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# **International Review for Spatial Planning and Sustainable Development**



**SPSD Press from 2010**



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### **International Review for Spatial Planning and Sustainable Development**

For investigation regarding the impact of planning policy on spatial planning implementation, International Community of Spatial Planning and Sustainable Development (SPSD) seeks to learn from researchers in an integrated multidisciplinary platform that reflects a variety of perspectives—such as economic development, social equality, and ecological protection—with a view to achieving a sustainable urban form.

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# **International Review for Spatial Planning and Sustainable Development**

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Special issue on "Spatial Modeling and Planning for Safer City"  
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## Editorial introduction

### *Special issue on "Spatial Modeling and Planning for Safer City"*

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As urbanization is a global phenomenon, cities and urban areas all over the world witness rapid population growth. According to 2011 World Urbanization Prospects ([Department of the Economic and Social Affairs, Population Division of United Nations, 2012](#)), 52.1% of the entire world population reside in cities. Rapid growth of urban areas has caused a wide range of urban problems such as shortage of affordable housing, traffic congestion, and environmental degradation. The human habits concentrated in urban areas have also been vulnerable to natural and man-made disasters and hazards which have constantly destroyed and threatened citizens' lives and private properties. A safer living environment is a critical issue for any urban area to address to create a prosperous and sustainable human habitat.

The 2011 nuclear power plant accident in Fukushima, Japan, the 2004 Indian Ocean Tsunami, and the 2000 earthquake in Sichuan, China, all have destroyed lives and livelihoods of numerous people in those urban areas. These and other disasters have heightened the awareness of the safety features of cities. In response, academics and practitioners have made great efforts to create safe cities.

Although disasters can be classified in several ways, it can be simply divided into two categories: natural and man-made ([Korean National Emergency Management Agency, 2004](#)). Most natural disasters include hurricanes, floods, storms, hail, snow, earthquake, and drought. Man-made hazards include crimes, fire, destruction, explosions, traffic accidents, forest fire, and environmental pollution. A disaster emergency management system is comprised of four stages: Prevention (checking facilities, and so on); Preparation (disaster prediction and the establishment of information delivery system); Coping (first aid and evacuation measures); and Recovery (damage survey and facility restoration).

There have been a growing body of research and real-world application that are focused on creating safe cities. The growing knowledgebase coupled with advanced spatial modeling technology has created great opportunities for planning and developing safe cities in much more effective and efficient ways than ever before. Safety-conscious urban planning and development practices that create safe public and open spaces are critically important in making a safer city that is functional, vibrant and livable at the same time. It calls for research projects that can help prevent disasters and crimes or minimize the impacts of those factors through rigorous and innovative spatial analysis in the context of urban space.

There is also a global movement for promoting the safe city such as the Safe Communities Certification of World Health Organization (WHO). The certification system of the international safety system was created for defining the concepts of safe city and encouraging many cities to adopt the

Manifesto of Safe Communities stating that “All human beings have the equal right to health and safety” in the 1<sup>st</sup> World Conference of Accident and Injury Prevention, held in Stockholm, Sweden in 1989. As a result, 317 cities in 33 countries around the world have been certified as international safe communities as of 2013. More cities are pursuing the certification ([WHO Collaborating Centre on Community Safety Promotion on behalf of the International Safe Community Network, 2012](#)).

A city must meet seven indicators established by WHO to be certified as a Safe Community: 1) An infrastructure based on partnership and collaborations governed by a cross- sector group; 2) Long-term, sustainable programs; 3) Programs that target high-risk groups and environments, and programs that promote safety for vulnerable groups; 4) Programs that are based on the available evidence; 5) Programs that document the frequency and causes of injuries; 6) Evaluation measures to assess their programs, processes and the effects of change; and 7) Ongoing participation in national and international Safe Communities networks. The Safe Community initiative is an evidence of global interests in safe cities.

This special issue is about scientific planning methods to create safe cities based on interpretation of spatial processes and patterns of disasters and crimes. It is expected that advanced spatial analysis and simulation of disasters or criminal incidents would help identify and describe the urban space and urban planning/management systems that can effectively prevent or mitigate the disasters and crimes. Four papers were selected through a rigorous examination among the collected papers for the publication of the special issue. The following paragraphs provide a brief summary of each article.

The first paper by Akira Ohgai and Takatoshi Yamamoto studied Japanese cities to develop a method which can evaluate degrees of difficulty to conduct emergency response activities in densely built-up areas during seismic disasters. The authors divided emergency response activities into three types, i.e., evaluation, firefighting, and rescue, and calculated the non-arrival probability and arrival distance for each building using physical condition data. They developed an evaluation method of emergency response activities. With spatial and qualitative analysis using evaluation results of the emergency response activities, this paper highlights the fact that the disaster mitigation plans of the small low-density cities should be different from those of large high-density cities. Based on the research, urban planners and policy makers should pay special attention to identifying locations of serious obstacles to the disaster mitigation activities and apply the spatial knowledge to develop safer urban space before disasters occur.

In the second paper, Xiaolu Gao and Haihong Yuan et al. argue that the precise assessment on social and economic system’s vulnerability is very important for cities to reduce the damages in the cities which are susceptible to rising risk of disaster. The authors set small blocks as a basic spatial unit for the analysis. The block-level space analysis has serious limitation in securing sufficient data and, therefore, the authors employed their own special data processing method in dealing with population and economic variables. The research identified hotspots of high vulnerability and the research outcomes would be useful for disaster prevention planning and emergency management.

The next two papers focus on Crime Prevention through Environmental Design (CPTED) which deserves a special attention as an innovative design element for safe communities. Seok-Jin Kang and Dong-Jin Kim, et al.

suggest a new method of crime risk assessment and application. The authors suggest an alternative method to existing crime risk assessment methods that used historic data. Their new method can assess crime risk integrated with the existing methods and various factors based on the CPTED principle using GIS. This study evaluated degrees of crime risks in different locations and visualized the spatial differences of the risks with graphics. This method can be useful in identifying ideal locations for the security cameras in streets or intersections.

The research of Hiroaki Sugino and Takafumi Arima tries to identify spatial pattern of vulnerability and resilience against a specific type crime, arsenic, in a specific district in Japan. The authors point out that the analysis on the occurrence of spatial crime in existing studies often targeted macro spatial unit such as a city. This macro-level analysis provided little help in identifying the cause and spatial patterns of criminal incidents. Therefore, this study detected spatial vulnerability for arsenic criminal activities in microscopic spatial level. It also tried to identify environmental factors which made it difficult to commit crimes. This study suggests a particular way to install CPTED in a research district based on the spatial analysis of the vulnerability and resilience of the district.

All studies will make significant contribution to the growing knowledgebase for creating safer cities or urban habits. They demonstrated that a variety of spatial analysis units can be used to analyse and evaluate spatial patterns of crime. Their studies showed the effective planning methods for preventive maintenance of city environment or preparing emergency management plans for disasters and crimes beforehand by discovering and evaluating the locations or spatial patterns which are vulnerable to disasters and crimes.

Finally, as a guest editor, I'd like to express my great gratitude to the authors and reviewers for the excellent manuscripts and reviews for this special issue. The spatial planning community should continue its efforts to provide rigorous theories and insightful best practices that will help create a safer living environment in our cities.

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# Evaluating Emergency Response Activities during Earthquakes in Local Cities of Japan

*To develop a tool to support community-based disaster mitigation planning*

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**Key words:** Earthquake Disaster mitigation, Emergency response activities, Evaluation method, Community-based planning, Local cities

**Abstract:** This study attempts to develop a method to evaluate the difficulty of emergency response activities in densely built-up areas, focusing on practical usefulness and issues in local cities of Japan. The emergency response activities are classified into evacuation, firefighting, and rescue, based on previous research. The method evaluates the difficulty of the activities by calculating the non-arrival probability and arrival distance for each building, using physical condition data. The developed method is applied to case study districts in Japanese local cities that have disaster mitigation issues. From spatial and quantitative analysis using evaluation results of the emergency response activities, we found that the difficulty of the activities in local cities is relatively low compared with results obtained in previous research dealing with densely built-up areas in big cities such as Tokyo and Osaka. Finally, we discuss the possibility of the proposed method as a support tool for community-based planning for disaster mitigation that can plainly offer residents useful information about the difficulty of the response activities.

## 1. INTRODUCTION

Japan has experienced many seismic disasters since time immemorial. However, there exist many densely built-up areas with a high proportion of old wooden structures and many narrow roads that are considered to have disaster mitigation issues. These areas face many problems, such as building collapse, fire spread, and safety of evacuation pathways. Improvement of densely built-up areas has been seen as one of the most urgent problems in urban policy in Japan ([Ministry of Land, Infrastructure, Transport and Tourism, 2002](#)). In order to solve the problem and reduce the risk level in these areas, it is crucially important to promote collaborative planning with public involvement at the community level for improvement of the local environment through consensus building among residents in areas concerned ([Pearce, 2003](#)).

However, for residents who have little professional planning knowledge, it is difficult to make effective and concrete plans for disaster mitigation. For this reason, development of planning support technologies to reduce the difficulty and help consensus building has been encouraged as a matter of

national policy in Japan ([MLIT, 2002](#)).

Road blockage by seismic-induced building collapse is one of the main problems for disaster mitigation. Road blockage causes difficulty during emergency response activities such as evacuation, firefighting, and rescue. It is important to evaluate that difficulty in collaborative planning with public involvement, especially when dealing with densely built-up areas with old wooden buildings and many narrow roads. If there were a method that could visually and quantitatively offer the residents information about the evaluation of the activities, the information would be useful for consensus building, enhancing awareness of the need for improvement of local environment, and decision making in planning for disaster mitigation.

The Ministry of Land, Infrastructure, Transport and Tourism ([2005](#)) released a list of densely built-up areas totalling 8,000 hectares nationwide that are considered to have disaster mitigation issues in case of seismic occurrences and need to be urgently improved. Half of the 8,000 hectares are found in Tokyo and Osaka, while the other half are in the local cities. Though densely built-up areas with old wooden buildings and narrow roads exist in local cities, there are also substantial amounts of open space, such as farmland and open-air parking. Additionally, the spatial size of these areas is small compared with the densely built-up areas in the metropolises. Accordingly, because of these differences in spatial scale, density level, and other measures, the characteristics of the disaster mitigation issues in local cities could be considered different from those in the metropolitan areas.

In Japan, there are many previous studies related to emergency response activities (for example, [Ichikawa, Sakata, et al., 2004](#); [Ieda, Mochizuki, et al., 1998](#); [Kato, Yusuf, et al., 2001](#); [Kugai and Kato, 2007](#); [Imaizumi and Asami, 2000](#)) including a comprehensive technology development project by the Japanese government ([Ministry of Land, Infrastructure, Transport and Tourism, 2003](#)). However, most of these studies deal with the built-up areas in metropolises such as Tokyo and Osaka and focus on analysis of accessibility of evacuation sites or collapsed buildings for firefighting or rescue activities. In order to offer residents information on the evaluation of emergency response activities in disaster mitigation planning in local cities, it is important to develop an evaluation method suited to the characteristics of the issues in local cities as well as to give residents easily understandable information.

Using the background described above, in this study, we try to develop a method for evaluating the difficulty of emergency response activities in case of seismic disasters and discuss the characteristics of urban vulnerability in Japanese local cities through applying the method to some case study areas. The goal of this study is to provide a support technology for community-based disaster mitigation planning, one that can plainly offer residents useful information on the difficulties of emergency response activities.

This paper is organized as follows: Following review of related research, (1) using the results of a previous study ([MLIT, 2003](#)), we try to develop an evaluation method for the difficulty of emergency response activities, focusing on practical usefulness and issues in local cities; (2) the developed method is applied to case study areas with densely grouped old wooden buildings and many narrow roads. Based on the visual and quantitative evaluation results, the usefulness and problems of the proposed evaluation method and the characteristics of vulnerability in local cities are discussed.

## 2. REVIEW OF RELATED RESEARCH

There are many previous researches dealing with emergency response against natural disasters. These can be roughly classified into two categories. One is related to evaluation methods of evacuation against various disasters like earthquakes, floods, tsunamis, and typhoons (for example, [Chen, et al., 2012](#); [Wang and Zhao, 2012](#); [Kim, et al., 2011](#); [Jelinek, et al. 2012](#); [Wood and Schmidtlein, 2012](#); [Zou, et al., 2006](#)). Another is researches dealing with methodology and its application for evacuation planning or decision support system against various disasters like earthquakes, floods or hurricane (for example, [Ye, et al., 2012](#); [Lindell and Prater, 2005](#); [Zhang, et al., 2013](#); [Coutinho-Rodrigues, et al., 2012](#); [Saadatseresht, et al., 2009](#)).

Among the former studies, Wood and Schmidtlein ([2012](#)), Zou, et al. ([2006](#)), Wang and Zhao ([2012](#)) and Chen, et al. ([2012](#)) assess the risk of evacuation or rescue focusing on the individual behaviors. But the subject of disaster taken by Wood and Schmidtlein ([2012](#)) and Zou, et al. ([2006](#)) is tsunami and typhoon respectively. Wang and Zhao ([2012](#)) analyze the potential risks during residents' evacuation when facing earthquakes or fire hazards in Chinese residential quarters. However, the analysis does not take account of road blockage caused by seismic-induced building collapse. Moreover, Chen, et al. ([2012](#)) takes a unique approach of assessing evacuation risk with consideration pre- and post-disaster factors. Although the post-disaster factors include the spatial impact of the disaster and the potential for traffic congestion caused by the evacuee routing behaviors, the subject to which is applied the proposed method is the transportation network of the whole city of Beijing, China, not a network for community-scale evacuation or rescue. The method we propose in this study focuses on evaluating community-scale evacuation or rescue risks caused by road blockage accompanying seismic-induced building collapse in densely built-up areas with old wooden buildings and many narrow roads.

Within the latter studies, Coutinho-Rodrigues, et al. ([2012](#)) and Saadatseresht, et al. ([2009](#)) introduce multiobjective optimization approaches related to evacuation paths, shelter locations and path lengths, of which the purpose is not to evaluate individual emergency response activities, but for evacuation planning. Lindell and Prater ([2005](#)) developed a hurricane evacuation management decision support system based on evacuation behaviors. Moreover, Ye, et al. ([2012](#)) propose a methodology for community-scale evacuation planning. The proposed methods by them could be used to formulate pre-event planning for organizing a rapid and smooth evacuation. The evaluation method we propose here is not for evacuation planning in local authorities, but to provide resident with useful information on the difficulties of emergency response activities during earthquakes for collaborative disaster mitigation planning at community-scale.

## 3. AN EVALUATION METHOD FOR EMERGENCY RESPONSE ACTIVITIES

### 3.1 The basic concept

In *Figure 1* and *Table 1*, the basic concept for developing a method of evaluating emergency response activities is summarized. The evaluation

method in this study uses geographical data representing the physical conditions of built-up areas (building and its attributes like year built, structure and story, road link and node, road width, evacuation site, and water intake point for firefighting). These data are needed for calculating the difficulty of the activities for each building. Emergency response activities to be evaluated were categorized into three types: evacuation, firefighting, and rescue. These activities are evaluated by two types of output data as shown in *Table 1*. The evaluation results are numerically determined and visually shown by building, not by block or road link.

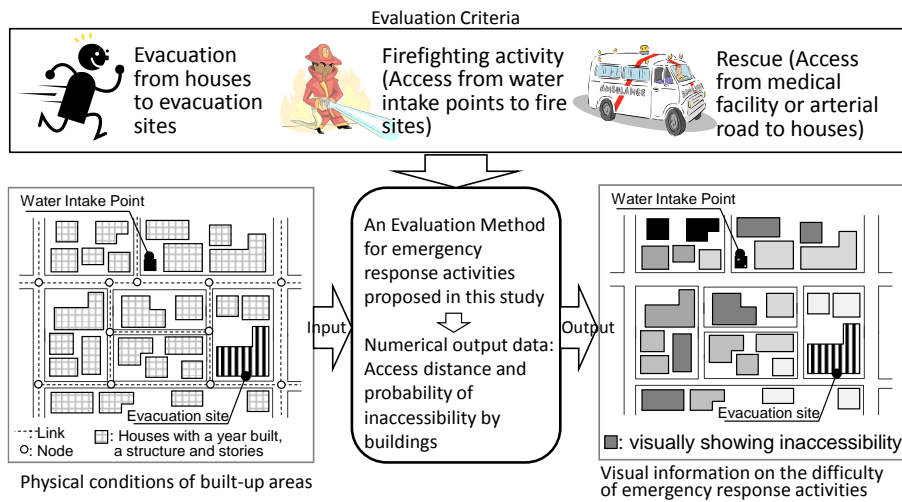


Figure 1. The image of the basic concept for developing a method of evaluating emergency response activities

Table 1. The basic concept of the evaluation method

Input data (physical conditions of built-up areas)	(1) Building, (2) Building attributes (year built, structure and story), (3) Road link and node, (4) Road width, (5) Evacuation site, and (6) Water intake point for firefighting
Output data	(1) Probability of inaccessibility and (2) Access distance [meters]
Evaluation unit	Building (not road link or node)
Evaluation activities (evaluation criteria)	(1) Evacuation, (2) Firefighting, and (3) Rescue (each is evaluated by the output data: probability of inaccessibility and access distance [meters] if accessible)

### 3.2 Evaluation criteria

The evaluation criteria are simplified on the basis of previous research focusing on provision of easy-to-understand information for residents. The previous research used nine criteria, as shown in the left column of *Table 2* (MLIT, 2003). However, it is generally thought that residents would find it difficult to understand the evaluation result if there are too many criteria. There is a need to reduce the amount of information for easy understanding while at the same time keeping the important factors that residents can recognize as critical needs and that can be useful during consensus building for improvement of the local environment. Based on this reasoning, the criteria used in this research are redefined to the following: (1) evacuation, (2) firefighting, and (3) rescue.

Table 2. Criteria of the evaluation method

Criteria (activities) used in previous works	Criteria proposed
1) Evacuation from buildings with risk of collapse, falling objects, and so on due to earthquakes 2) Evacuation from collapsed building 3) Evacuation from fire spread area	>> Evacuation
4) Access to fire site 5) Prevention of fire spread	>> Firefighting
6) Casualty rescue 7) Transportation of seriously injured person to hospital 8) Transportation of slightly injured person to aid station 9) Transportation of supplies to aid station	>> Rescue

### 3.2.1 Criterion 1: Evacuation

This study defines evacuation as an act to protect oneself from earthquake damage such as building collapse, falling objects due to earthquakes, and fire spread. This definition was chosen because it is meaningful for residents to get the information on the risk level of the entire act of evacuation itself rather than of particular dangers.

In Japanese local cities, there are many types of open spaces, such as farmland, open-air parking, and unused land, which can play the role of temporary evacuation space. In reality, many people would use these spaces during emergencies. Consequently, there is a need to consider the temporary evacuation spaces in addition to assigned evacuation sites. Therefore, the following two types of points are treated as evacuation sites for evaluating evacuation activity in this study:

1. temporary evacuation space in the neighbourhood: spaces such as open-air parking, parks, and farmlands that are safe from building collapse and falling objects
2. designated evacuation sites: evacuation sites such as elementary schools, junior high schools, and community centres assigned by local government

The difficulty of evacuation from each building to the evacuation site is evaluated by considering the following cases: (1) only the designated evacuation sites and (2) the nearest site, including both temporary and designated evacuation sites.

### 3.2.2 Criterion 2: Firefighting

For evaluation of the difficulty of firefighting activity in this study, the following three processes of firefighting were considered: (1) fire engines and firefighters arrive at the water intake points nearest to the fire site, (2) they take the water for firefighting to the fire site, and then (3) firefighters uncoil the hose and discharge the water.

The water intake points are the natural water supply and earthquake-proof tanks. They do not include fire hydrants because fire hydrants might fail to function as a result of earthquake damage. Therefore, firefighters will be forced to use only the water intake points considered in this research. In general, initial firefighting by residents is important for minimization of fire damage. Therefore, it is important to consider resident participation in firefighting. However, because of the difficulty of quantifying and modelling initial firefighting activities, the present experimental research only considers activities by firefighters.

Based on the above considerations, the difficulty of firefighting by

firefighters is evaluated by the accessibility of each building from the water intake points. Additionally, the access distance in this evaluation is limited by the fire hose extent, defined by the municipality.

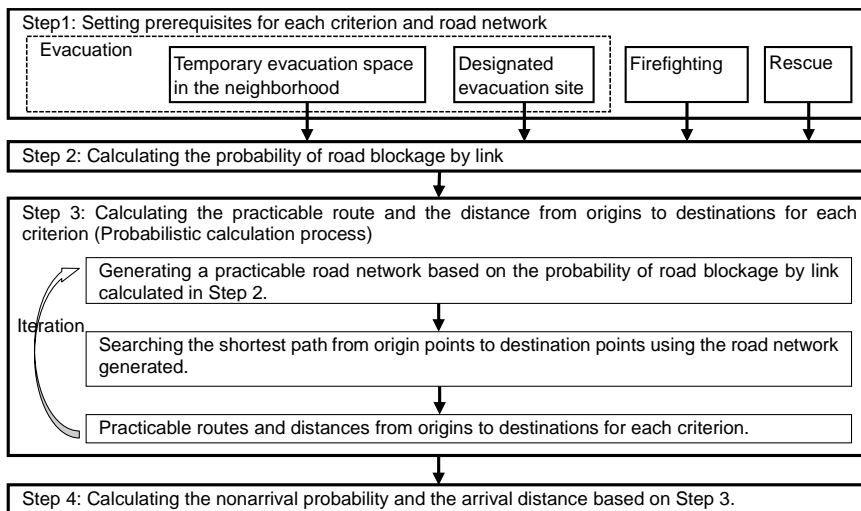
### 3.2.3 Criterion 3: Rescue

Rescue here implies the act of saving persons from collapsed buildings and transferring injured persons to medical facilities via arterial roads. The evaluation of such rescue activities is for emergency cars used by persons such as firefighters, police officers, and defence groups saving the injured persons. In reality, it should be considered that residents would participate in rescue and transfer of injured persons to medical facilities by private cars or stretchers. However, for the same reason as in criterion 2 (firefighting), the present experimental research considers only rescue by professionals using emergency vehicles.

Accordingly, the difficulty of rescue activities is evaluated on the basis of the accessibility of each building by emergency vehicles from medical facilities or arterial roads. Here, arterial roads are used as starting points for access to each collapsed building when there is no medical facility within the area to be evaluated. This is because emergency vehicles would arrive at the point nearest to collapsed buildings via arterial roads.

## 3.3 Evaluation procedure

The outline of the evaluation procedure is shown in *Figure 2*. Each step in the evaluation is explained below.



*Figure 2.* Outline of the evaluation procedure

#### *Step 1: Setting prerequisites for each criterion and road network*

First of all, the origin and destination points, the entity acting, and the road width for passage are set as prerequisites for each criterion, as shown in *Table 3*. The road width for passage means the minimum width that residents and firefighters need to use a road for evacuation or firefighting. Likewise, for rescue, it means a width that allows emergency vehicles to traverse the road. These values are referred to in MLIT (2003).

In community-based planning for disaster mitigation, the final focus of the evaluation of the difficulty of the activities would be on whether or not each resident can evacuate from his or her building and whether or not the

rescue team and firefighters can reach the building. In short, an output expression of the evaluation based on building unit is required for such planning. However, the road network used in the previous study (MLIT, 2003), as shown in the left-hand part of Figure 3, enables calculation of the difficulty of the activities by link, but not by building. A revised road network, adding links and nodes by buildings as shown in the right-hand part of Figure 3, is proposed in this study. This revision enables the calculation and output expression of difficulty for each building. Moreover, it allows evaluation of difficulty caused by a road blockage in front of a building from which residents evacuate.

Table 3. Prerequisites for each criterion

Criterion	Origin point	Destination point	Entity	Road width for passage
1. Evacuation	Each building	Temporary evacuation space in the neighbourhood	Residents	0.75 m
		Designated evacuation sites		0.75 m
2. Firefighting	Water intake point for firefighting	Each building	Firefighter	0.75 m
3. Rescue	Medical facility or arterial road	Each building	Emergency vehicle	3.00 m

Note: The range of firefighting activity is limited by the fire hose extent.

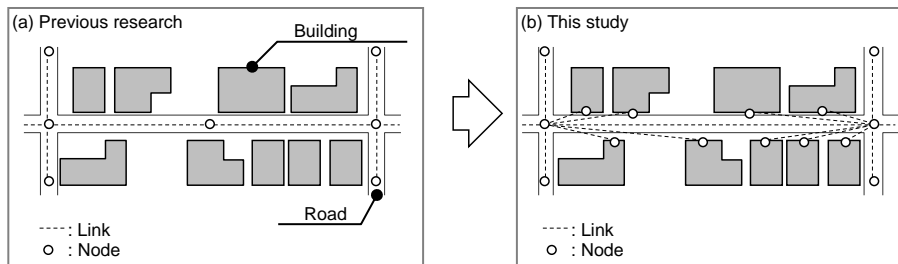


Figure 3. The road networks used in the previous research and in this study

### Step 2: Calculating the probability of road blockage by link

The probability of road blockage for each link of the road network in a subject area is calculated by using the following three probabilities:

1. Probability of building collapse,  $P_r$  (%): This is set by the fragility-curves that have been defined by the relationship between seismic intensity and building damage (Murao and Yamazaki, 2002), which were estimated by use of data obtained from the Hanshin-Awaji Earthquake in 1995. Here, the probabilities shown in Table 4 are used.

2. Probability of debris outflow into frontal roads,  $P_f$  (%): This shows the probability that debris of a collapsed building flows into the frontal road of the site. This probability is calculated by expression (1) (Ieda, Mochizuki, et al., 1998).

$$P_f = 1.1753 \times B_c - 0.0541 \quad (1)$$

where  $B_c$  is the building-to-land ratio.

3. Probability of road blockage due to debris outflow,  $P_b$  (%): This is the probability that the road in front of a building is blocked by debris outflow. This is obtained by expressions (2) and (3) (Ieda, Mochizuki, et al., 1998).



$$P_b = \text{Exp}\left(-\frac{W_r + W_b - W_t}{a}\right) \quad (2)$$

$$a = 2.58 \times P_r^{0.379} + 0.21 \times \left(\frac{B_r}{B_c}\right)^{2.23} + 4.9 \times B_c^{12} \quad (3)$$

where  $W_r$  is the road width in front of a building,  $W_b$  is the setback width from the road,  $W_t$  is the road width for passage, shown in *Table 3*,  $a$  is the average length of debris, and  $B_r$  is a floor area ratio.

Therefore, the probability of road blockage at link  $l$ ,  $P_l$  (%) is calculated by the expressions (4) and (5) ([MLIT, 2003](#)).

$$P_l = 1 - \prod_{i=1}^n (1 - P_{(i)}) \quad (4)$$

$$P_{(i)} = P_{r(i)} \times P_{f(i)} \times P_{b(i)} \quad (5)$$

where  $n$  is the total number of buildings on the roadside and  $P_{(i)}$  is the probability of road blockage in front of building  $i$ .

*Table 4. Probabilities of building collapse by earthquake intensity*

Building structure	Year built	Seismic intensity	
		6 upper	7
Wooden structure	Before 1952	0.55	0.75
	1952–1971	0.45	0.70
	1972–1981	0.20	0.40
	After 1981	0.05	0.15
Steel structure	Before 1971	0.35	0.50
	1972–1981	0.10	0.25
	After 1981	0.05	0.10
Reinforced concrete structure	Before 1971	0.10	0.20
	1972–1981	0.05	0.10
	After 1981	0.02	0.05

*Step 3: Calculation of the practicable route and the distance from origin to destination for each criterion (probabilistic calculation process)*

A practicable road network excluding links blocked by debris overflow is generated by comparing the probability of road blockage by link calculated in Step 2 and a randomly generated number. The shortest practicable route from each origin point to each destination point for each criterion (activity) is then determined by using a shortest-path search. The result of this calculation depends on the road network generated by using the probabilistic Monte Carlo method. Therefore, iteration of the above calculation is needed in order to obtain reliable values probabilistically. In this study, the number of iterations was set at 2000, as in the previous study ([MLIT, 2003](#)).

*Step 4: Calculation of nonarrival probability and arrival distance*

Finally, the nonarrival probability for building  $i$ ,  $P_i$  (%), and the arrival distance,  $D_i$  (m), are calculated, using the results of Step 3. The values are obtained from equations (6) and (7). The nonarrival probability is the probability that the entity cannot arrive at the destination point from an origin point because, as a result of road blockage, no practicable route exists. The arrival distance is the average of the shortest distances from an origin point to the destination point when practicable routes exist on the road network.



$$P_i = \left(1 - \frac{A_i}{T}\right) \times 100 \quad (6)$$

$$D_i = \frac{\sum_{k=1}^{A_i} D_i^k}{A_i} \quad (7)$$

where  $i$  is the identification number of the building (if the criterion is evacuation, it corresponds to the origin point, but in firefighting and rescue, it corresponds to the destination point),  $A_i$  is the times it can take to arrive (at the destination from building  $i$  if evacuation or at building  $i$  from the origin point in firefighting or rescue activities),  $T$  is the iteration times, and  $D_i^k$  is the shortest distance between building  $i$  and the origin or destination point if practicable routes exist in the  $k$ th iteration time.

### 3.4 Data Set

Use of the building-to-land ratio and plot ratio was a precondition for calculating road blockage probability in a previous study ([Ieda, Mochizuki, et al., 1998](#)). However, in actual application, it is necessary to evaluate easily without putting too much time and effort into data collection and preparation, while ensuring some degree of data accuracy. In view of these considerations, the data collection and preparation are simplified as explained below.

#### 1. Building-to-land ratio, $B_c$

When calculating the building-to-land ratio, plot size is required. The GIS data of block and building shape are available through local government in Japan, but the borders of the plot on which the building stands are not included in the data. Therefore, it is difficult to prepare the building-to-land ratio data. In this research, the floor space of all the buildings in a block are summed up and divided by the block area, and the resultant value is used as the building-to-land ratio.

#### 2. $B_r/B_c$

Likewise, it is difficult to survey and obtain the plot ratio data,  $B_r$ . However, the GIS data of the structure and the number of stories are available through local government in Japan. Therefore, the approximate value of  $B_r/B_c$  can be obtained by using the structure and the number of stories, as shown in *Table 5*. The value is a generally accepted value in Japan because of the characteristics of Japanese buildings.

*Table 5.* Approximate values of  $B_r/B_c$

Building Stories	Building Structure	Approximate values of $B_r/B_c$
1	Wooden, nonwooden	1
2	Wooden	1.5
	Nonwooden	2
3 or more	Wooden, nonwooden	Number of stories

## 4. APPLICATION

The evaluation method is applied to the following three districts of local cities in Japan: Akumi, Komoguchi, and Akabane. The first two districts are in Toyohashi city, and the last is in Tahara city (see *Figure 4*).

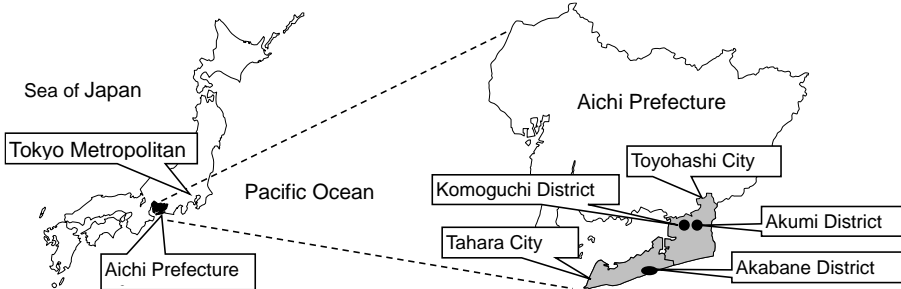


Figure 4. The location of case study districts

### 4.1 Overview of Case Study Districts

These districts have seismic disaster mitigation issues due to the existence of many narrow roads and densely built-up areas with old wooden buildings, as shown in Figure 5. Furthermore, occurrences of huge disaster damage due to big earthquakes are feared in these municipalities. The Japanese central government had designated these municipalities as priority areas for seismic disaster mitigation measures in 2002. Therefore, the municipalities in these case study areas are seriously working on improvement projects for mitigating the vulnerability of the built-up areas.

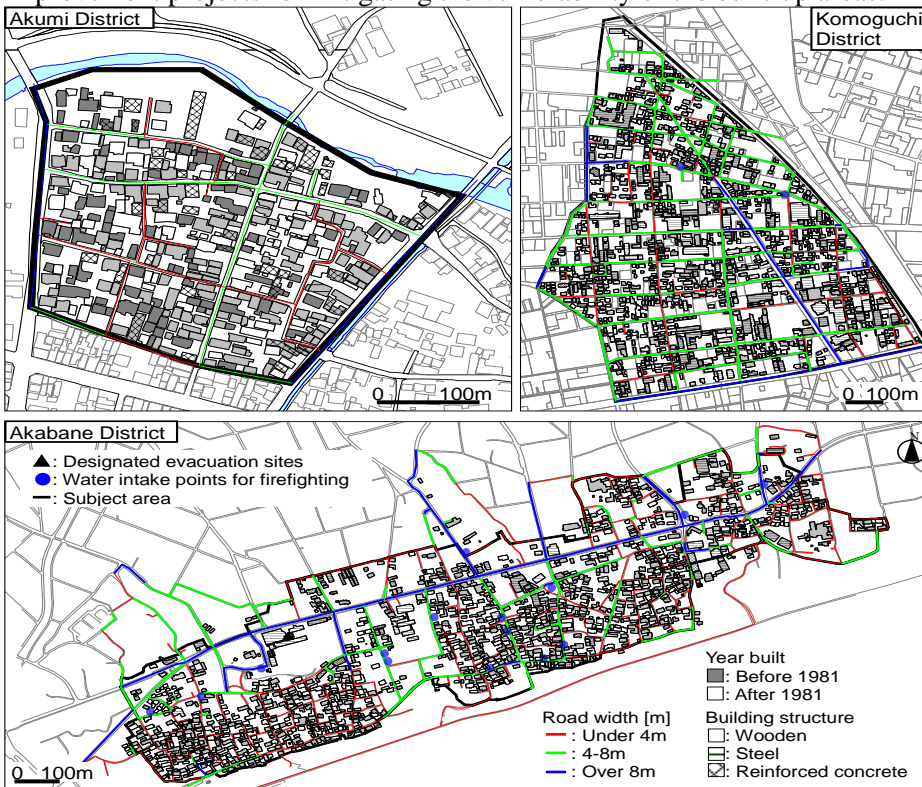


Figure 5. Case study districts

The characteristics of these case study districts are shown in Table 6. The Akumi district is a small-scale densely built-up area that never encountered world war damage. Additionally, because of the lack of damage, this district was not involved in the improvement of urban infrastructure after the war. Therefore, while the number of buildings is the smallest, the area still has the highest ratio of old wooden buildings. Moreover, there are relatively many narrow roads, lacking water intake points for firefighting. On the other hand, the Komoguchi district is a built-up area developed by arable land

readjustment, sprawling over 60 hectares with a low building density, 20 buildings/hectares. Thus, the area has many open spaces and open-air parking lots.

The Akabane district is a fishery and agricultural settlement of 70 hectares. The size of each plot in the area is large, and designated evacuation sites such as elementary schools, community centres, and many open spaces exist within the district. While the road density is the highest among all the case study districts, the percentage of narrow roads is also the highest.

If there would be a local fire station, the accessibility to the fire station by firefighters would be critical for evaluating the firefighting activity. However, in all districts, there is no local fire station within the subject area. Therefore, in this case study, assuming that firefighters can arrive at water intake points, we evaluate the difficulty of firefighting by firefighters by the accessibility from the water intake points to buildings.

Table 6. The characteristics of case study districts

	Akumi	Komoguchi	Akabane
Population (persons)	617	2,655	2,596
Area (hectares)	7.1	59.8	71.8
Number of buildings (buildings)	386	1,247	1,339
Percentage of wooden buildings (%)	83.4	60.2	75.2
Total road length (meters)	2,345	14,412	20,283
Percentage of narrow roads (%)	38.1	28.2	61.0
Population density (persons/hectare)	86.3	57.7	36.1
Building density (buildings/hectare)	54.1	20.9	18.0
Road density (meters/hectare)	328.1	241.0	282.4
Designated evacuation site within the district	N/A	N/A	1 place
Water intake points* within the district	N/A	2 points	5 points

\* the natural water supply and earthquake-proof tanks, excluding fire hydrants

## 4.2 Data preparation and assumptions

The input data for calculation consist mainly of building attributes such as structure, number of stories, year built, road network with link and node, road width, and location data like evacuation sites or water intake points. The text-formatted data are generated from GIS data of case study districts. Within the GIS, the structure, number of stories, year built, and building-to-land ratio data are attributed to each building shape. The data of road width are added to the road link. The descriptive statistics of the data of case study districts for calculation is shown in *Table 7*. And *Figure 6* shows road network (links and nodes) and the width by link in three case study districts. The locations of evacuation sites and water intake points within the districts are shown in *Figure 5*. Moreover, each building is given a node linked with the nearest road intersection node. This enables each building to be evaluated individually.

As assumptions for evaluation, the earthquake scale was set to an intensity of 6-upper, based on an expected earthquake damage survey that had been done by the municipalities. All buildings that do not directly border any road in a block were assumed to be inaccessible because the difficulty of evacuation to the outside of the block would be very high as a result of possible collapse of surrounding buildings. The maximum fire hose extent was set at 400 m (20 m per piece by 20 pieces) for firefighting activity.

Table7. Physical conditions related to emergency response activities by districts

		Akumi	Komoguchi	Akabane
Number of	Before 1952	119	245	179

buildings by year built	1952–1971	79	278	373
	1972–1981	74	206	406
	After 1981	114	518	381
Number of buildings by structure	Wooden	329	751	1,052
	Steel	2	94	286
	Reinforced concrete	55	402	1
Number of buildings by story	1	192	593	1,005
	2	189	590	324
	Over 3	5	64	9
Road length by width (meters)	Below 4 m	940	4,061	15,602
	4 m-8 m	899	8,264	6,383
	Over 8 m	484	2,293	3,861
Number of nodes		34	139	330
Number of links		43	199	437

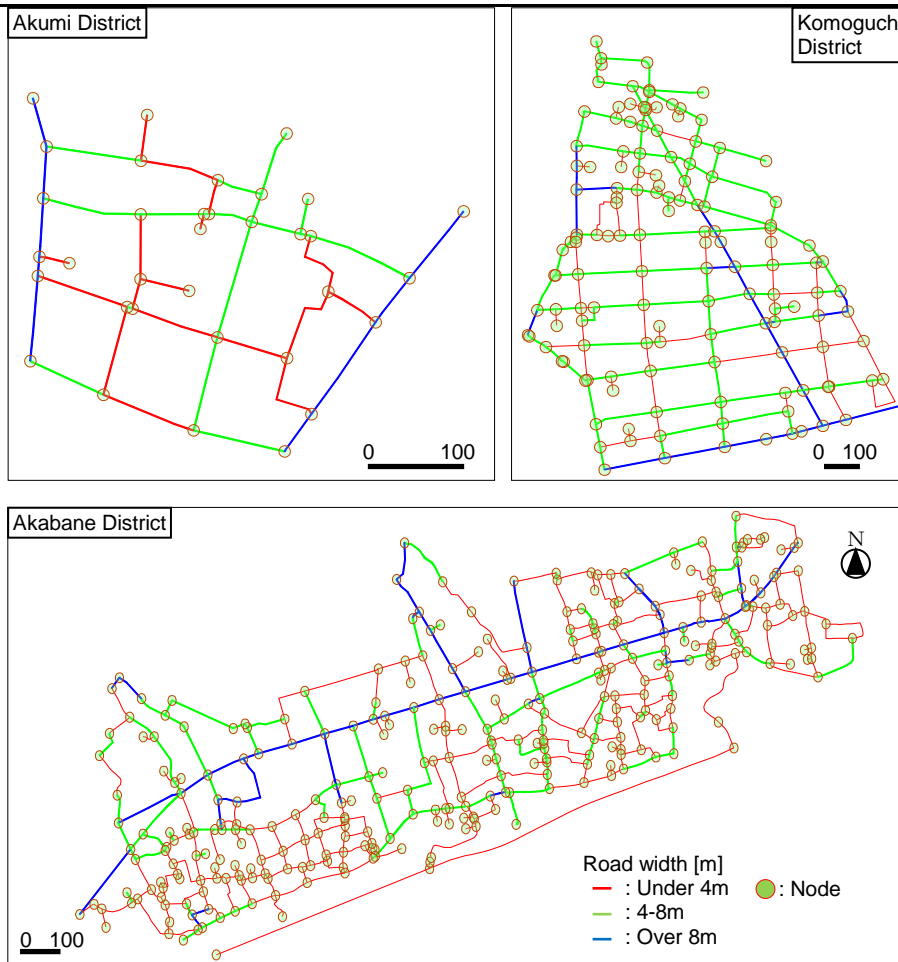


Figure 6. Road network (links and nodes) by case study districts

### 4.3 Application results

As mentioned in previous section, the output expression of the evaluation must use the building unit to be useful for community-based planning for disaster mitigation. Therefore, the evaluation output is as shown in *Figure 7(b)* for each building, not as in *Figure 7(a)* for link units.

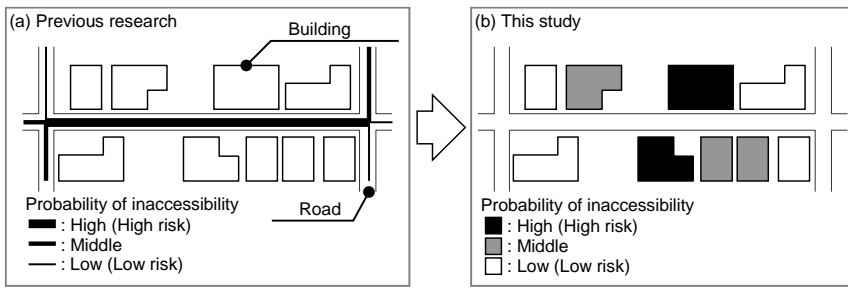


Figure 7. Difference in the output expression between the previous research and this study

The application results are shown in Figures 8 to 10 and Tables 8 to 11. The nonarrival probability and arrival distance for each district are analyzed for each activity as follows.

4.3.1 Evacuation

Looking at the distributions of nonarrival probability shown in Table 8 and Figure 9, we can find that the difficulty of evacuation to temporary evacuation spaces in the Akumi district is the highest among the three districts. This is because the Akumi district has a high building density and few temporary evacuation spaces in the neighbourhood. The peak of the arrival distance from buildings to a temporary evacuation space in the district is between 100 m and 200 m, as shown in Figure 8.

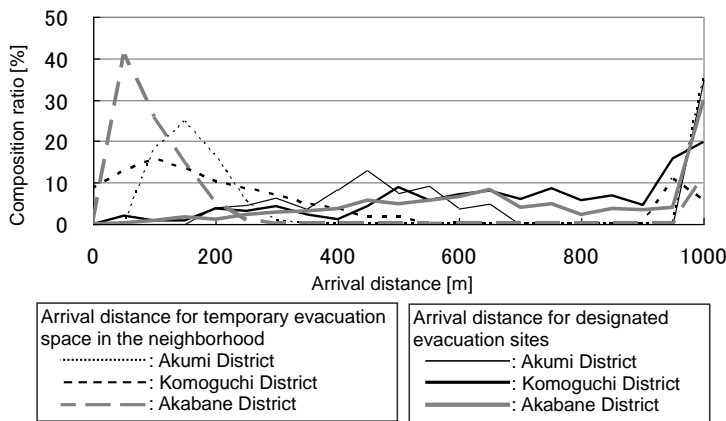


Figure 8. Evaluation results of arrival distance for evacuation

Komoguchi District has few temporary evacuation spaces in the neighborhood, as shown in Figure 8, and the ratio of narrow roads is less than 30% (see Table 6). The arrival distance to a temporary evacuation space tends to be longer than in the Akumi district, but about 85% of all buildings have a nonarrival probability under 25%.

On the other hand, focusing on the Akabane district, because there are many temporary evacuation spaces in the neighborhood (see Figure 9), the arrival distance from most buildings is less than 100 m, as shown in Figure 8. However, because there are many narrow roads (the ratio is 61.0%), more than 70% of buildings are concentrated between 25% and 75% nonarrival probability.

The evaluation results of evacuation to designated evacuation sites have a tendency similar to those of evacuation to temporary evacuation spaces.

Comparing these results with those in extremely densely built-up areas of big cities such as Tokyo (Ichikawa, Sakata, et al., 2004), that have many inaccessible buildings in the districts, we find that the difficulty of



evacuation activity in local cities is dramatically low. This is because a lot of farmland and open spaces, open-air car parks, and so on can be used as temporary evacuation spaces in local cities.

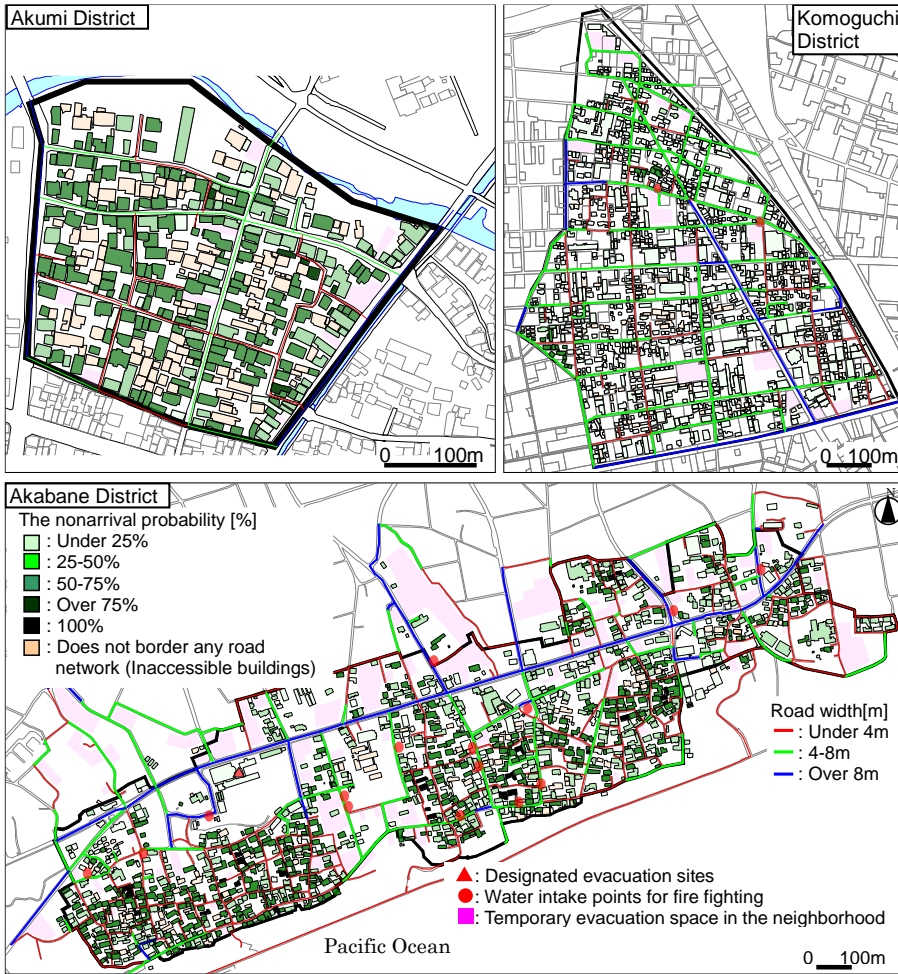


Figure 9. Evaluation results of the nonarrival probability for temporary evacuation spaces in the neighborhood

Table 8. Evaluation results of nonarrival probability for evacuation

Nonarrival probability	Akumi		Komoguchi		Akabane	
	Temp.	Desig.	Temp.	Desig.	Temp.	Desig.
Under 25%	17 (4.4)	17 (4.4)	1,067 (85.6)	867 (69.5)	190 (14.2)	190 (14.2)
25-50%	68 (17.6)	76 (19.7)	22 (1.8)	128 (10.3)	467 (34.9)	467 (34.9)
50-75%	158 (40.9)	151 (39.1)	23 (1.8)	61 (4.9)	490 (36.6)	482 (35.9)
Over 75%	8 (2.1)	7 (1.8)	0 (0.0)	10 (0.8)	37 (2.8)	45 (3.4)
Inaccessible	135 (35.0)	135 (35.0)	135 (10.8)	181 (14.5)	155 (11.6)	155 (11.6)
Total	386 (100.0)		1,247 (100.0)		1,339 (100.0)	

Note: (1) Numerical value is number of buildings and parenthesis is composition percentage.  
 (2) Temp.; Temporary evacuation space in the neighborhood; Desig.; Designated evacuation sites.

Table 9. Evaluation results of the arrival distance for evacuation

Arrival distance	Akumi		Komoguchi		Akabane	
	Temp.	Desig.	Temp.	Desig.	Temp.	Desig.
Under 200m	231 (59.8)	18 (4.7)	632 (50.7)	45 (3.6)	1,173 (86.9)	57 (4.2)
200-500m	20 (5.2)	198 (51.3)	453 (36.3)	235 (18.8)	11 (0.8)	303 (22.4)
Over 500	0 (0.0)	35 (9.1)	27 (2.2)	786 (63.0)	0 (0.0)	824 (61.0)
Inaccessible	135	135	135	181	155	155

	(35.0)	(35.0)	(10.8)	(14.5)	(11.6)	(11.6)
Total	386 (100.0)		1,247 (100.0)		1,339 (100.0)	

Note: (1) Numerical value is number of buildings and parenthesis is composition percentage.  
 (2) Temp.; Temporary evacuation space in the neighborhood; Desig.; Designated evacuation sites.

### 4.3.2 Firefighting

As shown in *Table 10*, the nonarrival probability from water intake points to buildings by firefighters is 'inaccessible' for all buildings in the Akumi district and for 82.5% of buildings in the Komoguchi district. This is because the inadequate water intake points for firefighting result in areas that cannot be reached because of the limit of fire hose length, not the road blockages.

On the other hand, in the Akabane district, because of well-developed water intake points, the nonarrival probability is under 25% for 67.4% of buildings. Therefore, the difficulty faced by firefighters during firefighting activity is relatively low.

In this study, the firefighting evaluation considered only the activities of firefighters. However, it would be a more effective tool for enhancing awareness if there were a way to compare the evaluation results when residents do and do not participate in the firefighting activity.

*Table 10.* Evaluation results of the nonarrival probability for firefighting

Nonarrival probability	Akumi	Komoguchi	Akabane
Under 25%	0 (59.8)	164 (13.2)	902 (67.4)
25–50%	0 (51.3)	47 (3.8)	182 (13.6)
50–75%	0 (9.1)	7 (0.6)	92 (6.9)
Over 75%	0 (0.0)	0 (0.0)	3 (0.2)
Inaccessible	386 (100.0)	1,029 (82.5)	160 (11.9)
Total	386 (100.0)	1,247 (100.0)	1,339 (100.0)

Note: Numerical value is number of buildings and parenthesis is composition percentage.

### 4.3.3 Rescue

As you can see from *Figure 10* and *Table 11*, because of the arterial roads passing through the Akabane district, the nonarrival probability for buildings along these roads is relatively low. The other districts more or less have a similar tendency. However, since there are many narrow roads in the inner part of the districts, buildings inaccessible by emergency vehicles exist in large numbers. This is especially true in the Akabane district, where the built-up area is structured along the arterial road but has excessively high difficulty levels for rescue activities in the inner area.

However, the walking distances from arterial roads to buildings in all three districts are relatively short, about 500 m at the longest. Therefore, it is possible for persons to carry the injured on stretchers from buildings to arterial roads. Because of this ability, when considering rescue activities in local cities, it is important to also add rescue activities by residents into the evaluation method.

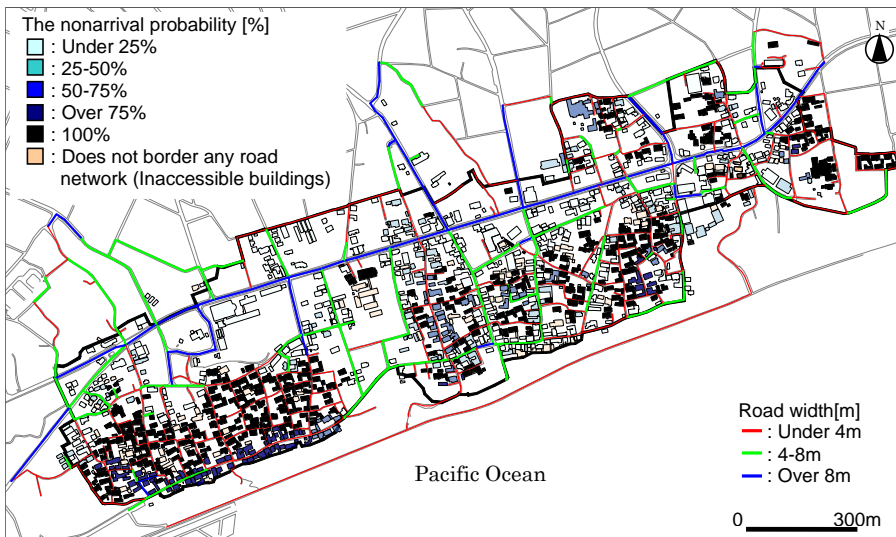


Figure 10. Evaluation results of the nonarrival probability for rescue

Table 11. Evaluation results of the nonarrival probability for rescue

Nonarrival probability	Akumi	Komoguchi	Akabane
Under 25%	80 (20.8)	630 (50.5)	447 (33.4)
25–50%	82 (21.2)	215 (17.4)	128 (9.6)
50–75%	31 (8.0)	142 (11.4)	60 (4.5)
Over 75%	0 (0.0)	104 (8.3)	77 (5.8)
Inaccessible	193 (50.0)	156 (12.5)	627 (46.8)
Total	386 (100.0)	1,247 (100.0)	1,339 (100.0)

Note: Numerical value is number of buildings and parenthesis is composition percentage.

#### 4.4 Discussion of the estimation results

Discussion of some of the bias in the estimations is needed because the evaluation method proposed in this paper adopts a probabilistic calculation process with some assumptions as mentioned in the previous section.

In order to obtain reliable values probabilistically, the estimation of non-arrival probability and arrival distance for each building is based on two thousand road networks generated by using the Monte Carlo method as shown in equations (6) and (7). Actually, a margin of error in the estimation would be inevitable if focusing on the absolute value of evaluation by building. If we attempted to obtain estimation results having a steady value, a substantial time would be required for calculation. However, the purpose of the evaluation method proposed here is to offer residents useful and easily understandable information on the difficulties of emergency response activities. Therefore, in consideration of the practical utility of a quick response time for calculation in the community-based disaster mitigation planning setting, while allowing for a margin of error, it is important to give information that might not be optimal in value but has been obtained based on a scientifically sound method.

From this point of view, the application results to the three case study districts is meaningful in that those results show reasonable correspondence to the characteristics of each district.

## 5. CONCLUSION AND DISCUSSION

In this study, we have attempted to develop an evaluation method of emergency response activities during seismic disasters in order to provide



useful information for participants or residents collaborating in community-based planning for disaster mitigation. Based on a method in previous research, we have proposed a revised method that can numerically evaluate and visually show the difficulty of the activities by building. Moreover, the evaluation criteria were simplified, focusing on provision of easy-to-understand information for residents.

The developed evaluation method is applied to case study districts having disaster mitigation issues in Japanese local cities where there is a risk of road blockage because of many narrow roads and collapse of old wooden buildings. From spatial and quantitative analysis using the evaluation results of the emergency response activities, we found that the risk level and the difficulty of the activities in local cities are relatively low compared with the results obtained in previous research dealing with densely built-up areas in big cities such as Tokyo and Osaka.

Using the proposed evaluation method, we can also explore the effect of improvements such as road widening or construction of earthquake-resistant buildings on the safety of emergency activities. Thus, the method has the possibility of being a useful planning support tool for disaster mitigation. Future work toward provision of a tool supporting community-based disaster mitigation planning in local cities of Japan is recommended as follows.

The areas having disaster mitigation issues in Japanese local cities and in big cities differ in their physical and social characteristics, such as existence of open spaces (for example, farmland and open-air parking lots) and vulnerable persons (for example, the solitary aged). Accordingly, the characteristics of local cities should be considered when making disaster mitigation plans. Therefore, an evaluation method that can deal with such characteristics is required. For example, because of a relatively low level of difficulty of emergency activities in local cities, an evaluation output using arrival distance or time would be important and required for more detailed evaluation, adding the nonarrival probability used in previous research dealing with big cities.

The revision of the method to evaluate more realistic disaster prevention activities (for example, considering residents' activities and using stretchers) by including passable farms and parking lots as road networks would result in a more realistic evaluation method.

As for technical issues remaining, a revision can shorten the computation time needed to obtain the evaluation results. However, so far we have developed the system incorporating the method to enable on-site use for group discussion in collaborative disaster mitigation planning ([Karashima, Ohgai, et al., 2012](#)) by revision of the system environment and computing program optimization.

As mentioned in the introduction, development of planning support technologies to help consensus building in collaborative planning with public participation has been encouraged as a matter of national policy in Japan. Using the evaluation method proposed in this paper, the provision of information on the difficulty of emergency response activities for each building helps residents perceive and understand where the areas having high difficulty of the activities are within the subject district. This perception and understanding of the risks in local areas not only activates discussion during workshops for exploring the improvement, but also becomes a trigger for them to make a disaster mitigation plan and implement the plan. Therefore, the other remaining work is to improve the provision of easy-to-understand evaluation results through experimentation in an actual community participatory discussion for disaster mitigation.

In addition, in order to make the proposed method more useful in the discussion, the further studies on micro level risk analysis and evaluation, for example, adding collapse of concrete block wall or telegraph pole with building collapse are needed. The reason is that the importance in perception and understanding of the risks lies in satisfying the needs of residents who care about risks in their daily life with the provision of appropriate information on micro level risks.

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# Spatial Vulnerability and District Resilience for the Next Generation of CPTED

*A case study of crime preventive spatial design targeting arson*

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**Key words:** Crime prevention, CPTED, Spatial design, Arson

**Abstract:** Concurrently with the advance of urbanization, many urban problems have increased in our everyday life. It is said that there has been a decrease in the number of crimes committed in Japan, but the number of urban crimes is, on the contrary, increasing. Accordingly, crime prevention has been one of the biggest issues in city planning. A number of arguments about CPTED (crime prevention through environmental design) or other crime preventive methods have been already carried out. While most papers show the relationship between macroscopic geographical aspects and the occurrence of a specific crime, the impact of more microscopic objects and/or spatial design in the crime site as the spatial vulnerability against a crime has not been clarified. Moreover, there is a clear need to find resilience, in other words the difficulty to commit a crime. Therefore, this paper's purpose is to reveal the vulnerability and resilience against one specific crime, arson, in Fukuoka and more specifically in Haruyoshi district, through consecutive researches from urban planning and environmental psychological viewpoints. As a result, we found that there are temporal and spatial vulnerabilities against arson in Fukuoka and Haruyoshi which remain to be improved intensively. However, at the same time, Haruyoshi has some resilience against arson, and we conclude that the human traffic, observability and anonymity are high in the district. Consequently, at the end of this paper, based on the knowledge about both vulnerability and resilience of the district, specific suggestions are proposed on the way to install CPTED in Haruyoshi against arson.

## 1. INTRODUCTION

### 1.1 Research Background

With the advance of urbanization, many urban problems have increased in our everyday life. For example, the number of urban crimes is increasing. The consequent concern of citizens towards crime is considered an important issue that must be solved immediately. Given this issue, urban planning aiming at crime prevention is increasingly called for in Japan. Among major crimes in Japan, arson is famous for its cruelty and harmfulness, yet we can't live without buildings that are common targets for arsonists. It is necessary therefore to aim towards the realization of cities where people can live comfortably without the fear of arson.

## 1.2 Previous Studies

Since when “Defensible Space ([Newman, 1996](#)),” “CPTED (Crime Prevention through Environmental Design) ([Jeffery, 1971](#))” and “Situational Crime Prevention ([Clarke, 1983](#))” were imported into the research field of crime and crime prevention in Japan, it had led to the participation of many other study fields, such as architecture and urban planning, and many studies have focused on the relationship between the occurrence of crimes and external and spatial factors. In Japan, besides the studies about fear of crime which can improve the residents’ quality of life and is important to take into account ([Taylor and Hale, 1986](#)), CPTED is especially considered as one way to reach to methods of crime prevention, as it prevents criminals from committing crimes through the design of buildings and/or places.

For example, as one of an old study focusing on arson, Yamaoka clarified some characteristics of arson, and compares some factors of one-time arson and those of consecutive arson ([Yamaoka, 1978](#)). Also, Omata conducted a study analyzing the relationship between the occurrence of crimes and environmental/psychological aspects ([Omata, 1998](#)). Then, in order to focus on the physical environment for human beings, the relationship between crimes and the characteristics of cities and districts has been clarified in many papers. Kashiwara et al. focus on the spatial factors of a city in order to examine whether they are related to the occurrence of crimes in convenience stores ([Kashiwara, Ito, et al., 1996](#)). Also, as one of the studies analyzing the relationship between the occurrence of situational crimes and spatial designs, Ito et al. evaluated the spatial aspects and examined the occurrence of arson in a city ([Ito, Oue, et al., 1999](#)). Arima et al. also conducted a study on the spatial characteristics of urban crime focusing on the districts in which more arson has occurred ([Arima et al., 2004](#)).

The previous studies could clarify some crime-related factors which are usually macroscopic, but on the other hand, microscopic factors of the crime spots have not been clarified and evaluated enough. In the history of the studies related to crime and crime prevention accumulated, only one variable, vulnerability, has been used to find how defensible a place is, and now the knowledge is summarized and utilized for urban planning ([Schneider and Kitchen, 2001](#)). However, crime attempters recognize not only vulnerability but also resistance when they try to commit a crime. Therefore, there is a need to handle these two variables to reach to more accurate defensibility.

## 1.3 Research Purpose

Up to date, CPTED has attracted attention as an essential concept aiming at preventing roadside crimes leading to the promotion of safer cities in Japan. But in many cases, it may not be effective since city structures of Japan and those in western countries are different. Also, as it was mentioned in the previous section, previous studies above clarified some crime-related factors which can help researchers to find vulnerable spots against specific crimes. On the other hand, the factors which can indicate the resilience of spots against crimes have not been clarified.

Therefore, it is of critical importance to develop ways in which CPTED targets specific kinds of crime, in a limited district, or country, and time zone. In particular, advancing methods to evaluate the vulnerability and

resilience at the same time is the first step to an effective design and implementation of CPTED so that not only sites which need to be improved but also concrete methods of improvement can be clarified. In order to promote the next generation of CPTED, it is surely needed to conduct a consecutive research from a quantitative research for vulnerability to a qualitative research for resilience of the places which need the practice of crime prevention. Consequently, this paper's major purpose was set to reveal the vulnerability and resilience against one specific crime, arson, in Fukuoka and more specifically in Haruyoshi district, through consecutive researches from urban planning and environmental psychological viewpoints.

## 1.4 Research Methodology

The purpose of this study is, in other words, to produce knowledge which can contribute to the promotion of the next generation of CPTED based on both vulnerability and resilience of the targeted place. To fulfill this purpose, in this study, Fukuoka City (Fig.1), Fukuoka Prefecture, JAPAN, is macroscopically taken as the target of study, and arson is chosen as the target crime.



Figure 1. Map of Fukuoka City and Haruyoshi District

The analyzed data was provided by the Fire and Disaster Management Bureau of Fukuoka city; it includes detailed address of the arson spots, date and time, classification, and ignited materials.

We start, in chapter 2, by clarifying the actual condition of arson occurrence in Fukuoka by visualizing and analyzing the data for specific places in which arsons have occurred. After that, the hot spots of arson are

identified on the map. Among the districts which have a concentration of arson spots, Haruyoshi (Fig.1) was chosen as the target for microscopic analysis on spatial designs of hot spots. Next, in chapter 3, the relationship between the occurrence of arson and the spatial design and temporal situation of Haruyoshi has been analyzed in order to verify the vulnerability of the district against arson. Additionally, in chapter 4, and based on the on-the-site fieldwork survey conducted in the district, the spots evaluated as “difficult” to commit arson in are selected. The objects and the contexts they are embedded in are clarified as the environmental factors which can strengthen the resilience of the district through an analysis based on M-GTA (modified grounded theory approach), one of the qualitative analysis method. At the end of this paper, chapter 5, based on the target place’s vulnerability and resilience, the ideas and implementation of the next generation of CPTED matching with the nature and characteristics of Haruyoshi are proposed.

## 2. MACROSCOPIC STATISTICS

### 2.1 Summary of Arson Data in Fukuoka City

At first, in order to understand the actual conditions of arson in Fukuoka, the data about arson provided by the Fire and Disaster Management Bureau of Fukuoka City is summarized. Fig.2 shows the number of arson in each year divided by target.

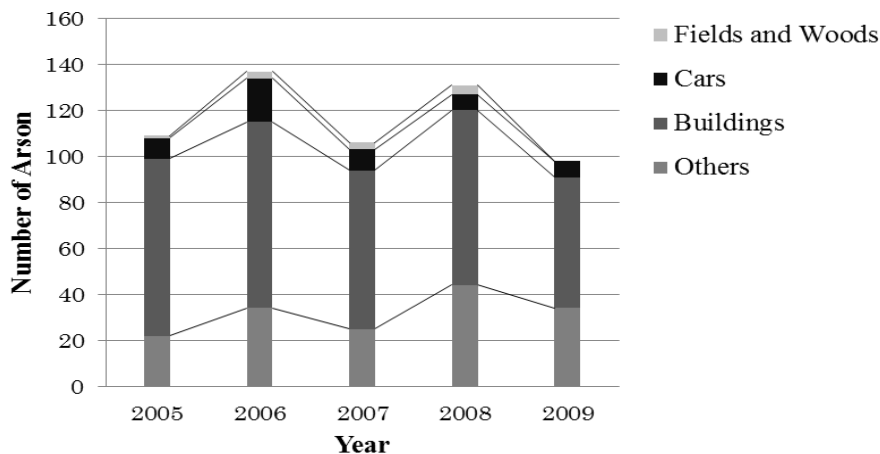


Figure 2. Number of arson in each year divided by target

The summarized data above indicates that Fukuoka City generally has about 120 arsons in each year, and has suffered about 600 arsons from the beginning of 2005 to the end of 2009. Compared to other cities in Japan, the number is statistically significant, and there is a clear need to consider preventive urban planning against arson. We can also see that most of the targets are buildings. Accordingly, to counter arsons in Fukuoka, it can be said that crime prevention methods targeting building is majorly effective and must be taken in consideration.

## 2.2 Temporal Analysis

In Fig. 3, it is indicated that there is a specific time range (from 9 pm to 4 am) in which most arsons have been committed. Generally speaking, arsons are easy to commit after sunset because there will be more dead angles. Also, from the viewpoints of human activities, the result is understandable since arson is well-known as a crime majorly committed by people who live in a society and chronically feel stressed by something like work in Japan. Since these arsonists are engaged in working in daytime, it is thought that there is the specific time range in Fig. 3, and so it is needed to consider crime prevention which can work at night.

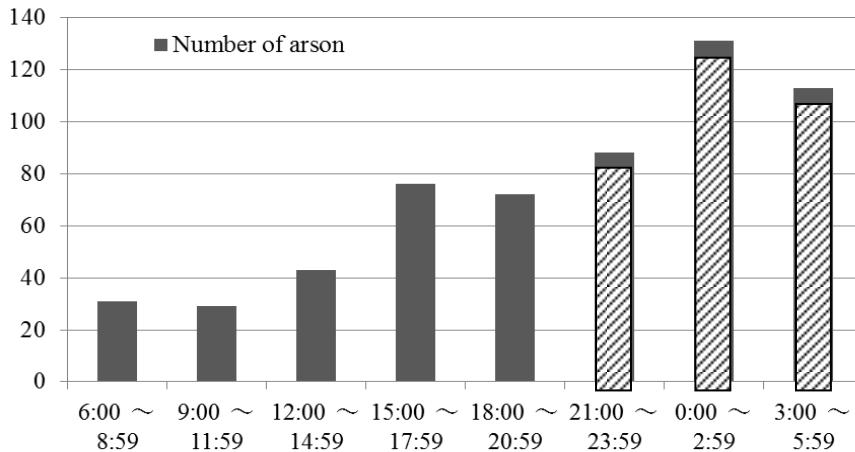


Figure 3. Time Zones of Arson in Fukuoka City

Also, Fig.4 shows the statistic data of arson occurrence sorted by month. Accordingly, it seems that there are some of the months (May and December) when arson happened many times. Related to the viewpoint of stressors, people tend to feel stressed more compared to other months in Japanese society since there are many stressors. In May, as we have a specific term “May sick” to describe a depression people tend to have in May after April which is a busy month since Japanese financial and academic year starts. Also, in December, people are very busy to finish up working for the year and prepare for the next year.

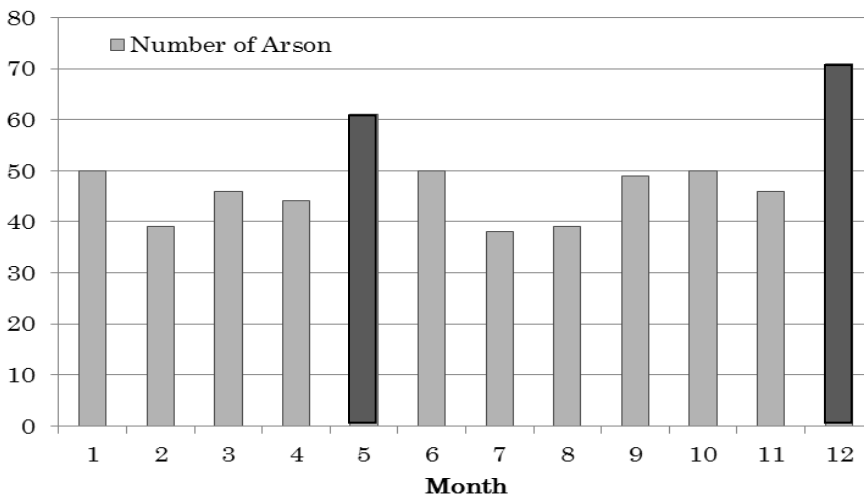


Figure 4. Month and Arson Occurrence



In order to discuss the actual conditions of arson occurrence in the past five years from the geographical point of view, the data of all arson in Fukuoka City is plotted on the map of Fukuoka in GIS by using the Address Matching Service. To visualize the density of the spots in which arsons have been carried out, Kernel density estimation method is utilized. The result is shown in Fig.6, and the hot spots of arson are clearly identified in the map.

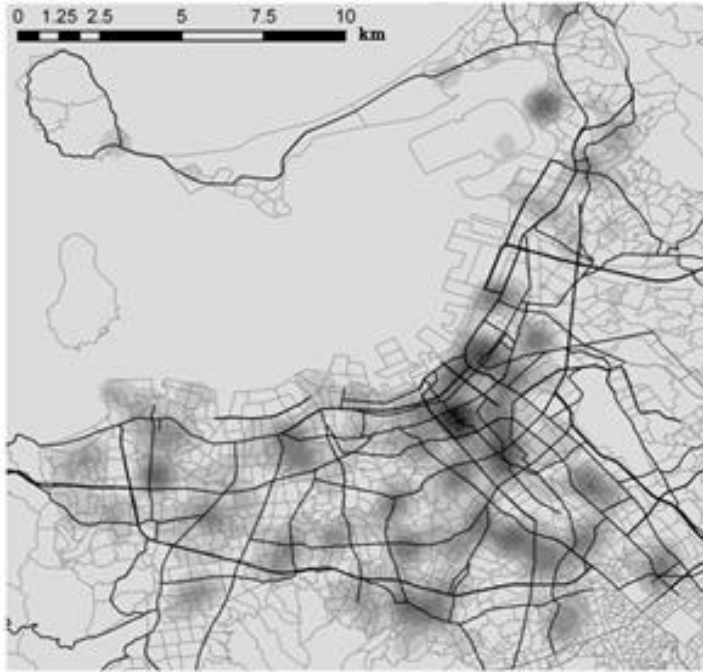


Figure 5. Density of Arson Spots in Fukuoka City

Interestingly, the hot spots are do not appear in the locations of Tenjin and Hakata, the core areas of Fukuoka, but Haruyoshi, Yoshizuka, and Hibu, the districts located in the rim of the core areas of Fukuoka.

Also, as a macroscopic analysis, the relationship between the number of arson occurrences and the distance from arson spots to major arterial roads is summarized in Fig.7. The figure indicates that the majority of arson crimes were committed in the area within 50m to 150m away from major arterial roads.

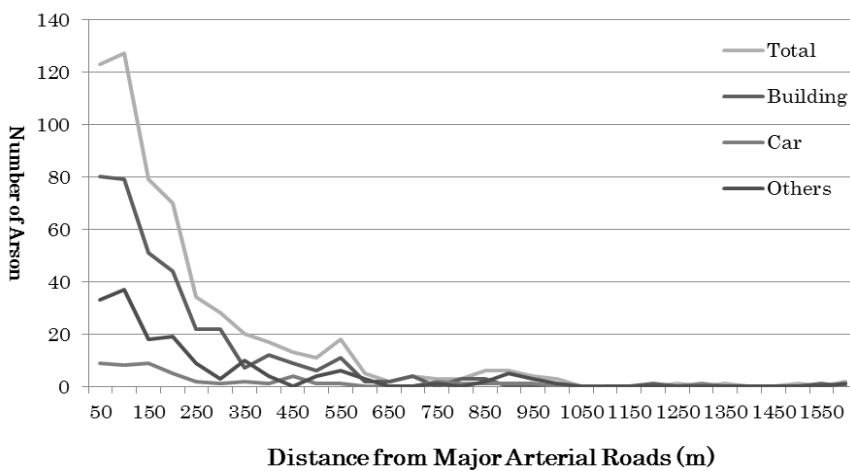


Figure 6. Number of Arson Spots and Their Distance from Major Arterial Roads

## 2.3 Fukuoka's General Vulnerability against Arson

Taking into account all the results provided in this chapter, it is clear that there are definite trends that rule the temporal and geographical vulnerabilities against arson in Fukuoka, and they are distinguishable.

Consequently, it is suggested that in general, prevention methods must focus on arson targeting buildings at night in Fukuoka City. Also, the temporal tendency focusing on days of arson occurrence differ from each district. So, it is suggested that residents need to leverage the day and month when many arsons have been committed in the district when they want to strengthen the patrols around their districts.

Moreover, from the geographical analysis of arson spots, the districts located in the rim of the core areas of Fukuoka should be considered as those where serious improvement in crime preventive planning against arson is needed, focusing on the areas which are within 50m to 150m from major arterial roads.

## 3. MICROSCOPIC ANALYSIS IN A HOT DISTRICT OF ARSON IN FUKUOKA

### 3.1 Selection of Target District

To conduct a microscopic analysis in a hot district of arson in Fukuoka, Table.1 is provided to see the districts that possess a concentration of arson points based on the data of all arson in Fukuoka City. Since some arson crimes have been carried out in the same spots, the number of arson spots does not exactly match with the result of density, but the district that has the greatest number of arson spots is Haruyoshi (Fig.8). In the figure, there are 10 arson spots, and some spots have had several arsons at the same spot. The number of arson crimes is the same as the one seen in the analysis of density. Consequently, Haruyoshi is a suitable district to examine the actual condition of arson from microscopic point of view.

Haruyoshi still has old city structures in many areas, but we can also find new apartment blocks and houses. There are a lot of individual houses which have walls and gates as the old Japanese style houses, while many apartments have pillars that lift them above ground to create parking spaces for cars and bicycles of residents. Besides, there are many alleys and backstreets with a width that is less than 4m.

Table 1. Districts with Concentration of Arson

District Number	Districts		Number of Arsons
1	Haruyoshi	Chuo-ku	14
2	Hibaru	Minamia-ku	11
3	Nanakuma	Jounan-ku	10
4	Hakozaki	Higashi-ku	10
5	Yoshizuka	Hakata-ku	10
6	Chiyo	Hakata-ku	10
7	Kashiwabarū	Minami-ku	9
8	Fukushige-danchi	Nishi-ku	8
9	Ozasa	Chuo-ku	8
10	Ijiri	Minami-ku	8

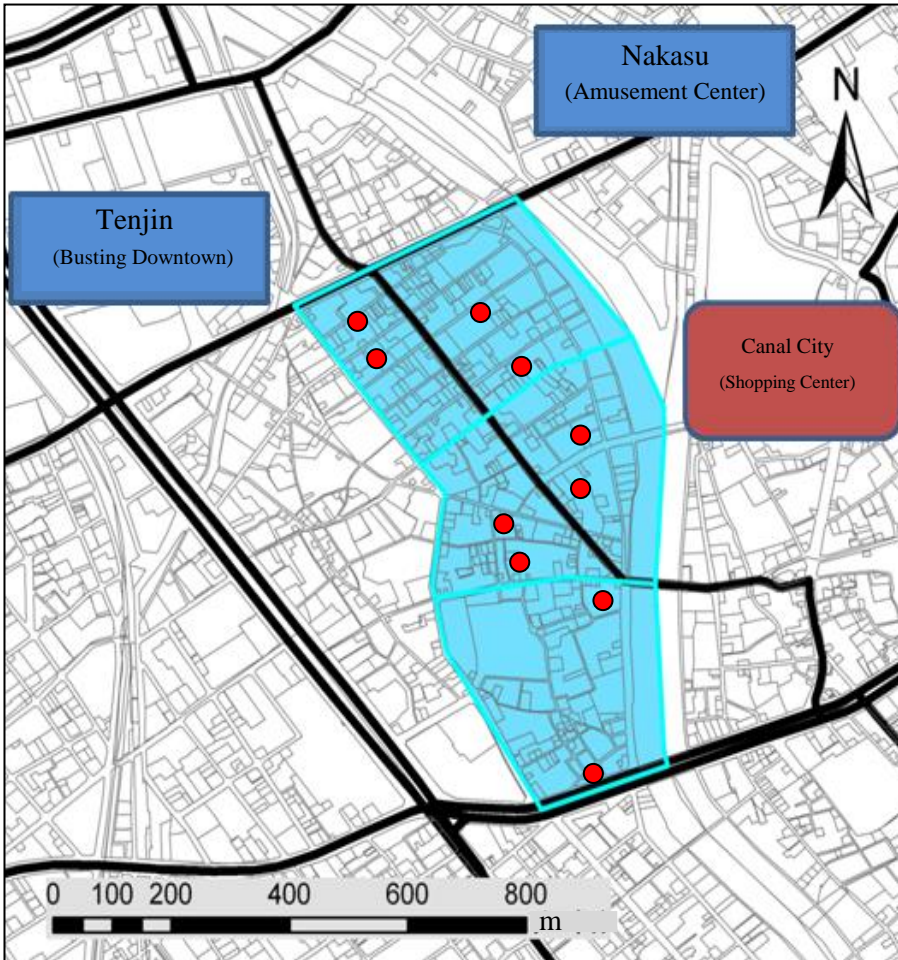


Figure 7. Haruyoshi and Its Surrounding

### 3.2 Microscopic Analysis

For further understanding of microscopic spatial characteristics of the arson spots in Haruyoshi, on-the-site surveys were conducted. The approximate (not exact) locations of arson are plotted in Fig.8. Some of the arsons in Haruyoshi were committed at the same location, so 10 points were chosen for the on-the-site survey.

Table.2 shows the result of the survey. Interestingly, all of the spots are located in the places which are 100m or less away from major arterial roads. Also, at least 2 or 3 usages of land are observed (Fig. 8). Furthermore, most of the roads in which the arson spots are on have less than 5m of width. Void spaces in which people can pass are also often to be observed in the arson spots or in adjacent sites (Fig. 9).



Figure 8&9. Multiple Land Usage and Permeable Space in Haruyoshi

Table 2. Spatial Characteristics of Arson Spots in Haruyoshi

No.	Distance from major arterial roads(m)	Variety of adjacent buildings	Width of the road where the building is located (m)	Void • Permeable Space (◎: very permeable, ○: permeable, △: not so permeable)	
1	5.1	Detached house, Commercial Building	3.4	○	In the adjacent sites
2	28.9	Detached house, Apartment, Commercial Building	14.1	◎	In the site where the building is located
3	32.8	Detached house, Apartment, Commercial Building	4.2	◎	In the site where the building is located
4	64.8	Detached house, Apartment, Commercial Building	2.6	○	In the adjacent sites
5	32.8	Detached house, Apartment, Commercial Building	4.3	◎	In the site where the building is located
6	73.3	Detached house, Apartment, Commercial Building	13.3	◎	In the site where the building is located
7	91.7	Detached house, Apartment, Commercial Building	4.5	◎	In the site where the building is located
8	75.8	Apartment, Commercial Building	4.7	○	In the adjacent sites
9	54.5	Apartment, Commercial Building	4.2	△	In the block where the building is located
10	53.2	Apartment	4.2	○	In the adjacent sites

### 3.3 Haruyoshi's Vulnerability against Arson

Up to here, the spatial characteristics of the arson spots in Haruyoshi have been discussed. To summarize, the specific points to leverage for prevention against arson are: 1) the spots located appropriately away from major arterial roads, 2) the spots surrounded by a variety of buildings used for many purposes, and 3) the spots with void spaces through which people can go and come.

In contrast, in the next chapter, more specific environmental and psychological analysis is provided to clarify the resilience the district has.

## 4. FIELDWORK AND ENVIRONMENTAL PSYCHOLOGICAL ANALYSIS

### 4.1 General Information of Fieldwork

In chapter 2 and 3, with quantitative approaches, the trends and characteristics of arson in Fukuoka and Haruyoshi are analysed to see the vulnerability against arson. Through this analysis, we discovered where the need to leverage for preventive actions against arson, but specific methods is still essential and is to be even furthermore explored.

Therefore, this chapter is aimed at exploring various factors which can prevent people from committing arson in Haruyoshi from a qualitative viewpoint. Specifically, at first, an on-the-site survey was conducted to obtain the places in which it is evaluated as “difficult” to commit arson. This survey was conducted all over the district at night in the period going from 2010 July to 2011 January intermittently. Each place in which author felt it was “difficult” to commit arson, pictures and field notes (the texted data of ideation which emerged when the author tried to commit arson at those places) were taken. After the survey, the author added captions on all the pictures taken from the field, and the pictures, their captions, and field notes were holistically analysed by M-GTA.

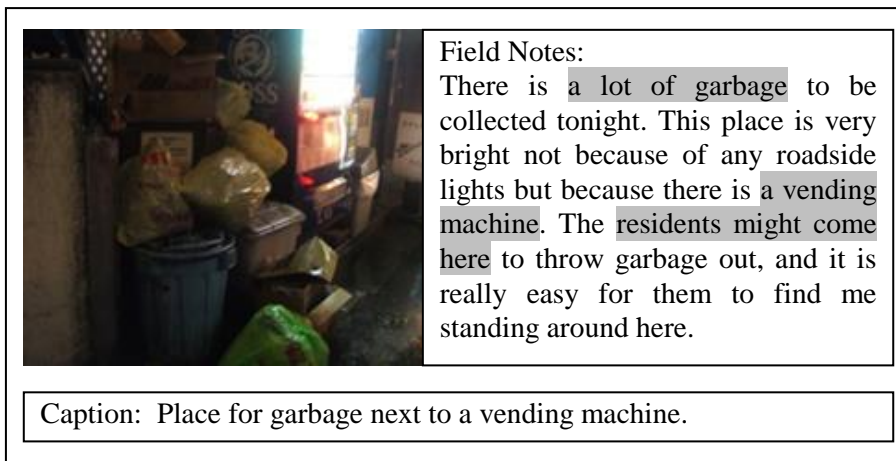


Figure 10. Sample of the Data for M-GTA

### 4.2 Methodology of Analysis

Grounded Theory Approach (GTA) is generally used for developing a theory inductively from a corpus of text data ([Glaser and Strauss, 1967](#)). The basic idea of the GTA is to read a textual database, such as field notes repeatedly, and “discover” or label variables, called categories, concepts and properties, and their interrelationships. The ability to perceive variables and relationships is termed “theoretical sensitivity” and is affected by a number of things including one’s reading of the literature and one’s use of techniques designed to enhance sensitivity. Of course, the data does not have to be literally textual, and it could be observations of behavior, such as interactions and events in a specific place.

One of its merits is the open-ended nature of its interaction which makes it possible to reveal and arrange implicit knowledge about a person’s own thoughts. Of course, GTA has been criticized for its process which is

impossible to free oneself from preconceptions in the collection and analysis of the data, but its constant comparative method is still worthy among other qualitative method ([Thomas and James, 2006](#)).

Therefore in this study, GTA is considered as a qualitative inquiry method, not a quantitative approach like the developers, Glaser and Strauss, have intended it to be. As a constant comparative method of clinical data of urban spots, GTA is suitable to use for this study since it can reveal the implicit knowledge which cannot be revealed by directive questionnaires and predefined criteria.

The general process of GTA is; 1) take text data like field notes, 2) conduct constant comparison for clustering, 3) review the data based on the result of clustering, 4) repeat 2) and 3) until all the data is settled down in categories or a theory that can be explained by the categories. The original version of GTA requires researchers to segment down text data as small as possible, but the process might destroy the contexts of the data. So, M-GTA brought by [Kinoshita \(2007\)](#) is utilized for this study. With M-GTA, key words and sentences are directly extracted from text data, and they are compared to each other as a small concept to generate bigger categories and concepts. In the next section, the result of M-GTA on the data for this study is explained.

### 4.3 Result of Analysis

#### 4.3.1 Visually Recognized Objects

In this study, visually recognized objects which appeared in the corpus of text data are focused on as one of the key aspects to analyze the resilience of Haruyoshi district against arson. There are many objects observed in the field and they can be categorized into 2 categories: Objects which are proactive in crime prevention, such as surveillance cameras and security lights, and objects derived from residents' life, such as parked bicycles and garbage. Table 3 shows the summary of the recognized objects in 2 categories.

Table 3. List of Visually Recognized Objects

Category	Objects
Objects which are proactive in crime prevention	Surveillance Camera
	Security Light
	Gate
	Fence
	Warning Sticker
	Pebbles
Objects derived from residents' life	Bicycle
	Taxi
	Vending machine
	Parked Car
	Convenience Store
	Bar / Restaurant
	Garbage
	Garbage truck
Planter	



### 4.3.2 Crime Preventive Factors of Visually Recognized Objects

Through M-GTA, visually recognized objects are clustered, and the result of clustering is shown in Table 4. According to the results, 9 clusters are defined, and the characteristics of each cluster are introduced and examined below.

Table 4. Clusters of Crime Preventive Factors

No.	Clusters
1	Temporal Settings
2	Existence of Other's Behaviour
3	Access Point
4	Unclear Idle Time
5	Surveillance Appeal
6	Openness of Space
7	Recoiling of Action
8	State of Territory
9	Parting

#### 4.3.2.1 Temporal Settings

This cluster is formed from the sentences and words about objects seemed to be set temporally. For example, a car parked at a coin-operated parking space seems that it is parked there for a short time, and indicates that the owner of the car will come back soon. In addition, bicycles parked informally are in this cluster. Additionally, Fukuoka is famous for its unique system to collect garbage from houses and apartments, and residents usually put garbage bag out at designated places at night on designated day. The garbage can also indicates that someone can come to the garbage collecting place abruptly at night. This cluster is related to the human traffic as in the resilience categories.



Figure 11&12. Thrown-out Garbage Bags and a Garbage Wagon Collecting at Night

#### 4.3.2.2 Existence of Other's Behavior

This cluster consists of the sentences about both visible and invisible existence of people's behaviours, not only pedestrians themselves but also the hotels that rent rooms to couples either overnight or for short times (Fig. 13). Haruyoshi is famous for concentration of such hotels, and this cluster is one of the features of Haruyoshi's crime preventive factors. Also, due to the location near to Tenjin, the downtown of Fukuoka, and Nakasu, an

amusement centre especially for night activities, Haruyoshi is used as backstreet area to pass by taxis. Therefore, compared to other district, Haruyoshi has a lot of taxis passing through especially at night (Fig. 14).

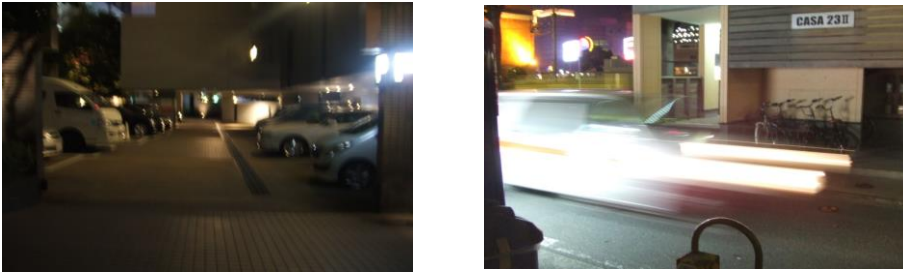


Figure 13&14. A Casual Motel So-called “Love Hotel” and Traffic of Taxi in Haruyoshi

#### 4.3.2.3 Access Point

The objects categorized in this cluster have the ability to attract people to do something around there. For example, a vending machine of cigarettes located near to an izakaya, a Japanese-style bar, can bring around not only pedestrians but also the customers of the bar, and the place with the vending machine has become one of the access points where people often come (Fig. 15). Needless to say, convenience stores which are open overnight in Japan are able to be access points for residents at night (Fig. 16).

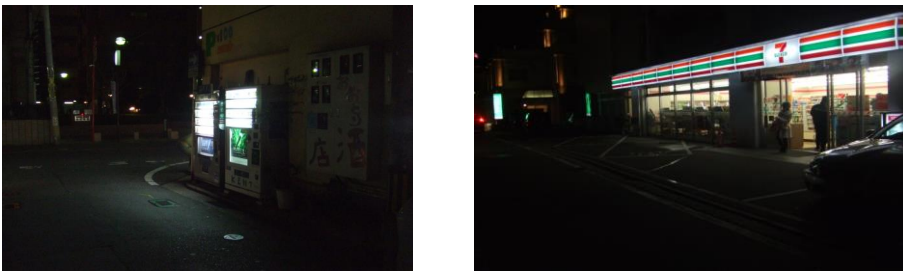


Figure 15&16. A Vending Machine Set by a Bar and a Convenience Store Open at Night

#### 4.3.2.4 Unclear Idle Time

This cluster is strongly related to the temporal setting cluster, and defines that objects set or parked permanently cannot let people know the exact time of the owner’s return. If someone tries to do something illegal, he/she needs to pay attention to others coming to the place. In Haruyoshi, there are some coin-operated parking lots for people to park their cars and go to restaurants near to the parking lot or other adjoined areas such as Tenjin or Nakasu. The important point is that it is really difficult to predict how long the idle time is due to the multi-purpose characteristic and location of the district.

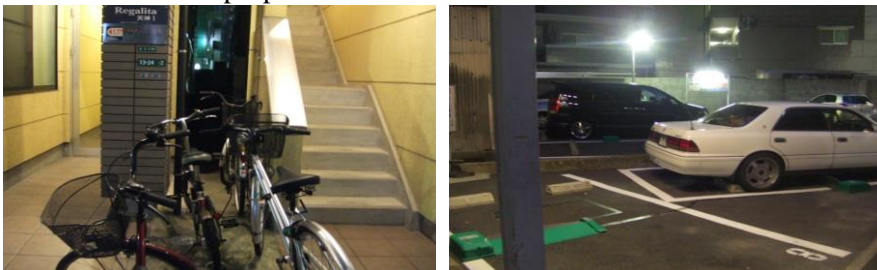


Figure 17&18. Bicycles Parked at an Unofficial Place and a Coin-operated Parking Lot



#### 4.3.2.5 Surveillance Appeal

In Haruyoshi, there are some places at which security lights or surveillance cameras were observed. Of course, surveillance cameras and security lights are one way to enhance surveillance. Besides these proactive devices for crime prevention, a garden, yard and planter make people feel the place is arranged and managed by somebody, and so their effort can also be this surveillance appeal.



Figure 19&20. A Security Light and a Surveillance Camera

#### 4.3.2.6 Openness of Space

The descriptions of spatial characteristics focused on the openness of space in and around the site are grouped in this cluster. This cluster is strongly related to the observability as in the resilience category. If the Pilotis are enlightened enough, people feel this openness strongly (Fig. 21). Also, in some places, in order to clarify the border of two different sites, fences are used, and they create more openness than walls do (Fig. 22). Of course, it is more difficult to commit arson if there is more observability. Therefore, it is important to make open and observable places against arson.



Figure 21&22. Fully Lighten Pilotis and a Places Parted by a Fence

#### 4.3.2.7 Recoiling of Action

There are some devices set to make recoiling of action which can be helpful for the residents and scary to someone who doesn't belong to the place. As an example of the devices set unintentionally, the steps made of iron, pebbles scattered in front of an entrance of a house, and rusty gates which make a creak when people open or close them are observed.



Figure 23&24. Scattered Pebbles in Front of a House and Steps Made of Iron

**4.3.2.8 State of Territory**

This cluster consists of the sentences related to the inanonymity as in the resilience category. Fences and gates are examples of the hard state of territory, but not only that, there are also some soft states such as the settlement of planters and difference of pavement.



Figure 25&26. Settlement of Planters and Difference of Pavement to State of Territory

**4.3.2.9 Parting**

This cluster defines on of most important notions for crime prevention. If there is someone standing in the parted places from roads, the person will be suspected. This is not only about making private spaces, but it will work to make public spaces which can limit the access of people, such as an alcove and parking lots for specific and limited users.

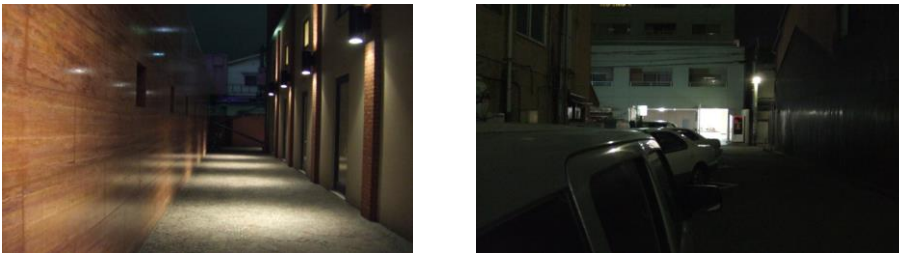


Figure 27&28. An alcove with Only One Exit and a Parking Lot for Limited Users

**4.3.3 Resilience against Arson in Haruyoshi**

After clustering the observed objects, 9 clusters are grouped into 3, and each of the groups is named. The result is shown in Table 5. In here, these 3 groups are considered the resilience against arson in Haruyoshi, and explained below.

Table 5. Resilience against Arson in Haruyoshi

Resilience	Clusters
Human Traffic	Temporal Settings
	Existence of Other's Behaviour
	Access Point
	Unclear Idle Time
Observability	Surveillance Appeal
	Openness of Space
	Recoiling of Action
Inanonymity	State of Territory
	Parting

**4.3.3.1 Human Traffic**

Human traffic is related to the temporal settings, existence of other’s behaviour, access point, and unclear idle time. Human traffic does not have to be the real traffic, but some settings, conditions, and devices which can make people feel that somebody might come can create this resilience. Specifically, the bicycles parked in front of an izakaya have this resilience, unlike those parked in a parking lot attached to an apartment. That is because, the bicycle can indicate that the owner is in the izakaya and he/she might come out from the izakaya soon. Also, there are vending machines selling beverages and cigarettes in front of izakaya, but the latter can create a lot of human traffic.


	<p>Field Notes:          There is a vending machine settled aside a wall of izakaya so that people eat and drink in the izakaya conveniently can come to this place to buy cigarettes. Since the izakaya is open till late night, it is possible to make human traffic even at night. If this vending machine is for beverages, the relationship with the izakaya may be different.</p>
<p>Caption: A vending machine set aside an izakaya</p>	

Figure 29. Representative Picture and Script for Human Traffic

**4.3.3.2 Observability**

This resilience is related to the surveillance appeal, openness of space, and recoiling of action, and is about the risk and/or feeling of being observed by other people. This resilience will appear not only when a criminal stands on a road with some other pedestrians, but also when a criminal feels the appeal of surveillance or the possibility of being observed even though there is no one around the site. For example, in Haruyoshi, there are some low-level old apartments with stairs made of iron which make sounds when people use them and generate observability and prevent non-residents from using them.


	<p>Field Notes:          This place is located in a site of an apartment but easy to come into. However, if people try to go up these stairs made of iron, big sound will be made, and it is possible to let people around here know that here is a person weirdly. So, it is difficult to go up these stairs at night.</p>
<p>Caption: Iron stairs found in a site of an apartment</p>	

Figure 30. Representative Picture and Script for Observability

### 4.3.3.3 Inanonymity

Inanonymity consists of the state of territory and parting. Because of this, potential criminals will feel that they can be identified and give up trying to commit a crime in the site. If there is a state of territory, there is a great risk of being observed by the owner of the site or those who know who is the owner or user of the site. Also, there are some roads with dead ends all along in Haruyoshi, and it is difficult to commit arson at the deep side of the road since there is a risk that someone identifies the weirdness of the criminal being there.

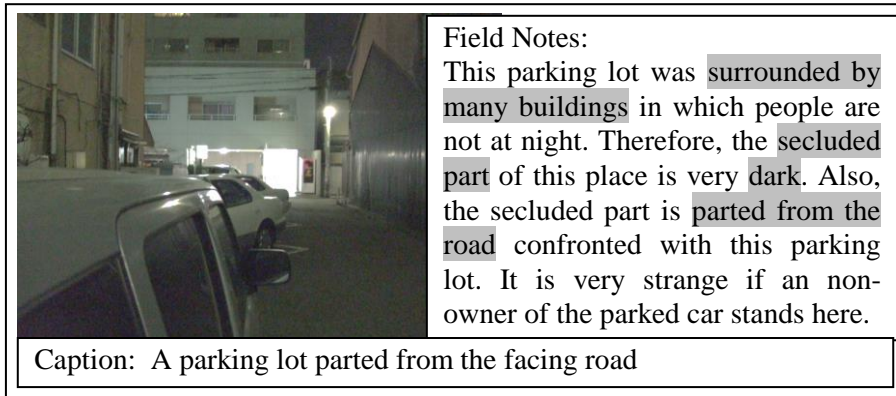


Figure 31. Representative Picture and Script for Inanonymity

## 4.4 Haruyoshi's Resilience against Arson

Through the fieldwork in Haruyoshi and analysis of the qualitative data by M-GTA, some resilience against arson in Haruyoshi, and related factors and objects is revealed. By parsing the crime preventive factors, the resilience is summarized into 3 main clusters: 1) Human traffic, 2) Observability, and 3) inanonymity. As an interesting result throughout the analysis, it is implied that the resilience does not rely on the observed objects' usage, but the environmental compatibility; in other words, specific settings of the objects and surroundings are of a great matter. This point should be considered when planning urban reforms regarding crime prevention.

## 5. CONCLUSION

In this study, first, the temporal and geographical vulnerabilities against arson in Fukuoka are explained. Then, a more localized district, Haruyoshi, is chosen being on the highest concentration of arson sites and which needs to be improved with specific crime preventive methods.

As a result of temporal analysis of Fukuoka, specific months (May and December) and time zones (9 p.m. to 6 a.m.) were clarified to leverage for prevention against arson. In CPTED, there is a concept of formal organized surveillance, and especially in Japan, they used to have such a surveillance activity conducted by residents for their village, town and district. Recently, due to the increased number of large-scale apartments, there are few meetings of local residents and such surveillance activities. It is also hard for people to be engaged in surveillance activities all the time. However, based on the information of vulnerable time zones and months, it may be possible to

conduct semi-formal organized surveillance only in the time zones of the months to prevent major arsons.

In addition, the result of the geographical and spatial survey and analysis in Fukuoka and Haruyoshi concludes that there are specific points to leverage for prevention against arsons especially targeting buildings: 1) the spots located appropriately away from major arterial roads, 2) the spots surrounded by a variety of buildings used for many purposes, and 3) the spots with void spaces through which people can go and come. Based on the knowledge of CPTED, it is understandable that these three spots are vulnerable; however, considering the unique characteristic in urban structure of Haruyoshi, it is difficult to conduct hardening access control and improving surveillance unless implementing a readjustment of district itself. In addition, the sequential results of this study strongly suggest that it is needed to clarify the vulnerability of a small range of cities or districts ahead of crime preventive urban planning since their spatial and social characteristics differ from each other. CPTED has offered a vast and general idea of crime prevention related to spatial designs so far, but this study suggests that it is needed to think of each characteristic of the targeted district, town, or city from spatial and temporal viewpoints macroscopically and microscopically.

Given the dilemma mentioned above, indicating where improvements should take place is not enough, but the how can those improvements be implemented is also crucial to improve the resilience of each district, and not only vulnerability but also resilience should be revealed to conduct practical crime preventive urban planning. To add such knowledge to the concept of CPTED, finally, as a result of the qualitative survey and analysis on the places evaluated as “difficult” places to commit arson, focusing on the visually observed objects, Haruyoshi’s resilience, 1) Human traffic, 2) Observability, and 3) inonymity, are revealed. These preventive factors can be integrated into the previous CPTED method of urban planning, and it is possible to improve the condition more.

Consequently, the importance of considering those two axes (vulnerability and resilience) at the same time is implied for the next generation of CPTED. For this purpose, the consecutive method about crimes by joint quantitative and qualitative methodologies is called for.

Of course these results are specifically derived for Fukuoka and Haruyoshi based on their current condition. Therefore, there is very small versatility of the results, and if the vulnerability and resilience are needed to be clarified for another place, it is needed to conduct another research. Furthermore, if these kinds of researches are going to be accumulated like medical clinical researches, it will be also possible to find out some versatile outcomes in the future.

Additionally, M-GTA, the method of analysis used for the qualitative data in this study is not the only method to evaluate qualitative data. There is a difficulty to try to combine both quantitative and qualitative methodologies, but considering the results of qualitative method as clinical data which should be accumulated by a number of “urban doctors,” it will be possible to promote such methodology in urban planning field in the future. For further consideration, clinical examinations of the survey to detect the resilience of the city remain an important matter.

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# Assessing the Social and Economic Vulnerability of Urban Areas to Disasters: A case study in Beijing, China

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**Abstract:** For urban areas with complicated functions and facing rapidly increasing exposure to disaster risks, reducing vulnerability is the most effective way to alleviate damages and losses, which requires first and foremost precise assessment of the social and economic system's vulnerability. Considering the strong variations of social and economic factors by location and convenience for emergency management, it is very important to take small blocks as the basic spatial unit for vulnerability assessment. However, thus far appropriate evaluation method at such scale is quite inadequate in terms of theoretical framework, data acquisition method and analytical model. Taking Haidian district in Beijing as an example, a set of models was developed to solve these problems. Day and night population estimation model, population vulnerability assessment model, economic scale model, and economic vulnerability assessment model were designed to assess the population and economic vulnerability of urban areas. Results of the case study in Beijing demonstrated the population and economic vulnerability of each block in the study area, and suggested a difference between daytime and nighttime. The hotspots of high vulnerability were also identified and the land use characteristics and function agglomeration of these areas were discussed. Clearly, these results provided an important base for making effective disaster prevention plan and emergency management.

## 1. INTRODUCTION

In 2010, Beijing has a total of 19.61 million residential populations ([Zhu, 2012](#)). It is a mega-city with a huge size and increasingly complex urban structures. In the rapid urbanization process of China, Beijing is the most attractive place in north China where population and industries consistently agglomerate, which has brought about large-scale urban expansion. Nonetheless, Beijing is located in disaster-prone areas ([Wang, 2008](#)). This situation brings many potential factors that could contribute to disasters, such as high population density, overcrowded and unsafe living environment, pollution and garbage, hazardous industries, under-developed and complicated lifeline system, environmental deterioration, poverty and inequality, and a huge temporary population (mostly consists of low-skilled migrant workers). All these factors make Beijing very vulnerable to disasters.



Like Beijing, most cities in China face high and rapidly increasing exposure to natural hazards and the risks of public safety events, calling for in-time and effective countermeasures. However, as revealed by catastrophes such as SARS, 2008 Wenchuan earthquake, 2010 Zhouqu Large debris flow, and 2010 Yushu earthquake, there are still many obstacles for the implementation of effective control and prevention strategies over public safety events ([Wang, 2012](#)). One of the main obstacles is inadequate studies on the uncertainty of public safety events, on the formation, transition and chaining of disasters, and on disaster forecasting and precaution. As these problems are hard to be solved for the time being, reducing disaster vulnerability is recognized as a more direct and effective way to reduce disaster risks.

Besides the vulnerability of infrastructure and physical environments, that of social and economic system is an essential part of disaster risk assessment. It may provide crucial information necessary for emergency management and making recovery plans, because risk reduction and disaster preparedness to hazards require the precise assessment of vulnerability of different places, people and industries ([Birkmann, 2006](#)).

A review of literature indicates that vulnerability has as many as a dozen different definitions, depending on the purpose and perspective of research ([Cutter et al., 2003](#)). No consensus has been achieved on what should and should not be included in vulnerability assessment, and different evaluation models were used by researchers, planners, and disaster managers ([Alaghi, 2012](#)). While definitions and approaches diverse, it is commonly agreed that vulnerability should take into account of exposure, sensitivity, and the capacity to adapt to perturbations or stresses. Exposure is the nature and degree to which a system experiences perturbations or stresses. Sensitivity is the predisposition and degree to which a system is modified or affected ([Adger, 2006](#); [Field et al., 2012](#)). Adaptive capacity the ability or capacity or resilience of the system to cope, adapt or recover from the effects of hazardous conditions. In general, a system which is more exposed and sensitive to disasters is more vulnerable, and vice versa, one with higher adaptive capacity less vulnerable ([Smit and Wandel, 2006](#)). In this paper, we define population vulnerability as the state of susceptibility for population to be harmed from exposure to disasters and economic vulnerability as the potential loss from disasters.

Many studies have been conducted on social vulnerability and a variety of indices and approaches at different scales were proposed. For example, [Adger et al. \(2004\)](#) developed predictive indicators of vulnerability at the national level and made country comparisons; [Cutter et al. \(2003\)](#), [Cutter and Finch \(2008\)](#), and [Fekete \(2010\)](#) presented county-level social vulnerability indices to natural hazards. In contrast, [Rygel et al. \(2006\)](#), [Granger et al. \(1999\)](#) and [Dwyer et al. \(2004\)](#) have elaborated social vulnerability at census block, community, and even household levels. It is noticed that the selection of spatial scale was largely determined by availability of data at the concerned scale. Moreover, if the basic study unit was too large, it is usually hard to provide practical information to emergency management.

Significant progress has been made in recent years on economic analysis of disasters, such as modeling for and empirical analysis on the economic impact of disasters ([Okuyama, 2007](#); [Rose, 2004](#); [Tierney, 1997](#); [Wagner and Neshat, 2010](#)). The theoretical assessment of economic vulnerability has also been addressed, despite relatively small number of researches ([Chang, 2002](#); [Wagner and Bode, 2006](#); [Hiete and Merz, 2009](#)). Empirical studies on

economic vulnerability have mainly focused on business vulnerability ([Zhang et al., 2009](#)), and economic system's vulnerability at regional scale such as islands ([Adrianto and Matsuda, 2002](#)) and national scale ([Saldaña-Zorrilla, 2006](#)), but few have been conducted at small scale within cities. To some extent, this reflected the view that the economic system is interrelated and the direct and indirect effects of disasters on economic system are not limited to a predefined scope like a city. But still, we think that evaluation of economic vulnerability at a local scale is highly meaningful from the perspective of emergency management and mitigation of direct damages.

Social vulnerability is most often described using the characteristics of people ([Cutter et al., 2003](#)), and since people are the core and the main hazard-bearing bodies of the human social system, this paper conducts study on population vulnerability directly.

For Chinese cities, the assessment of social (population) and economic vulnerability is a relatively new research theme. Some studies were conducted ([Xu, 1998](#); [Ge et al., 2005](#); [Lin, 2007](#); [Du et al., 2008](#); [Zhang et al., 2012](#); [Nie, 2012](#); [Shi, 2013](#)), however, most studies had been carried out on highly aggregated spatial units in the form of administrative units like district, town, county, and prefecture ([Zhou et al., 2009](#); [Lou et al., 2009](#); [Chen et al., 2012](#); [Shi, 2013](#)). Although they helped in understanding the social and economic vulnerability to disasters at national and regional level, such over-aggregated scale may obscures the different impacts of disasters on population and economy within the affected region ([Zhang et al., 2009](#)). Therefore, wherever strong spatial variation in vulnerability exists, micro-scale analysis is indispensable ([Turner, 2003](#)). Doubtlessly, this is the case for large metropolitan areas such as Beijing.

In this paper, we attempt to conduct a micro-scale assessment on the social and economic vulnerability of urban areas. We intend to develop some new theoretical framework, data acquisition methods and analytical models.

## 2. DATA AND METHODOLOGY

### 2.1 The study area and data

With the support of Beijing Institute of Surveying and Mapping (BISP) on detailed spatial data, we selected Haidian, one of the 16 administrative districts in Beijing as the study area. The district covers an area of 431 km<sup>2</sup>, and is located in north-west Beijing, with the southern part being built-up areas and the northern part hilly mountain areas. The district has 29 lower level administrative units, called Jiedaos and townships, where the basic population and economic statistics were publicized.

#### (1) The definition of spatial unit

Appropriate scale should be predicated upon research goals. In order to identify the vulnerable places, people, and industries in urban areas as well as to draw useful implications for relevant policies, we took blocks as the basic spatial unit of this study, considering that blocks, which are confined by urban roads, constitute the basic unit of urban fabric and the smallest component in urban planning and spatial governance.

To focus on urban areas, the northern part of the district which was mostly forest and agricultural land use was taken out from the study area. Then, with ArcGIS application, the study area was divided by urban roads into

647 blocks.

### **(2) Data for population vulnerability assessment**

For population vulnerability assessment, permanent resident population data of Haidian district from the sixth national census in 2010, and employment data from the second Economic Census Yearbook were used. According to the age classification, infant and aging people referred to children under 4 years old and people above 60 respectively. In addition, population related to schools, hospitals, and tourism from the Statistic Yearbook of Haidian District in 2010, and land use survey data were employed. The daily numbers of tourists, outpatient and hospitalization population were calculated with the annual average.

As most data were aggregated at district or Jiedao scales, we used a population estimation model to calculate the block-level data. To do so, spatial data on buildings, including floor area and usage, and on hospitals, nursery, primary and secondary schools, nursing home, and land use map provided by BISP were used. The detailed information of buildings was used to estimate the population of blocks from that of larger scales.

### **(3) Data for economic vulnerability assessment**

Lack of appropriate data is a big difficulty for economic vulnerability assessment. Only a limited part of economic data was available from statistic books, including GDP of the district, total assets of industries, education and professional levels of employees, water and electricity consumption of each Jiedao, and the total amount of transportation infrastructure in the district. In 2010, Beijing had also publicized the input-output table of 42 industrial sectors.

The above data were helpful for identifying the relative importance and interaction of various industrial sectors. However, as most data were aggregated at district or Jiedao scales, spatial attributes were deficient. To solve this problem, we used the data of registered enterprises in Beijing Haidian district in 2010. The dataset included 138,380 firms and provided a wide range of information including annual turnover, total assets, number of employees, registered capital, industry code (in two-, three- and four-digit), ownership type, founding time, and location. The enterprises were mapped as a point layer by the geo-coding function of ArcGIS (Fig.1).

Screening the original data, we found that data of some firms were incomplete. Therefore, we tested the distribution of founding time and location of enterprises with incomplete attribute data. If they were randomly distributed over time and space, the records with incomplete data could just be removed. If not, a conditional mean imputation could be employed, i.e. stratified the firms according to predictor variables such as industrial type and enterprise scale, then replaced the missing value of firms with the average value of the layer to which they belong. Previous study of [Mao \(2005\)](#) showed that conditions mean imputation was suitable if missing data rate was 20% - 30%, which is alike the missing data rate of our dataset.

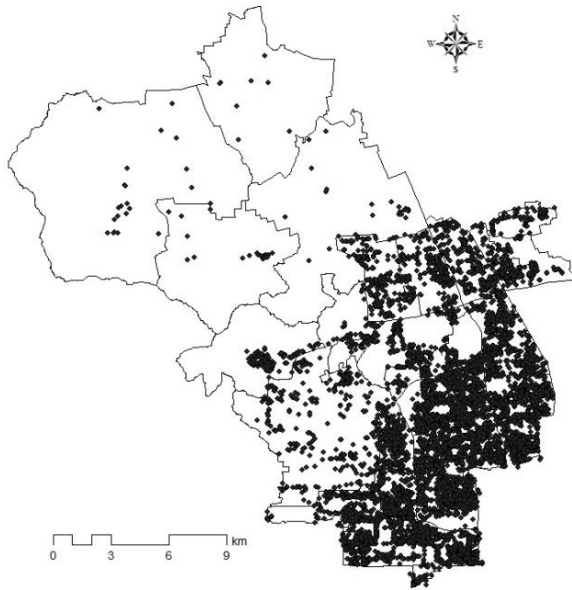


Figure 1. Distribution of enterprises in Haidian district, Beijing

## 2.2 Method for population vulnerability assessment

Presumably, population vulnerability differs across person and varies over space and time. Therefore, we evaluated it from three dimensions: demographic feature, space and time. Specifically, which groups of people are vulnerable, the difference of day and night, and the spatial distribution of population were considered.

Three steps were followed to conduct population vulnerability assessment. Firstly, theoretical indicator framework for population vulnerability assessment was established. Secondly, the day and night population of each spatial unit were calculated. Then, the population vulnerability of each unit was evaluated.

### (1) Indicators of population vulnerability

Vulnerable population groups were defined, including females, who are generally less strong than males; the elderly over 65, whose mobility and physical function of bodies decline; minors under 16, whose mental and physical development are immature; the sick, whose physical functions are worse than healthy people; unemployed and poorly educated people, who get fewer organized assistance and are usually from low income families. When it comes to the population vulnerability of megacities in China, we also need to consider floating (temporary) population and population density.

Accordingly, an indicator system composed by physiological, social and spatial aspects was constructed as shown in Fig. 2. The sub-indicators of physiological factors include gender, age and health. As a result, eleven sub-indicators were included.

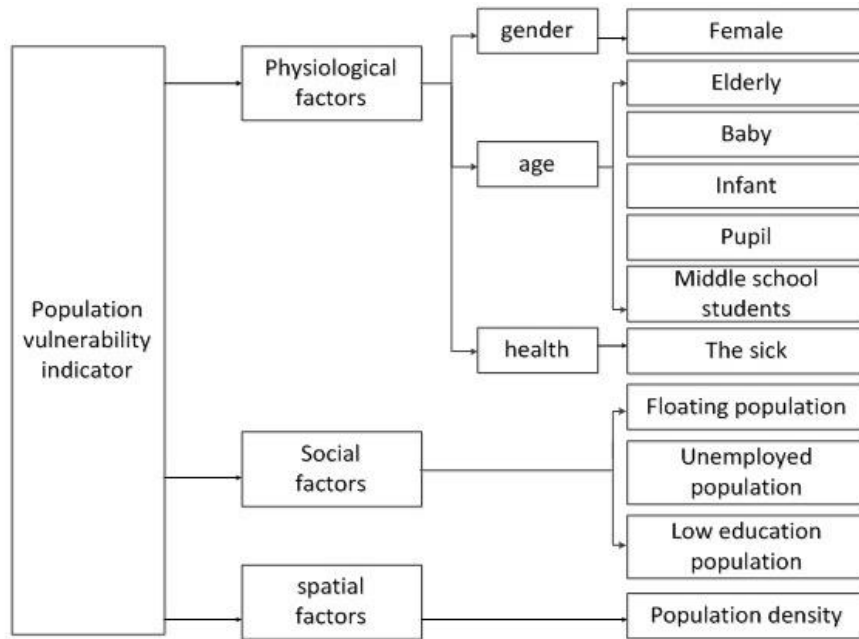


Figure 2. The indicator system of population vulnerability assessment

**(2) Method for calculating day and night population**

Spatial distribution of the population changes significantly between day and night, and across different land use types, we already have the night resident population data, and we need to calculate the daytime population, here we introduced population disaggregate model to solve this problem.

Urban land uses in this paper were divided into 15 subtypes, including urban residential land, industrial land, mining land, warehouse space etc., additionally, we paid special attention to 7 types of space where the vulnerable populations were located, such as hospitals, kindergartens, and nursing homes.

The basic idea of population disaggregate modeling is: (1) for people inside buildings, per capita land use was assumed to be the same on land of the same type. Then, given the area of per capita land use for certain land use type (employee population divided by the construction area) and the gross floor area of buildings (provided by building database), we can get the population of the buildings; (2) for people in the tourist attractions, we also assumed that per capita land use is identical. Then given per capita land use area of tourist attractions and the area of scenic spots, we can calculate the tourism population; (3) for people on farmland, woodland or other areas, the similar assumption was made, and we used the patch area to estimate the population.

The temporal and spatial distribution characteristics of the population are shown in Table 1. Accordingly, the populations of different spatial units were estimated.

Table 1. Temporal and spatial distribution of the population

Land use type	Time section	
	Daytime	Nighttime
Urban residential land	Elderly +baby +unemployed	City-dwelling population
Commercial land and public facilities	Employees of commercial and public service industries	No
Industrial land	Manufacturing workers	No
Mining sites	Employees of mining industry	No

Warehouse land	Warehousing workers	No
Rural residential land	Elderly +baby +unemployed	Rural residential population
Colleges	College Student +college teacher	College students
Hospitals	Healthcare workers+ emergency patients+ outpatient+ inpatients	Inpatient +healthcare workers (partial)
Nursery schools	Preschool children + preschool staff	No
Primary schools	Primary school students+ faculty	No
High schools	Secondary school students+ faculty	No
Charity organizations	The elderly and children + charity organization staff	The elderly and children + nursing home staff (partial)
Tourist attractions	Tourists+ staffs	No
Arable land	Primary industry workers	No

**(3) Evaluation of populaiton vulnerability**

First, population data was normalized:

$$y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}, \tag{1}$$

Where,  $y_{ij}$  is the standardized values of indicators  $j$  of unit  $i$ ,  $x_{ij}$  is the original data of indicators  $j$  of unit  $i$ ,  $\max(x_j)$  and  $\min(x_j)$  are the maximum and minimum values of indicators  $j$  among all units.

The population vulnerability of each unit was calculated with equation (2):

$$M_i = \frac{\sum_{j=1}^n (y_{ij} \times k_j)}{\sum k_j} \tag{2}$$

Where,  $M_i$  is population vulnerability of unit  $i$ ,  $k_j$  the weight of indicators  $j$ , and  $y_{ij}$  the standardized values of indicators  $j$  in unit  $i$ . The standardized value of each indicator stands for its state of susceptibility, and their different influences on population vulnerability were reflected by the weights.  $k_j$  were obtained with a Delphi method based on an expert knowledge survey. Accordingly, we could calculate population vulnerability of daytime  $M_i^{day}$  and nighttime  $M_i^{nig}$  separately.

Based on  $M_i^{day}$  and  $M_i^{nig}$ , we also calculated the comprehensive population vulnerability,  $M_i$ , which is necessary for daily risk management.

$$M_i = a_1 \times M_i^{day} + a_2 \times M_i^{nig} \tag{3}$$

In Haidian district, day and night population are both very large and population is more concentrated at night. Based on the survey of expert knowledge, 0.4 and 0.6 were assigned to  $a_1$  and  $a_2$  in equation (3), respectively.

## 2.3 Method for economic vulnerability assessment

### (1) Factors and assessment model

Economic vulnerability to disasters refers to the potential economic loss. In practice, it is fairly complex and difficult to quantify the economic loss from disasters, because direct loss, indirect and secondary loss, and other losses should all be included. So far, methods for evaluating indirect disaster loss and vulnerability are immature ([Okuyama, 2007](#); [Hiete and Merz, 2009](#)). In the literature, more efforts have been delivered to the development of theoretical models than empirical studies. The number of empirical studies is limited, probably due to the complexity of the problem and insufficient data.

Among the three components of vulnerability (exposure, sensitivity or susceptibility, and coping ability), we focus more on the former two. In particular, we attempt to assess relative vulnerability, which is measured by the product of exposure and sensitivity of economic system.

[Tierney \(1997\)](#) ever pointed out that economic losses are mainly due to three causes: first, physical damage such as that of raw materials, equipment and products in stock; second, production interruptions due to industrial process interruptions; and third, the disruptions of critical infrastructure.

For individual enterprises, exposure can be roughly measured by total assets of the enterprises. Because the number of individual enterprises is very large (about 15 0000), we estimated the sensitivity of industrial sectors in the three-digit (most are three-digit, still some are two-digit or four-digit) list of industries announced by National Statistics Bureau of China, and used the sensitivity of industrial sectors to which the enterprises belong to substitute the sensitivity of enterprises.

The sensitivity levels were estimated by combining the susceptibility and importance indices of each industrial sector. Susceptibility reflects the possibility of loss, and different industries have distinct sensitivities to disasters. Importance reflects the role of certain industries in emergency management and emergency rescue such as food and water supply and medical production, and that the disruption of some crucial industries to daily running of cities may lead to serious consequential damages. First, a semi-quantitative approach was adopted to select susceptible and important industries. Based on the selected industries, the industrial susceptibility and importance can be quantified by Delphi method.

We also took economic density as a supplement of the economic exposure to disasters. Given the limited emergency resources, priority should be given to regions with higher economic density and those which can bring greater economic benefits.

Next, we studied the functional relationship between the above factors in order to establish the evaluation model. Vulnerability can be assessed by the product of exposure and sensitivity ([Adger, 2006](#)), therefore, the product of economic exposure and the sum (which can represent the sensitivity) of susceptibility and importance of industries can measure the vulnerability of the enterprises. The vulnerability of enterprises and the economic density are two complementary components. Therefore, the following assessment model was established:

$$V = \alpha * S * (\beta * X_1 + (1 - \beta) * X_2) + (1 - \alpha) * X_3 \quad (4)$$

Where  $V$  is the regional economic vulnerability,  $S$  enterprise's scale representing the exposure,  $X_1$  and  $X_2$  are indices of industrial susceptibility and importance, respectively,  $X_3$  the economic density, and  $\alpha, \beta \in [0, 1]$  are weighting parameters.



As  $X_1$ ,  $X_2$  and  $X_3$  are different in physical meaning; their values should be standardized in order to obtain the overall level of economic vulnerability of the concerned region.

## (2) Susceptibility assessment by industrial types

Some industries may experience secondary disasters (such as fire and explosion), such as chemical industry, and special industry may lead to unconventional emergencies, such as nuclear power industry. They are typical susceptible industries. Industrial susceptibility is affected by such factors as input factor dependency, supply chain dependency, infrastructure dependency and the local concentration of industries. They were summarized in Table 2.

Table 2. Influencing factors of industrial vulnerability and underlying mechanism

Influencing factors	Mechanism
1. Supply shortage or damage of input factors (labor, capital, equipment, raw material, etc.)	An industry is more susceptible if its input requirements are higher and more specialized, e.g., highly educated and skilled workers, high value equipment, high intermediate input rate, capital requirements, because such industries may encounter greater direct losses and the possibility of production interruption due to poor input factor substitution is higher.
2. Disruption of lifeline systems (water, electricity, transportation volume)	An industry is susceptible if it is highly dependent on lifeline systems, e.g., extensive consumption of electricity, water and energy and transportation facilities, because it is more likely to be affected by the disruption of lifeline systems.
3. Supply chain interruption	Industries with large backward linkage effect (demand for the upstream industries) are more susceptible to the interruption of upstream industries.
4. Degree of industrial agglomeration	An area is expected to be more susceptible if the industries are more agglomerated in this area because of greater exposure to disasters.

Influence coefficient was introduced to reflect the relative dependence degree of certain industrial sectors on the supply chain, which was computed using Input-Output Table. The Input-Output Table is based on the balance between input and output of various sectors of national or regional economy. It can be used to reveal the quantitative relation of economic and technological interdependence and mutual restraint in various sectors. Larger influence coefficients indicate that the industries need more input from the other sectors.

As lifeline systems are particularly susceptibility to disasters, industries highly dependent on lifeline systems are more vulnerable. Therefore, we chose water consumption, electricity consumption and transportation volume (road and railway) of each industrial sector as indicators to measure the industry's dependence on lifeline systems; the gross production (GDP) of the industries were used to measure the spatial agglomeration degree of the industries. Scrutinizing the summing up values of the indicators, 69 susceptible industries were identified.

A Delphi method was adopted to assess the susceptibility of them. We conducted a questionnaire survey and asked 70 experts in the field of regional economics and disaster science to classify and score the selected industrial sectors: 7 for highly susceptible, 5 for very susceptible, 3 for medium susceptible, and 1 for low susceptible. With the answers, the standardized average scores of industrial susceptibility were calculated. Table 3 demonstrates the results for industrial sectors with high susceptibility.

Table 3. The susceptibility level of industrial sectors

Industrial sector	Susceptibility	Industrial sector	Susceptibility
Nuclear fuel processing industry	6.27	Coal mining and dressing	4.75
Nuclear radiation processing industry	6.21	Air transport industry	4.75
Gas production and supply industry	5.70	Pipeline transportation industry	4.63
Electric power supply	5.51	Basic chemical raw materials manufacturing	4.38
Oil processing and coking and nuclear fuel processing industry	5.34	Rail transit	4.38
Hydraulic production and supply industry	5.20	Chemicals technical manufacturing	4.30
Chemical materials and products	5.14	Railway passenger transportation	4.21
Electric power generation	5.09	Urban public transportation	4.21
Special chemical products manufacturing	4.89	Chemical drug preparations	4.18
Refined petroleum products manufacturing	4.86	Internet information service	4.18
Petroleum and natural gas extraction	4.83	Public passenger transportation	4.04
Biological and biochemical products manufacturing	4.78	Non-ferrous metal smelting and rolling processing industry	4.01

### (3) Importance assessment by industrial types

Important industries include the industries which are crucial to emergency management and the industries that are significant to the production of other industries, we could identify the first kind of industries through qualitative analysis methods (e.g. literature and media information), and we used inducing coefficients to choose the second kind of industries, inducing coefficient refers to a comparison of the production needs of one industrial sectors caused by one more unit of final product of all industrial sectors and the average level of production needs of the various industrial sectors caused by one more unit of final product of all industrial sectors. Larger inducing coefficient indicates that the industry is the basic industry; the inducing coefficient can be calculated with regional Input-Output Table. Finally, 49 important industries were selected.

With the Delphi method, the average scores of the industrial importance were computed, as shown in Table 4.

Table 4. The importance level of industrial sectors

Industrial sector	Importance	Industrial sector	Importance
Hospital	6.61	Railway freight transportation	5.31
Hydraulic production and supply industry	6.49	Pharmaceutical industry	5.25
Disease prevention and control and epidemic prevention activities	6.38	Hygienic material and medical supplies manufacturing	5.23
Electric power supply	6.32	Road passenger transportation	5.23
Hospitals and community health care activities	6.07	Social security	5.23
Electric power generation	5.96	Satellite transmission service	5.2
Gas production and supply industry	5.96	Food manufacturing industry	5.17
Telecommunications profession	5.73	Radio and television transmission service	5.06
Internet information service	5.51	Rail transit	4.94
Railway passenger transportation	5.45	Environmental management	4.92
Urban public transportation	5.39	Municipal public facilities management	4.92
Road freight transportation	5.34	Public trolley bus and bus passenger transportation	4.89

#### (4) Estimation of the size of individual enterprises

The scale of enterprises can be reflected by annual turnover, number of employees and total assets. In order to get a comprehensive evaluator from the three factors, we extracted common factors from them with factor analysis method. If the values of the obtained common factors were negative, they were transferred to a positive set by adding the absolute value of the minimum value.

The estimated sizes of individual enterprises were then aggregated for each block. Fig. 3 shows the result.

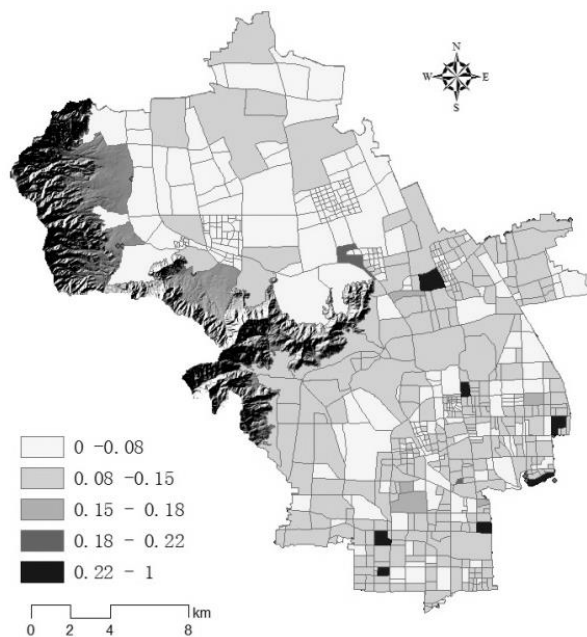


Figure 3. Distribution of enterprise scales of blocks in Haidian district, Beijing

**(5) Economic density of blocks**

According to [Alaghi \(2012\)](#), any tangible or intangible economic resources that are capable of producing value and that hold some positive economic value can be considered as an asset. Thus total asset is a better representative of economic scale than GDP.

At the block level, no economic data in China is publicly available. Therefore, we need to divide the economic data of Haidian district into the block level. As the total assets and total floor area of buildings in each industrial sector at the district level, and the gross floor area of buildings in these sectors at the block level are available, we could just allocate the asset values to each block by the proportion of gross floor area of each block in the district, assuming that per unit area asset values are equal. This assumption is somewhat arbitrary, and there might be significant difference between different blocks. In-depth study is necessary for improving the accuracy of spatial data.

With formula (5), the asset value of the j-th block,  $E_j$ , was estimated.

$$E_j = \sum_i \lambda_{ij} * \varepsilon_i , \tag{5}$$

where, i indicates industrial types,  $\lambda_{ij}$  is the proportion of gross floor area for sector i in the j-th block in the whole district, and  $\varepsilon_i$  is the total asset value of the i-th industrial sector in the district. Fig. 4 shows the result.

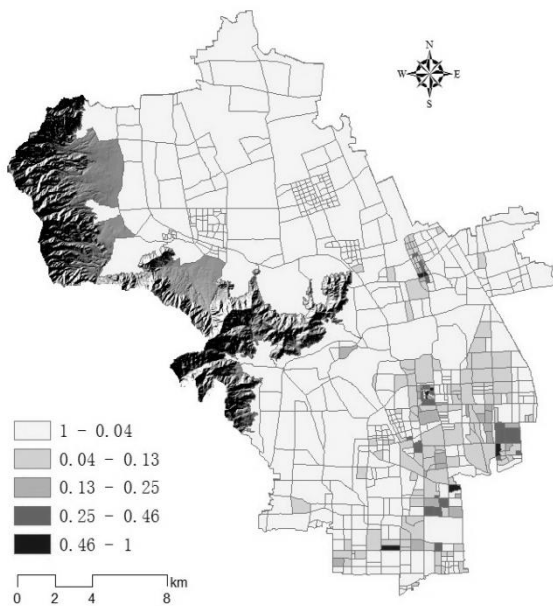


Figure 4. Distribution of economic density levels in Haidian district, Beijing

### 3. ANALYSIS RESULT OF POPULATION VULNERABILITY

#### 3.1 Spatial pattern of population vulnerability

With the method described in section 2.2, the population vulnerability index of every block was obtained. Among the methods for the classification and grading a single variable, such as equal interval, equal proportion, standard deviation, and natural breaks, appropriate one should be chosen according to the specific distribution of data set (Huang, 2007; Gao et al., 2012). For the convenience of emergency management and planning, objectivity and clear physical significance are required. So we chose standard deviation method for the population vulnerability classification.

As a result, the 647 blocks of Haidian district were classified into four levels, with population vulnerability within the interval of  $<-0.5$  standard deviation (low vulnerability), of  $\pm 0.5$  standard deviation (medium vulnerability), from  $+0.5$  to  $+1.5$  standard deviation (high vulnerability), and  $>1.5$  standard deviation (very high vulnerability). The population vulnerability of blocks was mapped in Fig. 2 and Fig. 3 (upper left part is the hill-shade of mountain areas).

Table 5. Result of population vulnerability assessment

Vulnerability levels		Number of blocks	Percentage (%)	
			By number	By area
Low	daytime	210	32.46	25.17
	nighttime	214	33.07	25.91
	comprehensive	209	32.3	26.8
Medium	daytime	293	45.28	46.38
	nighttime	269	41.58	46.55
	comprehensive	315	48.69	51.43
High	daytime	51	7.88	12.28
	nighttime	118	18.24	16.46
	comprehensive	77	11.9	12.19
Very high	daytime	93	14.37	16.15
	nighttime	46	7.11	9.07
	comprehensive	46	7.11	9.5

Table 5 presents the overall daytime, nighttime, and comprehensive population vulnerability. 144 out of 647 blocks (accounting for 28.4% of the total area of Haidian district), 164 blocks (25.5% of the area of the district), and 123 blocks (21.7% of the area of the district) are at high and very high levels of population vulnerability in daytime, nighttime, and comprehensively.

Fig. 5 and Fig. 6 suggest that blocks with high and very high population vulnerability concentrate in residential and service areas in the south and Hi-Tech Park areas in the east part of the study area. West and north areas for tourism and agricultural use are relatively less vulnerable.

The common spatial agglomeration areas of high and very high in daytime, nighttime and comprehensive population vulnerability are Balizhuang, Qinghuayuan, Wanshoulu, Xisanqi, Qinghe Jiedaos and Baiwangshan area.

However, the spatial agglomeration of some vulnerable places has significantly shifted over time. For example, Zhongguancun Jiedao is the most vulnerable area at daytime because this is the center of Hi-tech industry in Beijing and many people come to work in the office buildings in this area, but at night the vulnerability level is significantly lower.

In addition, we found that at nighttime the maximum and average levels of population vulnerability were higher than that of daytime. This could be explained by the fact that Haidian district generally loses more working population at daytime. Moreover, in the daytime, population is scattered in residential land, commercial land, and industrial land, but they gather in residential land at night. Although the area ratio of high and very high vulnerability classes is lower in nighttime, net population density in residential blocks is much higher.

We calculated comprehensive population vulnerability index by considering both day and night time. This is beneficial to daily risk management and planning. For instance, more emergency facilities and resources should be placed to vulnerable areas.

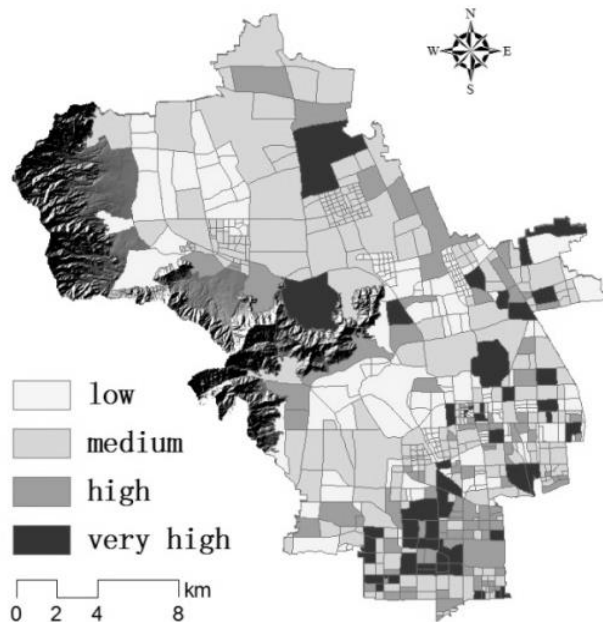


Figure 5. Distribution of population vulnerability levels in daytime

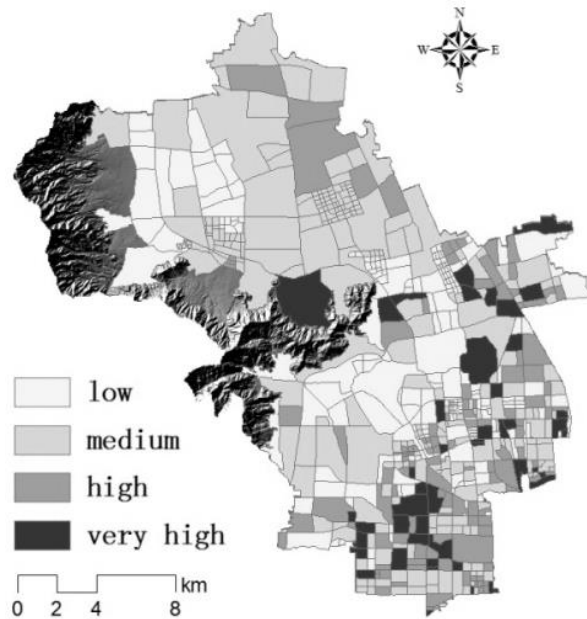


Figure 6. Distribution of population vulnerability levels in nighttime

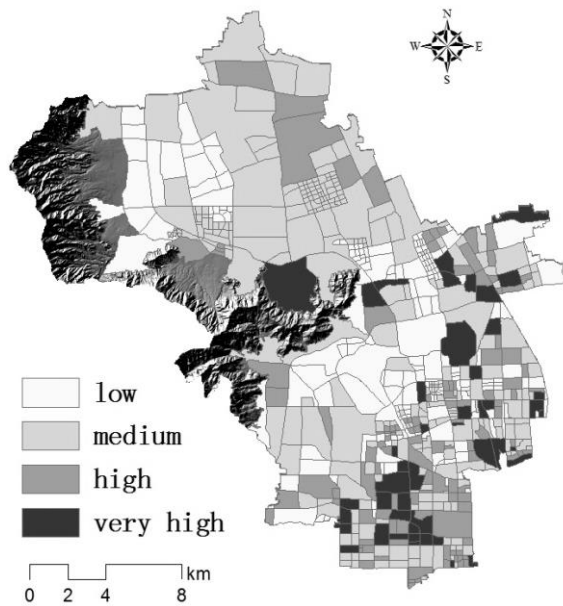


Figure 7. Spatial pattern of the comprehensive population vulnerability

### 3.2 Hotspots of population vulnerability

Getis-Ord  $G_i^*$  is a statistic for significant spatial clusters of high values (hot spots) and low values (cold spots) (Wang & Duan, 2010), which is calculated by:

$$G_i^* = \frac{\sum_j (w_{ij} x_j)}{\sum_j x_j} (i \neq j) \quad (7), \quad (6)$$

Where  $x_j$  is the vulnerability index at  $j$  block, and  $w_{ij}$  is a spatial weighting matrix. Positive and negative  $G_i^*$  statistic with high absolute values implies



clusters of high- and low-value events, a  $G_i^*$  close to zero indicates a random distribution of events.

Here, we used inverse distance method to create the weighting matrix. The significance level of 0.05 is chosen to identify the hotspots of population vulnerability. The result is shown in Figure 8.

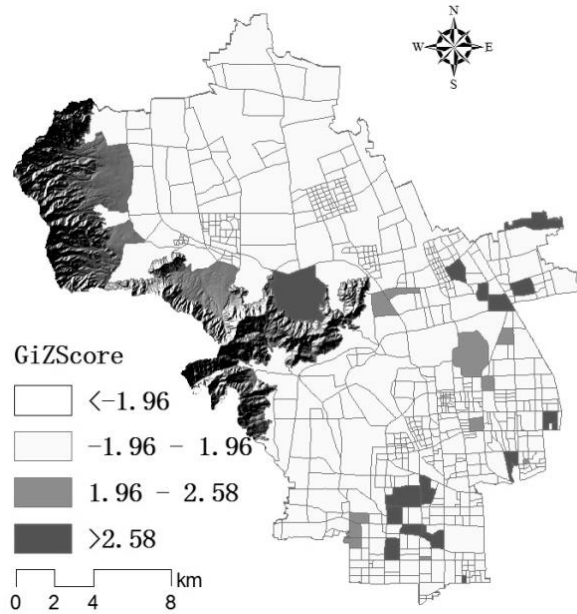


Figure 8. Hotspots of comprehensive population vulnerability

## 4. ANALYSIS RESULT OF ECONOMIC VULNERABILITY

### 4.1 Spatial pattern of economic vulnerability

With an indicator system approach, it is hard to determine the parameters of economic vulnerability assessment model in equation (4). In previous studies on economic vulnerability assessment, weights were often artificially assigned (e.g. based on expert knowledge or on experience).

To determine the appropriate parameters, we tested the stability of economic vulnerability while changing the two parameters in equation (4). With  $\alpha$  and  $\beta$  taking values at intervals of 0.1 between 0.3 and 0.7, their combinations were applied to the model. The results showed that the coefficient of variation was less than 30% for all 647 blocks, and that of blocks at the level of high economic vulnerability was less than 20%. This indicated that the economic vulnerability was not sensitive to weight parameters when they were set between 0.3 and 0.7. Taking this into account and referring to some relevant literature ([Adrianto and Matsuda, 2002](#); [Cutter, 2003](#)), we assigned 0.5 and 0.6 to  $\alpha$  and  $\beta$ , respectively.

A standard deviation method was used for classifying the economic vulnerability index of blocks. As a result, four levels of economic vulnerability were obtained, low for  $<-0.5$  standard deviation, medium for within  $\pm 0.5$  standard deviations, high for between  $+0.5$  to  $+1.5$  standard deviations, very high for  $>+1.5$  standard deviations.

Table 6 shows the overall economic vulnerability of Haidian district. 103

out of 647 blocks which account for 4.91% of the area of Haidian district are at the level of high and very high economic vulnerability.

Table 6. Statistics of blocks by economic vulnerability levels

Vulnerability levels	Number of blocks	Percentage (%)	
		By number	By area
Low	330	51.00	73.10
Medium	214	33.07	21.97
High	65	10.04	3.71
Very high	38	5.87	1.20

Fig. 9 shows that blocks with high and very high economic vulnerability are mainly concentrated in the southern urban living and service area and the eastern Hi-Tech Park. Western tourism and agricultural areas have low vulnerability.

The spatial agglomeration areas of high and very high economic vulnerability are Zhongguancun, Haidian, North taipingzhuang, Ganjiakou, Shangdi, North Xiaguan, Yangfangdian, Wanshoulu , and Zizhuyuan Jiedaos, specially, blocks with high and very high economic vulnerability are highly concentrated in Zhongguancun, Haidian, North taipingzhuang, Ganjiakou, and Shangdi Jiedaos. According to Beijing Haidian Municipal Commission of Urban Planning (2009), these regions have been the agglomeration areas of high-tech industries, commercial, exhibition, medical, and the government services, all of which play important roles in Haidian's economy as well as Beijing's. Thus, we suggest that more attention should be paid to these areas in emergency management and day-to-day risk management.

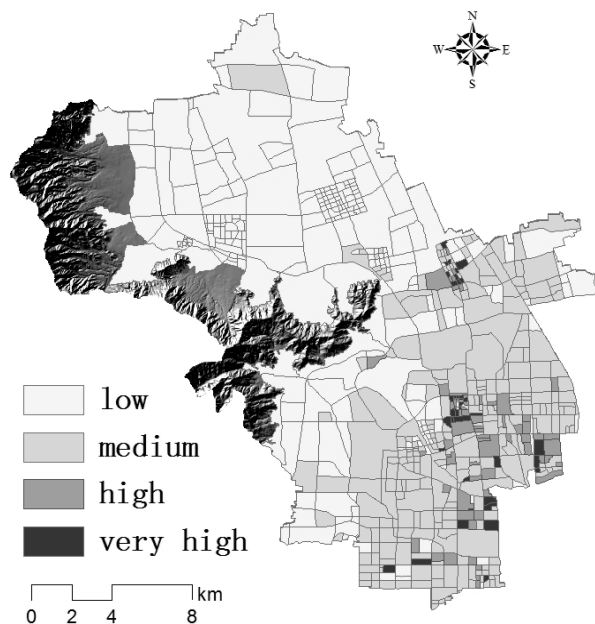


Figure 9. Spatial pattern of economic vulnerability levels in Haidian district, Beijing

## 4.2 Hotspots of economic vulnerability

With Getis-Ord  $G_i^*$  statistic, significant spatial clusters of economic vulnerability were identified, as shown in Fig. 10.

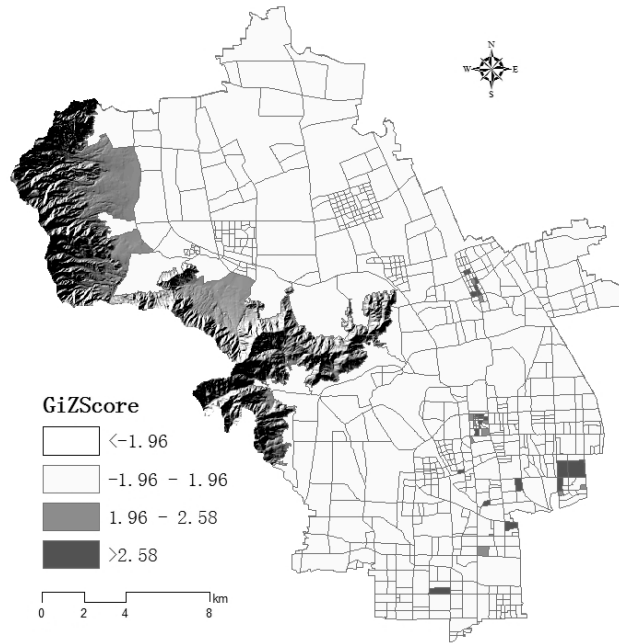


Figure 10. The hotspots of economic vulnerability

In the hotspots of economic vulnerability, the main industrial types are telecommunications and information transmission services, communication equipments, computer and electronic equipment manufacturing, banking, tourism, hotel, real estate development and management. Moreover, the shares of enterprises in the same industrial types are quite high, suggesting very high level of industrial agglomeration.

These blocks, together with the vulnerable areas suggested by the map of population vulnerability in Fig. 5, 6, and 7, constitute the areas in risk in the study area. According to the investigation of [Ji and Gao \(2012\)](#) on emergency shelters in Beijing, the accessibility as well as the size of emergency shelters in the built-up areas of Haidian district, especially in the east part are insufficient. As crucially important problem areas, special attention should be paid to the hotspots of population and economic vulnerability in the future.

There were some discussions on the need and methods for integrating social and economic vulnerability, as well as indices generated from other perspectives, but no consensus had been achieved ([Tapsell et al., 2010](#)). From the viewpoint of risk management and disaster mitigation, we think that creating a single evaluator is not indispensable. Therefore, the results on population and economic vulnerability are separately presented and not integrated.

## 5. DISCUSSION AND CONCLUSION

Assessing social and economic vulnerability of urban areas is a significant step in risk assessment, a prerequisite for effective disaster prevention and an important base for emergency management. It sheds light on where, who and which of the population and economic systems are most vulnerable, and led to planning and policy to deal with the specific problems in concern. In this paper, we made several progresses on population and economic vulnerability assessment comparing to previous studies.

First, we succeeded in carrying out social and economic vulnerability

assessment at the scale of blocks, which could provide crucial information for decision-makings in disaster management in urban areas. So far in practice, the selection of spatial scale depends more on available data rather than on the appropriateness of scales. We used a plenty of up-scaling and down-scaling to solve the data problems. The proposal of taking block as the basic spatial unit greatly increased the resolution of the assessment, and advanced previous studies in China which had been conducted at least at the district level. The results of our study, for example in Fig. 5 to 7 and Fig. 8 to 9, suggested that the spatial pattern of population and economic vulnerability would be seriously masked beyond the block scale.

Second, in the population vulnerability models, we have noticed the difference between social groups and between day and night times. By introducing demographic, space and time dimensions, the results provided useful knowledge and helped us in perceiving the real world situation better.

Third, we advanced previous models for economic vulnerability assessment, many of which took the form of linear aggregation of various indicators. The developed model has considered economic scale, density, and the susceptibility and importance of various industrial sectors. Their integral relationships had been carefully treated, and with a non-linear model specification, the collinearity problem is avoided. We think that susceptibility and importance are very important notions for the vulnerability of industrial sectors and suggest a theoretical direction of relevant studies. The selection of industries and ratings of them in this study, though preliminary, can be applied to many other cities.

In metropolitan areas, the structures and interactions of different people and industrial sectors are extremely complicated and the vulnerability of urban areas to different kinds and intensity of disasters may differ. Our study only took account of selected aspects and factors, and some measures and parameters relied on expert knowledge and experience. For simplicity, the intensity of disaster influence and interactions between the bearing system and disasters were not considered. We also ignored the impact of different disasters by assuming that the study area suffers from the same kind and the same intensity of disaster. Consequently, the theoretical model of social and economic vulnerability is a function of the region's internal conditions and without external factors. But these factors should be considered in the future and how to incorporate these factors into the model will be the direction for future studies.

## ACKNOWLEDGEMENTS

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# Application and Assessment of Crime Risk Based on Crime Prevention Through Environmental Design

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**Key words:** CPTED, Crime risk assessment, CCTV, MLRA

**Abstract:** This study is to suggest a new methodology of crime risk assessment and application method. The current crime risk assessment method is to infer the possibility of crime occurrence by analyzing the past crime data. But there are many limitations and problems to depend on the analysis with past data. Considering these problems, this study proposes the new methodology to assess crime risk integrated with the existing methods and various factors based on the CPTED principle. This methodology is named as 'Multi-Layered Risk Assessment (MLRA)' because it uses the various factors layered using GIS. The results of MLRA represent a visual graphic for easy interpretation after grading the crime risk. The characteristics of MLRA are able to grade the crime risk on the street and intersection and to be applied in CCTV positioning.

## 1. INTRODUCTION

Crime Prevention is a significant social issue that affects the quality of life. Recently frequent crimes on vulnerable society members (e.g., children and women, etc.) have become serious social problems and increased in Korea. And the countermeasures against these problems are summarized as installing CCTV, reinforcement of patrol and application of Crime Prevention Through Environmental Design<sup>1</sup> (CPTED). In case of CCTV, it is utilized as important crime prevention method since CCTV that installed in England to watch terrorists from Ireland has been proved to be very effective to prevent crime. In 2009, 4.2 million CCTVs were installed in England. In Korea, around 2 million (0.3 million by the public sector and 1.7 million by the private sector) are installed since five were done for the first time to prevent crime at residential area of Nonhyun-Dong, Kangnam in 2004.

However, although the number of CCTVs for crime prevention is being increased rapidly, crime occurrence does not decrease and that of serious crime is even being increased. The reason is under discussion in various perspectives and it is thought that the wrong or inefficient positioning of CCTVs is one of

<sup>1</sup>CPTED has emerged and been given considerable academic and administrative attention recently as a new paradigm and an important dimension in crime prevention. CPTED, as proposed by C. Ray Jeffery in 1972, is a theory for crime prevention and community activation composed of five design principles: natural surveillance, access control, territoriality reinforcement, activity support, and maintenance. CPTED in Korea has been developing since the 2000s ([Kang, 2013](#)).



major cause of an increase in crime occurrence. Especially the much arrest of major criminals are accomplished by CCTV for traffic control or other intention not CCTV for crime prevention, and this is one of reasoning for inference that the CCTV positioning for crime prevention is wrong or inefficient. It was found that CCTV positioning for crime prevention in Korea is determined by the hot-spot analysis dependent on the existing crime occurrence data, the inference of experienced policeman and a civil petition according to an interview with the persons concerned police administration. However CCTV positioning is determined randomly on the alley of the residential area and the connected spot between main road and residential area for the uncertainty of hot-spot analysis by inadequate crime data and furthermore the CCTV for crime prevention is not installed sufficiently as a demand for crime prevention by reason of limitation of a crime prevention budget.

In this respect, this study is to suggest a new methodology of crime risk assessment method and CCTV positioning. The scope and process of this study are as follows: 1) a theoretical study and literature review about crime analysis and risk assessment through space analysis software; 2) a discussion of new methodology about crime risk assessment and CCTV positioning.

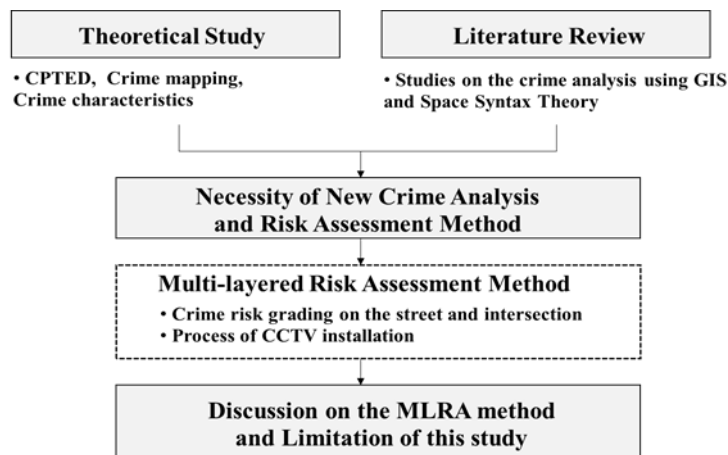


Figure 1. Research Process

## 2. THEORETICAL STUDY AND LITERATURE REVIEW

### 2.1 CPTED and Crime Mapping

#### 2.1.1 CPTED (Crime Prevention through Environmental Design)

CPTED has emerged and been given considerable academic and administrative attention recently as a new paradigm and an important dimension in crime prevention. CPTED is a theory for crime prevention and community activation composed of five design principles: natural surveillance, access control, territoriality reinforcement, activity support, and maintenance. CPTED is applied in the area of architectural and urban planning to eliminate of criminal opportunities through a comprehensive analysis of three main elements that lead to crime: motivated criminals, vulnerable victims, and environmental opportunities (Kang, 2013).



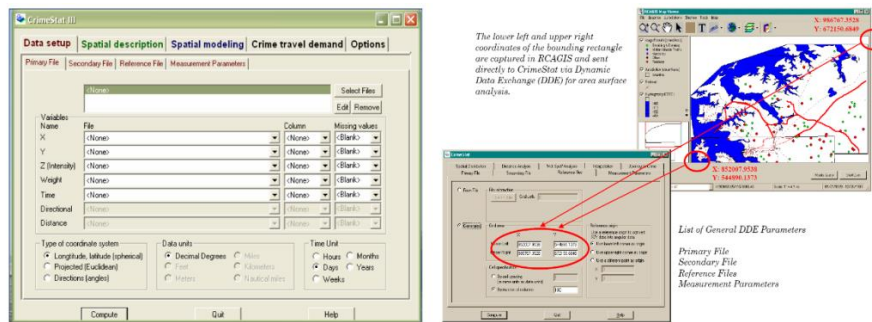


Figure 3. Screen shot of CrimeStat analysis (Levin, N., Levine, N., et al., 2004)

In Korea, Crime Information Management System (CIMS) which is plug-in of Crime Stat and Geopros is commonly used for crime analysis.

## 2.2 Literature Review

Regarding verification of the environmental factors causing crime occurrence, there are many researches in urban and architectural planning field focusing on CPTED through statistical analysis of relationships among urban planning variables (building use, characteristics of street and spatial structure, etc.), social-economic variables and demographic variables using GIS and Space Syntax Theory, etc.

### 2.2.1 Studies on the Crime Analysis using GIS

Researches using GIS usually analyse the environmental conditions of crime occurrence among districts or cities by analyzing the layered variables in macro level. This method using GIS has a strong point that various analyses can be possible if provided with geographic variables. But because it is very complicated and time-consuming work to set up geographic variables, it is difficult to be used for generalized method. In spite of this problem and limitation, crime analysis researches using GIS are being activated because crime occurrence in itself has relation to geographical attributes. The essence of this method is hot-spot analysis. Among various methods, Kernel Density Estimation (KDE) is known to get the most consistent result in hot-spot analysis of crimes occurred on the road (Chainey, S., Tompson, L., et al., 2008)<sup>3</sup>. Through crime analysis researches using GIS, it has been known that crime is related to various factors including building use, distance from main road and bus stop, the deteriorated level of building, adjacency with park and empty lot, the ratio of vacant house, the density of streetlighting and existence of dead-end alley, etc (Brantingham, P. L. and Brantingham, P. J., 1993; Goff and Vigne, 2001; Eck, J., Chainey, S., et al., 2005).

### 2.2.2 Studies on the Crime Analysis using Space Syntax Theory

Natural surveillance and target accessibility are considered as major factors of crime occurrence or deterrence in field of CPTED and these factors can be analyzed with axial map to calculate integration value, connectivity value, control value and space depth of Space Syntax Theory. For this reason, crime

<sup>3</sup>The effectiveness of hot-spot analysis on the district level using Kernel Density Estimation has been verified steadily (Ackerman and Murray, 2003).

analysis researches using indexed of Space Syntax have been increased.

According to the literature review, it has been known that the traffic and pedestrian pattern or volume are closely related to natural surveillance, and the pattern or volume can be inferred by integration value. And also the traffic and pedestrian pattern or volume are related to land use and space structure, and those can be inferred by spatial configuration analysis using connectivity value, control value and space depth (Hillier and Hanson, 2005). For example, it is known that commercial areas are usually located in the centre of the region and residential areas are relatively located in the secluded region, and this contribution of land use can be inferred by axial map analysis. For this reason, the relationship among land use, traffic and pedestrian volume and crime occurrence can be inferred using Space Syntax Theory<sup>4</sup>. However as it is hard to get meaningful result by only Space Syntax analysis, the Space Syntax analysis integrated with GIS by parameter using axial lines is increased. According to those studies, it was known that there was much possibility of burglary occurrence in the area with low integration and connectivity value (Hillier and Sahbaz, 2005) or low integration and high space depth value within 2km from residence of criminal (Shu, 2000).

### 2.3 The Necessity of New Crime Risk Assessment Method

Although it is known that studies on crime pattern analysis by spatial analysis software and studies on searching the relation between urban and architectural planning elements and crime occurrence focusing on CPTED have been much processed, there has been little discussion about crime risk assessment and more specifically the positioning of CCTV for crime prevention.

The results of studies processed in field of urban and architectural planning are actively used as guideline for crime prevention focusing on CPTED. But the results of studies of crime risk assessment and hot-spot analysis dependent on the statistical analysis of the existing crime occurrence data are not activated as practical crime prevention measure, the reason is thought that crime analysis or risk assessment method has some problems as follows: 1) As less than half (about 1/3) of real occurred crime are being announced officially as crime statistical data, it is hard to trust the result of existing crime occurrence data analysis. In other words, there are a lot of hidden crimes. Therefore, depending only on the existing data analysis, it cannot be assessed the accurate crime risk of target area in which crime occurred but not recorded; 2) A wrong or rough address information of spot on the crime occurred can make it hard to infer the hot-spot. Using spatial analysis software, the most important thing is geographical information of crime (street address). Therefore wrong or rough information such as 'alley in Sangdae-dong, Jinju city' or 'neighbourhood of Jinju city hall' unlike '296-76, Sangdae-dong, Jinju city' cannot be used for crime analysis and risk assessment; 3) In redevelopment region and new town, the result of existing crime occurrence data analysis cannot be used for risk assessment. Because the physical, socio-economic environment and population composition are changed completely under those circumstances, it is necessary to assess crime risk through a new analysis measure; 4) Because the hot-spot analysis is a macroscopic analysis, the result of that cannot be classified by crime risk grade in micro area such as street and intersection. Therefore if CCTV positioning is determined by only hot-spot analysis, its positioning would be

<sup>4</sup>It was known that there was close relationship among the street crime, spatial configuration and pedestrian volume (Hillier and Hanson, 2005).

generally inferred but could not be inferred an accurate spot. For these reason, it is thought that it is necessary to study the other methodology for crime risk assessment and CCTV positioning on microscopic area in new perspective.

### 3. CRIME RISK ASSESSMENT THROUGH MLRA METHOD

#### 3.1 Summary of Multi-Layered Risk Assessment (MLRA) Method

It is impossible to assess crime risk exactly because crime is a complicated social phenomenon and is affected by many uncertain parameters. By this reason, there were few researches regarding quantitative and effective risk assessment. But crime risk assessment is certainly necessary for urban safety management, this assessment should be processed. In this respect, this study proposes the new methodology to assess crime risk integrated with the existing methods and various factors. And this methodology is named as ‘Multi-Layered Risk Assessment (MLRA)’ because it uses the various factors layered on GIS. The result of MLRA represents a visual graphic for easy interpretation after grading the crime risk.

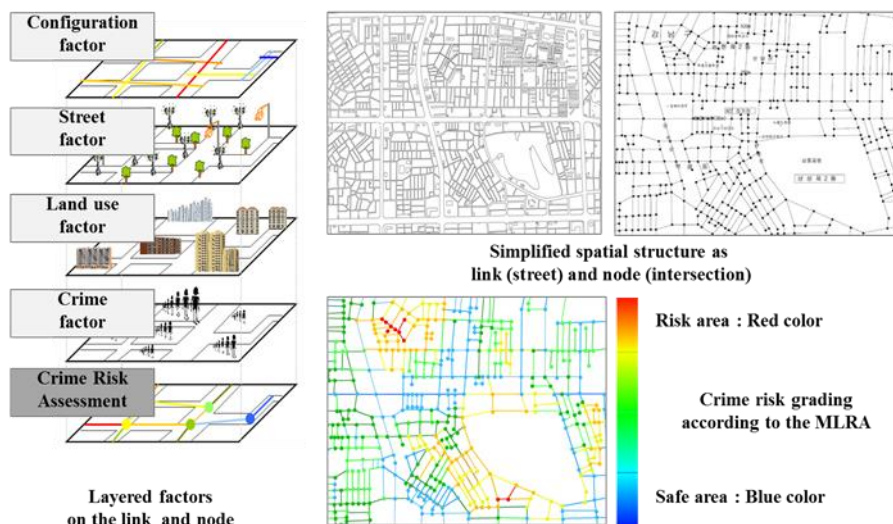


Figure 4. Example of MLRA process

To grade crime risk in space, it is necessary to decide how to analyze the spatial structure. Generally, urban space is composed of streets, intersects, and blocks formed by streets and intersects. Therefore, complicated spaces can be analysed with simplified method by considering streets as links and intersects as nodes. The MLRA method uses the simplified method with attributed value applying specific algorithm. The reason for this is that most crimes except burglary occur in streets and CCTVs are usually installed at streets and intersects<sup>5</sup>.

<sup>5</sup>In the criminology aspect, most crimes occur on the street and criminal considers the street and intersection as an escape route. In urban and architecture aspect, human behaviour takes place in the space composed of point (intersection), line (street) and plane (block). Therefore it is thought that crime risk assessment method by classification space with street and intersection is a reasonable method.



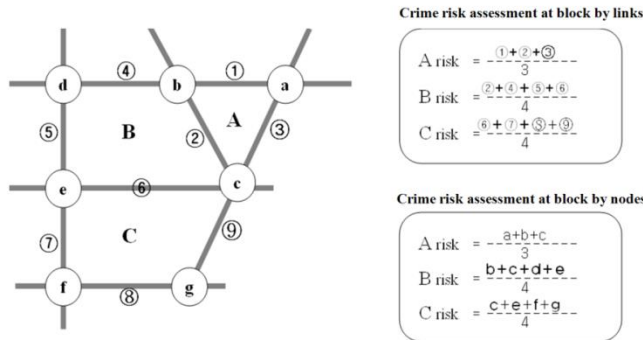


Figure 5. Summary of crime risk assessment at streets, intersects and blocks

### 3.2 Crime Risk Assessment Variables and Method

#### 3.2.1 Crime Risk Assessment Variables

Variables to assess crime risk of each street are classified by crime factor (street crime and burglary), configuration factor (integration value of Space Syntax), land use factor (ratio of commercial building and distance to school) and street factor (street width and number of streetlight). And attributes of the variables are summarized by CPTED principle such as ‘the higher the surveillance opportunity is, the lower the crime risk will be’. And the hypothesized attributes are as follows: 1) regarding crime factor, it is supposed that the higher the crime ratio is, the higher the crime risk will be; 2) regarding configuration factor, integration value by Space Syntax that has been proved to be related closely to crime occurrence by previous researches is to be used. It can be inferred that the higher the integration value, the lower the crime risk will be because pedestrian volume inferred from integration value is related to natural surveillance; 3) regarding land use factor, it is supposed that the higher the ratio of commercial buildings is, the lower the crime risk will be because pedestrians led by those can make higher possibility of natural surveillance. And it is supposed that crime risk will be higher when there is a school in the site. This reflects the possibility of violence or burglary by students. For this assumption, risk level around school is set by 50m radius such as 50m, 100m and 150m to assess crime risk; 4) regarding street factor, it is supposed that the wider the street is, the lower the crime risk will be. In the case of street lighting, the lower the interval of street lighting is, the lower the crime risk will be.

Variables and factors above are assigned with weighed value per each importance and a functional formula is set up to be used at GIS. The crime risk by these factors are graded into “100(very risky) to 0(very safe)” to be easily understood visually.

#### 3.2.2 Method to set up weighed value of each variables and to assess crime risk

Linear interpolation is used to calculate variables for crime risk assessment. Interpolation is a method to estimate function value  $f(x_i)$  for arbitrary parameter value  $x_i$  which is within the range of known data points of parameters  $x_i$  ( $i = 1, 2, \dots, n$ ), when the function is not complete such as  $y=f(x)$  and the parameter values ( $x_i$ )s are known. This is one of the easiest method to get wanted result using a linear function ( $y = ax + b$ ).

$$f(x) = f(x_0) + \frac{f(x_1) - f(x_0)}{x_1 - x_0} \times (x - x_0)$$

The characteristics of interpolation are to reflect existing condition of a region and to standardize data. And also it can be used for comparison analysis with the other region applied the same data because it draws median value of each variable based on the maximum and minimum value of it. And it can resolve the difficulty in comparison when the standard units of the variable are different each other. If range of each variable is set between 100and0point using interpolation based on the maximum and minimum, all variables can be compared within the range. In this study, the linear interpolation is thought to be appropriate as basic formula for MLRA method because the relationship between crime and related factors is unknown as whether it is linear, quadratic or cubic function.

Table 1. Weighed value of each factor for MLRA method

Variable		Sub -factor	Inclus ive-factor	Risk- factor	Relation ship with crime
Crime(1.0)	Street crime	0.5		0.15	+
	Vehicle crime	0.3	0.3	0.09	+
	Burglary	0.2		0.06	+
Configurati on (1.0)	Integration value	1.0	0.2	0.2	-
	Ratio of commercial bldg.	0.7		0.175	-
Land use (1.0)	Distance from school	0.3	0.25	0.075	-
	Street characteristics (1.0)	Street width	0.5	0.25	0.125
	Street lighting	0.3		0.075	-
SUM		4.0	1.0	1.0	

The sum of inclusive-factors drawn from function based on the interpolation such as crime, configuration, land use and street factor is set to 1 point. Since this is the method to assess crime risk, weighed value of the crime factor is set to 0.3 and that of configuration factor by integration value which is used to infer the crime risk from pedestrian volume is set to 0.2. And land use factor and street factor are weighed value of 0.25 because influence of those to crime is judged to be similar from each other.

And also the sum of sub-factors of inclusive-factor is set to 1 point. Weighed value of the street crime is set to 0.5 under assumption that CCTV generally watches criminal behaviour on the street, that of crime related vehicle is 0.3 and that of burglary is 0.2. Integration value is weighed 1 because integration value ( $r = n$ ) is only used for configuration factor. Weighed value of commercial building is set to 0.7 and that of school is 0.3. Weighed value of street width is 0.5 and that of street lighting is 0.5.

The relationship between crime and variables is expressed as + when the value of variable is positive related to crime risk and it is -for inverse case.



## 4. CRIME RISK ASSESSEMENT AND CCTV INSTALLATION ON RESEARCH AREA

### 4.1 Research Area

Yeonsoo-1-dong, Incheon city was selected as the research area and field survey was carried out to identify factors hard to verify in maps such as street lighting, spatial structure and building use, etc.

It was found that the area was composed of residential buildings, residential-commercial buildings (commercial on the ground level and residential on the second or higher level) and commercial buildings. In the middle of the area, there was T-shaped circulation road and along the road, commercial buildings and street lightings were located.



Figure 6. The distribution of buildings, street lightings, and street trees

### 4.2 Discussion of results

It was found that the research area was composed of 139 streets (links) and 87 intersections (nodes) through analysis by simplifying spatial structure of the area into link and node.

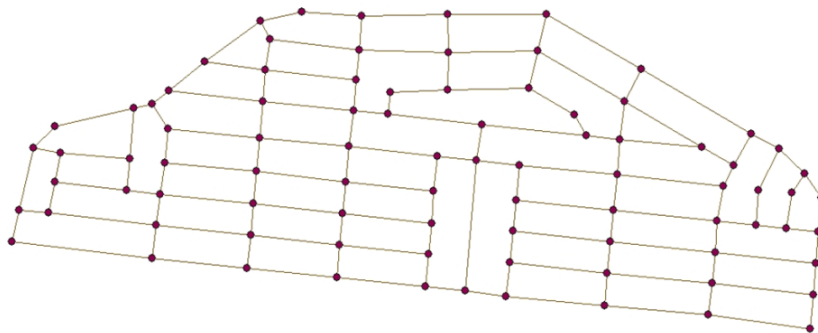


Figure 7. Simplified spatial structure of the research area

#### 4.2.1 Crime risk assessment by crime factor

In this study, the hot-spots of crime (street crime, vehicle crime, and burglary) occurred in the research area in 2007 were analyzed. The GIS ArcMap 9.3 was used to analyze crime spots.



Figure 8. Crime spots in the research area in 2007

For the risk assessment by crime factor, the point of crime occurrence is matched up the near street and the result shows in figure. 9 that visualized as various colour. Red lines show streets with much crime occurrence (high crime risk) and blue lines do those for inverse case (low crime risk).

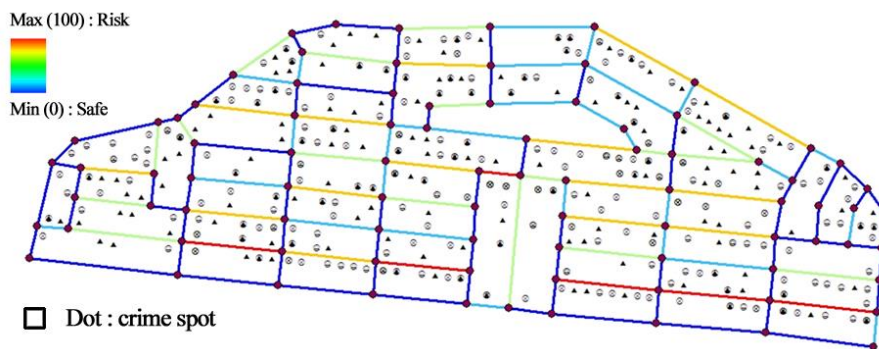


Figure 9. The result of crime risk assessment by crime factor

#### 4.2.2 Crime risk assessment by configuration factor

Crime risk by configuration factors was assessed based on the general principal that the higher the integration value is the more the pedestrians are. That is to say, it was inferred that the possibility of surveillance changes according to spatial structure. It was visualized as below that red lines show streets with more pedestrian volume (safer street) and blue lines do those with less volume (more dangerous street)<sup>6</sup>.

<sup>6</sup> For the factor analysed through Space Syntax, red line shows lower crime risk unlike other factors of which red line shows higher crime risk. The reason is that the result of Space Syntax is applied as it is. Red line shows higher integration value in Space Syntax.

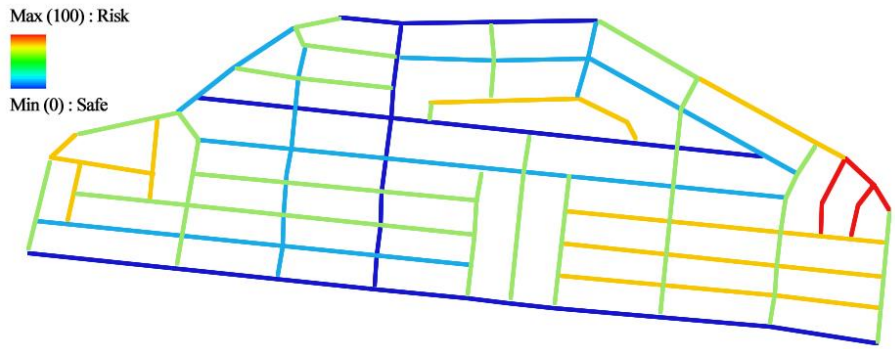


Figure 10. The result of crime risk assessment by configuration factor

### 4.2.3 Crime risk assessment by land use factor

Rectangles are commercial or residential-commercial buildings. For the risk assessment by land use factor, the point of building was matched up to the near street. Because it was premised that the more commercial buildings were the more the pedestrian volumes would be, and this increased the possibility of natural surveillance. Therefore the streets with higher commercial building ratio are blue (lower crime risk) and those with lower ratio are red (higher crime risk) as shown below.



Figure 11. The result of crime risk assessment by land use factor: commercial building ratio

Meanwhile, there are two schools across the main street in the south. Crime risk by school factor is assessed through the formula per 50m. The result shows that bottom left and bottom right areas have higher risk and the areas the further from schools towards north have lower risk.

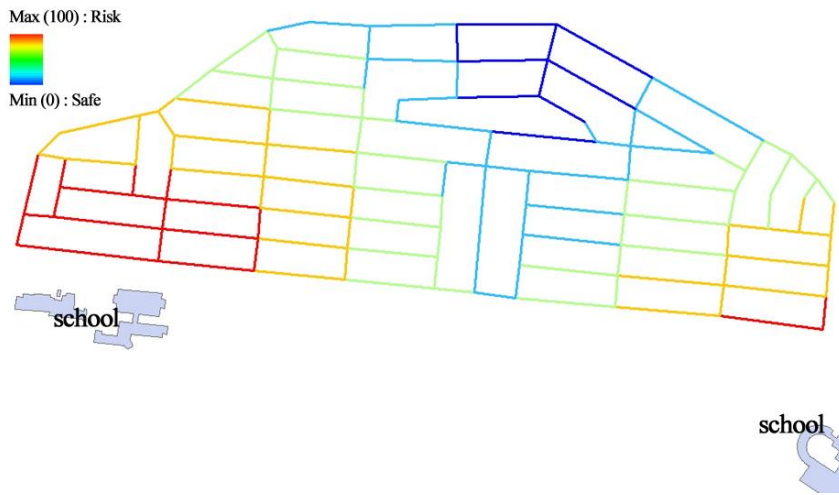


Figure 12. The result of crime risk assessment by land use factor: distance from school

#### 4.2.4 Crime risk assessment by street factor

In case of street lightings, street lightings were presumed to be more likely to reinforce natural surveillance. The result shows that crime risk on the street without lightings is high.



Figure 13. The result of crime risk assessment by street factor: the number of street lightings

Streets are classified from 1<sup>st</sup> grade (wider) to 5<sup>th</sup> grade (narrower) in Korea and the research area is composed of three kinds of street: 1<sup>st</sup>, 2<sup>nd</sup> and 4<sup>th</sup>. The result shows that the inner streets with narrow width are risky (red color) and the main streets and the circulation roads with wide width are safe (blue and green color).

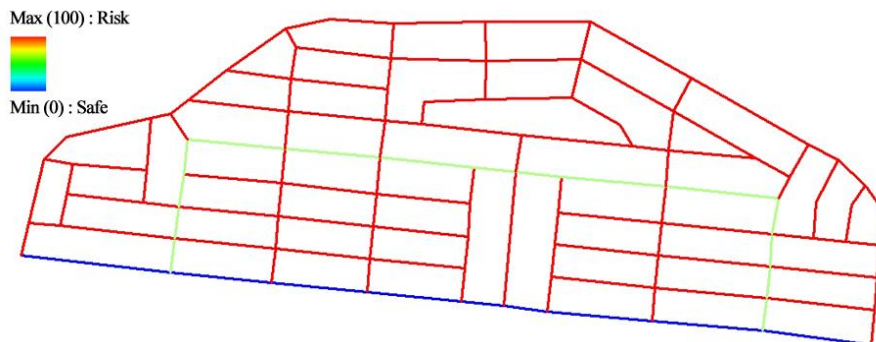


Figure 14. The result of crime risk assessment by street factor: width of street



### 4.2.5 Crime risk assessment through MLRA method

Gathering individual results, crime risk per each street through MLRA method was assessed. Red lines show streets with high crime risk and blue ones show low crime risk.

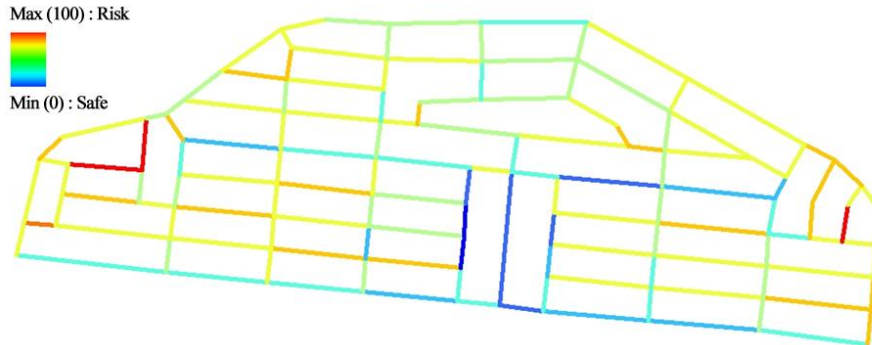


Figure 15. Crime risk of streets assessed through MLRA method

Crime risk at each intersection is assessed by average value of streets connected to those. Red dots show intersections with high crime risk and blue ones show low crime risk.

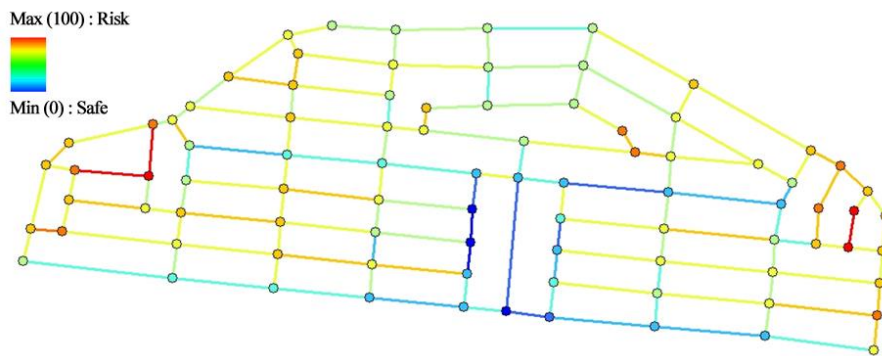


Figure 16. Crime risk of intersections assessed through MLRA method

## 4.3 CCTV Installation through MLRA Method

The process of CCTV installation through MLRA method is as follows.

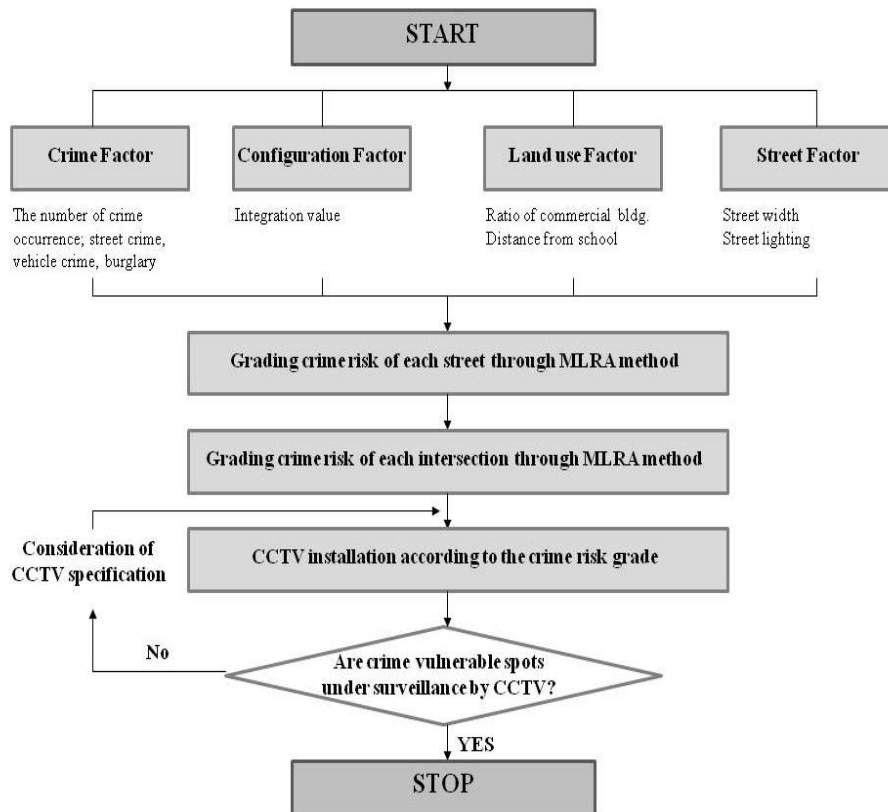


Figure 17. The process of CCTV installation

As the CCTV positioning is shown below, some CCTVs are allocated first to intersections of the main street which is entrance to target area and others are allocated to intersections according to crime risk grade in second priority. By the way, where the streets are too long to exceed the visible range of CCTV, it can be installed somewhere in between the two intersections and the spacing depends on the performance of CCTV. The locations of 20 CCTVs are as shown in figure 18.

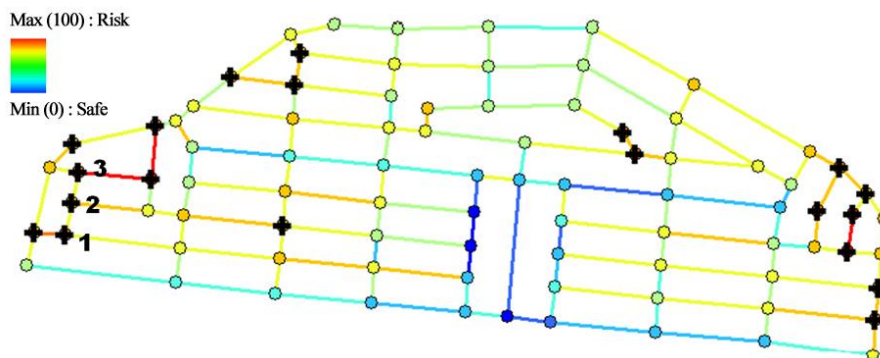


Figure 18. The locations of 20 CCTVs on the target area

The '+' marks indicate where CCTVs are installed. If the range of CCTV's surveillance overlaps according to the visibility range, some CCTV can be eliminated for effective surveillance. For example, because the surveillance ranges of CCTV 1, 2 and 3 overlap as shown in figure 18, the CCTV 2 can be eliminated and installed other risk point.

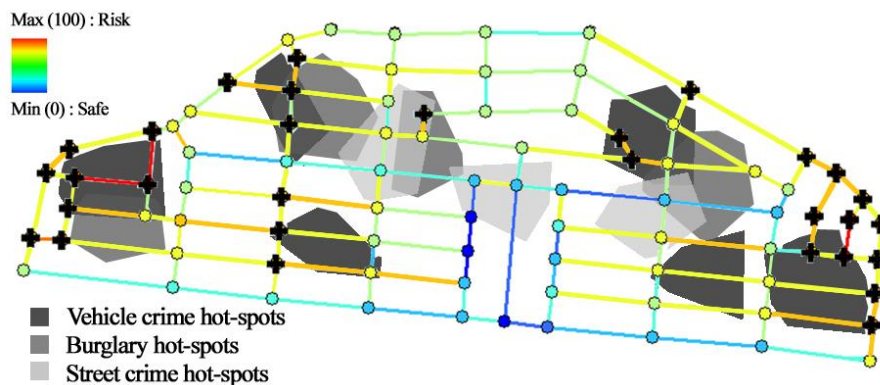


Figure 19. The comparison of CCTV positions and hot-spots

It is inferred that the CCTV positions through MLRA method correspond with hot-spots by approximately 50% as shown in figure 19. This result can be interpreted that the correspondence comes from the highly weighed crime values. Therefore, it is necessary to study about the method of crime risk assessment without crime factor through succeeding research.

## 5. CONCLUSION

Korea is ranked 24<sup>th</sup> in quality of life among 30 OECD countries notwithstanding the top 10 ranked for economic size evaluation. But it is a pressing question to develop social security measures including crime prevention measure because one of the most significant current discussions in Korea is the crime problem.

In the crime prevention aspect, it is necessary to develop technology and to support research such as ‘crime analysis and crime risk assessment methodology’, ‘making a safe society by application of crime prevention through environmental design on vulnerable areas and facilities’, ‘optimized and efficient technology for crime prevention facility such as CCTV’ and ‘integrated urban crime prevention system design’ for public welfare and safety. Especially, it is thought that attention and support for crime analysis and crime risk assessment methodology are urgent and necessary.

The essence of CPTED is to prevent crime and minimise damage by controlling and eliminating various situational factors that provide crime opportunity. Therefore, it is necessary to assess crime risk on target area objectively and accurately so that CPTED may be effective crime prevention measure.

Existing crime risk assessment was processed through the analysis of criminal records. This method is possible because the opportunistic crime focused on environmental criminology occurs in specific patterns in the frequency and distribution where present conditions are maintained. But criminal records have their limitations and not all the number of crimes occurred are recorded, therefore, alternatives for crime risk assessment are needed in case there is no criminal records, and also for areas that have undergone redevelopment (and reorganization) of the existing urban configuration, making the previous data meaningless. For this reason, it is important that crime risk is assessed without criminal records and it should be processed with crime-related variables, which consists of various factors.

In this study, MLRA method for crime risk assessment on the street and intersection of urban space is proposed based on the CPTED principle. It is the



characteristic of MLRA method to enable to grade the crime risk and assess crime risk on the micro level (area) by various data analysis focused on the street and intersection contrary to the existing method that is inferred the hot-spot through only crime data analysis. But this method has some problems such as complexity of methodology and insufficient verification of variables, etc. In conclusions, it is considered that the MLRA method is worthwhile on behalf of the existing crime analysis and risk assessment has both its merits and demerits such as follows: The pros of the MLRA method are 1) applicable without criminal records, 2) various analysis ranges from large urban area to small block area, 3) and optimization of CCTV installation. The cons are 1) insufficient verification of risk assessment variables and functional formula for MLRA method, 2) limited method with focused physical factors, 3) and impossible method without geographical data used in GIS. Therefore, following research has to be succeeded for improvement of above problems. If following research related crime risk assessment similar to MLRA method is continued, it may be able to apply the fitted crime prevention measures and especially to install the CCTVs according crime risk grade and to designate the optimized route of patrol.

## ACKNOWLEDGEMENT

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