Estimates of business interruption losses to industrial sectors due to floods disaster: A case study of Tokai heavy rain

Lijiao YANG[1], Hirokazu TATANO[2], Yoshio KAJITANI[3],and Xinyu JIANG[2]

1 Corresponding author PhD candidate, Graduate School of Informatics, Kyoto University
(Gokasho, Uji, Kyoto 611-0011, Japan)
e-mail: yanglj976@gmail.com
2Disaster Prevention Research Institute, Kyoto University, Japan
(Gokasho, Uji, Kyoto 611-0011, Japan)
3Central Research Institute of Electric Power Industry, Japan
(Abiko, Abiko-shi, Chiba 270-1194, Japan)

A methodology to estimate business interruption loss is proposed in this paper. It will be conducted in the following four steps: (1) Estimates of business interuption loss rate for each sector. (2) Spatial distribution of water depth is interpolated through Kriging method using surveyed points of water depth and area of inundation. (3) Fine geographical scale census and economic census data are adopted to overlay with inundation to identify affected firms and corresponding employees. (4) The BI loss in each sector could be estimated based on above information. A questionaire survey data collected from local business following Tokai heavy rain in 2000, Japan is adopted to estimate BI loss in each sector. Simutanouly, validation results will be provided to demonstrate the accuracy and feasibility of proposed methodology by comparing our estimated BI loss with index of industrial production (IIP) of Aichi prefecture in the following three months after the heavy rain event. This result indicates that estimated values are close to the actual production indices in most manufacturing sectors.

This proposed methodology could be used to make a quick estimates of BI loss given hazard information right after disaster. It also could provide information for individual firms to make their business continue plan before disaster, and is considered as significant input in the design of risk management strategies after disaster.

Key Words : *Business interruption loss, Functional fragility curves, Accelerated failure time model, Index of industrial production, Tokai heavy rain*

1. Introduction

Natural hazards are one of primary sources of disasters especially when they spatially overlap with areas where human settlements and business are located. Economic loss from natural disaster are particularly in the spotlight in recent years. Data from the Emergency Events Database (EM-DAT) shows total damage losses caused by reported natural disasters from 1950 to 2014 are in an increasing trend with the growth of years. As the continent with the largest area and population, Asia accounts for the most severe damage losses. The water-related disaster, such as floods and storm account for larger proportions of losses. IPCC-SREX finds that the key driver behind increases in losses are exposure changes in terms of rising population and economic assets at risk. Meanwhile, according to the report of World Urbanization Prospects, nearly one of eight persons live in the 28 since 1990, and by 2030, 41 urban agglomerations are projected to house at least 10 million inhabitants each. What is worse, IPCC-SREX anticipates that “it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. And a 1-in-20 year annual maximum daily precipitation amount is likely to become a 1-in-5 to 1-in-15 year event by the end of the 21st century in many regions”. The heavy precipitation is a main cause of floods, and therefore floods may become major and most common disaster for many regions in the next decades.

Many researches focused on estimating economic losses mainly from the engineering field, address primarily the stock loss (i.e., damage to physical and human capitals) (Kircher et al. 2006; Dutta and Herath 2003; Smith 1994; Thieken et al. 2005). The estimates of business interruption losses, on the other hand, has mainly been the domain of economic community by employing input-output model (IO model) (Hallegatte 2008; Santos and Haimes 2004; Okuyama 2004; Haimes et al. 2005; Crowther 2007), and computable general equilibrium model (CGE) (Tatano and Tsuchiya 2008; Rose and Liao 2005; Tsuchiya et al. 2007). These models could invest the indirect economic impacts caused by ripple effects across different sectors among different agents. However, these models also creates a set of weakness. For instance, the classical IO framework is considered as an overestimation of economic impact due to linear structure and rigid coefficients. In reality, business may catch up their steps by postponing the maintenance of machines if basically they could keep working, or employ more part-time workers to cope with the shock (Hallegatte 2014). So these models are likely to be pessimistic because of weak flexibility in production processes and no supply constraints (Okuyama 2008). CGE model could fill up the gap of flexibility with non-linear production function ,and also could respond to the change of market price, and could accommodate input and import substitutions. And could handle supply capacity constraint (Okuyama and Santos2014). Recently it has been gaining its popularity. Still, this model also faces to a big weakness, underestimation of economic impact due to too flexible to handle changes in short term, and therefore it is likely to be optimistic even in the long run because prices can not adjust perfectly and instantly.

In these two types of models, an assumption that maximum production capacity in different sectors is still roughly made due to lacking of real data, especially lacking of local scale data. For instance, the assumption of production capacities in different sectors are assumed to be homogenous for manufacturing sectors in an adaptive regional input-output (ARIO) model proposed by Hallegatte (2008). The new version of ARIO model make up for this shortage by providing capital losses in each sector to obtain the loss ratio of production capacity. Still, the estimates of capital losses in sectors are calculated by a share of total business interruption loss according to their respective size of value-added. This solution could show the heterogeneity of sectors to some extent. However, to be precise, the production capacities of sectors should be evaluated in the aftermath of disaster according to their actual losses. The factor that influence the remaining production capacity could be hazard level, robustness of industrials themselves, but not greatly related to annual value-added. But still this approach emphasized the importance of assessment of remaining production capacities in different sectors. The similar estimation of production capacity loss rate (PLCR) in sectors has been proposed by Kajitani and Tatano (2014) , which has been applied to East Japan earthquake.

Another point need to be noted, the main reasons to lost products in this paper are emphasized in stemming from direct damage to facilities and infrastructure (non-market effects). This differs from the above methdologoies (I-O table and CGE model) reviewed, which are considered as higher-order impact (market effects) models which are caused by demand loss and supply shortage. This is not to deny that the significance of maket effects, it is merely to consider the importance of non-market effects. Because we argue that hazard threat to firms (exposure), vulnerability of firms themselves could directly affect maximual production capacity greatly, which should be seriously considered beforehand rather than to be determined in an ad hoc manner or ignored in conventional I-O models (Kajitani and Tatano (2014). Therefore, the estimation of PLCR of firms right after disaster becomes sighificant. It should be an indispensable information to analyze higher-order impact. For example, cases in which a factory have to shut down because electricity is cut off or machines are damaged right after disaster.

Not only vulnerability of sectors right after disaster is captured by estimates of PLCR, but also recovery period including stagnation time and recovery time in sectors is estimated in this research. Then, an integrated model is developed with combination of vulnerability level right after disaster and recovery period to obtain business interruption losses (lost products) caused by facility damage and lifeline interruption. Moreover, in order to verify the feasibility of the integrated model, we compare our estimated business interruption loss with index of industrial production (IIP) in the disaster month, the following month and the third month after disaster.

The rest of this paper is organized as follows. In Section 2, the basic framework of the proposed BI loss estimation methodology based on business survey data sets after the Tokai Heavy Rain will be provided. In section 3, the damage to industrial sectors are introduced, in addtion, the process of estimates of BI losses are provided in four steps: (1) Estimates of business interuption loss rate for each sector. (2) Spatial distribution of water depth is interpolated through Kriging method using surveyed points of water depth and area of inundation. (3) Fine geographical scale census and economic census data are adopted to overlay with inundation to identify affected firms and corresponding employees. (4) The estimates of BI loss in each sector are shown. Section 4 provide validation results by our estimated BI loss compared with index of industrial production (IIP) of Aichi prefecture in the following three months after the heavy rain event. Finally, concluding remarks and discussion are provided in Section 5.

2. Methodology

The questionnaires sent to firms in the inundated area were conducted by the MLIT of Japan. The main concept of the surveys is illustrated in Fig. 1. When a disaster occurs, production capacity (PC) or sales of firms may decrease to a certain proportion of the normal state. The remaining PC may persist without recovery due to disruptions of lifeline, labor shortages, and other adverse conditions. We define this period as "stagnation time." After the stagnation period, PC gradually or rapidly bounces back to the normal state. This period is defined as "recovery time," which is normally a nonlinear process but is simplified as a linear process to reduce the complexity of survey forms. The definition of affected time refers to these two periods.

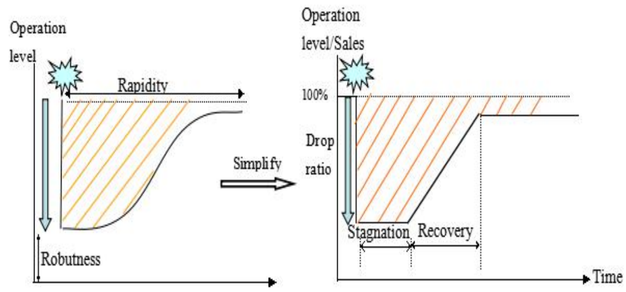

Fig.1 Description of business recovery process

The methodology framework in this research is shown in Fig.2. In order to esimate real BI loss in each sector in Aichi prefecture, estimates of BI loss rate is proposed based on the surveyed data including inundation, PCLR, stagnation time, and recovery time. Then, spatial distribution information of hazard and exposure are needed. Water depth in Aichi prefecture by Kriging interpolation in GIS with the help of information of inundated area will be provided. Also distribution of firms should be confirmed within inundated area. In order to reflect the outputs of firms, the number of employees will be adopted in consideration of value added in each sectors. Finally, a validation will be provided to show the superiority of this model.

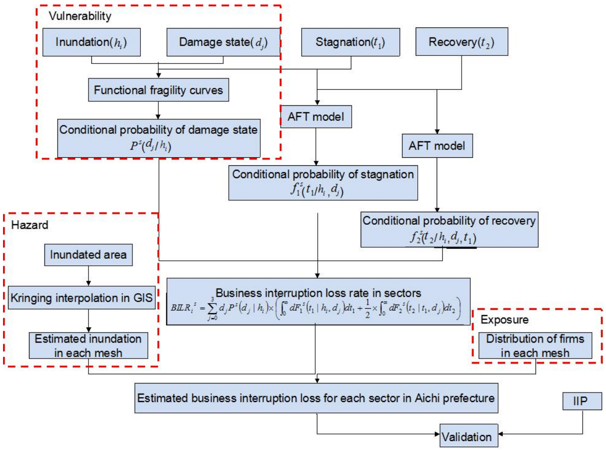

Fig.2 Methodology framework

3. Case study

(1) The damage to industrial sectors

The study area Aichi prefecture is located in the Tokai region of Japan. Nagoya is the capital of Aichi prefecture, the third largest city after Tokyo and Osaka. This area focus on automobiles with an outstanding concentration of industries, including aircraft, space and machine tools. Many world famous companies are located in this area such as Toyota car factory, Fuji Heavy Industries, Mitsubinshi Motors Corporation, Brother Industries Ltd.,Aisin Seiki Co.Ltd.and so on.

From 11-12th September 2000, there was astoundingly heavy rain in Tokai region, Japan. It brought great damages to a wide area of the Tokai region, including the most densely populated area, Nagoya city. From the meteorological observation data of Nagoya, the total rainfall accumulated 567 mm in two days, hourly rainfall reached 93 mm, which is nearly one third of annual precipitation. More than 100 m of the dykes of Shinkawa River were broken. The significant damage to Nagoya city was huge, amounted to 4 deaths, about 380,000 people were advised or instructed to evacuate, 9,983houses flooded above their floors, and 22,689 houses flooded under their floors. This damage to Nagoya city is the second one after typhoone Vera since records. Thousands of firms are affected by this great heavy rain. According to offical statistical data, in Nagoya city, totally 4209 firms are affected, accounts for 3% of total firms. However, in some area where are damaged seriously, for instance, in Nishibiwazimatyaou area, 99.9% of firms are damaged, in Kita zone and Tennhaku zone, about 10% of firms are damaged. Mainly two reasons affect the normal production activities of firms. The interruptions of lifelines and the damage to facilities, which may directly stop their work. Another reason is the spread affect on industrials, such as the shortage of supply materials or demand losses. According to Japanese economic news on 13th September, the partial facilities in Kariya Toyota car factory are affected, which cause all of chain Toyata factories are stopped from the afternoon of 12th.

(2) Estimates of business interruption loss rate

The expected BI loss rate (lost production in the dimension of time) in sectors is given by Equation (1):

$$BILR_i^{\,s} = \sum_{j=0}^{3} d_j P^s\left(d_j \mid h_i\right) \times \begin{pmatrix} \int_0^{\infty} dF_1^{\,s}\left(t_1 \mid h_i, d_j\right) dt_1 \\ + \dfrac{1}{2} \times \int_0^{\infty} dF_2^{\,s}\left(t_2 \mid t_1, d_j\right) dt_2 \end{pmatrix} \quad (1)$$

where P^s is the probability of damage state d_j conditioned inundation h_i for sector s . And $F_1^{\,s}\left(t_1 \mid h_i, d_j\right)$ is the probability of stagnation time conditioned at inundation h_i or damage state d_j for sector s . $F_2^{\,s}\left(t_2 \mid t_1, d_j\right)$ is the probability of recovery time conditioned at stagnation time t_1 and damage state d_j for sector s .

(3) Hazard (Estimates of inundation in Aichi prefecture)

In order to calculate business interruption loss caused by hazard in Aichi prefecture, the water depth of inundated area should be evaluated. However, no water depth information could be available for the whole area. Flood simulation could be one possible way to get information of water depth, but complex requirement of many parameters, detailed initial condition and boundary condition make it time-consuming and difficult to be applied in many inundated area in large scale. Another possible way to get information of water depth is interpolation which taking advantage of survey water depth, inundation area and digital elevation model (DEM). The information of inundation areas and survey points of water depth are provided by MLIT. The digital elevation information and other geographical data are provided by Geospatial Information Authority of Japan. Fig 3 shows the inundation area overlapped on digital elevation model of Achi prefecture.

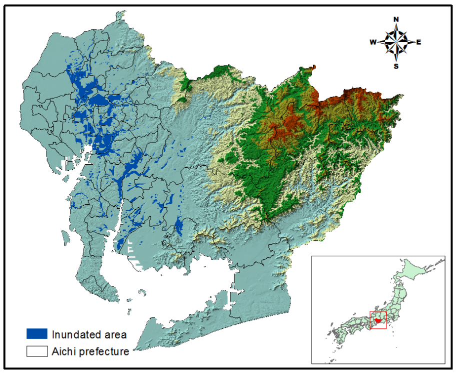

Fig.3 Inundated area

The basic idea of interpolation of water depth at inundation area is firstly using the elevation of inundation area boundary on which water depth are zero and elevation and water depth of survey points to interpolate a water surface at inundation area; Then using interpolated water surface to minus the elevation of inundation area to obtain water depth.

Two categories of interpolation techniques could be adopted for water depth interpolation: deterministic and geostatistical (Childs,2004). Deterministic interpolation techniques create surfaces based on measured points or mathematical formulas, such as inverse distance weight interpolation (IWD) which determines values using a linear-weighted combination set of sample points; global polynomial interpolation and local interpolation which fit a smooth surface using a polynomial function to the input sample points. Geostastical interpolation such as Kriging are based on statistics that considers both the distance and the degree of variation between known data points when estimating values in unknown areas. In this study, Kriging interpolation is adopted.

To achieve Kriging interpolation, proper data processing procedure is necessary. First, it is necessary to examine the distribution and summary statistics of observed value, so that the main characters of value could be understood. Then, examine the spatial variability and stationary to check the exceptional values. Next, examine spatial trends of data which will improve accuracy of interpolation. Spatial dependence was evaluated by the semivariogram cloud and covariation cloud. Finally, Kriging interpolation and cross validation could be achieved (Jiang et al, 2011).

In our study, there are totally 495 inundation areas. To avoid the interaction effect that a survey point value may be used to interpolate other inundation area which it do not located in, the interpolation is conducted for each inundation area individually. To increase sample numbers, boundary of inundation area which include information of zero inundation are also considered. The interpolation is conducted in the following procedure. Firstly, the boundary lines of inundation area are converted to some equally distributed points with a distance of 5 meters and elevation of these points are assigned, these points are merged to survey points; Then, Kriging interpolation is adopted to interpolate an water surface of inundated area; Next, the interpolation are validated through plot of measured values and predicted values as well as plot of error values and predicted values; Finally, after validating the interpolation of water surface, the water depth could be calculated from water depth minus elevation of inundation area. Repeat above steps for each inundation area, the water depth of Aichi prefecture could be interpolated as shown in Fig 4.

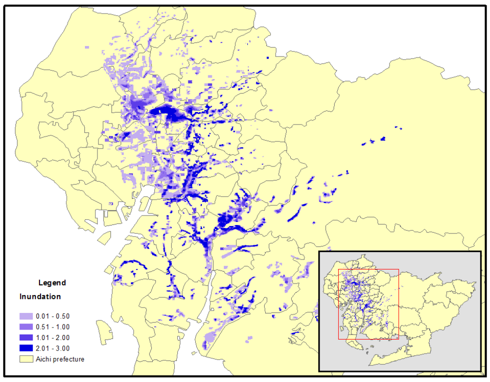

Fig.4 Estimated inundation in Aichi prefecture

To demonstrate the feasibility of the method of interpolation, a scatter plot between estimated inundation and observed inundation of survey points is shown in figure 5. The R- square is 0.87 which proves the inundation interpolation is fulfill the requirement of our study.

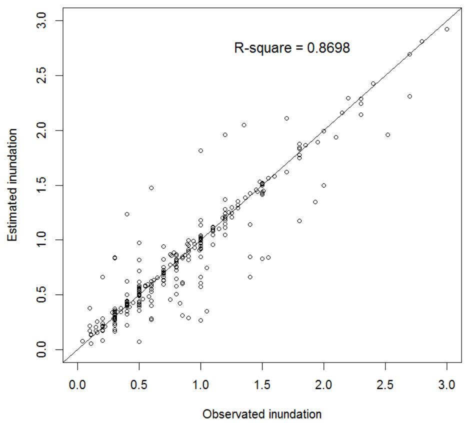

Fig.5 Validation of estimated inundation

The interpolation method is a quick way to get water depth information. It requires much less input data and parameters compared with inundation simulation. Although its accuracy may not as good as inundation simulation, for large areas, it could be adopted to evaluate water depth for rapid loss estimation.

(4) Exposure (Downscaling of economic census data)

In order to calculate business interruption loss caused by inundation for the whole area, besides the water depth of inundated area, the spatial distribution of economic data, such as location of enterprises, industrial types, number of employees should be considered.

In Japan, the economic census is takes advantage of a standard areal mesh system (grid square system or longitude and latitude system). In this system the entire area of the country is divided into areal meshes of equal size with the aid of the specified longitude and latitude lines (Tobler W,1970). There are three basic levels of meshes. The primary area partition is denoted by 40′ of latitude and 1° of longitude (about 80 km). The secondary area partition is denoted by dividing the primary area partition into 64 (8×8) equal parts vertically and horizontally (about 10 km), and the basic grid square is denoted by dividing the secondary area partition into 100 (10 × 10) equal parts vertically and horizontally (about 1 km). Then, the basic grid square is divided into 4 (2 × 2) equal parts reaching the fourth level (about 500 m) or 16 (4 × 4) equal parts reaching the fifth level (about 100 m).

The establishment and enterprise census data which used in our research is from the fourth level 500 m meshes. To estimate the loss caused by inundation, the 500 m meshes economic census data should be combined with water depth information. It is no so reasonable to assign a water depth value into 500 m mesh. Therefore, downscaling of economy survey data is necessary. Definitely the smaller the better for the downscaling, however, the resolution downscaling is much depends on additional information. In this study, 100 m land use meshes provided by Ministry of Land, Infrastructure, and Transport of Japan (MLIT) is adopted to downscale the economic census.

The basic idea of downscaling is the following: Each 500 m economic census contains 25 land use meshes. Among types of land use, the enterprises are just located at meshes of construction land use type. Therefore, the economic census data is then averagely distributed into 100 m land use meshes according to the type of land use, as is shown in figure 6. 100m meshes are taken as basic unit for loss estimation. Water depth and economic census data are all assigned into 100 m meshes.

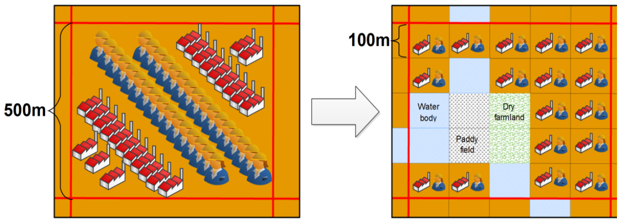

Fig.6 Concept of downscaling of economy survey data

(5) Estimates of business interruption loss in sectors

The definition of business interrption loss is given by Equation (2).

$$BIL^s = M^s \times BILR^s \times Z^s \qquad (2)$$

where M^s refers to the employee of sector S . Z^s refers to the value added (yen/person day).

Based on Equation (2), business interruption loss in different sectors are calculated in Table 1.

Table 1 Estimates of business interruption loss

Sector	Business interruption loss (million)
Livelihood related manufacturing	5,981
Raw materials manufacturing	8,560
Processing and assembly manufacturing	19,894
Construction	17,156
Wholesale and retail	47,948
Services	21,755

4. Validation

In this section, estimated business interruption loss are compared to the index of industrial production (IIP) in September, October, and November in 2000. In principle, business interruption loss estimated in this paper differs from IIP value, where IIP is estimated on the basis of actual products, which are affected by many factors, such as higher-order impact, mac economic recession and so on. But if we think the influence of direct facility damage to business interruption loss is large in this case study area, there must be close to IIP at least in September. Examples of validation of our estimated business interruption losses in clothes fiber sector, wood sector and general equipment sector are provided from Fig7. to Fig9.

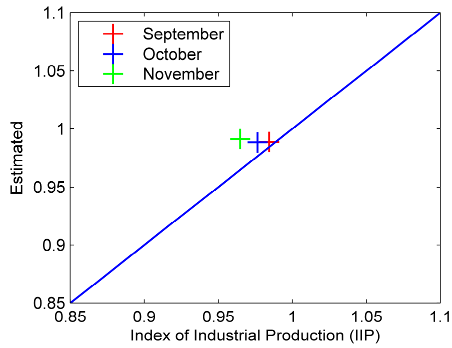

Fig.7 Validation of clothes fiber sector

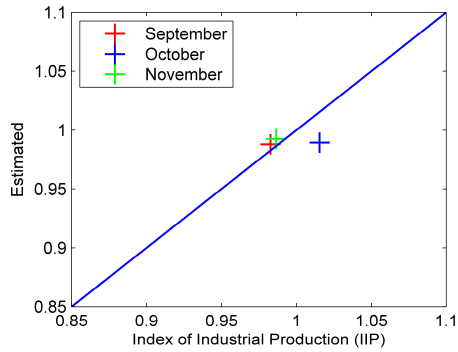

Fig.8 Validation of wood sector

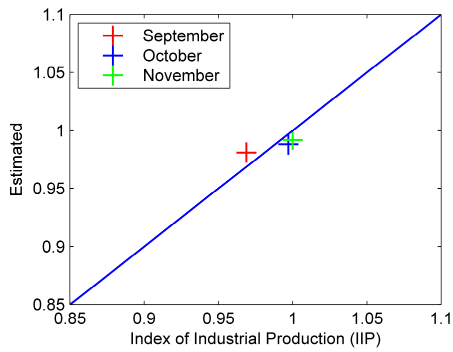

Fig.9 Validation of general equipment sector

5. Conclusion

This study invetigated a methodogy with which to estimate business interuption losses in sectors mainly caused by facility damage. The analysis showed that, facility damage could reasonably regarded as main sources of impact on business interruption losses.

Comparative analysis on different sectors made it possible to screen out applicable sectors, which included livelihood related manufacturing sectors, such as food, furniture; raw materials manufacturing sectors, such as wood, plastical materials, mental sector; processing and assembly manufacturing sector, such as general equipment sector. However, business interrption losses in some sectors related to auto industry are not estimated well in this methodology due to higher-order impact and some other reasons, which need to be further investigate in future work.

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REFERENCES

[1] C.A. Kircher, R.V. Whitman, W.T. Holmes.Hazus earthquake loss estimation methods.Nat. Hazards Rev., 7 (2) (2006), pp. 45-5

[2] Dutta D, Herath S, Musiake K. A mathematical model for flood loss estimation[J]. Journal of hydrology, 2003, 277(1): 24-49.

[3] Smith D I. Flood damage estimation- A review of urban stage-damage curves and loss functions[J]. Water S. A., 1994, 20(3): 231-238.

[4] Thieken A H, Müller M, Kreibich H, et al. Flood damage and influencing factors: New insights from the August 2002 flood in Germany[J]. Water resources research, 2005, 41(12).

[5] Hallegatte S. An Adaptive Regional Input - Output Model and its Application to the Assessment of the Economic Cost of Katrina[J]. Risk analysis, 2008, 28(3): 779-799.

[6] Santos J R, Haimes Y Y. Modeling the Demand Reduction Input - Output (I - O) Inoperability Due to Terrorism of Interconnected Infrastructures*[J]. Risk Analysis, 2004, 24(6): 1437-1451.

[7] Okuyama Y. Modeling spatial economic impacts of an earthquake: Input-output approaches[J]. Disaster Prevention and Management: An International Journal, 2004, 13(4): 297-306.

[8] Haimes Y Y, Horowitz B M, Lambert J H, et al. Inoperability input-output model for interdependent infrastructure sectors. I: Theory and methodology[J]. Journal of Infrastructure Systems, 2005, 11(2): 67-79.

[9] Crowther K G, Haimes Y Y, Taub G. Systemic Valuation of Strategic Preparedness Through Application of the Inoperability Input - Output Model with Lessons Learned from Hurricane Katrina[J]. Risk Analysis, 2007, 27(5): 1345-1364.

[10] Tatano H, Tsuchiya S. A framework for economic loss estimation due to seismic transportation network disruption: a spatial computable general equilibrium approach[J]. Natural Hazards, 2008, 44(2): 253-265.

[11] Rose A, Liao S Y. Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions*[J]. Journal of Regional Science, 2005, 45(1): 75-112.

[12] Tsuchiya S, Tatano H, Okada N. Economic loss assessment due to railroad and highway disruptions[J]. Economic Systems Research, 2007, 19(2): 147-162.

[13] Hallegatte S. Modeling the role of inventories and heterogeneity in the assessment of the economic costs of natural disasters[J]. Risk analysis, 2014, 34(1): 152-167.

[14] Modeling spatial and economic impacts of disasters[M]. Springer Science & Business Media, 2004.

[15] Rose A, Guha G S. Computable general equilibrium modeling of electric utility lifeline losses from earthquakes[M]//Modeling spatial and economic impacts of disasters. Springer Berlin Heidelberg, 2004: 119-141.

[16] Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change[M]. Cambridge University Press, 2012.

[17] Okuyama Y. Critical review of methodologies on disaster impact estimation[J]. Background paper for EDRR report, 2008.

[18] Okuyama Y, Santos J R. Disaster impact and input–output analysis[J]. Economic Systems Research, 2014, 26(1): 1-12.

[19] Bruneau M, Chang S E, Eguchi R T, et al. A framework to quantitatively assess and enhance the seismic resilience of communities[J]. Earthquake spectra, 2003, 19(4): 733-752.

[20] Nakano K Kajitani Y Tatano H (2013) Functional fragility curves for a production facility of industrial sectors in case of earthquake disaster. Japan Society of Civil Engineers (JSCE) (in Japanese)

[21] Kajitani Y, Tatano H. Estimation of lifeline resilience factors based on surveys of Japanese industries[J]. Earthquake Spectra, 2009, 25(4): 755-776.

[22] Park J Y, Cho J, Rose A. Modeling a major source of economic resilience to disasters: recapturing lost production[J]. Natural hazards, 2011, 58(1): 163-182.

[23]Childs C. Interpolating surfaces in ArcGIS spatial analyst[J]. ArcUser, July-September, 2004: 32-35.

[24] Tobler W.: A computer movie simulating urban growth in the Detroit region. Economic Geography, Vol.46, pp.234-240, 1970.

[25] Sinfonica. 2006. Establishment and enterprise census of Japan. (In Japanese)