Doctor's Thesis

Risk analytical study on Industrial safety risk in multinational 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.

There are several methods for 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 occurrence of harm and the severity of the harm, where harm is physical injury or damage to the health of people, or damage to property or the environment (ISO/IEC Guide 51).

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.

As a specific example, the risks related to industrial safety in raw materials manufacturing are considered. A risk model was constructed in which Poisson distributions were adopted for the frequency of harmful events and exponential distributions were adopted for the scale of damage. The risks that should be handled and the appropriate measures are clarified.

Simulation using a Monte Carlo method was performed using a risk model incorporating each of the obtained parameters, as explained above. Crystal Ball™ software was used for simulation.

For the survey of the present study, the simulation results indicate that the reduction of the risks associated with fire and explosion was taken as a priority, thereby enabling the effective reduction of risks for industrial safety in multinational raw materials manufacturing.

Keywords:

Risks in industrial safety; Raw materials manufacturing; Risk model; Risk estimation; Risk prevention; Monte Carlo simulation

Table of Contents

Contents Page

List of Figures

Number Page

List of Tables

Number Page

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Chapter 1

1 Introduction

In the present paper, a risk estimation model is constructed for industrial safety in raw materials manufacturing in Japan, Asia (excluding Japan), and Europe. 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. For example, if a business experiences a fire, then the budget for 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 this requires an understanding of the various risks and the magnitude of each risk from a long-term perspective.

As a specific example, a risk model was constructed related to industrial safety in multinational raw material manufacturing, 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.

1.1 Background

In the management of organizations, the evaluation of each of many existing risks is an extremely important step in risk analysis for establishing risk management policies. In particular, the risks associated with industrial safety differ from those that may fluctuate, such as exchange rate risks and business risks, and risks associated with industrial safety are downside risks, which may only fluctuate downward for business. Since there is no possibility of upward fluctuation for business, the key question is how to minimize downward fluctuation. Regarding the characteristics of risks related to natural disasters, in particular, the likelihood of occurrence is small, and such risk are focused in both duration and location (Kai, 2006).

In order to curtail risks efficiently and effectively, the issue when tackling risks is which to prioritize. An investigation was conducted regarding the industrial safety risks of fire and explosion, earthquake, flooding, strong winds, and lightning. After obtaining a complete overview, an analysis was conducted in terms of events and region.

1.2 Research Objectives

The primary objective of the research described in the present thesis is to examine how to analyze the industrial safety risk related to multinational raw materials manufacturing. This objective can be broken down into the following sub-goals.

- A risk model was constructed for industrial safety affecting raw materials manufacture by adopting a Poisson distribution for the frequency of accident occurrence and an exponential distribution for the scale of damage.
- Parameters were determined for the models representing the risks faced by raw materials manufacturing due to fire and/or explosion, strong winds, flooding, lightning, and earthquake.
- Monte Carlo simulation was conducted using the obtained parameters, and a scatter plot was created, making it easy to understand the risks visually.

- The areas that should be considered as priorities in risk reduction are clarified in raw materials manufacturing by constructing a risk model for estimating the risks involved in industrial safety and by investigating and analyzing the obtained results.

1.3 Research Approach

An investigation and analysis of industrial safety among raw materials manufacturers, including subsidiaries in Japan, Asia, and Europe, for example, covering 101 sites, was conducted. Parameters for risk models may be obtained using experience-based methods, theoretical methods, accident case databases, and so on, but response data from questionnaires regarding past accidents and damage occurring in the workplace were adopted in the present investigation. Specifically, a survey regarding the frequency of accidents and the scale of damage occurring in the five categories of fire and/or explosion, strong winds, flooding, lightning, and earthquakes was conducted at each place of business, covering the 10 years since 1995. Regarding the scale of damage, a summation method based on the scoring system was adopted

Regarding the specific methods used to conduct the survey, a quantitative questionnaire covering the history of accidents and their types and scales of damage was delivered by the head offices of raw materials manufacturing firms for each factory and the associated company. Administrative and business offices not directly related to production were excluded from the survey. The head offices themselves requested this survey, and a response rate close to 100% was obtained. The responses were sent by each subject of the survey to his/her head office. The head offices confirmed the content of the responses, and, where necessary, conducted inquiries to ensure accuracy.

1.4 Outline of Chapters

Chapter 2

In this chapter, generally available databases related to industrial safety are considered with respect to the industrial safety risks associated with multinational raw materials manufacturing. These risks are ranked and compared by country, and the potential for applying generally available databases related to industrial safety is investigated.

Chapter 3

In this chapter, a risk estimation model is constructed for industrial safety in raw materials manufacturing. 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: fire and/or explosion, strong wind, flooding, lightning, or earthquake. Parameters obtained from 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.

There are several types of research methods, including interviews and focus groups, questionnaires, secondary data and documentary sources, participant observation, and action research. For the present study, questionnaires are the most suitable due to the following reasons.

- The targets are widely dispersed.
- The targets have already been identified.
- There are no useful secondary data and documentary sources.
- The respondents can ask a question(s) by e-mail, if they so wish.
- Observation does not directly reflect the industrial safety situation especially damage situation.
- Time and cost efficiency have to be considered.

Chapter 4

Responses were obtained for at total of 101 sites: 58 sites in Japan and 43 sites overseas. Among the overseas sites, 19 were in Asia, 19 were in Europe, three were in the US, and two were in Russia. Regarding their scales, 31 sites had over 500 employees, 39 sites had between 100 and 500 employees, and 31 sites had less than 100 employees.

Monte Carlo simulation was conducted using parameters obtained in this Chapter to investigate the industrial risk in multinational raw materials manufacturing. In the discussion, risk model validation, the effect of human damage evaluation on the scale of damage, and the significance of using risk theory are reviewed.

Chapter 5

This chapter presents conclusions.

In conclusion, the following items were achieved.

- A risk model was constructed for industrial safety affecting raw materials manufacturing by adopting a Poisson distribution for the frequency of disaster occurrence and an exponential distribution for the scale of damage.
- Parameters were determined for the models representing the risks faced by raw materials manufacturing in Japan, Asia and Europe due to fire and/or explosion, strong winds, flooding, lightning, and earthquake.
- Monte Carlo simulation was conducted using the obtained parameters, and a scatter plot was created, making it easy to understand the risks visually.
- The areas that should be considered as priorities in risk reduction are clarified in raw materials manufacturing in Japan, Asia and Europe by constructing a risk model for estimating the risks involved in industrial safety and by investigating and analyzing the obtained results.

Chapter 6

Future research and scientific value of the present study are described. The clarification of tolerable risk range and application to other industries, for example, are mentioned as future research areas. Finally, the scientific value of the present study is described.

Chapter 2

2 Comparison of existing databases of natural hazards and industrial accidents

2.1 Introduction

For business strategy in multinational businesses, it is crucial to grasp the risks related to industrial safety in countries in which production sites are located. In such operations, it is necessary to consider various factors, including the procurement of primary materials, the securing of a workforce, and changes in distance to market (Table 2.1). These factors must, of course, be considered with respect to industrial safety risks. Regarding country-specific industrial safety risks, while there are databases prepared by international organizations and reinsurance companies, among others, on the Internet that have been made public, the extent to which these data can be used to estimate the industrial safety risks during production activity in actual businesses is unclear. In this chapter, generally available databases related to industrial safety are considered with respect to the industrial safety risks associated with multinational raw materials manufacturing. These risks are ranked and compared by country, and the potential for applying generally available databases related to industrial safety is investigated.

Table 2.1 Example of business risk criteria (Noguchi, 2003a)

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, Lightning, 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

2.2 Natural disasters around the world and the circumstances of industrial accidents

2.2.1 Event-specific industrial safety risks according to EM-DAT

The database EM-DAT was initially established with the support of the World Health Organization (WHO) and the Belgian government and is currently maintained and managed by the WHO Collaborating Center for Research on the Epidemiology of Disasters (CRED). The database contains more than 16,000 disasters that occurred between 1900 and the present and that satisfy at least one of the following conditions:

- 10 or more people reported killed
- 100 people reported affected
- A call for international assistance was made
- A state of emergency was declared

EM-DAT provides information regarding international disasters.

Figure 2.1 shows the numbers of natural disasters that occurred between 1976 and 2005 by country. In Figure 2.2, the proportions of each type of disaster for the period of 1974 to 2003 are shown by United Nations sub-region. The types of international disaster covered, presented in order of decreasing number of incidents since 1980, are Transport Accidents, Floods, Wild Storms, Industrial Accidents, Epidemics, Miscellaneous Accidents, Earthquakes, Droughts, Slides, Extreme Temperatures, Wild Fires, Volcanoes, Insect Infestations, and Wave/Surges (Figure 2.3). Among these, Floods, Wild Storms, Industrial Accidents, and Earthquakes have a sizeable direct influence on raw materials manufacturing, which is considered as a type of enterprise. Lightning also accounts for a large proportion of the causes of Wild Fires, and the effect of Lightning on operations cannot be ignored. The most common types of Industrial Accident are, in order of decreasing frequency, those involving Explosion, Fire, Collapse, Gas Leak, Poisoning, Chemical Spill, and Radiation. Explosion and Fire, in particular, account for 71.1% of Industrial Accidents (Figure 2.4).

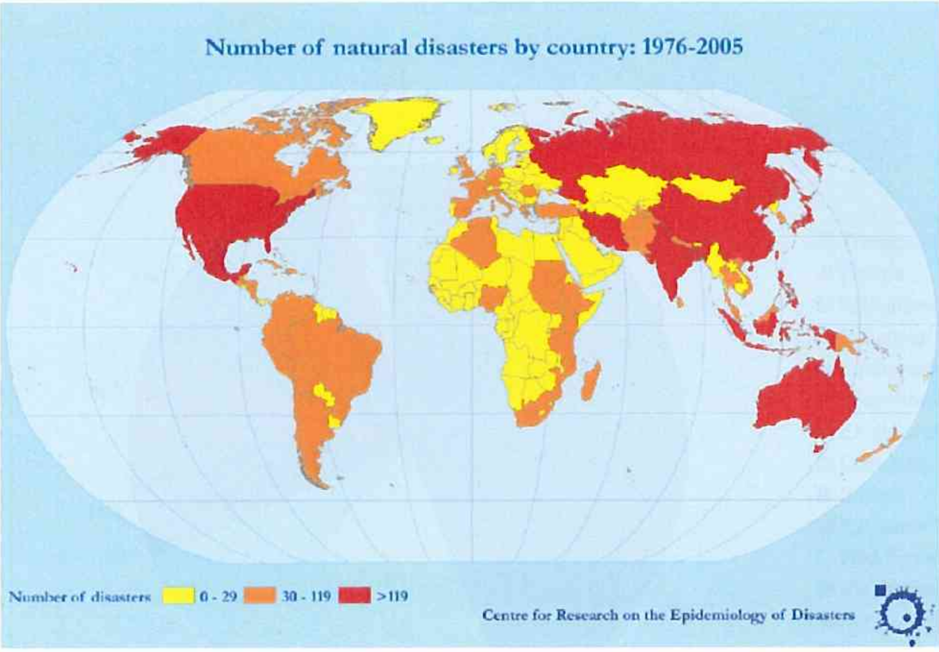


Figure 2.1 Number of natural disasters by country: 1967-2003 (CRED, 2007)

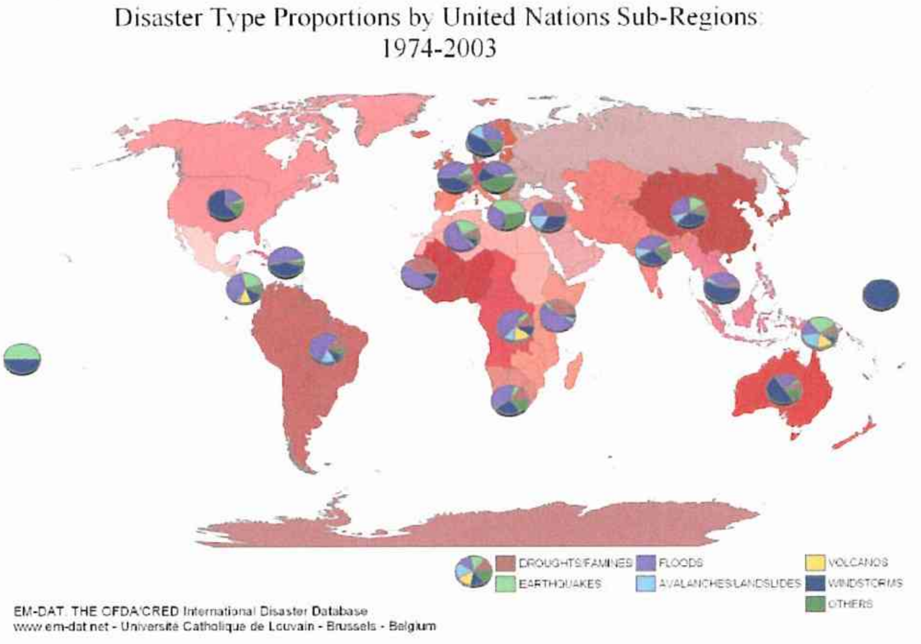


Figure 2.2 Proportions of disaster type by United Nation Sub-Regions (EM-DAT, 2007)

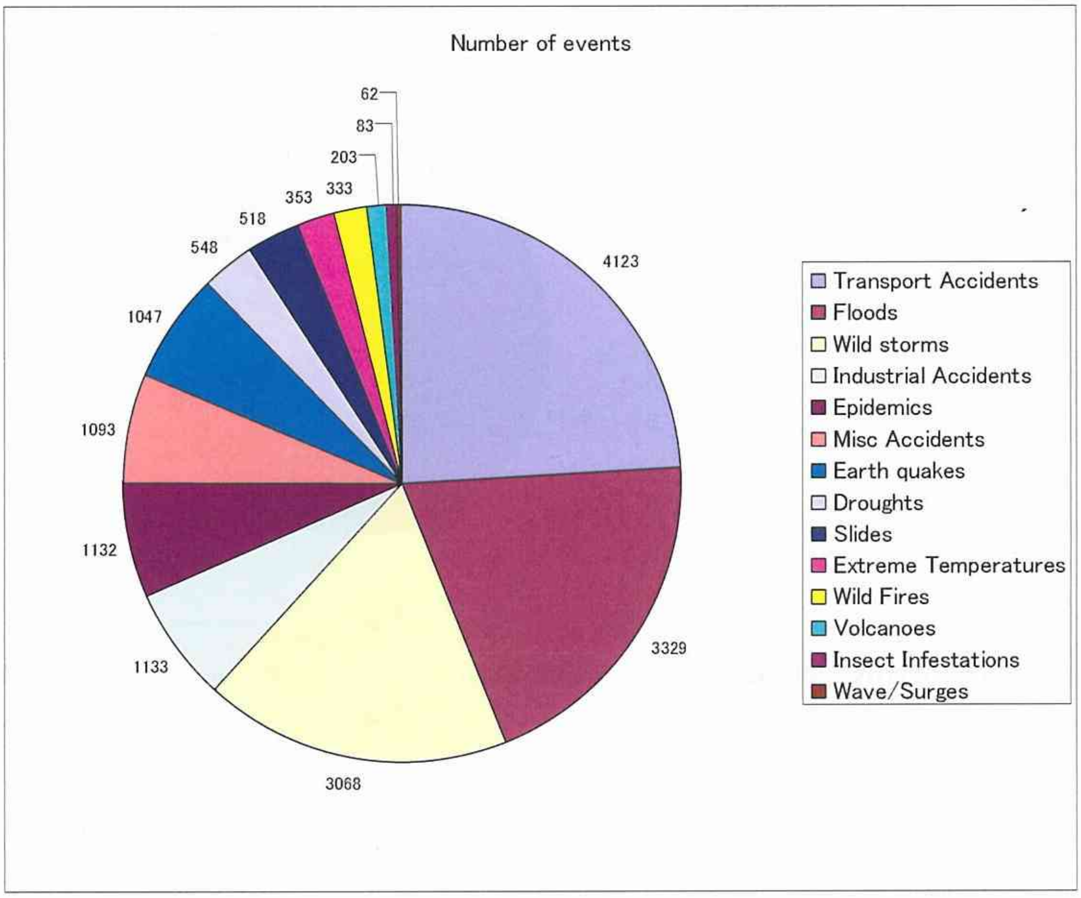


Figure 2.3 Number of natural disasters and industrial accidents occurring internationally (between January 1900 and October 2007)
(EM-DAT: OFDA/CRED International Disaster Database - www.em-dat.net - Université Catholique de Louvain - Brussels – Belgium)

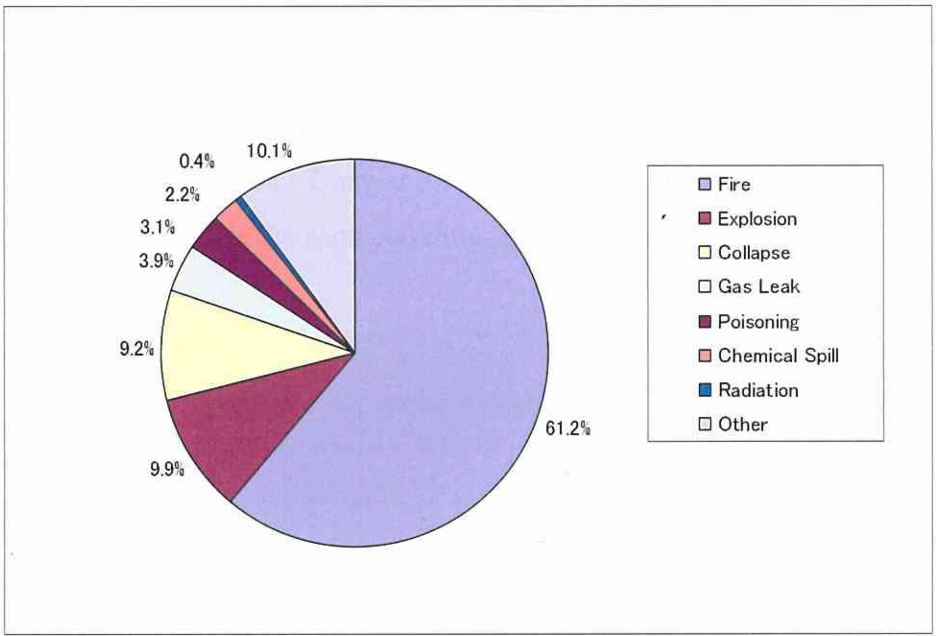


Figure 2.4 Proportion of industrial accident types occurring around the world (between 2000 and 2007)

(EM-DAT: The OFDA/CRED International Disaster Database - www.em-dat.net - Université Catholique de Louvain - Brussels – Belgium)

2.2.2 Industrial safety risks by incident type according to NATHAN

NATHAN (Natural Hazards Assessment Network) is a database that is maintained by the Munich Reinsurance Company of Germany. NATHAN catalogs major disasters that have occurred since 1980 and currently includes over 20,000 incidents.

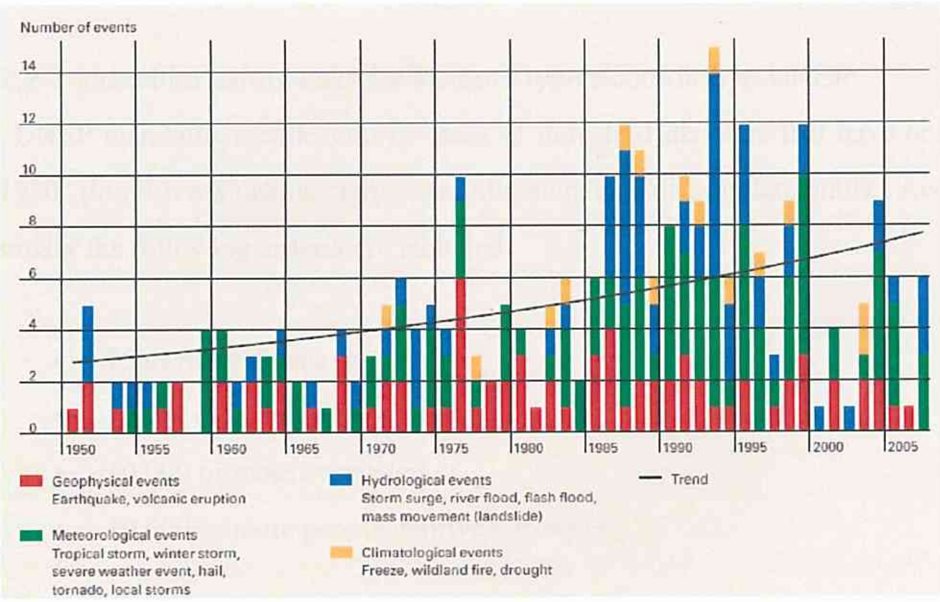


Figure 2.5 Great natural catastrophes (Munich Reinsurance Company, 2007)

According to NATHAN, between 1950 and 2006, the world experienced 277 Great natural catastrophes. Among these, 40% were Meteorological events such as Tropical storms and winter storms, 29% were Geophysical events such as Earthquakes and volcanic eruptions, 25% were Hydrological events such as Storm surges and River floods, and 6% were climatological events such as Freezing and Drought. The trends in the number of occurrences of Great natural catastrophes between 1950 and 2005 are shown in Figure 2.5.

Definition of Great natural catastrophes is as follows.

In line with United Nations definitions, natural catastrophes are classified as "great" if the affected region's ability to help itself is clearly overstretched and supraregional or international assistance is required. As a rule, this is the case when there are thousands of fatalities, when hundreds of thousands of people are *left homeless, or when overall losses – depending on the economic circumstances of the country concerned – and/or insured losses are of exceptional proportions. (Munich, R., Company, Topics Geo Natural catastrophes 2007 Analyses, assessment, positions, Available at http://www.munichre.com/publications/302-05699_en.pdf, (2007).)*

2.2.3 Industrial safety risks by incident type according to UNEP

UNEP maintains a collection of cases of industrial disasters that have occurred since 1970 (http://www.unepie.org/pc/apell/disasters/lists/disasterdate.html). Accidents that satisfy the following criteria are included:

- 25 or more deaths or
- 125 or more injured;
- 10,000 or more evacuated or
- 10,000 or more people deprived of water.

The information sources from which the data is collated include OECD, MHIDAS, TNO, SEI, UBA-Handbuch Stoerfaelle, SIGMA, and press reports. The data was assembled by UNEP and BARPI. According to this database, 127 of the 333 industrial accidents that occurred between 1970 and 1998 involved explosions and 166 involved fire. Thus, the proportion of industrial accidents accounted for by explosion and fire is 88%.

2.2.4 Industrial safety risks by incident type according to UNDP

According to UNDP reports, 94% of fatalities due to natural disasters were caused by four types of natural disaster: earthquake, tropical cyclone, flooding, and drought (http://www.undp.org/cpr/disred/documents/ publications/rdr/english/rdr_english.pdf).

2.3 Comparison methods

2.3.1 Countries included in the survey

The countries included in the survey were chosen as those countries in which multinational raw materials manufacturing is active being conducted, for cases in which it is possible to collate data for at least three production sites. As of the end of 2007, raw materials manufacturing involved as many as 30 countries and operations are expanding around the world. Table 2.2 shows the specific countries included in the investigation.

Table 2.2 Countries included in the industrial safety survey

	Number of sites in the survey
Belgium	5
Czech Republic	4
France	3
Indonesia	6
Italy	4
Japan	58
Thailand	3
USA	3

2.3.2 Industrial safety risks investigated by the survey

Existing databases that are appropriate for general use include EM-DAT and NATHAN, but the categories relating to industrial safety are completely uncoordinated, and there are also cases in which data has not been obtained. Table 2.3 summarizes the criteria related to industrial safety for EM-DAT and NATHAN.

A comparison of EM-DAT and NATHAN from the perspective of a survey of multinational enterprises reveals that they hold data in common regarding the risks of earthquake, flooding, and strong winds. A comparative investigation of these databases revealed that the EM-DAT data uses the number of incident occurrences, while the NATHAN data uses an expression for the risk of each incident as the probability of damage to the country as a whole in terms of surface area, or the probability of damage affecting the coastline or rivers in terms of their lengths. There are limits to the currently available data, and an investigation and comparison by country was conducted using this data as a basis according to the method stated below.

Table 2.3 Existence of comparable data in each database

Industrial safety incidents	EM-DAT coverage	NATHAN coverage
Risk of fire/explosion	Present (Explosion, Fire)	No data
Risk of earthquake	Present (Earthquake)	Present (Earthquake)
Risk of flooding	Present (Flood, Wave/Surge, Tsunami)	Present (Storm Surge, Flood, Tsunami)
Risk of strong winds	Present (Cyclone, Hurricane, Storm, Tornado, Tropical Storm, Typhoon, Winter Storm)	Present (Tropical Storm, Winter Storm, Tornado)
Risk of lightning	No data	Present (Lightning)

2.4 General-use country-specific industrial safety information and industrial safety risks in multinational raw materials manufacturing

A comparison was made regarding general-use country-specific industrial safety information and industrial safety risks in multinational raw materials manufacturing for the countries covered by the survey, that is, Belgium, the Czech Republic, France, Indonesia, Italy, Japan, Thailand, and the USA. The industrial safety risks investigated include an amalgamated country-specific total for the risk of earthquake, flooding and strong winds, as well as each of the individual risks mentioned above.

2.4.1 Industrial safety risks for each country according to EM-DAT

The number of occurrences of earthquakes (Earthquake), flooding (Flood, Wave/Surge, Tsunami), and strong winds (Cyclone, Hurricane, Storm, Tornado, Tropical Storm, Typhoon, Winter Storm) were extracted from the EM-DAT Country Profile for each country and the data for each incident was then extracted. The number of incidents occurring in each country divided by the area of the country was taken as the industrial safety risk for each country, and the results are shown in Table 2.4 (see Appendix A for details).

Table 2.4 Risk per unit area (incidents per 1,000 sq km) for each country based on EM-DAT data

	Earthquake	Flooding	Strong Winds	Total
Belgium	0.066	0.655	0.655	1.376
Czech Republic	0.000	0.101	0.038	0.139
France	0.002	0.051	0.080	0.133
Indonesia	0.063	0.048	0.005	0.116
Italy	0.096	0.096	0.053	0.246
Japan	0.122	0.138	0.357	0.617
Thailand	0.002	0.117	0.056	0.175
USA	0.004	0.016	0.049	0.068

2.4.2 Industrial safety risks for each country according to NATHAN

The six-grade ranking for each industrial safety risk, which expresses the level of danger as a proportion of the area of each country, or the length of its coastline or rivers, was taken as a score and multiplied by the proportion of the whole area or the whole length. In the case of flooding, the calculation was performed by averaging the scores associated with Storm Surge, Flood, and Tsunami, and in the case of strong winds, the scores associated with Tropical Storm, Winter Storm, and Tornado were averaged (see Appendix B for details). The industrial safety risks for each country according to NATHAN are shown in Table 2.5.

Table 2.5 Industrial safety risks for each country according to NATHAN

	Earthquake	Flooding	Strong Winds	Total
Belgium	178.0	37.0	158.0	373.0
Czech Republic	111.0	43.7	126.7	281.3
France	147.0	44.0	133.3	324.3
Indonesia	264.0	38.3	34.3	336.7
Italy	249.0	61.7	90.0	400.7
Japan	410.0	88.7	123.7	622.3
Thailand	207.0	48.7	74.7	330.3
USA	194.0	36.0	113.0	343.0

2.4.3 Risks related to industrial safety for countries covered by the survey of raw materials manufacturing

Table 2.6 shows the numbers of occurrences of injury-causing accidents and incidents associated with industrial safety due to earthquake, flooding, and strong winds, per site, over 10 years, for each of the countries covered by the survey of raw materials manufacturing.

Table 2.6 Industrial safety risks associated with multinational raw materials manufacturing for each country covered by the survey

	Earthquake	Flooding	Strong Winds	Total
Belgium	0	0.60	0	0.60
Czech Republic	0	0.25	0	0.25
France	0.67	1.00	0.67	2.34
Indonesia	0	0.50	0	0.50
Italy	0.50	0	0	0.50
Japan	0.28	0.34	0.81	1.43
Thailand	0.67	0.33	0.33	1.33
USA	0	0.67	0	0.67

(Data represent the number of occurrences over 10 years for each site)

2.5 Results

For each data set, the compounded risk for each country, as determined by summing the risks of earthquake, flooding, and strong winds, and the individual risks were ranked in decreasing order. Despite the differences between the absolute values of the risks in each database, it was possible to perform rank correlation analysis.

The rank of the compound industrial safety risk for each country is shown in Table 2.7. The rank of the risk of earthquake for each country is shown in Table 2.8, that for flooding is shown in Table 2.9, and that for strong winds is shown in Table 2.10.

Table 2.7 Rank of the compound industrial safety risk for each country

	EM-DAT	NATHAN	Multinational raw materials manufacturing
Belgium	1	3	5
Czech Republic	5	8	8
France	6	7	1
Indonesia	7	5	6
Italy	3	2	6
Japan	2	1	2
Thailand	4	6	3
USA	8	4	4

Table 2.8 Rank of the risk of earthquake for each country

	EM-DAT	NATHAN	Multinational raw materials manufacturing
Belgium	3	6	5
Czech Republic	8	8	5
France	7	7	1
Indonesia	4	2	5
Italy	2	3	3
Japan	1	1	4
Thailand	6	4	1
USA	5	5	5

Table 2.9 Rank of the risk of flooding for each country

	EM-DAT	NATHAN	Multinational raw materials manufacturing
Belgium	1	7	3
Czech Republic	4	5	7
France	6	4	1
Indonesia	7	6	4
Italy	5	2	8
Japan	2	1	5
Thailand	3	3	6
USA	8	8	2

Table 2.10 Rank of the risk of strong winds for each country

	EM-DAT	NATHAN	Multinational raw materials manufacturing
Belgium	1	1	4
Czech Republic	7	3	4
France	3	2	2
Indonesia	8	8	4
Italy	5	6	4
Japan	2	4	1
Thailand	4	7	2
USA	6	5	4

The correlations among the compound risks determined by straightforward summation of the risks of each type of incident, the risks of earthquake, the risks of flooding, and the risks of strong winds were analyzed using Spearman's rank-correlation coefficient, and the results are shown in Table 2. 11.

Table 2. 11 Spearman's rank-correlation coefficient for the two databases

	EM-DAT vs. NATHAN	EM-DAT vs. Multinational raw materials manufacturing	NATHAN vs. Multinational raw materials manufacturing
Compound risk	0.524	0.048	0.132
Risk of earthquake	0.786	-0.064	0.102
Risk of flooding	0.381	-0.310	-0.548
Risk of strong winds	0.619	0.536	0.069

2.6 Conclusions

As shown in Table 2. 12, among the risks calculated from the data available in EM-DAT and NATHAN, the value of the square of Spearman's rank-correlation coefficient exceeds 0.5, revealing a comparatively good correlation only for the risk of earthquake. A significant correlation could not be identified in any other case. These results suggest that while, in general, some industrial safety incidents that reveal comparatively good coherence with respect to industrial safety risks can be found in publicly available databases, existing databases cannot necessarily be used as a basis for determining the industrial safety risks associated with individual enterprises, in other words, when evaluating the industrial safety risks for each country for a given individual enterprise it is difficult to apply generally available industrial safety data in its existing form. It is considered that for a given enterprise, by using information concerning incidents in each region, implementing appropriate countermeasures, and planning in order to reduce the frequency of incidents and the scale of damage they cause, the resulting curtailment of risk may yield a difference in the country-specific data for general types of incidents. In addition, due to differences in the collation objectives, differences in the scales of the incidents of interest, and so on, generally available industrial safety data do not necessarily yield coherent industrial safety risks for each country.

Table 2. 12 Square of the Spearman rank-correlation coefficient for the two databases

	EM-DAT vs. NATHAN	EM-DAT vs. Multinational raw materials manufacturing	NATHAN vs. Multinational raw materials manufacturing
Compound risk	0.275	0.002	0.017
Risk of earthquake	0.618	0.004	0.010
Risk of flooding	0.145	0.096	0.300
Risk of strong winds	0.383	0.287	0.005

Chapter 3

3 Analytical approaches

3.1 Introduction

In this chapter, a risk estimation model is constructed for industrial safety in raw materials manufacturing. Businesses must deal with various types of risk, and, given the finite nature of their resources (people, materials, money, *etc.*), measures that 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, a policy has been adopted based on whether a business experienced an outbreak of fire, and the budget for the next year is redressed in order to curtail the risk of fire. Alternatively, 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, the risks related to industrial safety in raw materials manufacturing are considered. A risk model was constructed in which Poisson distributions were adopted for the frequency of harmful events and exponential distributions were adopted 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 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.

There are several types of research methods, including interviews and focus groups, questionnaires, secondary data and documentary sources, participant observation, and action research. For the present study, questionnaires are the most suitable due to the following reasons.

- The targets are widely dispersed.
- The targets have already been identified.
- There are no useful secondary data and documentary sources.
- The respondents can ask a question(s) by e-mail, if they so wish.
- Observation does not directly reflect the industrial safety situation especially damage situation.
- Time and cost efficiency have to be considered.

3.2 Concept of a risk model

There are several methods of considering risk. According to 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 regard to safety, risk is defined as the combination of the probability of occurrence of harm and the severity of the harm, where harm is physical injury or damage to the health of people, or damage to property or the environment (ISO/IEC Guide 51). The establishment of plans regarding risk management involves risk analysis, risk treatment, risk acceptance, and risk communication. Risk analysis is further divided into the source identification and risk estimation. For risk estimation, it is desirable to grasp both quantitatively and qualitatively the certainty associated with a risk's manifestation or probability of occurrence, as well as the magnitude of a risk in the case that it is manifested.

Risk analysis methods include methods that express the frequency of occurrence and damage from a risk's influence 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). Figure 3.1, Figure 3.2, and Figure 3.3 show three expressions of risk.

Frequency ↑

Middle	High	High
Middle	Middle	High
Middle	Middle	Middle
Low	Middle	Middle
Low	Low	Middle

Damage →

*Columns represent the degree of risk

Figure 3.1 Concept of the matrix method of risk expression

RISK = Frequency of occurrence + Damage

Figure 3.2 Concept of the sum method of risk expression

RISK = Frequency of occurrence × Damage

Figure 3.3 Concept of the product method of risk expression

Here, the risk associated with event i is defined as the product of the distribution function for the frequency of damage that occurs 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 as follows:

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

$F_i(x_f)$: distribution function for the frequency of harmful event i,

$D_i(x_d)$: distribution function for the scale of damage associated with event i.

3.3 Distribution function for frequency of 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 that 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:

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

λt: mean value of the frequency of the harmful events.

3.4 Distribution function for scale of damage

3.4.1 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 that occurred over a fixed period of time as a distribution function $D_i(x_d)$, each of which is described in Table 3. 1.

With a logarithmic distribution or gamma distribution, the event probability does not reach a maximum when the magnitude of the damage is infinitesimally close to zero. In other words, 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 $0 < a \leq x_d$. However, 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 accident ratio, for each major injury, there are 29 minor injuries and 300 non-injury accidents (harmless accidents in which critical damage was narrowly avoided). In addition, Bird's accident ratio indicates that there is a higher frequency of incidents of less significance compared to harmful accidents, and Tye-Pearson's accident ratio indicates that there is a pyramid structure in which serious incidents, such as fatal accidents, form the peak and non-injury accidents form the base (Everley, 2007).

Figure 3.4 summarizes the events that occur according to these accident ratios and the corresponding numbers of cases.

The application of an exponential distribution function for the scale of damage was verified based on these experimental accident ratios. The scale of damage is handled using an ordered segmentation of each of the zones into a single region, and non-parametric analysis was applied. Table 3. 2 shows the results of regression analyses conducted for each of the empirical rules, such as Heinrich's accident ratio, applied with an exponential function. These results indicate that an exponential distribution is applicable for the distribution of the scale of damage.

Table 3. 1 Candidates for the distribution function reflecting the scale of damage

Function name	Distribution function	Notes
Lognormal distribution	$D_i(x_d)=\frac{1}{x_d\sqrt{2\pi\sigma_1^2}}\exp\left[-\frac{\{\ln(x_d)-\mu_1\}^2}{2\sigma_1^2}\right]$ $\mu_1=\ln\left[\frac{\mu^2}{\sqrt{\sigma^2+\mu^2}}\right],\ \sigma_1=\sqrt{\ln\left[\frac{\sigma^2+\mu^2}{\mu^2}\right]}.$	μ : mean value σ : standard variation
Generalized Pareto distribution	$D_i(x_d)=\frac{\theta a^\theta}{x_d{}^{\theta+1}}$	θ: shape parameter a : location parameter
Gamma distribution	$D_i(x_d)=\frac{\beta^{-\alpha}x_d{}^{\alpha-1}\exp(-x_d/\beta)}{\Gamma(\alpha)}$	α: shape parameter β: scale parameter
Exponential distribution	$D_i(x_d)=\frac{1}{\beta}\exp(\ \frac{-x_d}{\beta}\ )$	β: mean value of event occurrences

3.4.2 Selection of an exponential function for the scale of damage

This section presents the relationships between the numbers of serious accidents and less significant incidents, beginning with Heinrich's accident ratio.

- Heinrich's accident ratio

Heinrich's accident ratio was presented in 1950 in a discourse by W. H. Heinrich and, as stated above, relates a major injury, minor injuries, and no injury accidents in the ratio 1:29:300 (Heinrich, 1959).

- Bird's accident ratio

Bird's accident ratio states that the ratio of a serious or disabling injury, minor injuries, property damage accidents, and incidents with no visible injury or damage is 1:10:30:600 (Bird, 1969).

- Tye-Pearson's accident ratio

Tye-Pearson's accident ratio states that the ratio of a fatal or serious injury, minor injuries, first-aid treatment injuries, property damage accidents, and near misses is 1:3:50:80:400 (Tye and Pearson 1974/75).

> *A major injury is any case that is reported to insurance carriers or to the state compensation commissioner. A minor injury is a scratch, bruise, or laceration such as is commonly termed a first-aid case. A no-injury accident is an unplanned event involving the movement of a person or an object, ray, or substance (slip, fall, flying object, inhalation, etc.), having the probability of causing personal injury or property damage (Heinrich, 1959).*

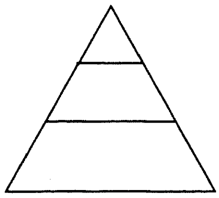
A serious or disabling injury, as described in Bird's accident ratio, refers to a serious accident such as a fatal accident or an event that will have enduring aftereffects. A minor injury is a personal accident of lesser degree, and a property damage accident is an accident that did not cause personal injury but involved physical damage such as broken equipment. An incident with no visible injury or damage is an incident in which no harm or trouble was observed, and this type of incident corresponds to the non-injury accident described in Heinrich's accident ratio.

A fatal or serious injury as described in Tye-Pearson's accident ratio refers to a case of extreme damage such as a major injury, as described in Heinrich's accident ratio, or a serious or disabling injury, as described in Bird's accident ratio. A minor injury is an injury of lesser degree and refers to an injury other than a first-aid injury. A first-aid injury refers to a personal injury of extremely light degree that can be resolved using the materials in a first-aid kit, such as an adhesive plaster. A property damage accident is an accident that, as in Bird's accident ratio, did not involve personal injury, but only material damage, such as broken equipment. A near miss incident (non-injury/damage incident) is an incident in which no actual injury or damage occurred, but which could have been linked to potential damage or a serious accident.

For Heinrich's accident ratio, conducting a regression analysis using an exponential function for the scale of damage at each level and the numbers of events yields a squared correlation coefficient of 0.989. A scale of 2 is allocated for damage of a major injury, a scale of 1 is allocated for damage of a minor injury, and a scale of 0 is allocated for damage of a non-injury accident. Likewise, conducting a regression analysis for Bird's accident ratio using an exponential function for the scale of damage at each level yields a squared correlation coefficient of 0.972. Conducting the same analysis for Tye-Pearson's accident ratio yields a squared correlation coefficient of 0.960.

The parameters of the formulae shown in Table 3. 2 reveal, for the scales of damage adopted under each accident ratio and the numbers of incidents, the results of conducting regression analyses using exponential functions. The formulae shown in Table 3. 2 are therefore not in the form of a distribution function.

According to these results, when approximating using an exponential function, the correlation coefficient is greater than 0.96 in every case, and the exponential function can be considered to be applicable as a distribution function for the scale of damage.

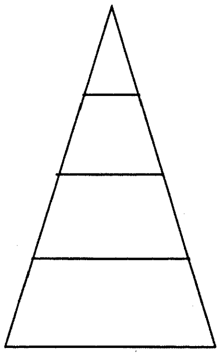


1 Major Injury

29 Minor Injuries

300 Non-injury Accidents

Heinrich (1950)



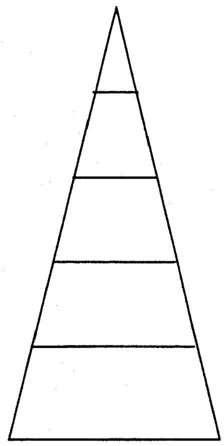
1 Serious or Disabling Injury

10 Minor Injuries

30 Property Damage Accidents

600 Incidents with No Visible Injury or Damage

Bird (1969)



1 Fatal or Serious Injury

3 Minor Injuries

50 First-aid Injuries

80 Property Damage Accidents

400 Near Miss Incidents (Non-injury Accidents/Damage Incidents)

Tye/Pearson (1974/1975)

Figure 3.4 Heinrich's accident ratio, Bird's accident ratio and Tye/Pearson's accident ratio

Table 3. 2 Fitting the number of accidents with an exponential function

	α	β	r^2
Heinrich	3.56×10^2	2.85	0.989
Bird	4.32×10^2	2.03	0.972
Tye-Pearson	4.60×10^2	1.53	0.960

Approximation by $f(x) = \alpha e^{-\beta x}$

r^2 : Coefficient of determination

3.5 Risk prediction equation for event i

As above, the risk associated with event i can be expressed as a product of the distribution functions for the frequency of the event, $F_i(x_f)$, and the scale of damage of the event $D_i(x_d)$ using the following equation:

$$R_i(x_r) = \frac{e^{-\lambda t_i}(\lambda t_i)^{x_f}}{x_f!} \times \frac{1}{\beta_i} \exp\left(\frac{-x_d}{\beta_i}\right),$$

λt_i: mean value of frequency of event i,

β_i: mean value of scale of damage of event i.

In the model, a Poisson distribution is used for the frequency of incidents, and an exponential distribution is used for the scale of damage.

Thus, if the parameters for a given group are obtained from investigations, they may be used to measure the risk under investigation, and it is then possible to effectively identify the particular factors and measures capable of reducing risk.

3.6 Goals and objects of investigation

The goals of the present project are as follows:

To grasp the industrial safety situation for the risk model of multinational raw materials manufacturing.

To contribute to the resolution of industrial safety in multinational raw materials manufacturing.

The objects of investigation are plants used in multinational raw materials manufacturing that produce primarily glass related materials, such as glass sheets and automotive windshields.

3.7 Research Methods

Although several types of research methods, including interviews and focus groups, questionnaires, secondary data and documentary sources, participant observation, and action research, are commonly used in this area of research, for the present study, questionnaires are the most suitable due to the following reasons:

- The targets are widely dispersed.
- The targets have already been identified.
- There are no useful secondary data and documentary sources.
- The respondents can ask a question(s) by e-mail, if they so wish.
- Observation does not directly reflect the industrial safety situation, especially the damage situation.
- Time and cost efficiency must be considered.

3.8 Quantitative or qualitative

There are two different research approaches: quantitative and qualitative. The characteristics of these approaches are as follows:

A distinction is usually made between two approaches to data collection and analysis: the quantitative and the qualitative. It is common to find these two approaches presented as representing divergent and opposing research traditions in the social sciences. This situation has been described as positivistic versus interpretative (Giddens, 1976). Emphasis is usually placed on the differences in the philosophical assumptions made about the nature of social reality and the relationship of the researcher and the researched.
(Nigel Gilibert, 1992, p.32)

Quantitative and qualitative research procedures are often viewed as providing 'macro' and 'micro' level perspectives on the social world respectively. Quantitative investigation entails adopting a numerical approach for the collection and analysis of data. This usually involves large-scale empirical studies using social survey techniques to collect data from representative samples of the population drawn from a wide geographical area. The aim is to produce useful factual data from which generalizations, often about characteristics of the society as a whole, can be made. In contrast, qualitative research provides a micro-level perspective based on case studies or data collected from individuals and groups. Here, the emphasis is on smaller-scale studies exploring the meaning that events and situations have for participants.
(Nigel Gilibert, 1992, p.34)

For the present study, the quantitative approach is more suitable than the qualitative approach, and the response data will be examined by numerical analysis.

3.9 Examination of details of the methods

The questionnaire method is used in the present study. However, there are several types of questionnaire surveys, including interview, postal, online, telephone, and group surveys. Each survey method has advantages and disadvantages. These questionnaires share some common traits: comprehending the questions, conducting, organizing and sampling. In the present study, three questionnaire methods—interview, postal, and online surveys—are discussed in detail using examples, and the other survey methods are then explained. The type of survey must be determined by considering the purpose of the study. Although there is no perfect method that can achieve all of the goals of the research, there is usually one method that is most suitable and reasonable for an individual study.

3.9.1 Interview survey

In interview surveys, interviewers visit respondents and ask questions using the questionnaires. The interviewers write down the respondents' answers and collect their answers. In this method, it is possible to ensure that the respondent is present in person. Furthermore, certain measures must be taken in order to maintain anonymity, and these measures may affect the accuracy of the survey.

Another advantage of the interview survey is that a third person cannot influence the survey. If the interviewers are well trained in communication skills, they can obtain numerous responses to several questions because they will be able to explain the questions properly. Moreover, since the survey involves face-to-face interaction, complex questions can also be asked, and the response rate is relatively high.

If the interviewers have good communication skills, the questions posed by interviewers can be understood sufficiently well. This is a crucial advantage of the interview survey. However, this method requires the efforts of several interviewers, and large-scale investigations have high transportation, training, and wage costs. The training of interviewers is the key factor in this method. The gender of the interviewer is likely to affect the answers of respondents. Furthermore, this method is not suitable for asking personal questions. In addition, adjustments regarding the time and place of the interview must be made according to each respondent's convenience. Another characteristic of this interview method is that information can be obtained both during the interview and after the interview has ended. One disadvantage of this method is that the number of respondents who can be interviewed is limited.

3.9.2 Postal survey

In postal surveys, the questionnaires and answer sheets are first sent to the respondents, and the answer sheets are filled in by the respondents and returned within a certain period. In this method, the interviewers do not have to be trained. This method is relatively inexpensive because it only involves the costs for mailing the surveys and not the costs for transportation, training, and wages. The survey can cover a wide area and can even be administered to overseas respondents.

A private survey can be conducted in which the respondents answer anonymously. Many questions can also be included in the survey because respondents can answer these questions at their convenience. In contrast to the interview method, the postal survey can be conducted by random sampling. This is an advantage of the postal survey. It is relatively easy to summarize the findings of a postal survey by numerical analysis. A rapid analysis can be conducted by computer. This method has recently gained popularity because it is easier to conduct than other methods. However, since the motivation to answer the questionnaires is low, the response rate is also generally low. Moreover, it is difficult to ensure that the answers are written by the respondents themselves, and the answers may be influenced by a third person. Furthermore, it is difficult to confirm the answers, and complex questions may be misunderstood. Since it takes time to obtain the results of this survey, this method is not suitable for surveys that require rapid results.

3.9.3 Online survey

In online surveys, the questionnaires are posted online on the Internet, and the answers are collected electronically.

Firstly, compared to postal surveys, this method can be used to reach a larger number of respondents from around the world. The number of Internet users is increasing every year not only in developed countries but also in developing countries. By using the Internet, it is possible to use animation and provide the respondents with pictorial information. These interactive tools present the respondents with new multimedia information.

For those who have access to the Internet, this survey is relatively inexpensive to conduct. The online survey does not require postage, transportation costs, or wages for interviewers. The results can be collected in a short period of time and can be received in real time. This real-time response is one of the remarkable advantages of this survey method. Furthermore, picture files, which cannot be collected by other methods, can be collected through this method. Additionally, certain groups that are ordinarily difficult to reach, such as hackers, can be contacted. Anonymous surveys can be conducted through this method, which minimizes interviewer error and bias. However, this method also has some disadvantages. One disadvantage of the online survey is that since it is conducted via the Internet its respondents are limited to those who can access the Internet and are interested in the survey. Second, there could be issues related to multiple and/or inappropriate responses. It is possible that false responses or double responses may be submitted, for example, an adult could pretend to be a child. The third issue is related to comparability. At present, there are few comparative studies of traditional and online surveys.

Another drawback is that it is unlikely that random sampling will be conducted through an online survey. Nonetheless, online surveys will undoubtedly be one of main survey methods used in the near future because of the ease with which they can be conducted. However, ensuring reliability will be expensive because of the requirement for a system and/or a procedure to obtain confirmation regarding the respondents and their answers.

3.9.4 Telephone survey

In telephone surveys, interviewers call the respondents and record answers to the questionnaires after obtaining the respondents' consent. This method can be used to quickly survey wide areas. The telephone survey is not expensive, and the response rate is relatively high because of the request is made directly over the phone. Misunderstandings regarding the questions can be avoided by mutual communication. Depending on the voice *etc.*, it may be possible to recognize whether the interviewer is speaking. Random selection can be achieved by selecting a random telephone number. The results can be gathered rapidly. This method is suitable for surveys that require rapid results. However, it is not suitable for numerous and/or complex questions because it is conducted by means of a telephonic conversation. This type of survey is not suitable for personal questions because the interviewers know the telephone numbers of the respondents. It is important to select the interview time so as to be convenient for the respondent. For example, a businessman cannot be interviewed on a weekday morning and people should not be interviewed in the evening because they may be preparing for supper. The timing of the interview should be carefully considered. This method also requires interviewers to be trained in the case of large-scale surveys.

3.9.5 Group survey

In group surveys, the questionnaires are distributed to and filled out by respondents who are gathered together. The investigator explains the contents of the questionnaire and provides instructions on how to fill out the answer sheets.

This method is inexpensive because the respondents are gathered in one specific place. The response rate is relatively high. The results can be obtained immediately and hence this method is suitable for surveys that require rapid results. The number of investigators can be minimized. The respondents can be answered on the spot. Anonymity can be maintained by collecting the questionnaires in a box placed near the exit. However, it is difficult to conduct random sampling with this method. The number of respondents is limited by the size of the meeting place. Furthermore, it is difficult to check the contents of the answers after the survey, and there is a possibility of influence by an outside party.

3.10 Advantages and disadvantages

A lack of comprehension of the question itself is a common issue in questionnaire surveys. In particular, this problem is crucial when comparing variables among different areas. For example, the meaning of one word may be different in different areas. Furthermore, the importance of this issue is very clear when making comparisons across different cultures. The second issue is related to the organization that conducts the survey, which may influence the attitudes of the respondents. In other words, the response rate and contents of the answers may change depending on the body of the survey. The third issue is related to the sampling method and sampling size. Although there are several types of questionnaire surveys, as described above, each survey method has its own advantages and disadvantages. In the present study, three questionnaire methods, namely, interview, postal, and online surveys, are discussed and examples are presented. The other survey methods, i.e., telephone and group surveys, are then explained following the review.

3.11 Chosen method

In the following, a summary of the advantages and disadvantages of each survey method is presented (Table 3. 3). The type of survey is determined based on the purpose of research. Although there is no perfect method that can achieve all possible research goals, there will be one method that is most suitable and reasonable for each type of research.

For the present study, a postal survey via e-mail was chosen. The disadvantages of the postal survey are low response rate, the impossibility of validating the responses, the difficulty of asking complex questions, and a long survey period. These problems will be remedied through the use of e-mail. Furthermore, a request from the parent company will contribute to increasing the response rate.

Table 3. 3 General comparison of survey methods

	Interview Survey	Postal survey	Online Survey	Telephone survey	Group Survey
Cost	Expensive	Moderate	Inexpensive	Moderate	Inexpensive
Response rate	Moderate	Low	Low	High	High
Consideration of time	Necessary	Not necessary	Not necessary	Necessary	Necessary
Investigator's skill	Necessary	Not necessary	Not necessary	Necessary	Necessary
Influence of a third person	No influence	Exists	Exists	No influence	Exists
Responding to questions	Easy	Possible	Easy	Easy	Possible
Response time	Brief	Long	Brief	Brief	Brief
Confirmation of contents	Easy	Impossible	Easy	Easy	Difficult
Verifying respondents	Easy	Impossible	Impossible	Possible	Difficult
Complex questions	Possible	Difficult	Possible	Difficult	Possible
Private questions	Difficult	Possible	Possible	Difficult	Possible
Many questions	Possible	Possible	Possible	Difficult	Possible
Investigators	Many	Not necessary	Not necessary	Moderate	Few
Range of the survey	Small	Wide	Wide	Wide	Small
Period of the survey	Moderate	Long	Moderate	Brief	Brief

Hideki Toyota (1998) Lecture of Investigation (in Japanese), Asakura Shoten, p.16

3.12 Design of Questionnaires

Table 3. 4 lists the specification of the survey.

Table 3. 4 Specification of survey

Main purpose	To grasp the industrial safety situation for modeling risk in multinational raw materials manufacturing To contribute to the resolution of industrial safety in multinational raw materials manufacturing
Body of the survey	Head office of a multinational raw materials manufacturing firm
Target	Multinational raw materials manufacturing plants
Scope of natural disasters and industrial accidents	Fire/Explosion Strong winds Flooding Lightning Earthquake
Period of investigation	10 years from 1995
Data collection	Use of multiple choice questions in the questionnaires (via e-mail)
Analysis	Quantitative analysis
Schedule	Six months, including the report production
Tools to increase the reply rate	Request by the Head Office Feedback on the comprehensive results

3.12.1 Scope of natural disasters and industrial accidents in the present survey

It is necessary to determine the scope of natural disasters and industrial accidents for the present study. There are several types of natural disasters and industrial accidents, such as floods, winds storms, epidemics, earthquakes, droughts, mudslides, extreme temperatures, wild fires, volcanoes, insect infestations, tidal waves, and storm surges. Regarding natural disasters, the following natural disasters are the main types that have a direct effect on industry: strong winds, flooding, lightning, and earthquake. The main cause of wild fires is lightning, which can also cause blackouts and critical damage to computer systems due to voltage surges.

Other natural disasters, such as epidemic, drought, and mudslide, have relatively indirect effects on industry, as compared to the four types of natural disasters mentioned above. However, the risk of pandemic should be investigated in another study in the future.

There are several types of industrial accidents, such as fire, explosion, collapse, gas leaks poisoning, and chemical spills. In Chapter 2, fire and explosion were reported to make up a significant portion of industrial accidents. Hence, fire and explosion are selected as industrial accidents for the present study.

In summary, the scope of natural disasters and industrial accidents considered in the present study is fire and explosion, strong winds, flooding, lightning, and earthquake.

3.12.2 Frequency of events

Five criteria of risk, including natural disasters and industrial accidents, are defined in Section 4.7.1. It is necessary to determine the period of frequency of these events. The period of the present study has to be set by the events considering the characteristics of the nature of these events.

There is a seasonal effect for the events of strong winds, flooding, and lightning. However, there is almost no seasonal effect for fire and explosion except for warming and for earthquake. Static electricity is also influenced considerably by seasonal factors.

In the present investigation, the target is a manufacturing enterprise. The damage situation will change year by year according to improvements in technology and the structure of industry, for example. An excessively long investigation will not properly reflect the actual situation. Furthermore, data of damage caused by accidents are generally not kept well, with the exception of major accidents. The period of this investigation is set as 10 years, starting from 1995, due to practical constraints.

3.12.3 Scale of damage

There are several methods by which to express the extent of damage. For example, the degree of fire is divided into four criteria in Japan: damage by flames/heat, damage by fire fighting activity, damage by explosion, and damage to person(s), such as fatalities and/or burns.

Damage by flames/heat is material damage caused by fire or heat. Damage by fire fighting activity is damage caused by fire fighters, water, and foam, for example. Damage by explosion is damage caused by explosive forces. The extent of damage by fire is divided into four categories: complete destruction, half destruction, partial destruction, and limited destruction.

In the present investigation, the scale of damage is measured in terms of personal damage, environmental damage, and material damage. The causes differ for each event. However, the results of natural disasters and industrial accidents are measured by same index, namely, the "end-point". Table 3. 5 is used as a scoring system, and a summation method is adopted in the present study.

Table 3. 5 Damage evaluation scores

Damage	Evaluation Score
Personal injury of employee	3
Damage to the neighboring area	3
Interruption of business for a period of over one month	3
Damage to building or structure	2
Damage to machinery	2
Damage to finished products, semi-finished products, or inventory	2
Interruption of business for a period of between one week and one month	2
Interruption of business interruption for a period of between one day and one week	1
Slight damage to any of the above options	1

Chapter 4

4 Results and discussion

4.1 Overview of survey results

Responses were obtained for a total of 101 sites: 58 sites in Japan and 43 sites overseas. Among the overseas sites, 19 were in Asia, 19 were in Europe, three were in the US, and two were in Russia. Regarding their scales, 31 sites had over 500 employees, 39 sites had between 100 and 500 employees, and 31 sites had less than 100 employees (Figure 4. 1 and Figure 4. 2).

Table 4. 1 shows a summary of the country and area of respondents.

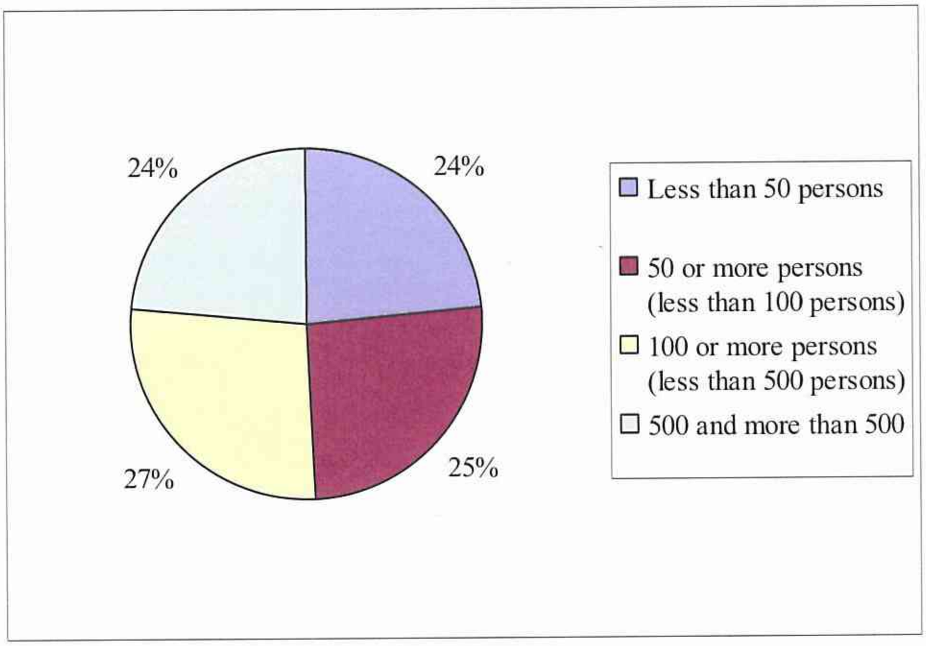


Figure 4. 1 Proportion of respondents by number of employees

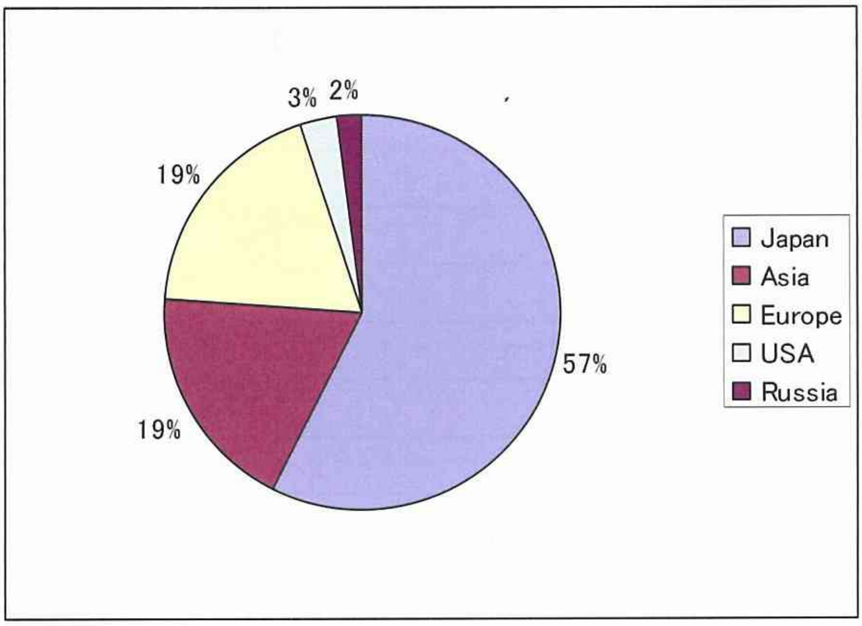


Figure 4. 2　Proportion of respondents by region

Table 4. 1 Summary of Respondents

Country and Area	Number of sites	Regional Category in the Present Report
Belgium	5	Europe
Czech Republic	4	Europe
China	2	Asia
France	3	Europe
Germany	1	Europe
Indonesia	6	Asia
Italy	4	Europe
Japan	58	Japan
Malaysia	1	Asia
Nederland	1	Europe
Pakistan	1	Asia
Philippine	1	Asia
Russia	2	Russia
Singapore	1	Asia
South Korea	2	Asia
Taiwan	2	Asia
Thailand	3	Asia
UK	1	Europe
USA	3	North America
Total	101	–

4.2 Industrial safety risks of the enterprise group as a whole

Table 4. 2 shows that the risk of fire and explosion is the largest at 0.206 among the risk investigated in the present study. This reveals that for this enterprise group as a whole, it is necessary to prioritize the means of tackling the curtailment of risk due to fire and explosion.

However, the activity of curtailing risks in practice should be conducted according to region and individual circumstances.

Regarding industrial safety risks for the enterprise group as a whole, it was revealed that the greatest risk is posed by fire and explosion, as in the EM-DAT data. Next, the risks of lighting and strong winds are on approximately the same level, followed by the risk of flooding and the risk of earthquake.

It was revealed that for Japan, the greatest industrial safety risks are those of fire and explosion and strong winds. However, the likelihood of occurrence is greater for strong winds, although the influence is larger for the risk of fire and explosion. The next is the risk of lightning, and the risks of earthquake and flooding are approximately the same. Japan is a country that is afflicted by earthquakes. However, from the perspective of the likelihood of the occurrence of damage-causing events, the risk of earthquake is the lowest compared to that of the other risks. However, the scale of influence is the largest after that of the risk of fire and explosion.

Regarding the industrial safety risks in Asia, as in Japan, the risk of fire and explosion is the greatest. This is followed by the risk of flooding, the risk of lightning, the risk of earthquake, and the risk of strong winds.

The risk of fire and explosion is also greatest among the industrial safety risks in Europe, followed in order by the risks of lightning, flooding, earthquake, and strong winds.

Thus, among the industrial safety risks faced in all the regions of Japan, Asia, and Europe, the risk of fire and explosion is the largest. Therefore, it is clear that, in all regions, the risk of fires and explosions should be curtailed.

The risk of fire and explosion decreases in order of Asia, Japan, and Europe, but the likelihood of occurrence in Asia is roughly double that of Japan and Europe. In Asia, activity emphasizing the prevention of fire and explosion accidents would therefore be effective. In addition, the influence of fires and explosions in Japan is high compared to the other regions, and it is thought that upgrading facilities conducive to preventing the propagation of damage when a fire or explosion occurs would be effective.

Regarding the risk of earthquake, the risk in Japan is more than twice that of the other regions. Despite the fact that there is not such a large difference in the likelihood of earthquakes occurring, the damage is between two and three times that in Asia and Europe. It is thought that this may be due to differences in production items, for example.

The risk of flooding is greatest in Asia, followed by Japan and then Europe. The likelihood of occurrence for each region is between 0.03 and 0.05 events per year, but the damage is notably greater in Asia compared to the other regions. In Asia and its coastal regions in particular, there are several factories sited at low elevation above sea level, and policies such as preparing factories, warehouses, and electrical rooms for floods by raising banks in advance are effective.

The risk of strong winds is greatest is Japan, and is around 10 to 20 times greater than that in the other regions. The scale of damage and the likelihood of occurrence are both high. It is desirable to change tent housing into permanent constructions and prefabricated or slate roofed buildings into robust reinforced structures in order to withstand typhoons and strong winds.

The risk of lightning in Japan is roughly twice that of the other regions. The scale of damage and the likelihood of occurrence exceed those of the other regions. Therefore, the risk of lightning is relatively high in Japan, and upgrading of lightning conductors, for example, is an effective policy.

4.3 Risks with respect to region

4.3.1 Japan

Japan is located in a region in which natural disasters are common. Such natural disasters include typhoons, torrential rain, heavy snow, flooding, landslides, earthquakes, tsunamis, and volcanic eruptions. For example, regarding the proportion of the entire world's disasters, between 1997 and 2006, 20.7% of the world's earthquakes with a magnitude of at least 6 occurred in Japan, which is an extremely high proportion considering that the area of the country only accounts for 0.25% of surface area of the earth (2007 White Paper on Disaster Prevention, Cabinet Office Compilation).

Responses were obtained from 58 sites in Japan. A comparison of each of their risks reveals the risk of fire and explosion is highest at 0.205, followed by that of strong winds at 0.184. In Japan, the risks of fire and explosion and strong winds are high. The risk of lightning is next at 0.150. The risks of flooding and of earthquake follow at 0.095 and 0.081, respectively, which are low risks in Japan.

Table 4. 3 shows the results of industrial safety risk for multinational raw materials manufacturing in Japan.

4.3.2 Asia (excluding Japan)

Responses were obtained from a total of 19 sites in Asia, including China, Indonesia, Singapore, South Korea, Taiwan, Thailand, Pakistan, and the Philippines. As in Japan, the risk for the locations in Asia is highest for fire and explosion at 0.211. The next highest risk is flooding at 0.132, followed by lightning at 0.084, earthquake at 0.032, and strong winds at 0.011.

Table 4. 4 shows the results of industrial safety risk for multinational raw materials manufacturing in Asia.

4.3.3 Europe

Responses were obtained from a total of 19 sites in Europe, including Belgium, Czech Republic, England, France, Germany, Holland, and Italy. The risk for the locations in Europe is highest for fire and explosion, as in Japan and Asia, followed by lightning at 0.084, flooding at 0.063, earthquake at 0.032, and strong winds at 0.021.

Table 4. 5 shows the results of industrial safety risk for multinational raw materials manufacturing in Europe.

4.3.4 United States and Russia

Responses were obtained from three sites in the US and two sites in Russia. Since the sample size is small from a statistical perspective, an analysis with respect to region was not performed.

4.4 Risks with respect to type of industrial safety event

Next, the characteristics of each region were analyzed with respect to each risk. However, since the number of respondents from the US and Russia was small, only the three regions of Japan, Asia, and Europe were compared.

4.4.1 Risk of fire and explosion

Regarding the risk of fire and explosion, the value of 0.211 in Asia is the highest. This is followed by 0.205 in Japan, and 0.147 in Europe. Considering the likelihood of occurrence, the likelihood in Asia is approximately twice that in Japan and Europe. However, the historical record of fire and explosion accidents occurring over the past 10 years was not available for 58% of the objects of the investigation taken as a whole.

4.4.2 Risk of strong winds

Regarding the risk of strong winds, the risk in Japan is 0.184, which is the highest among the regions. This is followed by 0.021 in Europe, and 0.011 in Asia. However, the historical record of strong winds occurring over the past 10 years was not available for 69% of the targets of the investigation taken as a whole.

4.4.3 Risk of flooding

Regarding the risk of flooding, the risk in Asia is 0.132, which is the highest among the three regions. This is followed by 0.095 in Japan, and 0.063 in Europe. However, the historical record of floods occurring over the past 10 years was not available for 77% of the targets of the investigation taken as a whole.

4.4.4 Risk of lightning

The value of 0.150 in Japan is the highest among the regions. This is followed by 0.084 in both Asia and Europe. The risk in Asia and Europe is roughly one half that of Japan. However, the historical record of lightning occurring over the past 10 years was not available for 65% of the targets of the investigation taken as a whole.

4.4.5 Risk of earthquake

Regarding the risk of earthquake, at 0.081, the risk in Japan is the highest among the regions examined. The risk in the rest of Asia and Europe is 0.032. However, the historical record of earthquakes occurring over the past 10 years was not available for 83% of the targets of the investigation taken as a whole.

Table 4. 2 Industrial safety risks for the entire enterprise group

	Scale of damage	Frequency of events per site (events/year)	Risk
Fire/Explosion	3.152	0.065	0.206
Strong winds	2.614	0.044	0.114
Flooding	2.541	0.037	0.093
Lightning	2.179	0.055	0.121
Earthquake	2.308	0.025	0.058

* including USA and Russia

Table 4. 3 Industrial safety risks by events for Japan

	Scale of damage	Frequency of events per site (events/year)	Risk
Fire/Explosion	4.103	0.050	0.205
Strong winds	2.892	0.064	0.184
Flooding	2.750	0.034	0.095
Lightning	2.559	0.059	0.150
Earthquake	3.133	0.026	0.081

Table 4. 4 Industrial safety risks by events for Asia (excluding Japan)

	Scale of damage	Frequency of events per site (events/year)	Risk
Fire/Explosion	2.000	0.105	0.211
Strong winds	2.000	0.005	0.011
Flooding	4.167	0.032	0.132
Lightning	1.600	0.053	0.084
Earthquake	1.500	0.021	0.032

Table 4. 5 Industrial safety risks by events for Europe

	Scale of damage	Frequency of events per site (events/year)	Risk
Fire/Explosion	2.333	0.063	0.147
Strong winds	1.000	0.021	0.021
Flooding	1.333	0.047	0.063
Lightning	1.778	0.047	0.084
Earthquake	1.000	0.032	0.032

4.5 Simulation using a Monte Carlo method

Simulation using a Monte Carlo method was performed by means of the risk model incorporating each of the obtained parameters. Crystal Ball™ software was used for simulation. Parameters for simulation are presented in Appendix C.

The Monte Carlo simulation was used to calculate $R_i(x_r)$ as the product of $F_i(x_f)$ and $D_i(x_d)$.

Concretely, the frequency and scale of damage were calculated using each estimated distribution function, and the products of both were calculated. The distributions of the risks of the corresponding events were calculated repeatedly by this method and the number of trials was 10,000 (Figure 4. 3).

The results of the risk simulation of industrial safety in raw materials manufacturing in Japan, Asia, and Europe are shown in Table 4. 6 and Table 4. 9.

Regarding the frequency distributions, the incidents occurring in each of the five categories were considered to be independent, and it was assumed that there were no cross-interactions among any of the distribution functions. Each of the risks (fire and explosion, strong winds, flooding, lightning, and earthquake) is expressed by the following equation:

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

$i = 1$: risk of Fire and explosion

$i = 2$: risk of Strong winds

$i = 3$: risk of Flooding

$i = 4$: risk of Lightning

$i = 5$: risk of Earthquake

The methods of treatment of risks according to their scale, *etc.*, include risk avoidance, risk optimization, risk transfer, and risk retention (ISO/IEC Guide 73). Among these methods, concerning reduction, it is necessary to consider the cost-effectiveness and treat higher risks on a prioritized basis. Figure 4. 4, Figure 4. 5, Figure 4. 6 and Figure 4.

7 show risk maps constructed using 500 points from each simulation. This allows the relative location of each of the risks in industrial safety to be observed visually.

The definition of risk adopted in the present paper is the product of the frequency of incidents and the scale of damage. Based on this definition, reducing either the frequency of an incident or the scale of damage by a factor of two yields the same reduction in risk. If risk is defined as the product of the frequency of incidents and the square of the scale of damage, reducing the scale of damage by a factor of two results in a larger reduction in risk. The definition of risk also influences the results of the subsequent step in which risks are curtailed. Therefore, it is necessary for the concerned parties to engage in discussion and reach a consensus.

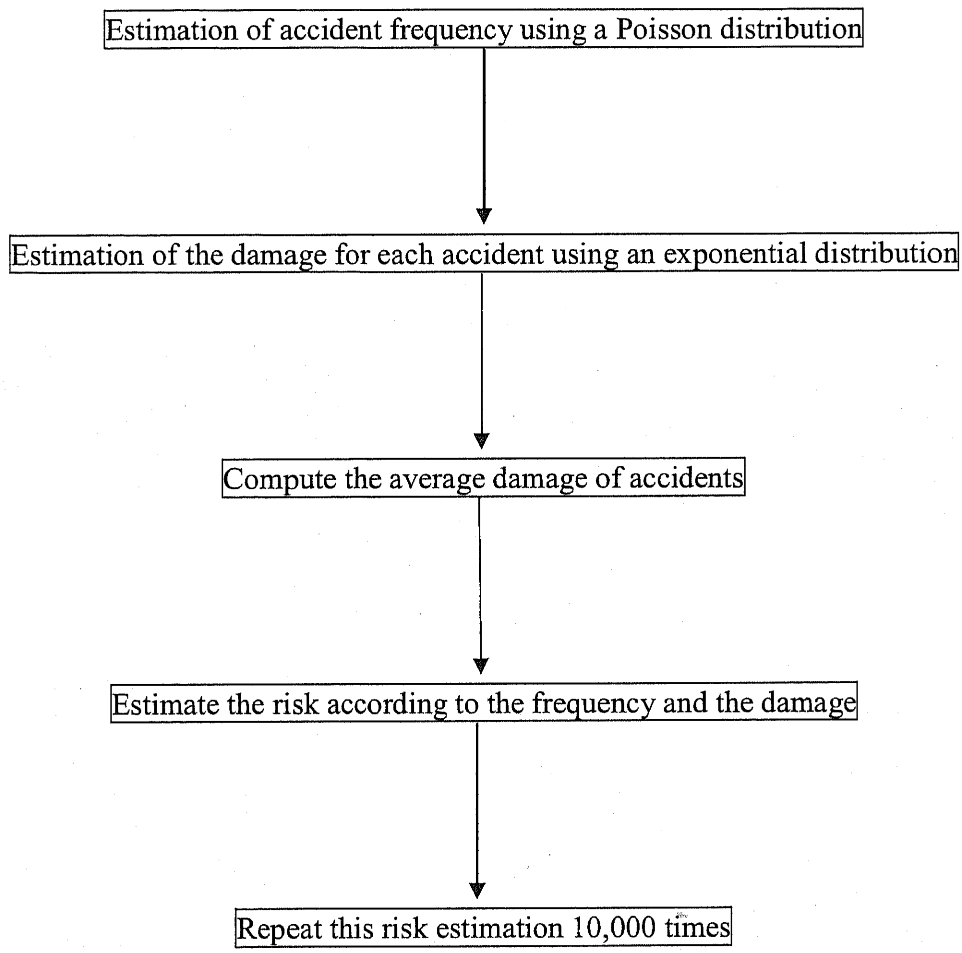


Figure 4. 3 Flow of risk estimation for industrial safety

Table 4. 6 Results of risk simulation for the entire enterprise group

Risk	Average	Median	Maximum	Minimum
Fire/Explosion	0.198	0.197	0.371	0.094
Strong winds	0.112	0.111	0.215	0.034
Flooding	0.092	0.091	0.195	0.033
Lightning	0.120	0.119	0.214	0.052
Earthquake	0.056	0.056	0.120	0.010

Table 4. 7 Results of risk simulation for Japan

Risk	Average	Median	Maximum	Minimum
Fire/Explosion	0.186	0.183	0.382	0.033
Strong winds	0.180	0.177	0.351	0.060
Flooding	0.092	0.090	0.221	0.006
Lightning	0.148	0.1446	0.294	0.045
Earthquake	0.078	0.076	0.229	0.003

Table 4. 8 Results of risk simulation for Asia (excluding Japan)

Risk	Average	Median	Maximum	Minimum
Fire/Explosion	0.210	0.205	0.541	0.032
Strong winds	0.011	0.004	0.117	0.000
Flooding	0.119	0.111	0.453	0.000
Lightning	0.084	0.080	0.252	0.000
Earthquake	0.031	0.027	0.220	0.000

Table 4. 9 Results of risk simulation for Europe

Risk	Average	Median	Maximum	Minimum
Fire/Explosion	0.147	0.141	0.440	0.004
Strong winds	0.021	0.018	0.108	0.000
Flooding	0.063	0.059	0.267	0.000
Lightning	0.084	0.079	0.261	0.000
Earthquake	0.032	0.029	0.117	0.000

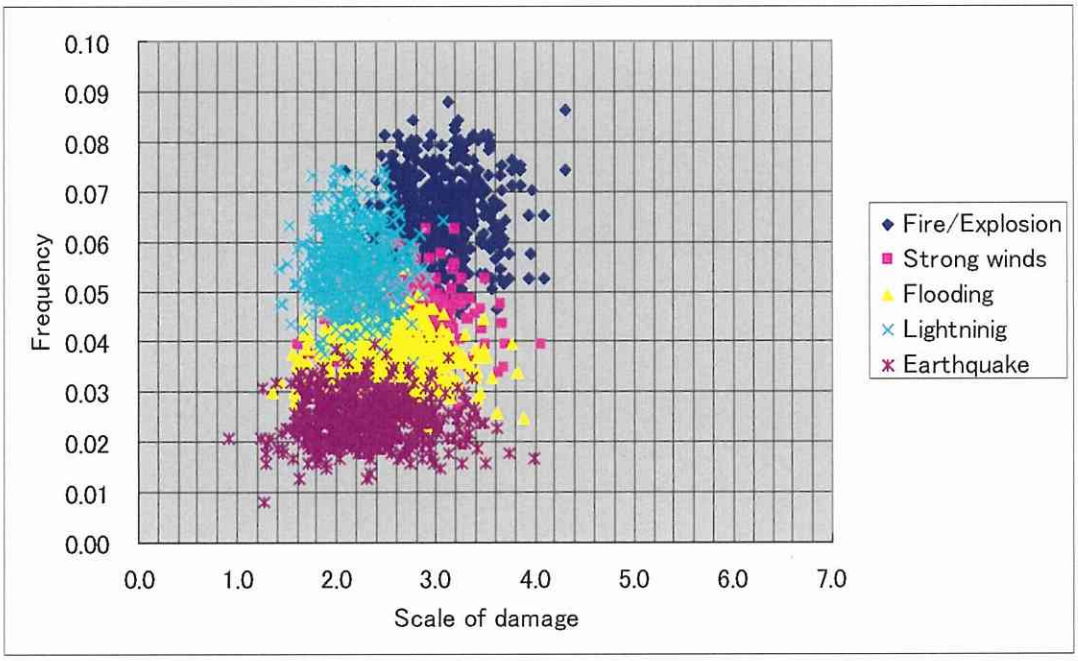


Figure 4. 4 Risk map for the entire enterprise group

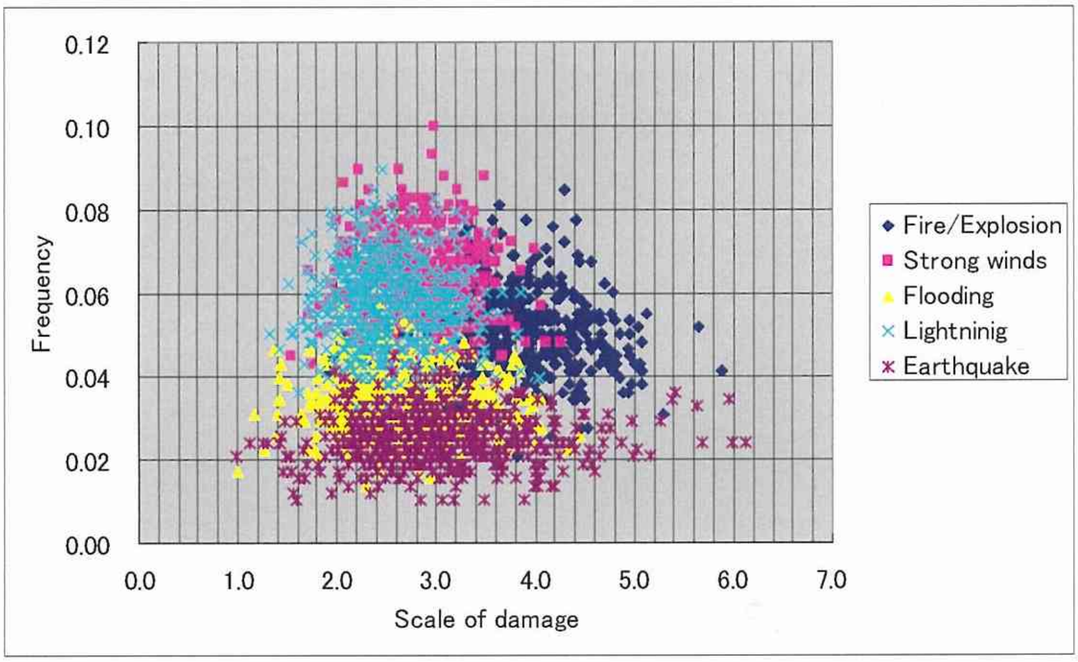


Figure 4. 5 Risk map for Japan

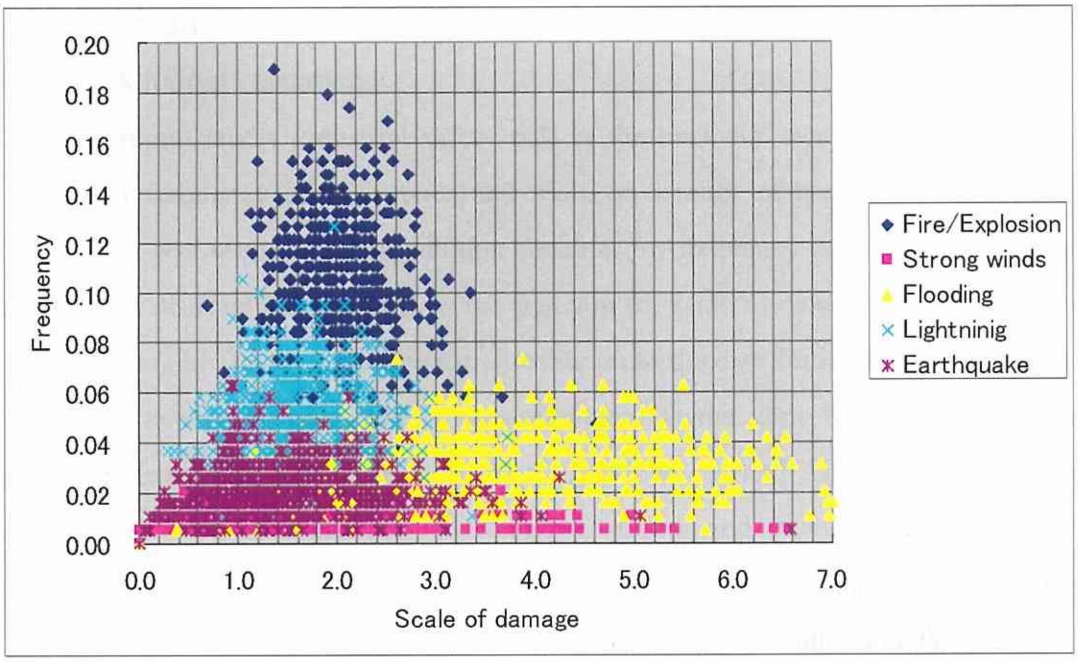


Figure 4. 6 Risk map for Asia (excluding Japan)

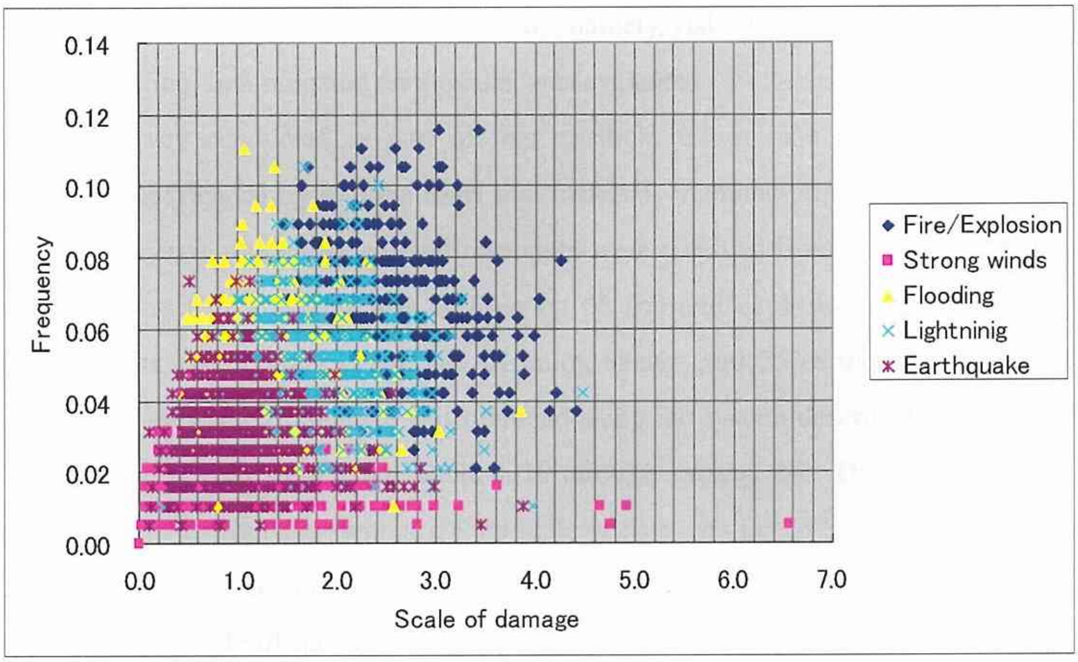


Figure 4. 7 Risk map for Europe

4.6 Discussion

4.6.1 Risk model validation

In the present study, industrial safety risk in the business sector is defined by the product of frequency of occurrence and scale of damage of each event. A Poisson distribution was used as the distribution function for frequency of occurrence, and an exponential distribution was used as the function for scale of damage. On the basis of previous research, the use of a Poisson distribution as the distribution function for event occurrence appears to be relatively unproblematic. At the same time, for distribution functions describing the scale of damage, previous research advocates the use of distributions such as lognormal distributions, generalized Pareto distributions, and gamma distributions. In the present study, an exponential distribution was adopted based on analysis of Heinrich's accident ratio, Bird's accident ratio, and Tye-Pearson's accident ratio, which are accident occurrence ratios in the field of industrial accidents. In addition, the applicability of this method to the scale of damage for the industrial safety risks investigated in the present study, namely, risk of fire and explosion, strong winds, flooding, lightning and earthquake, was evaluated.

In the survey conducted as part of this research, information on industrial safety incidents experienced by multinational raw materials manufacturing enterprises during the past 10 years was collected, and responses were received from a total of 101 sites. The breakdown of incidents was as follows: 66 fire and explosion events, 44 strong winds events, 37 flooding events, 56 lightning events, and 25 earthquake events. For each event, the scale of damage was obtained using the system described in Chapter 3, Section 3.12.3, Scale of damage. Table 4. 10 through Table 4. 14 Distribution of scale of damage for Earthquake summarize the scale of damage of each event and the number of events in each category. Regression analysis using an exponential distribution was applied to the scale of damage and the occurrence ratio of each industrial safety risk. The results of these analyses are shown in Figure 4. 8 through Figure 4. 12. These results confirmed that, with the exception of earthquakes, all risks had high goodness of fit, with squared correlation coefficients of 0.64 or above, while the squared correlation coefficient for earthquakes was 0.22, showing a low degree of correlation. Twenty-five earthquake events were reported, making the earthquake the least frequent event in the present industrial safety survey, and it is possible that the particular characteristics of earthquakes influenced the distribution profile of the scale of damage. The present survey did not however consider the number of "unfelt earthquakes", which cause no damage.

Table 4. 10 Distribution of scale of damage for Fire/Explosion

Scale of damage	Number of events	Proportion (%)
9	2	3.0
8	0	0
7	6	9.1
6	3	4.5
5	9	13.6
4	3	4.5
3	10	15.2
2	10	15.2
1	23	34.8
Total	66	100.0

Table 4. 11 Distribution of scale of damage for Strong winds

Scale of damage	Number of events	Proportion (%)
9	0	0
8	2	4.5
7	0	0
6	2	4.5
5	2	4.5
4	8	18.2
3	0	0
2	15	34.1
1	15	34.1
Total	44	100.0

Table 4. 12 Distribution of scale of damage for Flooding

Scale of damage	Number of events	Proportion (%)
9	0	0
8	0	0
7	2	5.4
6	0	0
5	2	5.4
4	10	27.0
3	0	0
2	7	18.9
1	16	43.2
Total	37	100.0

Table 4. 13 Distribution of scale of damage for Lightning

Scale of damage	Number of events	Proportion (%)
9	0	0
8	0	0
7	0	0
6	0	0
5	2	3.6
4	11	19.6
3	4	7.1
2	17	30.4
1	22	39.3
Total	56	100.0

Table 4. 14 Distribution of scale of damage for Earthquake

Scale of damage	Number of events	Proportion (%)
9	0	0
8	0	0
7	0	0
6	0	0
5	3	12.0
4	5	20.0
3	1	4.0
2	5	20.0
1	11	44.0
Total	25	100.0

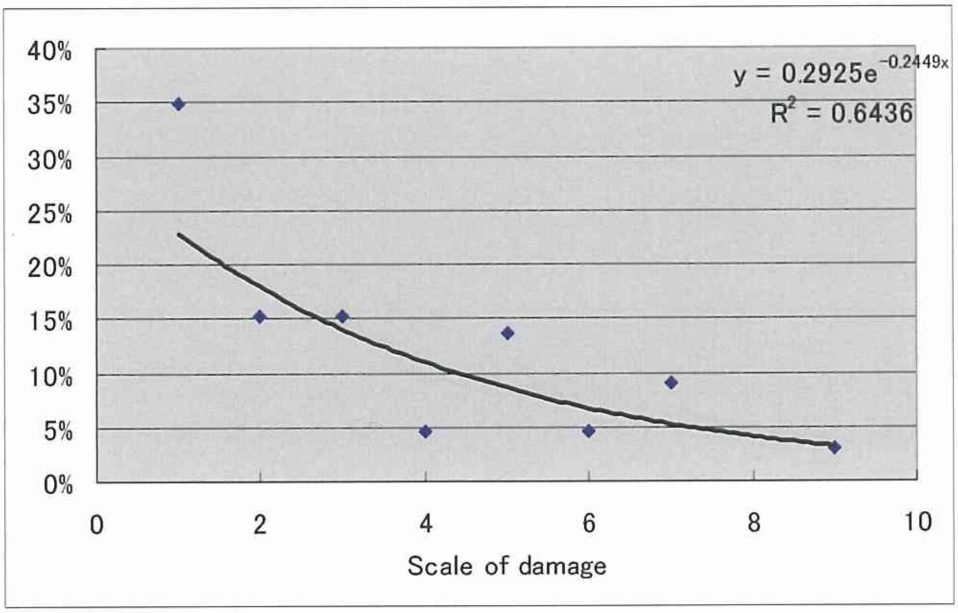


Figure 4. 8 Distribution of the scale of damage for Fire/Explosion with regression curve

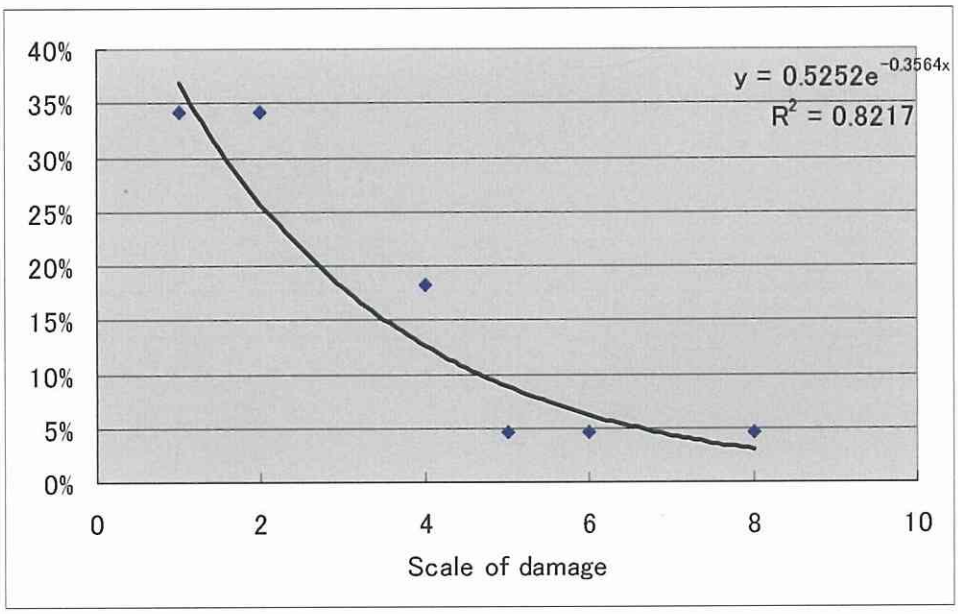


Figure 4. 9 Distribution of the scale of damage for Strong winds with regression curve

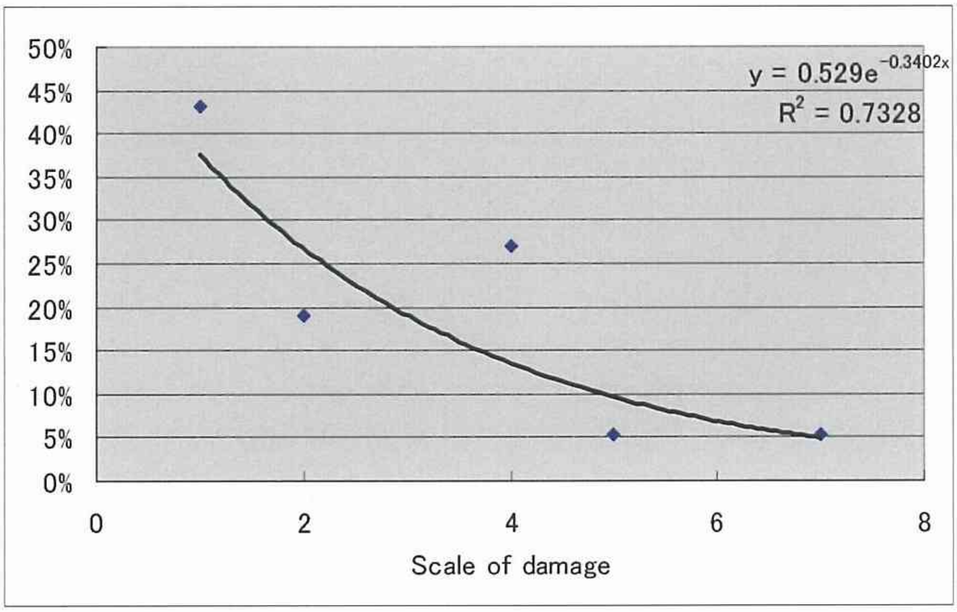


Figure 4. 10 Distribution of the scale of damage for Flooding with regression curve

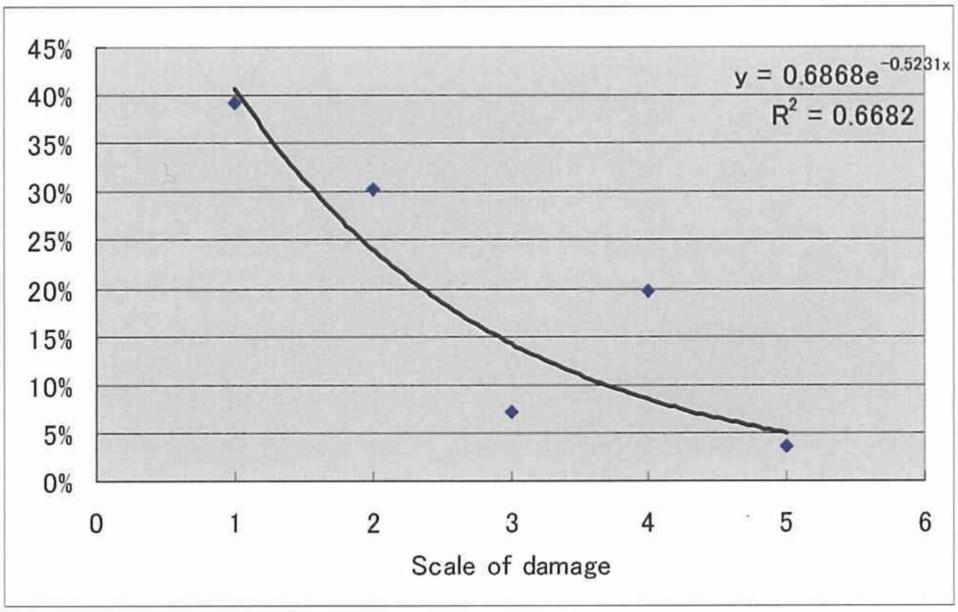


Figure 4. 11 Distribution of the scale of damage for Lightning with regression curve

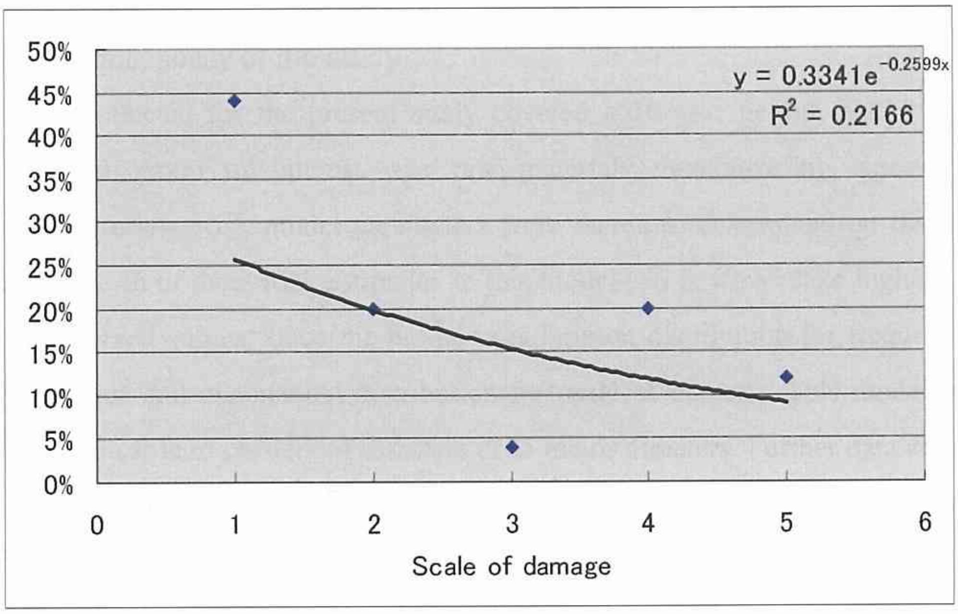


Figure 4. 12 Distribution of the scale of damage for Earthquake with regression curve

4.6.2 Applicability of the study

Data collected for the present study covered a 10-year period from 1995, and the industrial group of interest was raw materials manufacturing, specifically glass manufacturing. Risk model parameters were therefore determined on the basis of 10 years' worth of data. Risk estimates in this model can however take higher values than the observed values, since the model uses Poisson distribution for frequency of event occurrence and exponential distribution for scale of damage. This model is therefore also applicable to clusters of disasters or to major disasters. Further data collection will make it possible to obtain more robust estimates using these parameters; however, the following points need to be considered in attempting a more general application of the risk model parameters used in this study.

Although scale of damage clearly follows an exponential distribution for the four industrial safety risks excluding earthquake, it is necessary to carefully consider the significance of the parameters when broadening the scope of their application. Even if industrial safety parameters for each country and each industry are provisionally obtained, the utility of those parameters will need to be fully investigated. In real-world application, it is those parameters based on data collected over a suitable range which will prove to be significant. Therefore, although this risk model has wide applicability in the estimation of industrial safety risk (other than earthquake) in multi-national enterprises, when practically applying the risk model, risk model parameters must be determined after setting the appropriate range suitable for the intended use. In the present study, country-specific data were obtained for 19 countries. Data were collected for 58 events in Japan, but due to the small amount of data for other countries, data was collated by region. For countries with few data, although industrial safety risk can be estimated based on the data obtained, it is necessary to be fully aware of the limited amount of data available.

One of the characteristics of the scale of earthquake damage compared to other natural disasters is its limited geographical and temporal range. Accidents due to fire and explosion occur more frequently than earthquake, and in terms of total amount of damage, over a 10-year period in Japan the total losses due to fire and explosion exceeded those due to earthquake. In general, although damage from large earthquakes may include thousands of deaths, of the 25 cases of earthquake damage reported in the present study, there were no deaths and only one report of human injury. This may be because most earthquake deaths occur in the home, while industry has protected itself well against earthquakes. As the above points indicate, in considering earthquake risk to industry it is necessary to recognize that the circumstances differ from those of normal earthquake damage.

4.6.3 Effect of human damage evaluation on the scale of damage.

As stated above, in the present survey, the scale of damage was obtained using the system described in Chapter 3, Section 3.12.3, Scale of damage. According to Noguchi et al. (2003), a survey of media personnel conducted by Mitsubishi Research Institute, Inc., reported a weighting of 6:1:3 for human damage, physical damage, and environmental damage. When compared with these ratios, the scale of human damage in the present survey is not particularly large. The effect on each industrial safety risk when different weightings were given to human damage was investigated in a survey. Although this survey covered five categories of industrial safety events, human damage was only reported in two categories: fire and explosion and earthquake. There were six cases of human damage due to fire and explosion and one case due to earthquake. No deaths were reported. In the original evaluation, three points were added to scale of damage if human damage occurred. The effect on industrial safety risk was investigated when nine, 18, and 27 points were added.

Table 4. 15 through Table 4. 18 show the values of parameters for risk estimation, risk values, and relative ranking of each risk after changing the evaluation weightings for human damage. As the results show, there was no effect on the ranking of the individual industrial safety risks when the evaluation weighting for human damage was nine points, 18 points, or even 27 points.

Table 4. 15 Original evaluation (Human damage: 3 points)

	Number of events	Scale of damage	Risk	Rank
Fire/Explosion	66	3.152	208.0	1
Strong winds	44	2.614	115.0	3
Flooding	37	2.541	94.0	4
Lightning	56	2.179	122.0	2
Earthquake	25	2.360	59.0	5

Table 4. 16 Case 1 (Human damage: 9 points)

	Number of events	Scale of damage	Risk	Rank
Fire/Explosion	66	3.697	244.0	1
Strong winds	44	2.614	115.0	3
Flooding	37	2.541	94.0	4
Lightning	56	2.179	122.0	2
Earthquake	25	2.600	65.0	5

Table 4. 17 Case 2 (Human damage: 18 points)

	Number of events	Scale of damage	Risk	Rank
Fire/Explosion	66	5.060	334.0	1
Strong winds	44	2.614	115.0	3
Flooding	37	2.541	94.0	4
Lightning	56	2.179	122.0	2
Earthquake	25	2.960	74.0	5

Table 4. 18 Case 3 (Human damage: 27 points)

	Number of events	Scale of damage	Risk	Rank
Fire/Explosion	66	5.334	352.0	1
Strong winds	44	2.614	115.0	3
Flooding	37	2.541	94.0	4
Lightning	56	2.179	122.0	2
Earthquake	25	3.320	83.0	5

4.6.4 Significance of using risk theory

In this section, the significance of applying risk theory to industrial safety is discussed. The main feature of risk theory is that it allows risk to be quantified, albeit with attendant uncertainty. In their business activities, companies must respond to a variety of risks, and since finite resources are available for this purpose, funds need to be allocated efficiently. Apart from practicing risk avoidance, it is impossible to entirely eliminate the industrial safety risks discussed herein, namely, fire and explosion risk, strong wind risk, flooding risk, lightning risk, and earthquake risk. Similarly, it is unreasonable to seek zero risk when carrying out risk optimization. Risk can be dealt with using risk avoidance, risk transfer, risk retention, and risk optimization, and one of the goals of risk management in industry, particularly in manufacturing, is to achieve the optimization of different types of risk, by controlling risk retention so that it remains at a tolerable level. In the present survey on industrial safety risk, a standardized scale was used to compare the frequency of occurrence and the scale of damage across various industrial risks. This allowed us to make a relative comparison of each industrial safety risk. In addition, since a probability distribution function is used for the frequency of occurrence and the scale of damage of events, these can be quantified in a meaningful way while the uncertainty is retained. Different factories use a variety of strategies to deal with different types of industrial safety risk, and in this survey, the residential risk, excluding risk reduced by control measures from exposure risk, was obtained. While it is clear from the survey that in attempting to reduce risk, the priority in each region should be given to reducing fire and explosion risk, it is also necessary to attempt to reduce overall risk while bearing in mind that other risks also have a fixed probability of occurring and recognizing that, at times, this probability exceeds that of fire and explosion risk. For example, risk management geared only toward fire and explosion risk will not contribute to the reduction of other industrial safety risks, whereas a broader risk management strategy can contribute to the reduction of virtually all industrial safety risks. In addition, for companies, the setting of tolerable levels of risk is an extremely important aspect of risk management, and it must also be recognized that this tolerable level is not set at a fixed value but changes in response to changing social conditions.

The significance of applying risk theory to industrial safety risk is that it allows the development of an integrated strategy while identifying a range of possibilities, in contrast to the inflexible approach of devising measures based on a comparison of priorities within a simple ranking system.

Chapter 5

5 Conclusions

Risk estimation was performed using Monte Carlo simulation with a model for estimating each of the risks in industrial safety developed by setting each of the frequency distributions and damage-scale distributions along with their parameters according to empirically obtained data. Since there are various risks associated with industrial safety, dramatically curtailing all risks is more difficult than preparing measures for a particular risk, and in order to curtail risks effectively it is necessary to invest in dealing with events that are judged to have high risks. In addition, there are territorial characteristics and tendencies related to industrial safety, and it is necessary to grasp both global and regional risks.

In addition to the risk model established in the present study, a variety of alternative risk models have also been investigated. The placing of emphasis on a particular risk according to social situations and regional characteristics may also be considered. By establishing a model that obeys the opinions of interested parties regarding the risks that should be handled and performing analyses including sensitivity analysis, it is possible to effectively curtail risks with limited resources.

In conclusion, the following items were achieved.

- A risk model was constructed for industrial safety affecting raw materials manufacturing by adopting a Poisson distribution for the frequency of disaster occurrence and an exponential distribution for the scale of damage.
- Parameters were determined for the models representing the risks faced by raw materials manufacturing in Japan, Asia and Europe due to fire and explosion, strong winds, flooding, lightning, and earthquake.
- Monte Carlo simulation was conducted using the obtained parameters, and a scatter plot was created, making it easy to understand the risks visually.
- The areas that should be considered as priorities in risk reduction are clarified in

raw materials manufacturing in Japan, Asia and Europe by constructing a risk model for estimating the risks involved in industrial safety and by investigating and analyzing the obtained results.

Chapter 6

6 Future research and scientific value of the present study

6.1 Future research

6.1.1 Clarifying the tolerable risk range

The present study presents a clear analysis and assessment of industrial safety risks related to multinational raw materials manufacturing enterprises. In risk management, it is necessary to understand the current state of the risk and to clarify the tolerable risk level. Regarding risk levels above the tolerable level, it is necessary to control the risk and to perform the necessary optimization in order for the risk to be confined within a tolerable range. The tolerable risk level is not fixed, but rather changes in accordance with social circumstances and the time and place of these circumstances. Furthermore, it is considered that the risk level differs depending on the degree of completion of risk communication. As the next step, it is necessary to conduct research aimed at clarifying the tolerable risk level. It is also necessary to take into consideration citizens, employees, shareholders, and all other affected parties.

6.1.2 Application to other industries

The target of this risk-related research is multinational raw materials manufacturing enterprises. The analysis and assessment of industrial safety risk for different targets will be the subject of future research. Regional industrial safety risk is considered to have much in common with other industries. However, it has been suggested that there are significant differences regarding fire and explosion risk, which depend on the individual industry. For example, it can be said that the risk of fire and explosion in assembly industries is clearly low in comparison to that in the iron and glass industries, in which fire and devices operating at high temperatures are used on a regular basis.

6.1.3 Providing detailed regional information regarding country-specific risk

assessment

In the present study, due to data restrictions, regional analyses were performed with respect to Japan, Asia, and Europe. Regarding these regions, one of the problems for future research will be the collection of additional data and the assessment of industrial safety risk with regard to individual countries or regions. It will be possible to use the results of such research as important information input for feasibility studies associated with the building of new factories.

6.1.4 Examining the amount of damage inflicted by an earthquake

The results of the exponential distribution fitting technique applied to damage caused by an earthquake were less favorable than those yielded by the other four industrial safety risks. Although an insufficient amount of data can be given as the reason for this outcome, it is also true that the data for minute and imperceptible earthquakes was excluded from the scope of the collected data. With regard to the exponential distribution fitting technique, it is necessary to collect additional data and to attempt to verify the validity of this model.

6.1.5 Examining particular measures for reducing the damage caused by incidents

From the point of view of the CSR of companies, it is necessary to prevent accidents and incidents. Regarding the industrial safety risk analyzed and assessed herein, the creation and implementation of detailed plans are significant issues. Although there are effective measures for individual risks, there are also measures that become effective through participating in the establishment of an industrial safety management system. Since the resources used by companies are not limited to resources that can be assigned to industrial safety activities, it is extremely important to examine and implement highly effective risk reduction methods. The implementation of these measures and the reduction of industrial safety risk are related to the CSR policies of the respective companies.

6.1.6 Influence of global warming on the industrial safety risk of companies

The problem of global warming affects the entire planet, and it is expected that strong wind risk and flooding risk will affect the industrial safety risk of companies. It is possible that it will become necessary to consider the influence of global warming on industrial safety risk for companies.

6.2 Scientific value of the present study

6.2.1 Originality

- A model of industrial safety risk in multinational raw materials manufacturing enterprises was constructed and validated using an exponential distribution function for the scale of damage and the Poisson's distribution function for the frequency of occurrence.
- In assessing industrial safety risk, a unique set of indices was proposed for measuring the scale of damage. As a result, it was possible to compare relative risk between events in different categories of industrial safety risk.

6.2.2 Novelty

- A survey and analysis of industrial safety risk, in particular, fire and explosion risk, strong wind risk, flooding risk, lightning risk, and earthquake risk, was conducted, focusing specifically on multinational raw materials manufacturing enterprises.
- In a model recreating industrial safety risk in multinational raw materials manufacturing enterprises, region-based parameters were obtained for each industrial risk.
- A comparative assessment relating each of the different industrial safety risks was conducted.

6.2.3 Availability

- The present study clearly reveals which industrial safety risks in multinational raw materials manufacturing enterprises must be reduced and that efficient reduction of industrial safety risk can be achieved.
- It was clearly demonstrated that the scale of damage in industrial safety risk can be estimated using an exponential function.
- Instead of basing the reduction of industrial safety risk on an absolute ranking of

priorities, risk theory gives a quantitative indication, with attendant uncertainties, of the reductions that must be made in industrial safety risks.

References

1 Alistair, M.N., Process plant safety and the ISO STEP standard. Journal of Loss Prevention in the Process Industries 8 (1), 41-46 (1995).

2 Bateman., M., Tolley's Practical Risk assessment Handbook, 4th edution ed. (Lexis Nexis UK, Surry, 2003).

3 Bird, E., F.
Germain,G,L., Practical loss control leadership. (Institute Publishing (Division of international Loss Control Institute), Geogia, 1985).

4 Cabinet Office Government of Japan, 2007 White paper on Disaster Management. (Serco, Tokyo, 2007).

5 Carolyn, C.B., Interactions of risk analysis and contingency planning in risk management. Journal of Loss Prevention in the Process Industries 1 (3), 141-146 (1988).

6 Centers for Disease Control (U.S.), Poisson distribution. (Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, Atlanta, 1982).

7 Chua, D.K.H. & Goh, Y.M., Poisson Model of Construction Incident Occurrence. Journal of Construction Engineering and Management 131 (6), 715-722 (2005).

8 Company Evaluation and Business Continuity Working Group, Business Continuity Guidelines, 1st edition ed. (Cabinet office, Government of Japan, 2005).

9 Continuity of Government Commission., American Enterprise Institute for Public Policy Research., & Brookings Institution., Preserving our institutions. The continuity of Congress : the first report of the Continuity of Government Commission. (Continuity of Government Commission, Washington, DC, 2003).

10 CRED, EM-DAT, Available at http://www.em-dat.net, (2008).

11 Daniel, M.K. & David, M.H., Should we risk it? (Princeton University Press, New Jersey, 1999).

12 Evans, J.R. & Olson, D.L., Introduction to simulation and risk analysis. (Prentice Hall, Ner Jersey, 1998).

13 Everley, M., Accident investigation and reporting, Available at

http://www.mike.everley.freeuk.com/download/ac.pdf, (2007).

14 Fire and Disaster Management Agency ed., Annual Fire Report., No.63. (Japan Association for the Promotion of Fire Prevention Research., Tokyo, 2008).

15 Fukuda, K., Project Safety, Available at http://www1.neweb.ne.jp/wb/fukud/safety%20english.htm, (2008).

16 Giddens, A., New Rules of the Sociological Method. (Hutchinson, London, 1976).

17 Hallett, F.R., Physics for the biological sciences : a topical approach to biophysical concepts, 4th ed. (Nelson, Toronto, 2003).

18 Hashizume, T., Introduction of Business risk. (Waseda University Press, Tokyo, 2005).

19 Heinrich, H.W., Industrial accident prevention a scientific approach, 4th edition ed. (McGraw-Hill, New York, 1959).

20 Hirata, I., Legal Arrangements and Industry Practices in Risk Communication Relating to Process Safety management in the U.S.A. and UK. Journal of Japan society for safety engineering 41 (6), 423-429 (2002).

21 HSE, Successful health and safety management. (HSE Books, London, 1997).

22 ISO & IEC Guide 51 in Safety aspects - Gidelines for their inclusion in standards (International Organization for Standardization
International Electrotechnical Commission, Geneva, 1999).

23 ISO & IEC Guide 73 in Riskmanagement Vocabulary Guidelines for use in standards (International Organization for Standardization
International Electrotechnical Commission., Geneva, 1999).

24 Iwaki, H., Basic Statics, Kyoto University Graduate School of Economics, Available at http://pacific.econ.kyoto-u.ac.jp/~iwaki/statistics-5.pdf, (2005).

25 Iwama, K. et al., Development of Fire Risk Evaluation System. Technical Report of IEICE 102 (541), 21-24 (2002).

26 Jaime, S.-R. & Alan, N.B., Assessing safety management systems. Journal of Loss Prevention in the Process Industries 15 (2), 77-95 (2002).

27 James, T., Management introduction to total loss control, 9th., rev edition ed.

(Blitish Safety Council, 1976).

28 Jenq-Renn, C. & Yao-Tai, Y., A predictive risk index for safety performance in process industries. Journal of Loss Prevention in the Process Industries 17 (3), 233-242 (2004).

29 John V, G. & Rollin H, S., Safety Management, 4th edition ed. (Richared D. Irwin, Inc., Illinois, 1984).

30 Kobayashi, Y. ed., Management method by risk-return. (Chuokeizai, Tokyo, 2006).

31 Kusaka, A., Ishida, H., & Torisawa, K., Building Risk Management for Earthquakes and Fires. Kajima Texhnical Research Annual Report 53 (2005.9), 175-182 (2005).

32 Makimoto, N., Probability model approach to Business. (Asakura Shoten, Tokyo, 2006).

33 Masunaga, S. ed., Risk from the point of view of Science and technology, 1st ed. (Iwanami Shoten, Tokyo, 2007).

34 Mckinnon, R.C., Cause, Effect, and Control of Accidental Loss with Accident Investigation Kit. (CRC Press LLC, Florida, 2000).

35 Michael, J.C., Statistics An Introduction using R. (John Wiley & Sons, Ltd., West Sussex, 2005).

36 Mike, B., Tolley's Practical Risk Assessment Handbook, 4th ed. (LexisNexis, Croydon, 2003).

37 Mizuno, T. The statistic Analysis of the Fire Damage of Building which used the Technique based on a Normalized Risk Curve in Conference of Architectural Institute of Japan (Kantou, 2006).

38 Munich, R., Company, Topics Geo Natural catastrophes 2007 Analyses, assessment, positions, Available at http://www.munichre.com/publications/302-05699_en.pdf, (2007).

39 Munich, R., Company, NATHAN, Available at http://mrnathan.munichre.com/, (2008).

40 Nakagawa, H., Quantifying operational risk and scenario analysis, Available at

http://www.boj.or.jp/type/release/zuiji_new/fsc0608bj5.pdf, (2006).

41 Nakamura.A. & Kouda, M. eds., 72 hours after Crisis occurance. (Daiichihouki, Tokyo, 2006).

42 Nick, W.H., Stephen, Y., Ian, D., Huw, G., & Andre, M., Measures of safety management performance and attitudes to safety at majour hazard sites. Journal of Loss Prevention in the Process Industries 9 (2), 161-172 (1996).

43 Nigel, G. ed., Researching Social Life. (SAGE, London, 1992).

44 Noguchi.K., Risk Management Guide. (Japanese Industrial Standard, Tokyo, 2000).

45 Noguchi.K., Risk Management System Building Guide. (Japanese Industrial Standard, Tokyo, 2003a).

46 Noguchi.K., Risk Estimate in Crisis Management. Journal of Japan society for safety engineering 42 (12-15) (2003b).

47 Ohtomo, S. & Hirose, Y., The influences of situation-oriented and goal-oriented decesion-making on risk-related behavir in a natural disaster. Research in Social Psychology 23 (2), 140-151 (2007).

48 Okabe, M. & Ohtani, H., Risk estimation for industrial safety in raw materials manufucturing. Journal of Loss Prevention in the Process Industries (In press).

49 Programme, U.N.D., A Global Report Reducing Disaster Risk A challenge for development, Available at http://www.undp.org/cpr/disred/documents/publications/rdr/english/rdr_english.pdf, (2004).

50 Satou, H., Murai, H., Shida, K., & Kurioka, H., A Study on risk of Fire Spread based on the fire statistic data. Journal of Environmental Engineering.,AIJ. 605 (2006.7), 1-8 (2006).

51 Societies, I.F.o.R.C.a.R.C., World Disasters Report Focus on discrimination. (ATAR Roto Press, Vernier, 2007).

52 Suzuki, K. & Yoshida, H., Fire Simulation Using Spread Model with Probability Theory for Fire Risk Assessment. Journal of Environmental Engineering.,AIJ. 567 (2003.5), 15-19 (2003).

53 Suzuki, S., Understadable actual view point and analysis of risk. (The Nikkan Kogyo Shimbun, Tokyo, 2004).

54 Takahashi, H., Safety Goal in Technological Society. Journal of Japan society for safety engineering 41 (6), 364-370 (2002).

55 Takeichi, N., Building Regulation and Market. BULLETIN OF JAPAN ASSOCIATION FOR FIRE SCIENCE AND ENGINEERING 49 (6), 1-17 (1999).

56 Tamura, H., Yamamoto, K., Akazawa, K., & Taji, K., Modeling Decision Analysis for Mitigating Natural Disaster Risks. ISCIE Journal 'Systems, Control and Information' 13 (6), 268-276 (2000).

57 Tixier, J., Dusserre, G., Salvi, O., & Gaston, D., Review of 62 risk analysis methodologies of industrial plants. Journal of Loss Prevention in the Process Industries 15 (4), 292-303 (2002).

58 Toyota, H., Lecture of Investigation (Asakura shoten, Tokyo, 1998).

59 UNEP, Disasters Database, Available at http://www.unepie.org/pc/apell/disasters/lists/disasterdate.html, (2008).

60 Vince, R., The mathematics of money management : risk analysis techniques for traders. (Wiley, New York, 1992).

61 Vose, D., Risk Analysis A Quantitative Guide, 2nd edition ed. (John Wiley & Sons, Ltd., New York, 2000).

62 Wakakura, M., Fire & Explosion Risk of Chemical Substance. Powder Science & Engineering 40 (3), 64-70 (2008).

63 Watabe, H. & Matsumoto, M., Development of Quantitative Risk Evaluation Method for Fire. Fire 51 (3), 18-21 (2001).

64 Working, H., A guide to utilization of the binomial and Poisson distributions in industrial quality control. (Stanford Univ. Press, Stanford Univ., California,, 1947).

65 Yamamura, T., How to make a Enterprize accident prevention and Crisis management Manual. (Kinzai Institute for Financial Affairs, Inc., Tokyo, 2006).

66 Yamane, Y., Kosaka, Y., & Fuse, T., How to make a disaster prevention manual that protects an enterprize. (Management Corp., Tokyo, 2005).

67 井口武雄, 大規模災害リスクへの対応. オペレーションズ・リサーチ 41

(2), 18-22 (1996).
68　　橋本光憲, ビジネスリスク—海外での失敗事例から学ぶもの（上）. 神奈川大学国際経営論集 24 (2002.11), 1-52 (2002).
69　　橋本光憲, ビジネスリスク—海外での失敗事例から学ぶもの（中）. 神奈川大学国際経営論集 25 (2003.3), 363-382 (2003).
70　　近藤駿介, 安全を確保するための工学的アプローチ, Available at http://www4.jnes.go.jp/data/jeutoc/1/0102Kondo02.pdf, (2003).
71　　江里口隆司, リスクと損害保険, Available at http://www.nsc.go.jp/anzen/sonota/panel/panel001/12eriguchi.pdf, (2002).
72　　甲斐良隆, 自然災害とリスク・シェアリング. ESP. economy, society, policy 493 (2006.10), 26-30 (2006).
73　　綱木亮介, 自然災害に対するリスクマネジメント. 土木技術資料 48 (8), 22-23 (2006).
74　　高市悟, 海外進出とリスクマネジメント. 産業能率 558 (2003.9), 2-5 (2003).
75　　国際開発ジャーナル, 海外のリスクマネジメント. 国際開発ジャーナル 569 (2004.4), 17-29 (2004).
76　　佐藤博臣, 火災リスクの観点からみた防火設備の役割と実際. 火災 55 (6), 5-10 (2005).
77　　佐藤博臣, 管見—火災リスクへの備え. BELCA news 19 (112), 46-53 (2008).
78　　室崎益輝, 火災リスクの現状と消防防火の課題. 建築の研究 179 (2007.2), 1-4 (2007).
79　　酒井重人, 大規模自然災害とリスクマネジメント—ERM の観点から. 予防時報 225 (2006.Spr), 36-41 (2006).
80　　酒井重人, 自然大災害とエンタープライズ・リスクマネジメント—急拡大する保険リンク証券市場. あいおい基礎研 review 3 (2007.7), 44-57 (2007).
81　　重川希志依, 自然災害への対応. 地方自治職員研修 33 (10), 41-43 (2000).
82　　数原一男, 火災・爆発リスクとリスクマネジメント. バンコク日本人商工会議所報 463 (2000.10), 30-36 (2000).

83　増本清, 火災のリスク評価. 労働安全衛生広報 35 (827), 26-29 (2003).
84　損害保険料率算出機構研究部, 建物の火災危険度評価手法の開発—シミュレーションによる工場火災のリスクの定量化. RISK 64 (2002.6), 1-10 (2002).
85　大島英雄, リスクマネジメント最新事情（6）海外進出におけるリスクと対策. 企業診断 48 (9), 94-97 (2001).
86　田和淳一, 工場防火はリスク管理で—損保の観点からみる火災対策. 安全スタッフ 2049 (2007.9.1), 8-19 (2007).
87　島崎邦彦, 長期的な地震発生確率の評価手法について, Available at http://www.nliro.or.jp/disclosure/risk/risk55-3.pdf, (1999).
88　日本銀行金融機構局, 損失額分布やパラメータ推定手法の選択がオペレーショナルリスク計量結果に与える影響について, Available at http://www.boj.or.jp/type/ronbun/ron/research07/data/ron0706a.pdf, (2007).
89　能島暢呂, 被害情報の統合による早期被害把握の数理モデル, Available at http://www.orsj.or.jp/~archive/pdf/bul/Vol.47_07_432.pdf, (2002).
90　末吉竹二郎, 欧州保険会社が発表する自然災害リスク額. 環境会議 25 (2006.春), 234-238 (2006).

Glossary

Acronyms

BARPI:	Bereau d'Analyses des Risques et des Pollutions Industrielles
BCP:	Business Continuity Plan
CRED:	WHO Collaborating Center for Research on the Epidemiology of Disasters
Crystal Ball^{TM}:	Ball: Software developed and published by Decisioneering, Inc.
EM-DAT:	Emergency Disasters Data Base
IEC:	International Electrotechnical Commission
ISO:	International Organization for Standardization
MHIDAS:	Major Hazardous Incident Data Service
NATHAN:	Natural Hazards Assessment Network
OECD:	Organization for Economic Co-operation and Development
OFDA:	Office of U.S. Foreign Disaster Assistance
SEI:	Stockholm Environment Institute
SIGMA:	Support for Improvement in Governance and Management (EU, OECD)
TNO:	Geological Survey of the Netherlands
UBA:	Das Umweltbundesamt
UNDP:	United Nations Development Programme
UNEP:	United Nations Environment Program(me)

Appendix A

Table A. 1 Number of disasters in each country

	Explosion	Fire	Earthquake	Wind Storm	Flood
Belgium	30	4	2	20	20
Czech Rep	0	0	0	3	8
France	4	4	1	44	28
Indonesia	5	5	121	10	92
Italy	1	0	29	16	29
Japan	4	0	46	135	52
Thailand	9	5	1	29	60
USA	20	8	35	477	154

Data from: EM-DAT

Created on: Feb-27-2008 - Data version: v12.07 (From 1900 to 2007 October)

Source: "EM-DAT: The OFDA/CRED International Disaster Database

www.em-dat.net - Université Catholique de Louvain - Brussels - Belgium"

Table A. 2 Area of each country

	Area (sq km)
Belgium	30,528
Czech Rep	78,866
France	547,030
Indonesia	1,919,400
Italy	301,230
Japan	377,835
Thailand	514,000
USA	9,826,630

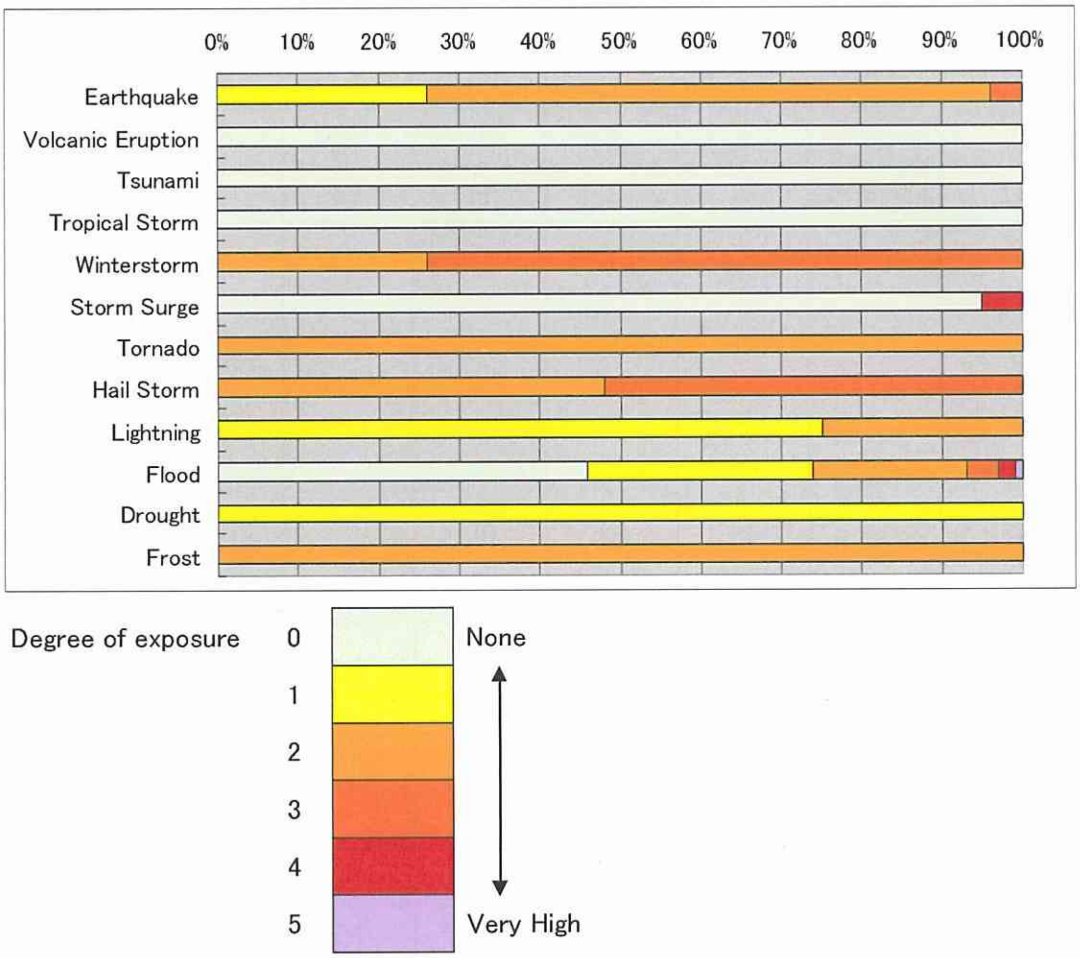
Data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Appendix B

Table B. 1 Affected country area percentage by degree of exposure in Belgium

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		26	70	4			178
Volcanic Eruption	100						0
Tsunami	100						0
Tropical Storm	100						0
Winter Storm			26	74			274
Storm Surge	95				5		20
Tornado			100				200
Hail Storm			48	52			252
Lightning		75	25				125
Flood	46	28	19	4	2	1	91
Drought		100					100
Frost			100				200

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



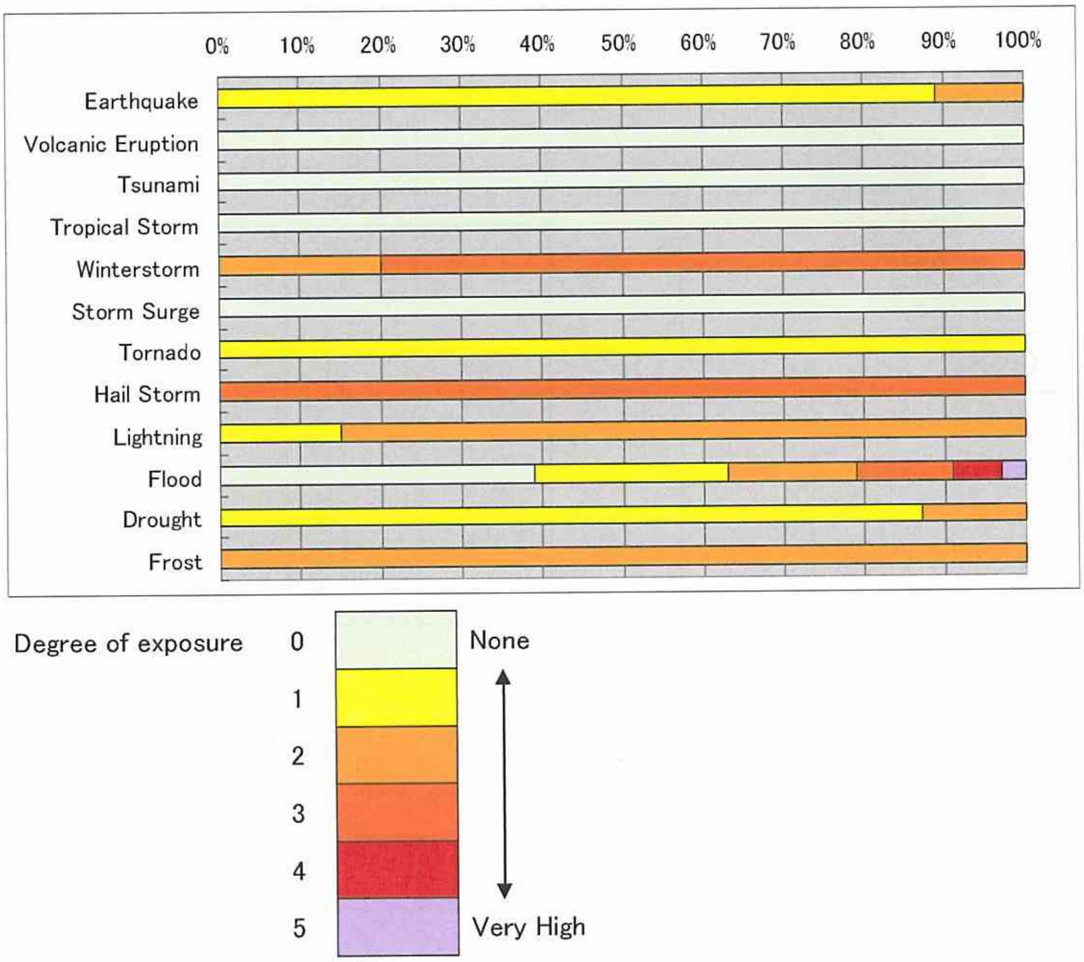
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 1 Affected country area percentage by degree of exposure in Belgium

Table B. 2 Affected country area percentage by degree of exposure in Czech Rep

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		89	11				111
Volcanic Eruption	100						0
Tsunami	100						0
Tropical Storm	100						0
Winter Storm			20	80			280
Storm Surge	100						0
Tornado		100					100
Hail Storm				100			300
Lightning		15	85				185
Flood	39	24	16	12	6	3	131
Drought		87	13				113
Frost			100				200

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



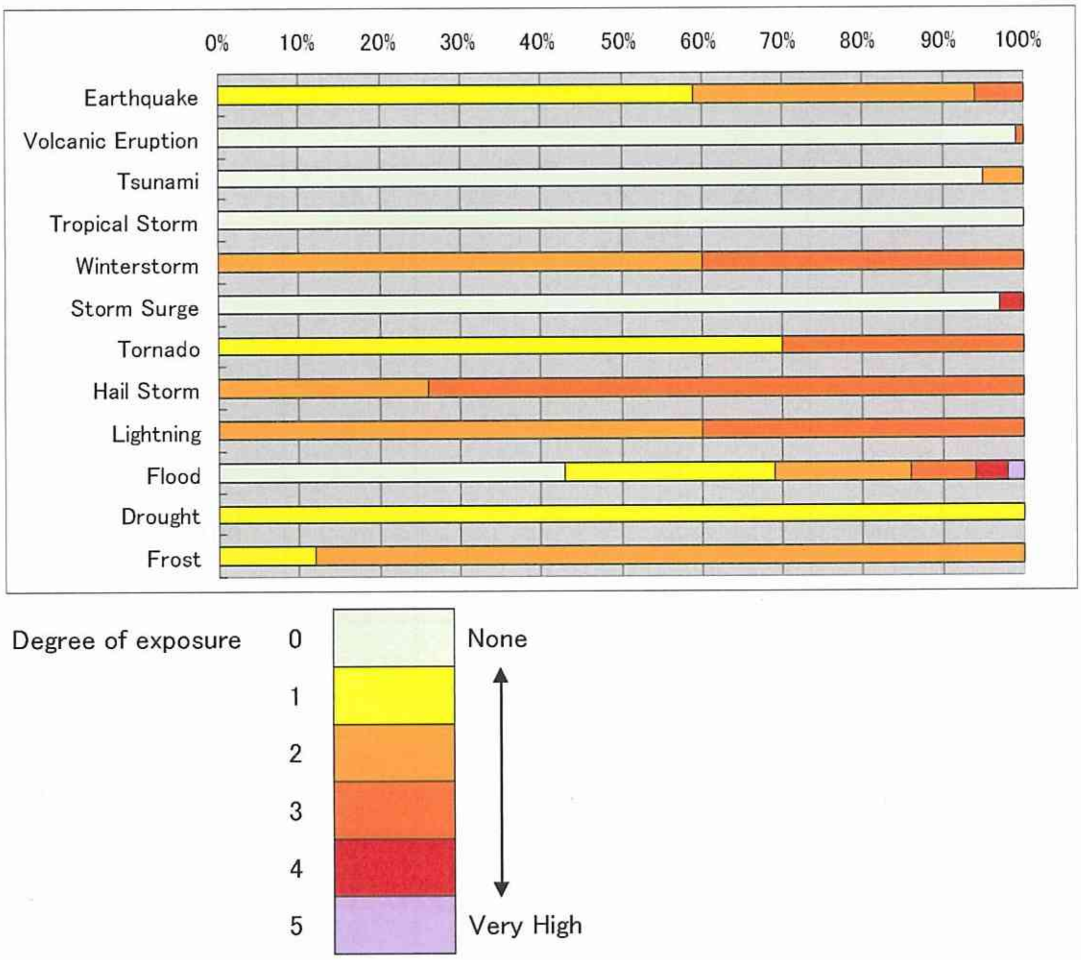
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 2 Affected country area percentage by degree of exposure in Czech Rep

Table B. 3 Affected country area percentage by degree of exposure in France

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		59	35	6			147
Volcanic Eruption	99			1			3
Tsunami	95		5				10
Tropical Storm	100						0
Winter Storm			60	40			240
Storm Surge	97				3		12
Tornado		70		30			160
Hail Storm							
Lightning			26	74			274
Flood	43	26	17	8	4	2	110
Drought		100					100
Frost		12	88				188

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



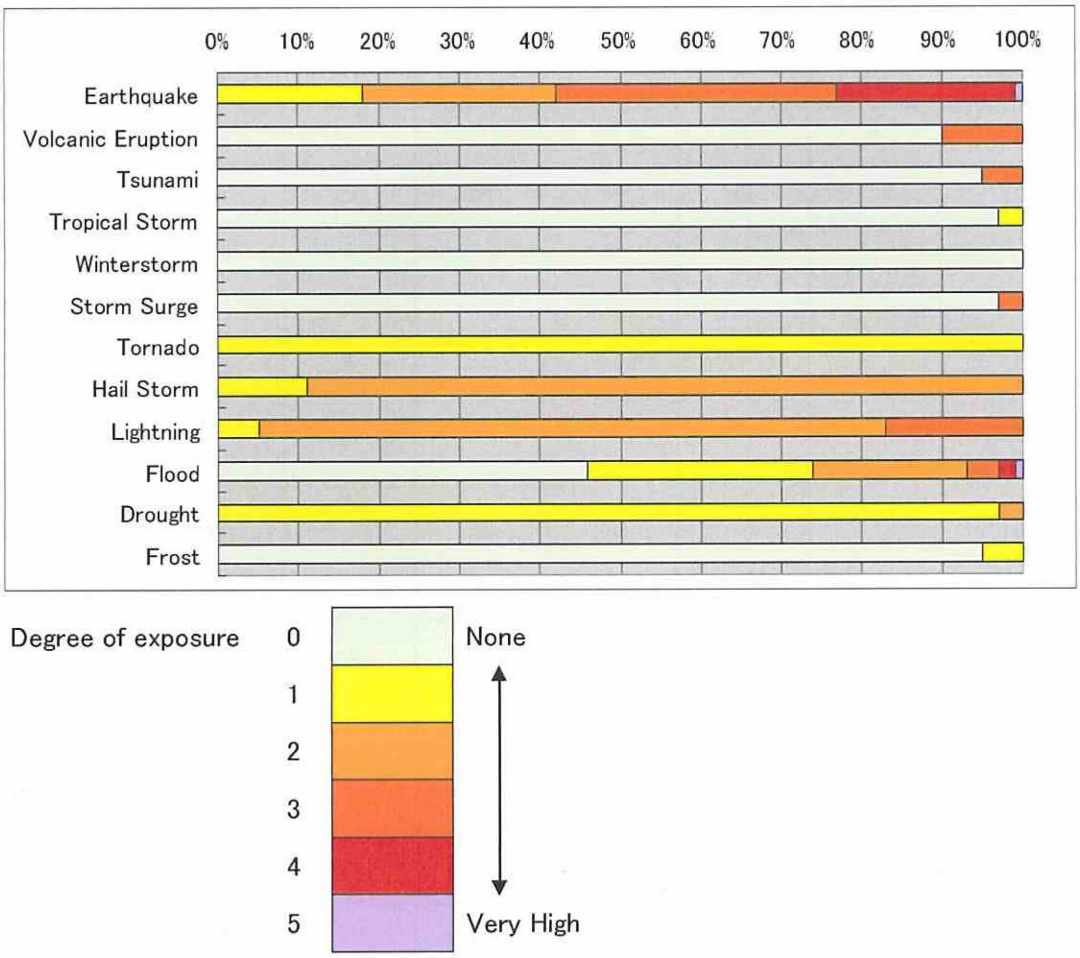
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 3 Affected country area percentage by degree of exposure in France

Table B. 4 Affected country area percentage by degree of exposure in Indonesia

	None 0	1	2	3	4	Very High 5	Evaluation
Earthquake		18	24	35	22	1	264
Volcanic Eruption	90			10			30
Tsunami	95			5			15
Tropical Storm	97	3					3
Winter Storm	100						0
Storm Surge	97			3			9
Tornado		100					100
Hail Storm		11	89				189
Lightning		5	78	17			212
Flood	46	28	19	4	2	1	91
Drought		97	3				103
Frost	95	5					5

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



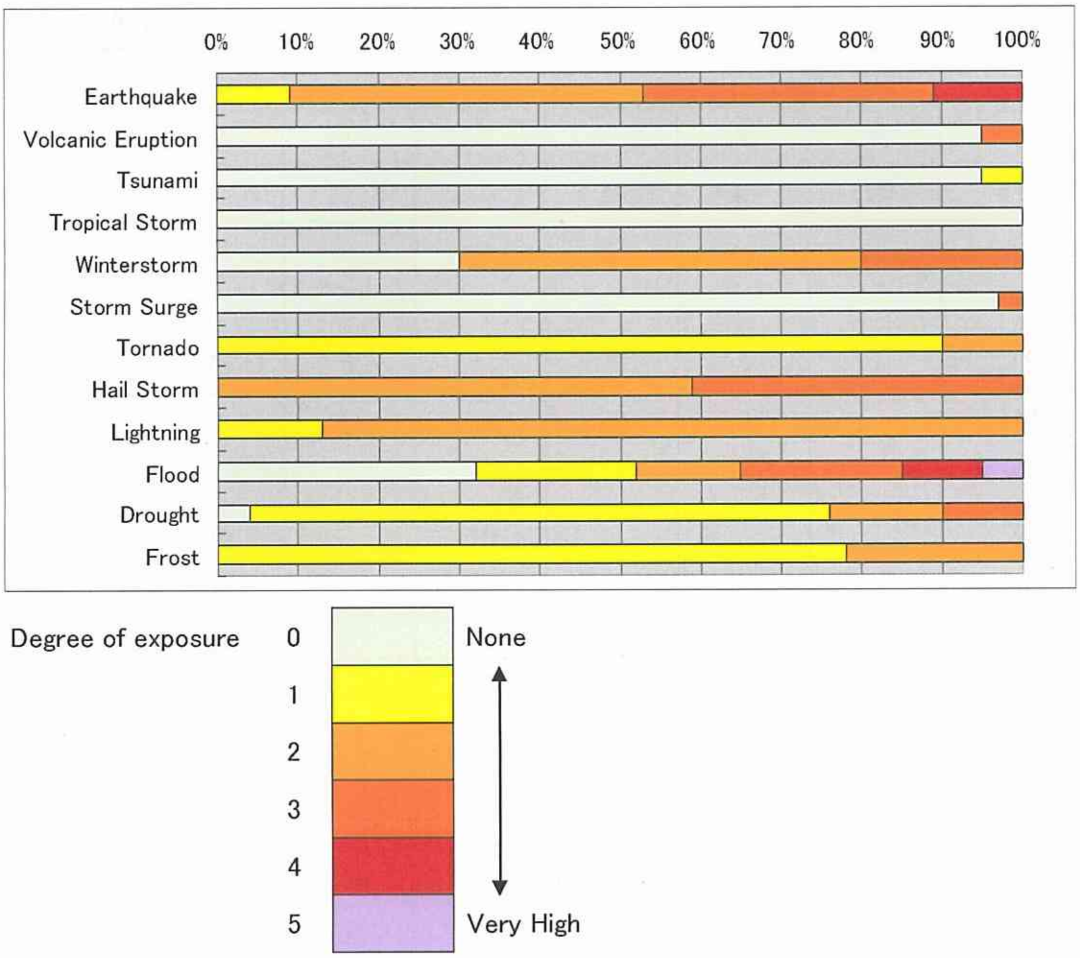
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 4 Affected country area percentage by degree of exposure in Indonesia

Table B. 5 Affected country area percentage by degree of exposure in Italy

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		9	44	36	11		249
Volcanic Eruption	95			5			15
Tsunami	95	5					5
Tropical Storm	100						0
Winter Storm	30		50	20			160
Storm Surge	97			3			9
Tornado		90	10				110
Hail Storm			59	41			241
Lightning		13	87				187
Flood	32	20	13	20	10	5	171
Drought	4	72	14	10			130
Frost		78	22				122

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



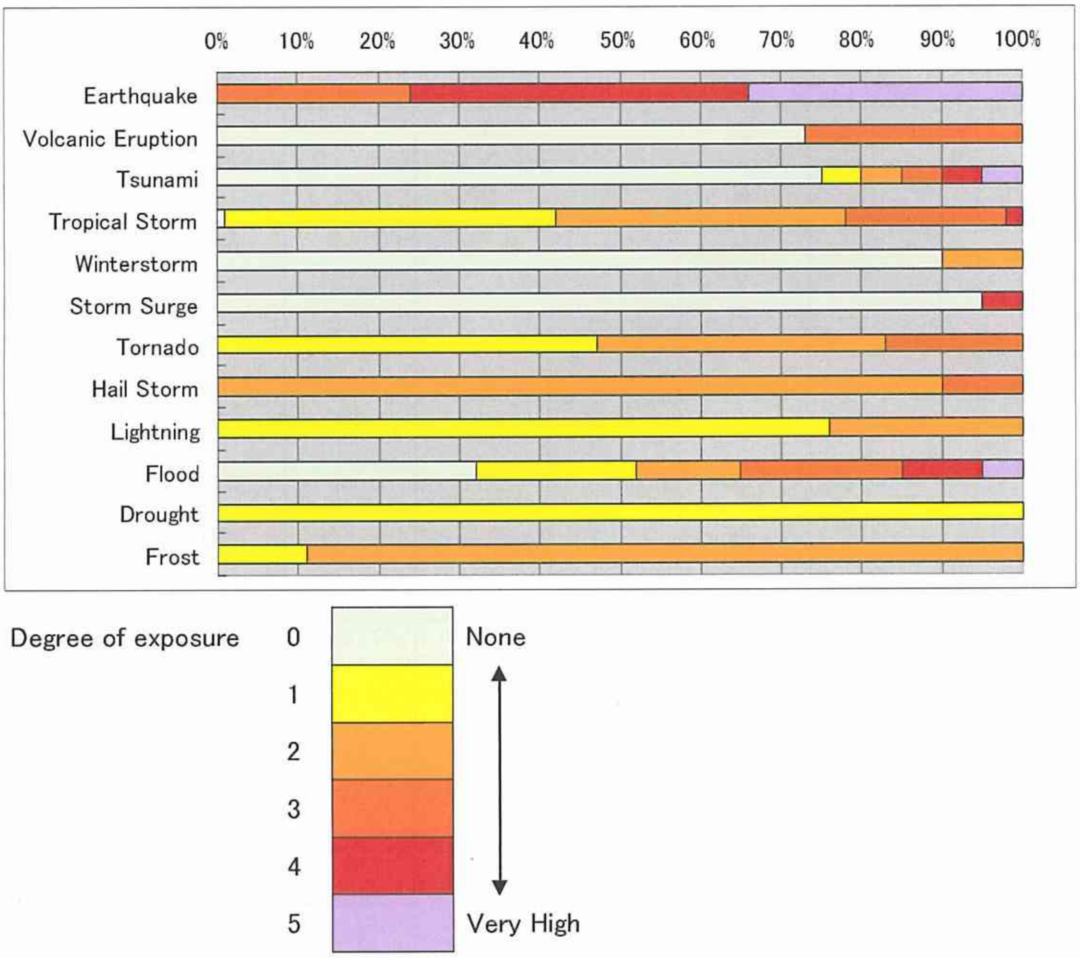
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 5 Affected country area percentage by degree of exposure in Italy

Table B. 6 Affected country area percentage by degree of exposure in Japan

	None 0	1	2	3	4	Very High 5	Evaluation
Earthquake				24	42	34	410
Volcanic Eruption	73			27			81
Tsunami	75	5	5	5	5	5	75
Tropical Storm	1	41	36	20	2		181
Winter Storm	90		10				20
Storm Surge	95				5		20
Tornado		47	36	17			100
Hail Storm			90	10			210
Lightning		76	24				124
Flood	32	20	13	20	10	5	171
Drought		100					100
Frost		11	89				189

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



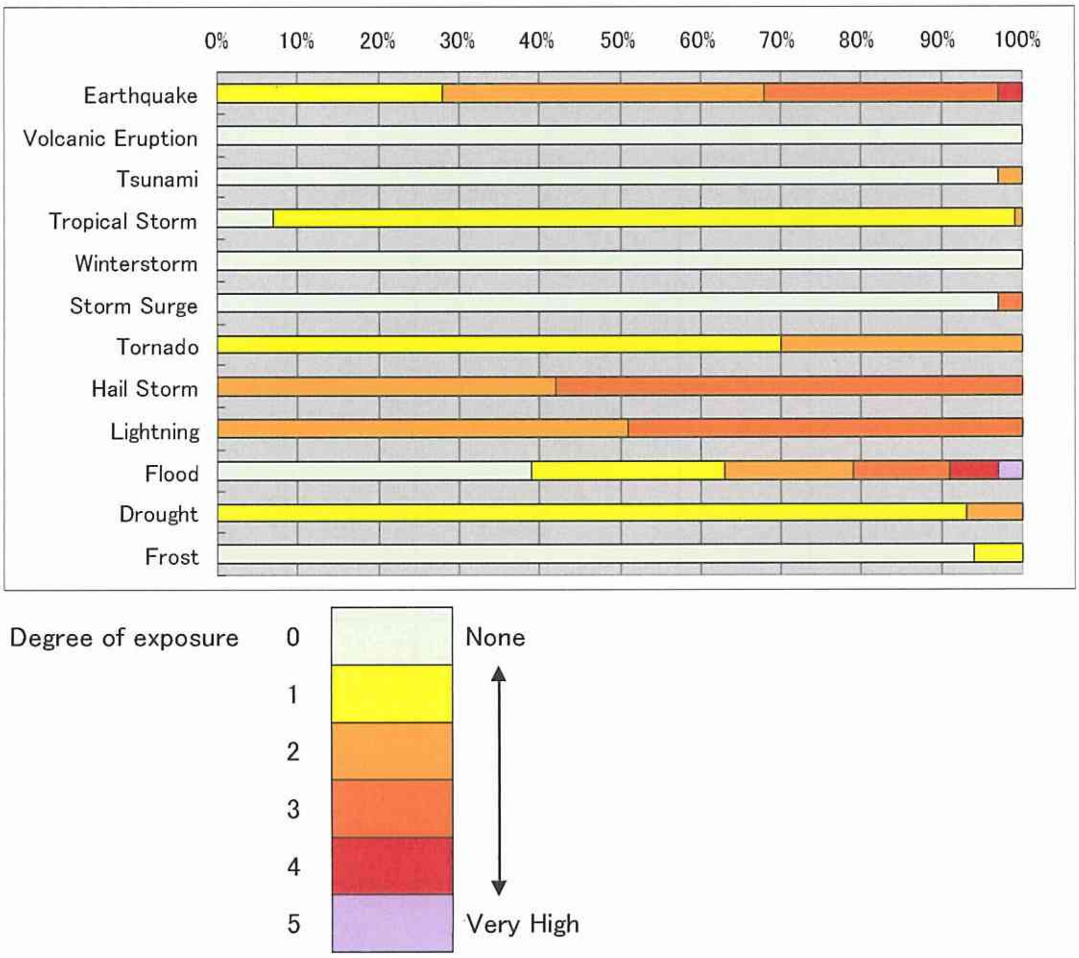
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 6 Affected country area percentage by degree of exposure in Japan

Table B. 7 Affected country area percentage by degree of exposure in Thailand

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		28	40	29	3		207
Volcanic Eruption	100						0
Tsunami	97		3				6
Tropical Storm	7	92	1				94
Winter Storm	100						0
Storm Surge	97			3			9
Tornado			70	30			130
Hail Storm			42	58			258
Lightning			51	49			249
Flood	39	24	16	12	6	3	131
Drought		93	7				107
Frost	94	6					6

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



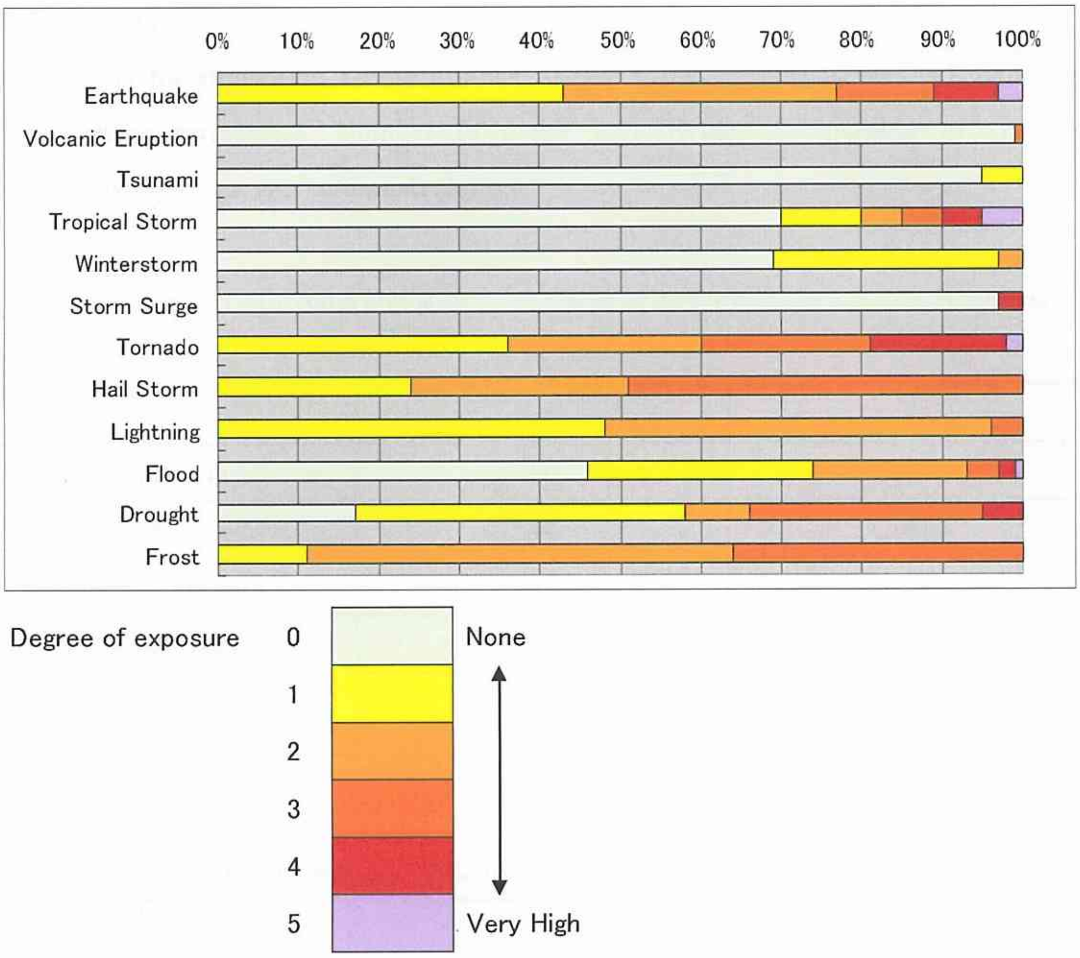
Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 7 Affected country area percentage by degree of exposure in Thailand

Table B. 8 Affected country area percentage by degree of exposure in USA

	None					Very High	Evaluation
	0	1	2	3	4	5	
Earthquake		43	34	12	8	3	194
Volcanic Eruption	99			1			3
Tsunami	95	5					5
Tropical Storm	70	10	5	5	5	5	80
Winter Storm	69	28	3				34
Storm Surge	97				3		12
Tornado		36	24	21	17	2	225
Hail Storm		24	27	49			225
Lightning		48	48	4			156
Flood	46	28	19	4	2	1	91
Drought	17	41	8	29	5		164
Frost		11	53	36			225

Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006



Original data source: Munch Re Geo Risks Research, Last update: 10/12/2006

Figure B. 8 Affected country area percentage by degree of exposure in USA

Appendix C

Parameters for simulation are as follows. Monte Carlo simulation was calculated by using these parameters. Number of event was divided by number of site for standardization "per site" after calculation.

Table C. 1 Number of events and scale of damage in as a whole enterprise (101 sites, 10 years)

	λt	β
Fire and explosion	66	3.152
Strong winds	44	2.614
Flooding	37	2.541
Lightning	56	2.179
Earthquake	25	2.308

Table C. 2 Number of events and scale of damage in Japan (58 sites, 10 years)

	λt	β
Fire and explosion	29	4.103
Strong winds	37	2.892
Flooding	20	2.750
Lightning	34	2.559
Earthquake	15	3.113

Table C. 3 Number of events and scale of damage in Asia excluding Japan (19 sites, 10 years)

	λt	β
Fire and explosion	20	2.000
Strong winds	1	2.000
Flooding	6	4.167
Lightning	10	1.600
Earthquake	4	1.500

Table C. 4 Number of events and scale of damage in Europe (19 sites, 10 years)

	λt	β
Fire and explosion	12	2.333
Strong winds	4	1.000
Flooding	9	1.333
Lightning	9	1.778
Earthquake	6	1.000