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VULNERABILITY ASSESSMENTS AND RISK MANAGEMENT FOR CRITICAL INFRASTRUCTURES FROM HOMELAND SECURITY VIEWPOINTS

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ABSTRACT: The employment of risk management theory in Urban Disaster Management System (UDMS) has become an important trend in recent years. The viewpoint of risk management is mainly a comprehensive risk assessment of various internal and external factors, and a subsequent handling of risks. Through continuous and systematic accumulation and analysis of risk information, disaster prevention and rescue system is established. Taking risk management theory as the foundation, Organization for Economic Cooperation and Development (OECD) has developed a series of UDMS in the mega-cities all over the world. With this system as a common platform, OECD cooperates with different cities to develop disaster prevention and rescue system consisting of vulnerability assessment methods, risk assessment and countermeasures. The paper refers to the urban disaster vulnerability assessment and risk management of OECD and the mega-cities of different advanced and developed countries in the world, and then constructs a preliminarily drafted structure for the vulnerability assessment methods and risk management mechanism in the metropolitan districts of Taiwan.

Keywords: sustainable city; urban disaster prevention; critical infrastructures; vulnerability assessment; risk managemen

1. INTRODUCTION

In recent years, due to the change of environment, population is concentrated in cities. In addition, because of the consequences of global warming, large-scale natural hazards and human-caused hazards happened frequently, such as the great earthquake happened in Sichuan of China[5], the hurricane disaster in Burma[6], the great earthquakes happened in Taiwan and Turkey, the tsunami in South Asia, the hurricane Katrina in the United States, and the intercontinental human-caused terrorist disaster, "911 attack"[7] happened in the United States. All of these disasters brought numerous casualties and massive property loss. The reconstruction after disasters wasted labor and material resources in huge

[5] According to the report of Chinese government, Wenchuan earthquake brought a great number of casualties and property loss to the city. Wenchuan Earthquake happened at the place of 90 kilometers northwest western side of Chengdu City, the capital of Sichuan Province of China on May 12, 2008. The number of deaths directly caused by the earthquake had been over 62,664. This earthquake created the most casualties in China ever since the last catastrophic Tangshan earthquake happened on Jul. 28, 1976 (BBC Chinese.com).

[6] A devastating tropical cyclone "Nargis" hit Burma on May 2, 2008, creating a huge disaster to the country. Burmese government announced that 22,464 people died and 41,054 people were missing. The United Nations' officials proved that the number of deaths exceeded 100,000. (BBC News).

[7] The 911 terror attack, simply called "911 events" was a suicide terror attack happened in the continent of the United States on Sep. 11, 2001, through terrorists' hijacks of several passenger jets to deliberately fly into skyscrapers. There were 2,998 people died in the incident, with a total of 6 buildings, including the landmark buildings of New York, the twin towers of World Trade Center, being completely collapsed. The headquarters of the US Department of Defense, Pentagon, was attacked as well. Subsequently, the US economy was also seriously affected. This incident had brought greater pressure to the anti-terrorist actions within international range, including the Afghan war, Iraq war, and the acts focusing on terrorist organizations and related countries (Wikipedia: http://zh.wikipedia.org/).

volume, causing great impacts to the economy and strength of the victim countries.

The implantation of risk management has become a trend of the whole world in working together to study the establishment of urban disaster prevention and rescue system [1] [2]. Since some great disasters shifted from regional type as in the past to be cross-national type as in recent years, such as SARS (severe acute respiratory syndrome) event and the tsunami in South Asia, both belonging to disasters of cross-national type, and in order to accelerate the research and development (R&D) efficiency of disaster risk management, many cross-national allied organizations, such as United Nations (UN), European Union (EU), Association of Southeast Asia (ASEAN), etc. have positively started the related risk management studies of disaster prevention and rescue.

Through literature reviews, and referring to the research results of vulnerability assessment methods and applications of risk management in different mega cities, this paper synthesizes and collates the risk management information for related application to disaster prevention in mega-cities, and then constructs a preliminarily drafted structure for the vulnerability assessment methods and risk management mechanism in the metropolitan districts of Taiwan. In future, the database of vulnerable space of critical infrastructures shall be established, and a systematic analysis on the cost loss possibly caused in vulnerable urban districts shall be made.

2. BACKGROUND

2.1 Global Urbanization Statistics

The proportion of urban population is an index for reviewing the concentration degree of urban population. It also reveals the importance of urban disaster prevention. According to the statistical data on the world's urbanization announced by Population Division, Department of Economic and Social Affairs, UN in 2007, in the 1950's urban population occupied 30% of the world's total population. Before 2008, half of the world's total population was concentrated in cities. In the 2050's, urban population shall occupy 70% of the world's total population. These results show the trend of urbanization in the world (see Figure 1).

In the early 20th century, around 2% of population lived in 14 metropolitan districts, but currently 20% of population is living in metropolises. It is estimated that in 2020 around 30% of population will live in these metropolitan districts, and the population of these metropolitan districts will grow very fast. Dating back to 1990, only 3 metropolitan districts (London, Paris and New York) owned population of over 3 million. Presently, over 60 cities have population of over 3 million, and there are even 19 mega-cities with population over 10 million. According to the survey report announced by UN on Feb. 26, 2008, the data of Population Division, Department of Economic and Social Affairs showed that among the 19 mega-cities with population over 10 million, 11 of them were in Asia, 4 in Latin America, 2 in North America, and 1 in Africa and Europe respectively. In 2025, the number of mega-cities will be increased to 27; and 5 mega-cities will be increased in Asia, 2 in Africa, and 1 in Europe. In 2050, the total population of the world shall be doubled, with population drastically increased from 3.3 billion in 2007 to 6.4 billion.

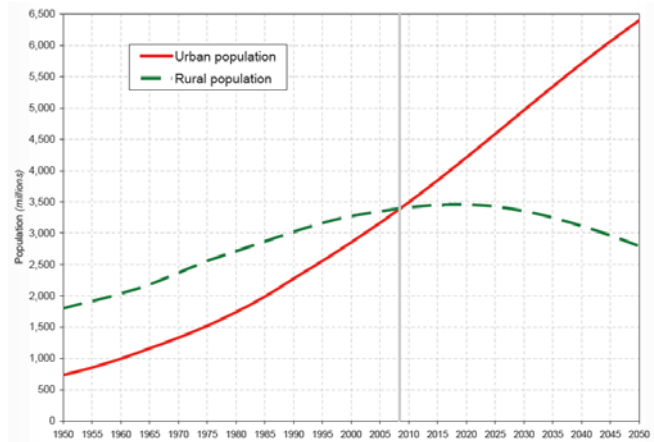

Figure 1. Statistics of the world's rural and urban population from 1950 to 2050 (Source: Statistical data of Population Division, Department of Economic and Social Affairs, UN)

2.2 Problems Derived from Urbanization

In recent years, due to the consequences of global warming and climate change, fast environmental change, population concentration in cities, excessively concentrated urban population, and formation of cross-national concepts like "global village" and "globalization," the interdependencies among different places of the world have been increased [3]. The national boundaries in the world have been blurred. The world starts to enter a process integrating the economy, culture, technology, governance and other areas of the various countries to be one wholeness. Driven by innovative technology, trade grows very fast; the direct investment of foreign countries rapidly expands; the financial markets of the world integrate; media business dominates the demand of information market; and the network world has been formed. All these factors have directly and indirectly accomplished the trend of globalization.

The events and activities handled by single country in the past have been inclining to internationalization and regionalization. And the various problems derived from urbanization, including organizational crime, terrorist activities, trading safety, network crime, family problem, multiplication of disaster and different kinds of human conflicts, shall leap over national boundaries.

As to the non-conventional national security and public order, the poisonous milk powder incident recently happened in Mainland China creating social panic and unrest was a very obvious case of Food Chain Security

System, being listed as a critical infrastructure protection mechanism formulated by Department of Homeland Security (DHS) of the United States. Therefore, the construction of sustainable cities is not merely a single problem of hardware equipments of utilities. Scholars think that critical infrastructures are affecting each other (e.g. the damage of power supply would relatively affect the running of mass rapid transit of the city), and the mutual effects are in an intricate network form.

3. DEFINITION OF URBAN DISASTER RSIK

3.1 Definition of Risk and Vulnerability

The term "risk" has many different facets of definition. American Risk and Insurance Association (ARIA) defines risk in this way, "Risk is defined here as uncertainty concerning the occurrence of a loss" [4]. From the definition, it can be seen that risk is correlated with uncertainty, probability and loss. And "risk" is also "a quantitative measurement method of the results of disaster, and is usually expressed by the probability of the happening conditions of disaster according to experience." Risk can also show the probability for an incident to have potential effects in the achievement of organization goals, and reveal the effect level of the incident.

"Risk management" is a set of procedures of systematic analysis, including risk identification, estimation of risk expectancy, risk assessment, and risk handling measures. Through the analysis of risk, we can take appropriate procedures to decrease or prevent the taking of risk, and further assess the results of risk management. Therefore, risk management refers to the procedures and systematic process to be implemented for effective management of an incident to be possibly happened and its unfavorable consequences. Sometimes, risk management is regarded as a kind of management of damage prevention.

As mentioned above, risk management is a kind of systematic use of the principles, standards and tools of management and process analysis in order to let all the related security items achieve the best situation under the limitation of operation effects, time and cost at different stages of missions. Therefore, to apply systematic risk management procedures effectively, different kinds of hazard have to be assessed, including equipment, hardware, procedures, and the people accomplishing the missions or creating the hazard. All of them have to be considered as a part of the system.

The term "vulnerability" has always been mixed up with "risk." Many references define vulnerability as "susceptibility" or "coping and dealing." Lowrance defines risk as measurement of the probability and severity of harmful function [5]. And Kaplan thinks that risk is a synthesis of scenario, likelihood and consequence [6]. The difference between them is: Kaplan is the first person mentioning the tactful saying that scenario is what can go wrong. NSTAC suggests that vulnerability system is the exposure, accessibility and susceptibility to natural disaster, and the deliberately involved intervention or terror attack [7]. Hence, vulnerability refers to the measurement of susceptibility under a certain situation, and assessment should be made under this situation. Risk assessment is helpful to understand what kind can be damaged easily, the possibility of damage, and the consequences derived.

In the book *Critical Infrastructure Protection in Homeland Security* [8], vulnerability (Vi) is defined as the probability of a fault, which is also the probability for the failure of component i (p_i). For each fault, there is an associated cost expressed in terms of casualties, loss of productivity, loss of capital equipment, loss of time, and so forth. This is called the component's value or, simply, damage (d_i), which is to be multiplied by the fault probability producing risk. Therefore, for component i, risk (r_i) is the product of vulnerability times damage.

For component i:
Risk = fault probability times damage, or
$r_i = p_i \times d_i$.

The vulnerability and risk of infrastructure sector are the total vulnerability and risk of all the components, and can be expressed as the following equations:

$$V = (1/n)\sum_i^n v_i = (1/n)\sum_i^n p_i$$

$$R = \sum_i^n r_i = \sum_i^n p_i \times d_i$$

where:

$v_i = p_i$ = component vulnerability (ranging from 0% to 100%).

d_i = fault damage (typically expressed in terms of dollars).

$r_i = p_i \times d_i$ = risk of component i (typically expressed in terms of dollars).

$a_i = (1 - p_i)$ = availability of component i (probability component does not fail).

g_i = degree of node i (number of links connecting node i to the network).

3.2 Applications of Risk Management to Disaster Mitigation

Regarding the application of risk management to disaster mitigation in cities, a Japanese scholar of Kyoto University, Norio Okada proposes the structure of "Integrated Disaster Risk Management (IDRM)." Focusing on the urban diagnosis, analytical procedures are suggested [9] [10] [11]. Among the various urban operation systems, the 13 major systems of critical infrastructure (see the contents of critical infrastructure in the following paragraphs) mentioned in the report of the Department of Homeland Security (DHS) of the United States are the most important ones. In order to ensure the stability and firmness of these 13 interdependent columns (13 major systems), and solidify the key basic conditions of national security, economic development and people's life, the study made an explanation on the structure of risk management and the substantial contents of critical infrastructure as follows:

(I) Integrated disaster risk management:

Norio Okada points out that the innovative concept applicable to the disaster prevention and control of the world is "Integrated Disaster Risk Management (IDRM)." Especially focusing on the aspect of urban vulnerability diagnosis, more complete and integrated viewpoints are proposed, and are further explained as follows [11]:

i) "Disaster" is different from "hazard," and the former occurs only after consequences (loss, damage) are resulted from the latter.

ii) "Disaster" is an outcome of risk management where unknowns and uncertainties are unavoidably inherent.

iii) "Disaster" is caused and promoted by the degree and patterns of vulnerability and exposure of involved object agents spatially and temporally distributed over a common region, city or local community.

(II) Definition of critical infrastructure:

The term "critical infrastructure" mainly appears in Marsh Report of the United States in 1996 and executive order EO-13010, in which infrastructure is defined as [12]:

"a network of independent, mostly privately-owned, man-made systems that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services."

And "critical infrastructure" can also be explained as "vital infrastructure, which is defined as:

"an infrastructure so vital that is its incapacity or destruction would have a debilitating impact on our defense and national security."

Although Marsh Report mentions that "vital infrastructure" has significant effects to the overall national security, the Report only mentions the contents of "vital critical infrastructure," but does not give clear definition to the term "vital." As a matter of fact, how to define which assets belong to the so-called "vital" "infrastructures" and need to be protected, which are not "vital," how to rank their vitality and make classification of them, and what are the mutual effects among different "infrastructures," this is a very great challenge.

According to the original text of Patriot Act of the United States in 2001, the definition of critical infrastructure is as follows:

Critical Infrastructure*: Those systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.*

Critical infrastructure refers to those physical or non-physical assets, whose potential systems being damaged or invalid would bring great impacts to the national security, economic security, citizens' health or security protection in any forms. In a paper about sustainable cities published by a scholar, Lewis [13], the author cites the report of the Department of Homeland Security of the United States, and thinks that critical infrastructure covers the following 13 major systems[8] [13]:

1. Agriculture system
2. Food supply system
3. Water supply system
4. Public health system
5. Emergency services system
6. Government operation system
7. National defense industrial base
8. Information and telecommunication system
9. Energy supply system
10. Transportation system of people and product
11. Banking and finance
12. Chemical industry
13. Postal and shipping

The above critical infrastructures are considered the basic essentials and foundation of national security, national economy and the daily life of citizens. Once any one of them is destructed or threatened, the effe ct levels will be comprehensive and connected, and t he damage will be doubled.

As seen from the above, critical infrastructures are not only the significant basic conditions affecting national security, economic security and development, and the life of citizens. The complicated interdependent system formed among them is even an essential for a country to achieve peace and good public order for a long time. Once this complicated system is damaged, irremediable chain effects must be caused within the territory of the entire homeland. Therefore, different countries pay great attention to the protection work of critical infrastructures. They successively put in a great deal of resources and

[8] Lewis thinks that every mega-city has to possess these functional systems of main infrastructure to serve as the foundation for basic operation of life and work. And the interdependence between system and system is very high, thus forming a mesh network. Each of them is indispensable.

efforts to study this problem, and positively implement necessary management strategies and revise the related legal standards. It is also mentioned in some references that in the era with so high interdependencies, solely spending a great deal of funds and time on substantial protection cannot improve and solve the problems of vulnerable public safety and national security [14] [15].

(III) Strategic Thinking of Critical Infrastructure Protection

Lewis points out that the most efficient way of protection for network-structured critical infrastructure is to understand the hubs of these major critical infrastructures. Its analytical way is just the use of critical hub analysis to find the locations of vital critical infrastructures [16]. The optimal protection strategy of vital critical infrastructures is to be implemented by using the 80-20% principle of resources, i.e. 80% of national protection resources should be placed on 20% of the vital critical infrastructures. But the point is: which are the vital 20% of the critical infrastructures, how to arrange the priority, and what are the consideration factors and weights? Lewis thinks that the first level of critical infrastructures is most important (water supply system, energy and power system, and information system), and has the highest level of effects on the functional operation mechanism of the entire city. The second important one is of the second level (banking system, transportation and chemical industry). The last one is of the third level, and has lowest level of effects [16].

In addition, we should also understand how to learn the dual-purpose thinking and behavioral model of private sector. Taking the United States for example, above 85% of critical infrastructures are under the control of private corporations or groups. And the thinking and behavioral model of these private corporations or groups are profit-making-oriented. Therefore, when implementing the strategic protection means of vital critical infrastructures, private sector should be made to know how much of their profit-making investments is on security, so as to strengthen these corporations' understanding of the risks of their internal and external investments while pursuing productivity and efficiency. This is the main reason why the protection of critical infrastructures has to stress "public-private partnership".

The main responsibilities for the protection of critical infrastructures should be borne by federal level. And the resistance against global massive disaster and destruction by local level must not be as effective as federal level. Resources and wisdom can be fully concentrated to perform effective analysis of the condition of disaster, and collect the information of possible destruction. Therefore, the past way of using local autonomous regionalism to fight against great disaster is in fact unable to achieve effects. The abilities and level of a single local level or community are not strong enough to resist global massive disaster and destruction.

4. EXPERIENCES FOR URBAN DISASTER RISK MANAGEMENT

4.1 Tool Kit Standard of Canada

Canada regards a city or district as a system. Studying the vulnerability of system has become a necessary act to be implemented by each district according to laws. In an implementation report of peril and vulnerability assessment made for Nanaimo, a British Columbia district in Canada [17], the analysis on damage frequency and the assessment of damage degree are made for different kinds of loss risk. The assessment of loss risk includes current emergency rescue and reorganization measures focusing on different language groups and age levels. Different infrastructures include water resources, energy, and communication and transportation facilities. In this research report, the assessment of loss risk is mainly divided into 4 grades. The first grade is low risk, which is located at the yellow zone (lower left corner) in Figure 2. For this kind of loss risk of disaster, risk mitigation measures can be easily implanted to reduce risk, and its handling is not as urgent as other kinds of risk. The second grade is moderate risk, which is located at the beige zone in Figure 2. Comparing with the risk of the first grade, this kind of risk needs to be handled more urgently. Both the occurrence frequency and severity of this kind of risk belong to intermediate level. The third grade is high risk, which is located at the orange zone (left) in Figure 2. For this kind of risk, it should be inspected and ensured that there are effective risk mitigation measures to reduce the risk to an acceptable level. The fourth grade is very high risk, which is located at the red zone (upper right corner) in Figure 2. This kind of risk is both of high occurrence frequency and of high severity of risk loss. Normally, immediate examination and risk mitigation measures are needed to reduce the risk to an acceptable level.

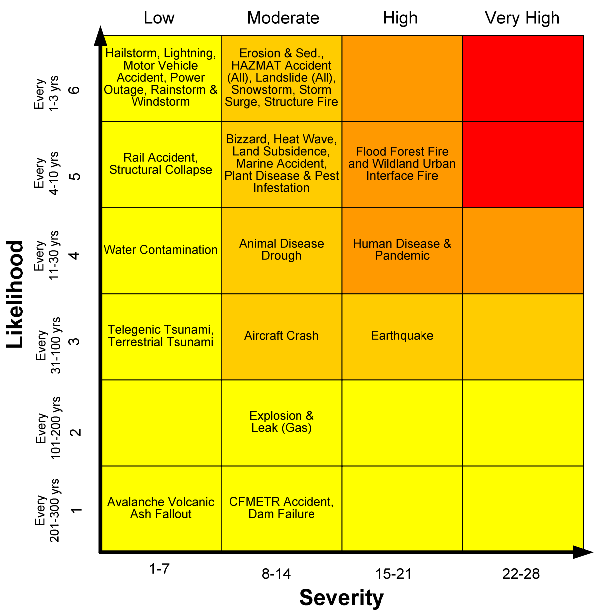

Figure 2. Hazard risk matrix [17]

4.2 Quantitative Risk Model of Important Asset Combination

Ayyub et al. establish a quantitative risk model of vital asset combination, which is a quite representative quantitative assessment of risk for vital urban critical infrastructure [18]. Meanwhile, in consideration of natural hazards and human-caused hazards, the analytical model of risk can simultaneously handle all the risks, such as the risk analysis in times of combination. The implementation of model contains 6 steps, as shown in Figure 3, namely the identification of the situation of perilous event, results and vitality assessment, vulnerability assessment of security, likelihood assessment of perilous event, analysis of cost effects, and risk-oriented strategic decisions. Making use of the first 4 steps, the authors calculate the risk of perilous event to specific assets (Greatest possible loss × Degree of greatest possible loss × Annual occurrence rate of perilous event). After that, the acquired risk and risk handling measures are used to analyze the cost effects, and the risk-oriented strategic decisions are used to handle risk.

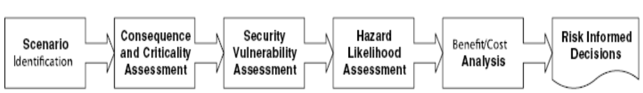

Figure 3. Framework for Critical Asset and Portfolio Risk Analysis [18]

4.3 Integrated Disaster Risk Management, IDRM

In the aspect of natural disaster, regarding the application of risk management to disaster prevention in cities, a Japanese scholar of Kyoto University, Norio Okada proposes the structure of "Integrated Disaster Risk Management (IDRM)." Focusing on the urban diagnosis, analytical procedures are suggested. Norio Okada indicates that the innovative concept being applicable to the disaster prevention and control of the whole world is IDRM [11]. Especially focusing on the aspect of urban vulnerability diagnosis, more complete and integrated viewpoints are proposed. Norio Okada points out that city (metropolitan district or community) can be regarded as a 5-layer tower model established by a complicated life support system. It integrates the abstract and physical geographical spatial environment, and conducts overlapping in the physical geographical spatial environment by GIS maps (see Figure 4).

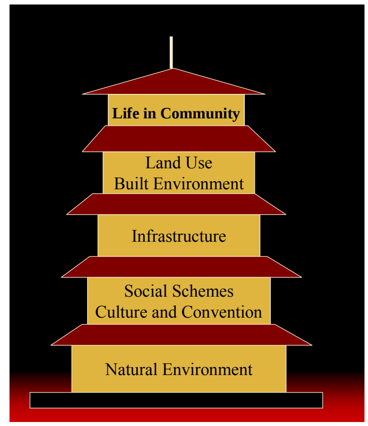

Figure 4. Framework for Critical Asset and Portfolio Risk Analysis [11]

4.4 Human-caused Hazards Risk Management

In the aspect of human-caused hazards, Ezell, B.C. [19] focuses on the medium-standard clean water system, and analyzes the vulnerability assessment by infrastructure vulnerability assessment model (I-VAM). The quantitative system can be divided into subsystems and components layer by layer. Each component has to be assessed of its vulnerability factor. After that, the importance weights of components and subsystems are used to make quantitative measurement of the vulnerability of subsystems and main system. Of this, the vulnerability factors of the component on the lowest layer after division can be subdivided into four forces, including deterrence, detection, delay and response, with their definitions and measurement facets explained as follows:

(I) Deterrence

It is meant by deterring the invasion of attacker or stopping an attack action after receiving a message of a risk of being arrested. The effects of deterrence shall change with the situation of attacker, attack characteristics attracted by facilities, and motives of attacker. This factor mainly focuses on human-caused and horrible destructive action. If the attack is a natural hazard, like earthquake, flooding or typhoon, this factor is excluded from vulnerability assessment. Meanwhile, the deterrence-related criteria, such as the situation of attacker, attack characteristics attracted by facilities, and motives of attacker, are both complicated and abstract. Hence, it is not easy to conduct quantitative measurement.

(II) Detection

Facility vulnerability detection includes the sensing of human-caused or natural attack action, confirmation of the detected attack, and transmission of appropriate information to hazard control team to give proper response. Thus, the vulnerability detection measures include: (1) Establishment of a mechanism that has a sensor to sense the happening of an abnormality and ring the alarm; (2) The sensed information and the related information of subsystem vulnerability assessment can be correctly produced and presented; (3) There is assessment information and an alarm mechanism with two times' confirmation. An effective detection alarm assessment system should be able to show whether the ringing alarm has correctly detected an abnormality and completely presented the real reasons for the ringing alarm. And the detection strength of a facility's vulnerability has to rely on the integration of the above three effects.

(III) Delay

Delay can be achieved by using fixed or moveable barriers (e.g. protective wall, door, different kinds of locks), or by using moveable sensor barriers (e.g. spraying liquid or foam). Excellent security guards, who undergo entrance-restricted, and are organized and well-trained, serve as delay of facilities. And different kinds of barriers and different security guards are regarded as the delay elements of facility vulnerability. The measurement of delay performance is to measure the time required to go through different delay elements after an abnormality happens.

(IV) Response

Response is just the action taken by the security and hazard control implementation team (normally the security guards and local policemen) to avoid the happening of abnormality. The hazard control actions include the termination and elimination of any abnormal intrusion or happening. Of this, terminating action not only should stop the happening of abnormality, but also has to include the transmission of the correct information of abnormal situation to the hazard control implementation team and the disposition planning team to take follow-up actions. The overall performance of response should synthesize the above three performances, which are response communication, termination and elimination.

5. ASSESSMENT OF URBAN HAZARD RISK AND QUANTITATIVE MEASUREMENT OF VULNERABILITY

Focusing on the quantitative regional risk of urban hazard, since urban combination contains general buildings, critical infrastructures and other infrastructures, if a city is cut into zones, these zones can serve as the targets of risk assessment. Each zone may contain general buildings, critical infrastructures and other infrastructures. The damage of these 3 types of buildings has a very wide range of effect levels on human life and properties. Regarding the assessment of their vulnerability factors, such as the related social and economic factors, the effects in the region with critical infrastructures are deeper and broader than those in the region with general buildings and in the region with other infrastructures. Thus, the study defines the regional urban hazard risk as the sum of 3 kinds of risks in buildings, as shown in Figure 5.

Regional urban hazard risk =
Risk of region with critical infrastructures +
Risk of region with general buildings +
Risk of region with other infrastructures

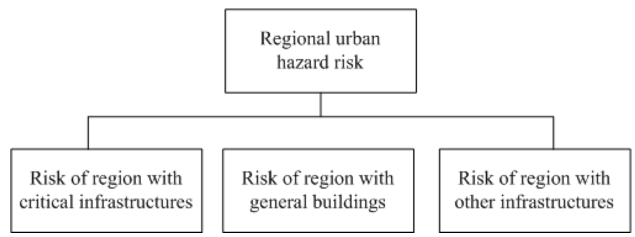

Figure 5. Formation of the hazard risk in urban regions (Source: Research team of the study)

The strategic decisions for urban hazard risk management have to rely on integrated regional hazard risk assessment, or risk analysis. And urban hazard risk is the function of hazard potential and vulnerability. Hence, quantitative regional urban hazard risk has to undergo quantitative measurement of regional hazard potential and regional hazard vulnerability simultaneously. Since this study belongs to a preliminary research, the quantitative measurement of risk, implying to the way of making integrated calculation of risk from hazard potential and vulnerability, and the way of summing up the risks of different kinds of buildings, all of which are issues covering a vast area, shall be continuously investigated in future studies. This study only focuses its investigation on the quantitative assessment of vulnerability.

Regional urban hazard risk = Function (Regional hazard potential × Regional hazard vulnerability)

Referring to UN's EPSON Hazards Project developed from climate change, it is indicated that the vulnerability of a region is the function of hazard exposure and coping capacity (or called protective coping capacity). Therefore, we have to thoroughly understand the vulnerability of a region first, and then combine with the hazard potential of specific hazard type in this region, and finally make integrated analysis of the risks of this region.

Having synthesized EU's theoretical foundation of risk assessment and the 5-layer tower concept for diagnosis of urban hazard proposed by Norio Okada, we can summarize the risk factors in cities to be factor of geographic natural condition, factor of land use and construction environment condition and socio-economic factor, all of which can be included in damage potential and coping capacity. Vulnerability contains exposure, and can be handled by weights. Coping capacity can decompose the main system of cities, as proposed by B.C. Ezell, to be the **3DIR** quantitative analysis model of subsystem and component. Having synthesized the above, the study constructs a structural chart of urban hazard risk assessment, as shown in Figure 6, after summarizing the types of hazard, exposure of hazard and coping capacity of hazard.

6. CONCLUSIONS

Implanting the concept and theory of risk management to urban disaster prevention and rescue system is a trend and a positive act of all advanced countries in the world. They take the viewpoint of risk to make optimal allocation of resources in urban disaster prevention and rescue system. The resource allocation strategy is formulated by taking the results of risk analysis as the main body, with vulnerability analysis as the main core of risk analysis. In the past, since vulnerability was not quantitatively measured and there was no assessment standard to follow, both the analyses of hazard occurrence probability and hazard damage severity could not be performed smoothly, just because of the lack of vulnerability information, thus causing rather great controversy over the analytical results of risk. In recent years, different countries in the world have been making more and more disaster prevention and rescue studies investigating the risk management structure, and gradually understand that vulnerability assessment is the core of risk analysis. Risk analysis needs the implantation of vulnerability information to calculate the occurrence probability of hazard and predict the severity of loss out of the hazard.

Therefore, the first task of risk management for urban disaster prevention and rescue is to establish a complete vulnerability assessment mechanism. The planned mechanism takes a city as a main system, and the various vital facilities under the jurisdiction of the city are regarded as its subsystems. Each subsystem has its composing components. For urban vulnerability assessment, through the lowest-layer components' assessment of different kinds of hazards, including the deterrence of hazard and destruction, detection of hazard damage, delay of hazard and response, quantitative measurement is made for the vulnerability of various components to different kinds of hazards. After that, through the interrelation among components, subsystems and main system, the vulnerability of subsystems and main system to different kinds of hazards can be analyzed.

From the local and foreign studies about risk management of different kinds of hazards, we can understand the imminence for the long-term establishment of vulnerability information of different components. For example, Taiwan Earthquake Loss Estimation System (TELES) mentions that the accuracy of damage assessment of earthquake hazard has to rely on establishment of the basic information of damaged facilities and buildings as well as the information of vulnerability, then more accurate prediction of damage can be made. While planning and constructing the vulnerability assessment mechanism, the study also finds that different kinds of facilities would have different vulnerability assessment items of a certain hazard type. And the research literature about the hazard vulnerability of different kinds of facilities is still insufficient. Therefore, it is suggested that the local academic units and the supervisory units of different facilities can put in more resources in future to conduct the related studies and construct the database so as to achieve the actual effects of risk management.

7. ACKNOWLEDGE

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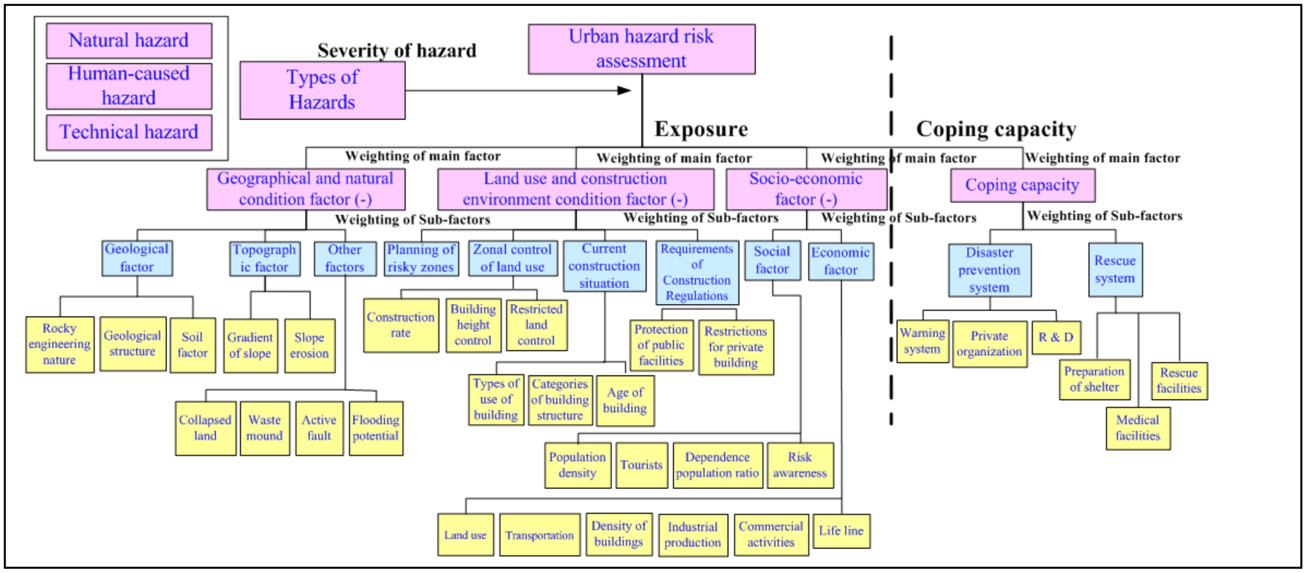

Figure 6. Structural chart of urban hazard risk assessment
(Source: Research team of the study)