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Risk estimation for industrial safety in raw materials manufacturing

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ABSTRACT

By constructing a risk model for estimating the risks involved in industrial safety, and by investigating and analyzing the obtained results, areas that should be considered as priorities in risk reduction are clarified. In the present study, the risks involved in industrial safety are classified into five categories: fire and/or explosion, strong winds, flooding, lightning, and earthquake. An analysis was conducted using parameters obtained for each of these events. For the survey of the present study, the simulation results indicate that the reduction of the risks associated with fire and/or explosion and strong winds were taken as a priority, thereby enabling the effective reduction of risks for industrial safety in raw materials manufacturing in Japan.

1. Introduction

In the present paper, a risk estimation model is constructed for industrial safety in raw materials manufacturing in Japan. Businesses must deal with various types of risk, and given the finite nature of their resources (people, materials, money, etc.), measures to handle higher risks first are sought.

However, rather than reducing industrial safety risks by taking a long-term perspective and considering which risks to prioritize, risks have generally been dealt with by formulating policies that deal with recently experienced damage. In other words, for example, if a business experiences a fire, then the budget in the next year is redressed in order to curtail the risk of fire, or, if a region experiences an earthquake and incurs damage, then the budget in the following year is redressed in order to deal with earthquakes. Rather than this type of reactive strategy, under normal conditions proactive policies are desirable, but these require an understanding of the various risks and the magnitude of each risk from a long-term perspective.

As a specific example, we consider the risks related to industrial safety in raw materials manufacturing in Japan. A risk model was constructed, adopting Poisson distributions for the frequency of harmful events, and exponential distributions for the scale of damage. The risks that should be handled and the appropriate measures are clarified. The risks associated with industrial safety were classified into five categories according to the event that occurs: fire and/or explosion, strong winds, flooding, lightning, or earthquake. Parameters obtained from these investigations were used in the models for each of these risks. The comprehensive perspective obtained in this manner effectively clarified which risks should be constrained.

2. Risk model for safety and accident prevention

2.1. Risks

There are several methods of considering risk. According to the ISO/IEC Guide 73 Definition 3.1.1 "Risk management – Vocabulary – Guidelines for use in standards", risk is defined as the combination of the probability of an event and its consequences. With respect to safety, risk is defined as the combination of the probability of the occurrence of harm and the severity of the harm, where harm is defined as physical injury or damage to the health of a person or damage to property or the environment (ISO/IEC Guide 51). By way of example, the main risks faced by businesses are summarized in Table 1 (Noguchi, 2003). The establishment of plans regarding risk management involves risk analysis, risk treatment, risk acceptance, and risk communication. Risk analysis is further divided into source identification and risk estimation. The relationship between terms, based on their definitions regarding risk is shown in Fig. 1 (ISO/IEC Guide 73). For risk estimation, it is desirable to grasp both quantitatively and qualitatively the certainty associated with a risk's

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Table 1
Example of business risk criteria.

Criteria	Example of risk
Damage type	Environmental, Occupational accident
Business	Commercial, Bank (Processing industry risks)
Service/Product	Financial risk
Effect of damage	Fire, Explosion, Structural damage, Plant trouble
Hazard	Earthquake, Typhoon, Storm and flooding, Abnormal drought, Lighting, Hazardous materials, Environmental pollution
Treatment	War/Civil war/Coup d'etat, Economic turmoil, Foreign currency shortage, Investment risk, Business risk, Exchange risk, R&D risk, Country risk, Credit risk
Management section risks	Safety and accident prevention, Environmental, Occupational safety, Personal affairs, Sanitation, Legal, Product liability, Major customer operation suspension, Bankruptcy, Raw material shortage, Fixer, Public relations, Systems, Clerical, New products, Leakage of secrets, Whistle-blowing

manifestation or probability of occurrence, as well as the magnitude of a risk in the case that it is manifested.

2.2. Risk model for industrial safety

Risk analysis methods include methods that express the frequency of occurrence and damage based on the influence of a risk as a matrix, methods that express event probabilities and the scale of their damage as a sum, and methods that express the event probabilities and the scale of their damage as a product (Suzuki, 2004).

One method of explaining risk is to express the risk as a product of frequency and degree of damage. For example, Suzuki (2004) introduced the concept of risk using the following equation: Risk = Probability of an event × Consequences. However, no detailed information concerning these distribution functions has been reported. The value of the risk is not absolute, but rather it is

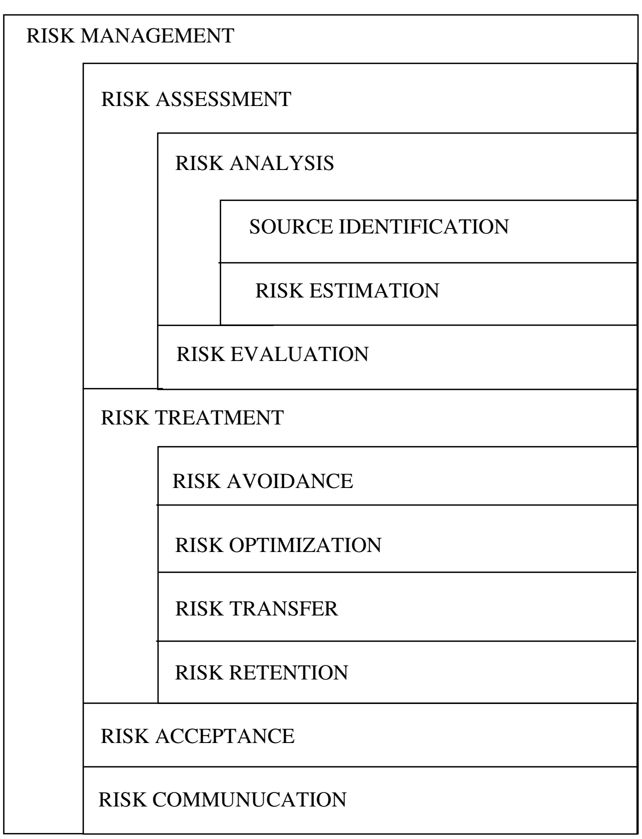

Fig. 1. Relationship between risk related terms. (From ISO/IEC Guide 73:2002).

relative. The number of incidents and/or accidents within a certain period may be zero.

Here, we define the risk associated with event i as the product of the distribution function for the frequency of damage occurrence and the distribution function of the scale of the damage, i.e., the distribution function $R_i(x_r)$ of risk x_r with respect to event i is defined by the following formula:

$$R_i(x_r) = F_i(x_f) \times D_i(x_d)$$

$F_i(x_f)$: distribution function for the frequency of event i
$D_i(x_d)$: distribution function for the scale of damage of event i

2.2.1. Frequency distribution of harmful events

Regarding the distribution function for the frequency of harmful events, in general, estimation models based on Poisson distributions and negative binomial distributions are used (Iwaki, 2005). Assuming the expected value of the binomial distribution is fixed, let us consider the Poisson distribution when n is increased to infinity.

The frequency distribution of incidents occurring over a fixed duration, $F_i(x_f)$, is given by the following equation:

$$F_i(x_f) = \frac{e^{-\lambda t_i}(\lambda t_i)^{x_f}}{x_f!}$$

λt_i: mean value of the frequency of event i

2.2.2. Candidates for the distribution function reflecting the scale of damage

Among the models that have been applied, lognormal distributions, generalized Pareto distributions, gamma distributions, and other distributions have been used for the distribution function reflecting the scale of damage (Nakagawa, 2006). These reflect the scale of the damage associated with the incidents occurring over a fixed period of time as a distribution function $D_i(x_d)$ and may each be described as shown in Table 2.

With a logarithmic distribution or gamma distribution, the event probability does not obtain a maximum when the magnitude of the damage is infinitesimally close to zero. To put it another way, if these distributions are adopted as distribution functions for the scale of damage, then there is a range in which a minor incident has a smaller probability of occurrence than a larger incident, i.e., there is a point of inflection.

In addition, for generalized Pareto distributions, the domain of definition is restricted by $0 < a \leq x_d$, but as a distribution function for the scale of damage, it is rational for the distribution to be a continuous function rather than a discontinuous function when minor incidents and potential incidents are also considered.

On the other hand, according to a rule of thumb for industrial accidents known as Heinrich's principle, for every major injury there are 29 minor injuries and 300 non-injury accidents (harmless accidents in which critical damage was narrowly avoided). In addition to Heinrich's principle, Bird's principle and Tye-Pearson's principle also reflect the knowledge that there is a higher frequency of incidents with less significance than harmful accidents, and there is a pyramid structure with serious incidents, such as fatal accidents, at the peak and a base formed by the "narrowly avoided" level (Everley, 2007). Fig. 2 summarizes the events occurring according to these principles and the corresponding numbers of cases.

The application of an exponential distribution function for the scale of damage was verified according to these experimental principles. The scale of damage is handled using an ordered segmentation of each of the zones into a single region, and