kansai-u.ac.jp

S. Abe et al. (eds.), *Science of Societal Safety*, Trust: Interdisciplinary Perspectives 2,
https://doi.org/10.1007/978-981-13-2775-9_5

As the industries advanced, transportation and logistics turned large-scaled, and today people and freight travel the world. Growth of computers and network technologies has now made high-speed transfer of large amounts of information across countries giving us great conveniences. Faster transportation and logistics, however, were factors that caused worldwide spread of food safety problems like mad cow disease (bovine spongiform encephalopathy, BSE) or pandemics. The quick information communication technologies have led to frequent problems of personal information leakage and harmful rumors.

The radius of the earth is about 6500 km, and the earth crust where we live in or on is only about 30 km thick. The theory of plate tectonics says the earth surface is covered by ten or so plates, and the mantle flowing underneath them moves in various directions. Japan, at the boundary of the Eurasian and other plates, is often shaken by major earthquakes caused by sinking of the plates.

Mountains cover about 70% of Japanese land, and since the ancient time, people lived and produced along rivers or near the oceans. Advancements of societies and economics caused people to concentrate in cities, where they cut and flattened mountains, filled lowlands, and built housings. As more people concentrated to cities, agricultural regions in the mountains are now facing depopulation and economic gaps with urban regions. We are living in an environment as a result of intertwinement of natural, societal, and historical factors.

5.2 Hazards in Natural and Social Environments

We will next explain about hazards in the natural and social environments with some examples. Large-scale inter-plate earthquakes or direct earthquakes cause large damages to the infrastructures, railways, and road networks. When tsunami waves follow them, like in the case of the Great East Japan earthquake, they cause large casualties as well as major damages to power plants and port facilities in coastal areas. An earthquake is a phenomenon of a rock bed shifting caused by relative motion between plates and fault activities; thus, force on the rock bed is the hazard in case of an earthquake. Concentrated heavy rainstorms directly cause sediment disasters, frequently taking place in recent years. If we, however, review the mechanisms of sediment disasters, housing development and forest damages weaken the water retention capacities of soil and the imbalance among inter-ground friction, and viscosity and gravity on ground are factors leading to sediment disasters as well. The hazard for sediment disasters is lower friction caused by rainfall.

In large cities, electricity grid wiring and gas and water piping are congested, and in addition, information, logistics, and transportation networks are overcrowded at high speed. These situations lead to small incidents triggering large catastrophes with huge damages. The 1977 passenger plane collision in Tenerife, Spain, and the 1985 airplane crash near Mt. Osutaka in Japan both ended up with over 500 casualties. Major NPP accidents include the 1986 Chernobyl plant explosion in former Soviet Union and the 1979 Three Mile Island (TMI) accident in the USA. In Japan in

March 2011, multiple cores melted down at Fukushima Daiichi NPP. With these accidents, using high-density energy is the hazard hidden in today's social environment.

5.3 Development of Hazards into Accidents and Disasters

Hazards expose themselves as incidents, depending on their intensities and environmental conditions around them. Incidents turn into accidents or disasters with casualties or property damages depending on the facilities around them, how people reacted to them, or social systems or natural environment that surrounds them.

In April of 2005, West Japan Railway had a derailing accident on the Fukuchiyama Line that caused 107 casualties. When the train passed through a curve, rotational moment due to the centrifugal force being a function of running speed exceeded rotational moment from gravity, and these physical factors led to derailing and overturn of the passenger cars. People that live along railway tracks and passengers are exposed to dangerous situations with railway cars or tracks that are not fully maintained, troubled train drivers, improper automatic train stops or fail-safe equipment, lack of frictional force between the tracks and wheels caused by rain, and many other factors that lead to incidents. Especially, when the cars are packed during the commute time, and when the train is speeding, like in the case of Fukuchiyama Line accident, the incident develops into an overturning accident with a huge number of casualties.

Infrastructures and industrial products consist of a large number of parts and elements, sensors, computers, and software that control them. If we count a very large-scale integrated circuits that compose the computer, we understand that our societies today are built on an extremely huge number of elements that construct hierarchical systems. For such complex systems, predicting processes or scenarios that cause hazards to turn into incidents and finally into accidents is extremely difficult. Even Space Shuttle Challenger, with sufficient safety measures, exploded immediately after its launch when the simple part O-ring failed. For this accident, the operation made the mistake in business decision of prioritizing schedule despite warning from engineers who had recognized the trouble with the O-ring. Organizational management and human factors place large effects on accidents and natural disasters when hazards turn into incidents and eventually into accidents or disasters.

5.4 Risks for Evaluating Accidents and Disasters

As ISO defines (ISO/IEC 2014), the combination of damage level and frequency determines the risk magnitude. Setting the frequency F_i of incident i, and the level of damage D_i,, the next equation evaluates risk R_i;

$$R_i = F_i D_i \tag{5.1}$$

This equation is an example of evaluating risk, and some evaluations define risk with the magnitude of damage alone and others with the probability of occurrence.

Chapter 1 discussed deterministic risk assessment and probabilistic risk assessment. Deterministic risk assessment evaluates risk with whether the safety meets the standards determined by evaluation guideline and tolerance based on scientific evaluations, technical discussions, or past experiences. Many of general safety standards, like those of nitrogen oxides (NO_x) and particulate matter (PM) in automobil exhaust gas, and aseismic standards are based on deterministic risk assessment.

On the other hand, the study known as Rasmussen Report "Reactor Safety Study – An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants" (U.S.NRC 1975; Lee & McCormick 2011) established the probabilistic risk assessment (PRA) methodology. The report evaluated risks with the magnitudes of effect and annual occurrence frequencies. In general, upon event that causes an accident, there is some time delay for the effects to propagate to related parts and elements, and the delay can cause the event to develop into another event. Rasmussen Report was a breakthrough at the time in that it developed a model that simulated dynamic system response to take this time delay into account. PRA is applied not only for risk assessment of NPPs but also for aerospace industries.

Risk assessment quantifies the smallest danger as risk, but at the same time, it tolerates certain levels of risk (Slovic et al. 2000); however, clarifying which risk to tolerate under what conditions is difficult. For example, WHO states the guideline for water quality requires that the probability of waterborne diseases is below the set standards, specialists to make judgment, and administration and majority of the public to accept the quality (Hunter and Fewtrell 2001). The requirement of being accepted by the public is a judgment standard along human psychology and is not based on scientific roots. What universally applies to risk evaluation is statistic numbers, like probability of occurrence.

H. J. Otway and R. C. Erdmann reported (Otway and Erdmann 1970) that if the death count is less than 10^{-6} per year, people do not take big interest in the risk thinking they will not get caught by it. When the count, however, reaches $10^{-4} \sim 10^{-5}$ a year, they turn active in reducing the hazard and will accept inconvenience to a certain extent to avoid the risk. Further at about 10^{-3} a year, they no longer accept the risk and take immediate actions. There is, perhaps, no clear reason why people accept the death rate of 10^{-6} a year, i.e., one out of a million a year. É. Borel, however, in his 1943 book, (Borel 1943) wrote that the chance of 10^{-6} (i.e., a little less than 3 out of 2.8 million, the population of Paris back then) is something that people would accept. The current world population is about seven billion, and for this size population to match Borel's victim count, the probability has to drop to $10^{-9} \sim 10^{-10}$ a year. This example means simple probability calculations do not reach judgments and the population size matters. The count of 1 out of 1 million is just a statistical number, and the situation surrounding each case is not taken into account. We tend not to pay much attention to accidents in remote locations; however, if it involves a neighbor or a family member, we suddenly turn intolerant. Whether we tolerate a risk or not is not just a matter of probability, but it also heavily involves time and spatial distance. Further detail can be found in, for example, P. Slovic's book (Slovic 2000).

5.5 Problems That Are Common to Accidents and Disasters

Each event of accident or disaster is an unusual event with different situations in the event itself, its cause, and surroundings. If we, however, neglect the special circumstances with them and relate the level of damage with the chance of occurrence, the probability distribution shows that large-scale accidents and disasters have small odds of happening, whereas small and minor events break out frequently. A typical example is "Heinrich's law" by H. W. Heinrich (Heinrich 1931) about industrial accidents in places like factories. It stated that among 330 incidents of the same type, 300 nearly escaped actual damages, but 29 cases involved minor damage, and 1 case had a major damage. Heinrich also pointed out that behind the 300 cases without injury, there were thousands of unsafe actions and situations.

Heinrich's basic idea was that we cannot change the structure leading to accidents and disasters; however, by reducing unsafe actions, situations could lead to less disasters without injury and at the same time decrease the numbers of accidents with minor injury and those with major consequences. We often refer to the 300 cases without injury "close call" events. Heinrich's law is applied to other fields like medicine or railway, and it is a basic concept for today's accident prevention measures.

The second characteristic about disasters is that accidents and disasters develop over time; however, they do not keep spreading forever. Automobile or airplane accidents happen in split seconds; however, an event at a nuclear plant takes hours to develop into an accident. Epidemics, at the beginning, start with a small number of patients, and the number of affected grows because of contact with the infected; however, over time, the infected will either cure or die, and the number of infected does not keep growing. In case of natural disasters as well, earthquakes are phenomena that happen over short periods, and in some cases, aftershocks can take long time to subside. Tsunami and heavy rain, on the other hand, have some time allowance until the most severe situation arrives; thus, guided evacuation at the right time can reduce the number of casualties. The time scale of accidents and disasters are important factors to think about in planning disaster management.

Thirdly, accidents and disasters are not self-contained. That is, those that avoided direct hits of accidents or disasters still, sometimes, suffer from related damages. The Great East Japan earthquake had a total count of 18,458 of dead and missing, among which, as many as 3331 were related deaths due to evacuation-related health matters like stress. We need to plan against related deaths when we plan countermeasures against accidents and disasters.

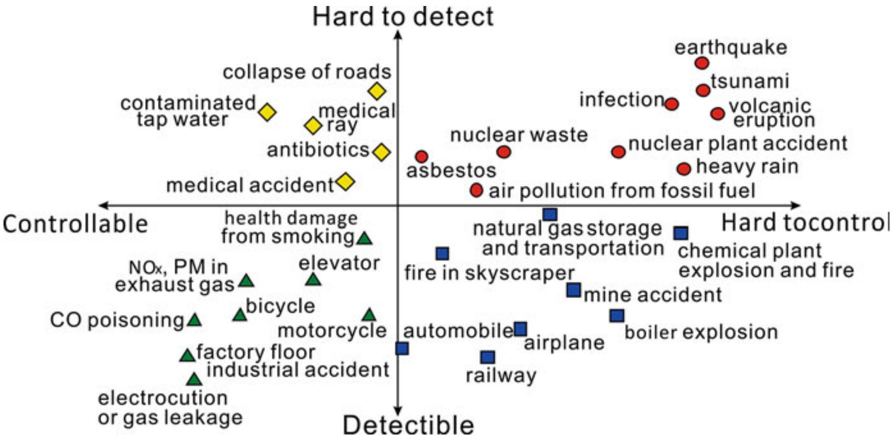

Fig. 5.1 Risk space. (Based on Slovic 2000)

We can put accidents and disasters in large categories depending on whether their occurrences are detectible beforehand or not; whether the events are controllable or not; whether their effects are within a short time period or they last over a long period, if the damages are local or over a wide area; or whether their damages can easily be removed or not. Among these factors, Fig. 5.1 picked out two and plotted different type accidents on the 2D plane, the risk space. Figure 5.1 took controllability for its horizontal axis and detectability for the vertical. The axes are free to pick depending on the discussion topic. The plots in Fig. 5.1 carry some arbitrariness in them. One may want to apply data from questionnaires to the general public or specialists or otherwise use risk numbers from rigorous risk assessment. In general, events in the first quadrant with difficulties in detection and control have high risk. Earthquakes, tsunami, and heavy rain are out of control, and their prior detections are difficult so they lie in the first quadrant. The target events are not only those in the first quadrant, but central theme for risk management is to understand characteristics of various hazards and find effective countermeasures to prevent them from growing into incidents to accidents, disasters, and major disasters and to minimize the damages.

References

Borel, E. (1943). *Les probabilités et la vie*. Paris: Presses Universitaires de France. English edition: Borel, E. (1962) *Probabilities and life* (M. Baudin, Trans.). New York: Dover Publications.

Heinrich, H. W. (1931). *Industrial accident prevention A scientific approach*. New York: McGraw-Hill.

Hunter, P. R., & Fewtrell, L. (2001). Chapter 10: Acceptable risk. In L. Fewtrell & L. Bartran (Eds.), *Water quality – Guidelines, standards and health* (pp. 208–227). London: IWA Publishing.

ISO/IEC Guide 51. (2014). *Safety aspects – Guidelines for their inclusion in standards*. Geneva: International Organization for Standardization.

Lee, J. C., & McCormick, N. J. (2011). *Risk and safety analysis of nuclear systems*. Hoboken: Wiley.

Otway, H. J., & Erdmann, R. C. (1970). Reactor siting and design from a risk viewpoint. *Nuclear Engineering and Design, 13*, 365–376.

Slovic, P. (2000). Perception of risk. In P. Slovic (Ed.), *The perception of risk* (pp. 220–231). London: Earthscan Publication.

Slovic, P., Fischhoff, B., & Lichtenstein, S. (2000). Fact and fears: Understanding perceived risk. In Slovic, P. (Ed.), *ibid* (pp. 137–153). London: Earthscan Publication.

U.S.NRC (U.S. Nuclear Regulatory Commission). (1975). Reactor safety study – An assessment of accident risks in U.S. Commercial Nuclear Power Plants, WASH-1400/NUREG 75/014.