Draft! June 2004

Modeling the Regional Economic Loss of Natural Disasters: Indirect Loss Diffusion due to the Electricity Disruptions and Interindustry Economic Activities

Norihiko Yamano*, Yoshio Kajitani**, and Yoshiharu Shumuta**

Keywords: Economic loss by natural disaster, Economic grid data, Multiregional IO model

Abstract

This paper examines the economic impacts of natural disasters by integrating district level economic data and Japanese interregional input-output model. Our model deals with the direct and indirect output losses due to the disruptions of electricity, damages of transport network, and the decrease in economic demand. We compiled the 500m district level output and employment data to analyze the precise output losses. Our numerical example of Hyogo prefecture shows that the indirect economic loss is much larger than the direct output loss in most districts. The damages on material manufacturers and business center will induce a great economic loss compared to suburban area. Our results, therefore, are utilized to make a policy decisions of retrofit and countermeasure investments.

* Socio-economic Research Center, Central Research Institute of Electric Power Industry, Email: yamano@criepi.denken.or.jp

** Civil Engineering Research Laboratory, Central Research Institute of Electric Power Industry

1. Introduction

This paper examines the economic impact of natural disasters using our Japanese interregional input-output model and the economic grid data[1]. The evidences from the interregional input-output tables and the interregional commodity flow surveys for previous dataset show that the importance of interregional and international trade has increased. The spatial sizes of Japanese regions are relatively small and interregional trade cannot be disregarded. As a result of globalization and regional specialization, the economic impact of catastrophic disaster may expand to national and world-wide economic issue.

Although an Isard type interregional input-output table has beneficial information about interregional and interindustrial economic activities, the classical input-output models cannot handle the negative influences of disasters. The difficulties with impact analysis of natural disasters are summarized as (Okuyama et al. 1999, etc)

- ambiguous consequences of direct and indirect damages,
- dynamic adjustment of production process: recovery process, resiliency, influence of network infrastructure disruptions, interregional substitution, inventory adjustment,
- change in labor supply: number of refugees, commuting problems,
- data availability: the scales of timeline and spatial size of damage by unscheduled events are much shorter and smaller than the usual published statistic data,
- change in final demand: a massive amount of relief goods, retrofit investment of public and private capital.

The precise geographical information of industrial agglomeration is required to estimate the realistic economic losses by natural disasters such as earthquake, flood, and typhoon. Although a great deal of effort has been made on investigating the recovery process after disasters to employ the input-output analysis (Rose et al. 1997 and Cho et al. 2001), little is known about the relationship between total economic loss and spatial distribution of production facilities in the disaster area. For example, earthquakes can be felt over large areas, but the severe building damages are observed along the fault lines and the

[1] Economic grid data is a spatial data counted in the same geographical unit size. The smallest available data in Japanese Urban area is a 500m x 500m grid.

damaged area is much different from the political boundaries The ordinal economic figures are published in the unit of political boundaries. The economic loss of devastating natural disaster, therefore, is difficult to estimate even the detailed damages of housings and production facilities are observed.

In this paper, we developed the integrated model of district data and interregional economic loss model. Direct impacts of disaster are captured by spatial level of grids. The indirect economic loss is estimated using our interregional input-output model under the condition of accessibility across regions. The map of economic fragility is finally given as the output of numerical simulations.

In the next section, we describe the methodology of grid data development and our Multiregional Input-Output model. The third section examines two numerical simulations and the hazard map of target region is plotted. Hyogo prefecture is the target region in this paper due to the data availability of electricity substation locations. The last section gives a summary of this paper.

2. Integration of Spatial Grid Data and Multiregional Input-Output Model

2.1 Economic Grid Data

Capturing the accurate direct losses of economic activities is the most important factor to estimate the total economic impact by natural disasters. Without spatial data in a district level, an estimation of the direct damage by disaster becomes much complicated. The information of housings and buildings spatial locations is also utilized as the basic source for the policies of disaster prevention and mitigation.

Since the grid data of output data by industrial sector is not available in the Japanese published statistics, the production data is estimated from the employment distribution and the regional output data. Each district's production is estimated from the prefectural real production in Annual Report of Prefecture Accounts and the grid employment data in the 1995 Population Census. The 500m x 500m grid data of population and employment by sector is surveyed every 5 years in Population Census of Japan. The labor productivity in the target region therefore is assumed to be the same in this type of data estimation. Basically we used the same methodology of Kanemoto et al. (1996) is applied to divide the prefectural data to smaller regional scale data.

< Table 1: Published and Estimated Data in Different Spatial Scale>

The base year in this study is 1995 and the number of sectors is 26 that are consistent to our multiregional input-output model. The target region in this study is Hyogo prefecture, the western part of Kansai region where the devastating Hyogoken-Nanbu Earthquake[2] took place in 1995.

Aggregating our originally developed economic grid data, the analysis of different spatial levels such as jurisdictional area of ward, city, and power substations analysis can be examined. Figure 1 and Figure 2 show the spatial distributions of steel manufacturers and business service production. Even their output level is nearly equal, the locational distributions are completely different and the economic loss heavily depends on where and which sector of the urban are damaged.

2.2 Multiregional Input-Output Model

2.2.1 Redefined Interregional Input-Output Table

The 1995 Japanese interregional input-output table of Ministry of Economy, Trade and Industry (METI table) is redefined to 11 power supply regions plus target region (Figure 3). Hyogo prefecture, the target region is extracted from Kansai region. The other major change in regional division is that of Kanto, the capital region is divided to North Kanto and Shutoken. Kanto region in the original METI table has nearly 40% of GDP in 1995, and Northern Kanto and Southern Kanto have quite different economic figures. North Kanto has an agglomeration of manufacturing sector and Shutoken is one of the largest agglomeration regions of services and financial centers in the world. The 46 sectors in METI table are aggregated to 26 sectors due to the availability of related statistics (Table 2).

＜Table 2: Sectors in Interregional Input Output Model＞

The original interregional interaction data is divided to 12 regions in the following procedures. The intraregional transactions within prefectures, domestic final demand and exports are given by the corresponding prefectural Input-Output tables. The difficulties are the interregional transactions. The manufacturing sectors are divided into sub regions using the commodity flows survey. Since there is no survey-based statistics for the tertiary sectors, the interregional activities are estimated by gravity model, one of the classical

[2] The earthquake killed more than 6000 and nearly 30,000 people lost homes. The earthquake caused more than 10 trillion yen in direct damage. The recovery of collapsed highway took many months.

non-survey methods.[3]

It is reasonable to assume that the interregional economic activity has the automobile travel time decay relationship, since the recent commodity flow survey shows that more than 90% of commodities are now transported by trucks. The road congestion is not considered here, so the travel times across regions are symmetric.

2.2.2 Multiregional Econometric Input-Output Model

The similar study (Yamano. 2002) using the Chenery-Moses type multiregional input-output model[4] shows that future introduction of new highway routes induces the change in interregional trade pattern. Basically the same methodology can be applied in our disaster analysis with the redefined set of regions.

The classic multiregional input-output model is written as

$$(1) \quad X = T_a(I-\hat{M})RX + T_f(I-\hat{M})F + EX$$

where X is the gross output column vector, $\hat{M}$ is the diagonal matrix of import coefficient, R is the interregional input-output technical coefficient matrix, F is the domestic final demand vector, and EX is foreign export vector.

T_a and T_f are the trade coefficients for interregional interactions of intermediation and final demands respectively,

(2) $T_a = \begin{bmatrix} \hat{t}^{kk} & \hat{t}^{kl} \\ \hat{t}^{lk} & \hat{t}^{ll} \end{bmatrix}$, where $\hat{t}^{kl}$ is the diagonal trade flows of sectors from region k to region l, and the trade coefficients are estimated by gravity type interregional trade model as

$$(3) \quad t_a(s,k,l) = f(d(k,l), x_s{}^k, x_s{}^l)$$

where $t_a(k,l,s)$ is the trade flows of sector s, $d(k,l)$ is the economic distance between regions k and l, x_s^k is the output of sector s in region k..

<Table x: Estimation Result of Interregional Trade Flows>

---

3 See Batten and Boyce (1987) for interregional trade models.

4 See Miller (1998) for the detailed formulation of multiregional input-output model.

The difficult part of trade pattern simulation is the setting of accessibility across regions after the natural disasters. It is impossible to predict the massive transportation demand increase and road closings prior to the catastrophic disaster. Unfortunately the change in accessibility is not solved within the simulation model, but it is exogenously set. Once the change in interregional accessibility is placed, then the change in interregional trade patterns is endogenously obtained in the model.

The domestic final demands are composed of private investment (*IP*), public investment (*IG*), personal consumption expenditure (*CP*), government consumption expenditure (*CG*), non household consumption expenditure (*NHC*), and change in private inventories (*INV*). Note that each series of domestic final demands has the interregional interactions.

Rearranging (1), the output series is obtained by following equation as

$$(4)\ X = (I-(I-\hat{M})T_a R)^{-1} T_f (I-\hat{M})(IP+IG+CP+CG+NHC+INV)+EX\ .$$

If there are no physical damages on transport network, residential housings, commercial buildings and production equipment, simply (4) is the solution of the multiregional model, and the sales of an industry equal its gross output.

2.3 Economic Damage Model by Natural Disasters

2.3.1 Direct Decrease in Production Capability

A devastating unscheduled event breaks the supply-demand equilibrium condition both from demand and supply sides. The damages of production facilities reduce the capability of supply and the damages of residential housings decrease the consumption demand in the damaged area. The change in final demand is not negative impact only, but there is a positive impact of reconstruction and recovery investment.[5] Certainly, many production facilities and public infrastructure are destroyed in devastating disasters, but in terms of annual production the most of economic loss is cancelled out by the increase in the construction sectors.

A definition of economic impact in this study is the economic loss calculated right after the disaster and the recovery and reconstruction investment and relief activities are not

[5] Recovery investment in interregional model is considered in the simulation model of Okuyama et al. (1999).

considered. It's assumed that the direct damage for each sector in a target region corresponds to the level of output observed in the multiregional input output interactions. In the following analysis, the halt of production activities are counted in a grid level. All economic activities in a grid are totally suspended by natural disasters.[6] If the anticipated demand exceeds the supply capacity, the demand is adjusted through the quantitative adjustment process.

2.3.2 Production Decrease in the Multiregional Input-Output Framework

The methodology used to calculate the economic loss in this paper is the adjusted version of Regional econometric input-output model (REIM). The REIM is the linkage model of a regional input-output table and an econometric model originally developed by Conway (1990) and Israelevich et al. (1997) for Washington and Chicago region respectively. Their single-region models are extended to multiregional framework by Central Research Institute of Electric Power Industry.[7] In the REIM framework the intermediation and final demand are adjusted simultaneously to meet a condition of supply equals demand. However the intermediation and final demands are separately adjusted in our disaster model.

The economic loss in our multiregional model is written as follows. Decrease in production capability is caused by decrease in labor supply, and damages of production equipment and network infrastructures in a damaged district. For simplicity, we assumed that all economic activities in a grid is totally suspended, so the decrease rate of production capability (γ) is written as

(5) $\Gamma = (\gamma_1, \cdots, \gamma_{26}); \gamma_i = ({X_i}^R - {X_i}^{Rg}) / {X_i}^R$

where ${X_i}^{Rg}$ is a production of sector *i* in grid *g* at region *R*. The restricted production capability (*Xc*) become

[6] The amount of direct decrease of production will be fluctuated by the inventory adjustment and survival situation of network lifelines.

[7] The structure of multiregional econometric input-output simulation model is briefly explained in Yamano (2002).

(6) $Xc = \begin{bmatrix} 1 \\ \cdots \\ \Gamma \\ \cdots \\ 1 \end{bmatrix} \otimes \begin{bmatrix} X_1 \\ \cdots \\ X^R \\ \cdots \\ X_{12} \end{bmatrix}$, where $\otimes$ represents the cell by cell product.

The damages on household sector by natural disaster cause change in final demand activity such as household consumption. Again the grid level population distribution data is a key variable in this study. The population of each grid is not homogeneously distributed in the urban area. Thus the change in final demand heavily depends on the locations of damaged grid. Figure 4 shows that the population in Southern Hyogo prefecture is remarkably concentrated on the southeastern area of Hyogo prefecture. The decrease in household consumption by residential damages is given by

(7) $CP' = CP - f(\Delta N),$

where ΔN is a change in population. If the household consumption decreases, the output and other final demands eventually decrease by simultaneous equation system as

(8) $X_d' = (I - (I - \hat{M})T_a A)^{-1} T_f (I - \hat{M})(IP' + CP' + NHC' + INV' + \overline{CG} + \overline{IG}) + EX$

(9) $NHC' = NHC - f(\Delta X_d), IP' = IP - f(\Delta X_d)$,

where $\Delta X_d = X - X_d'$ is the decrease in anticipated demand after the disaster. The government expenditure and investment (CG and IG) are independently given in the model.

If the production capacity becomes lower than the anticipated demand ($X_c < X_d$), then the demand is adjusted in the multiregional REIM model. The adjustment procedure starts in order from inventory, foreign exports, interregional trade and the sales to domestic demands.

(10) $INV' = INV + X_c - X_d$, if $X_c < X_d$ and $INV > 0$.

The change in trade patterns after disaster is replicated by taken account into the increase of travel time across regions after disaster duet to road closing and detouring.

(11) $T_a' = f(t_a'(s,k,l))$; and $T_f' = f(t_f'(s,k,l))$;

The gross output (X') right after the disaster is solved by

(12) $X' = \beta(I - (I - \hat{M})T_a' A)^{-1} T_f'(I - \hat{M})(IP' + CP' + NHC' + INV' + \overline{CG} + \overline{IG}) + EX'$.

where β is the adjustment coefficient for the final demand. If $X_c < X_d$ and $INV \leq 0$, then β become less than one. In the framework of multiregional demand-supply adjustment model (Multiregional REIM), β cannot be decomposed into the adjustment in trade, domestic purchasing rate, and final demands. Solving the simultaneous equation from (7) to (12), the output and interregional trade flows are obtained.

3 Numerical Examples: Estimating a Economic Hazard map

3.1 Economic Hazard map of All Districts in Hyogo Prefecture

In this numerical example, the influence of damages on each grid in Hyogo prefecture on total economy is calculated by solving 7130 lengthy simulations. The direct loss of production capability corresponds to the output by sectors of each grid because all activities are assumed to be totally suspended by a devastating disaster. Table 3 shows the small part of the simulation analysis. Even if two grids have the same production level, the effect of destruction would be very different. It does depend on the population density, and industrial composition of each grid. The interregional trade flows are endogenously obtained, but the accessibility, the travel time between regions in this simulation is kept at the same level.

＜Table 3: Result of Economic Loss Simulation by Grid＞

The hazard map for Hyogo prefecture using our model is finally plotted in Figure 5. The distribution pattern of total economic loss is similar to population distribution map in Figure 4, but it is not completely overlapped. The economic loss is not exactly proportional to the density of housings, business activity and production capabilities. It depends on the complicated factors of population distribution, industrial structures, and the transportation accessibility.

Less populated industrial districts on the harbor area have a tremendous economic impact and the functional damages to the buildings on the central business district also have the large impact on regional and other regions economy. The interindustrial structure of Hyogo region is well represented on the map, and the indirect economic loss is much larger than the direct loss especially in material manufacture sectors such as steel and chemical products in Southeast part of Hyogo prefecture.

3.2 Economic Loss due to Power Substation Damage

Another numerical example using the multiregional economic loss model in this study is the hazard map estimation for power substations. In a broad way, the power outage occurs at the unit of power substations.[8] If the substation equipment is damaged, the whole area of substation district suffers from a power outage until the distribution line is redirected to alternative circuit. The survey studies of ATC (1991) and Kajitani et al. (2004) show that most of economic activities are suspended under the electricity disruptive situation. We thus assume that all economic activities halt in a blackout condition. In this simulation the final demands are not affected.

Figure 6 shows the economic losses induced by power outage in all 172 power substation areas. Basically the size of total economic loss is in the order of the damages of production level in each grid. Again the total economic loss is much greater than the direct output loss in most substation areas. Plotting the level in the geographical map gives us the hazard map of economic loss induced by electricity blackout (Figure 7). This hazard map indicates "the importance of electricity" in terms of total economic loss right after the events.

4. Summary

Using the integrated model of economic grid data and interregional input-output model, the hazard maps of unscheduled events are obtained in the accurate spatial level. The hazard maps are utilized to make a policy decisions of retrofit and countermeasure investments. The results of electricity disruptions and grid damages show that the indirect economic losses are not exactly proportional to direct losses. In other words, there are many criterions of the recovery and retrofit priority orders. The policy of "the largest customer come first" is not always correct in terms of reducing the total economic loss. The estimated economic losses of each electricity power substation can be also utilized to distribute the reinforcement investment under the limited budget of utility companies.

Our methodology of the integration of grid data and multiregional input-output model can be applied to previous and forthcoming unscheduled events as the next step of this study. However many realistic assumptions of dynamic adjustment of production process and demand schedules must be given to estimate the gross amount of economic loss by a disaster.

---

[8] Not necessarily, the shaking and power station damage is not proportional. The precise electricity network line map and the fragility of equipment are required to develop the engineering model of electricity disruption.

References

Applied Technology Council. 1991. ″Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States.″

Batten, D.F. and D.E. Boyce. 1987. ″Spatial interaction, transportation and interregional commodity flow models,″ in Handbook of Regional and Urban Economics vol1 Regional Economics, 357–406.

Cho, S., P. Gordon, J.E. Moore II, H.W. Richardson, M. Shinozuka, and S.E. Chang. 2001. "Integrating Transportation Network and Regional Economic Models to Estimate the Costs of a Large Urban Earthquake," Journal of Regional Science, 41 (1), 39–65.

Conway, R. 1990. ″The Washington Projection and Simulation Model: a regional interindustry econometric model,″ International Regional Science Review, 13, 141–166.

Israelevich, P.R., G.J.D. Hewings, M. Sonis and G.R. Schindler, 1997. ″Forecasting Structural Change with a Regional Econometric Input–Output Model,″ Journal of Regional Science, 37 (4), 565–590.

Kajitani, Y., H. Tatano, N. Yamano, and Y. Shumuta. 2004. ″Economic Impact of Lifeline Disruptions after Natural Disasters – A Questionnaire Survey to Industries in Tokai Area–″ CRIEPI Report U03061 (In Japanese).

Kanemoto, Y., T. Ohkawara, and T. Suzuki. 1996. ″Agglomeration Economies and a Test for Optimal City Sizes in Japan,″ Journal of the Japanese and International Economies 10, 379–398.

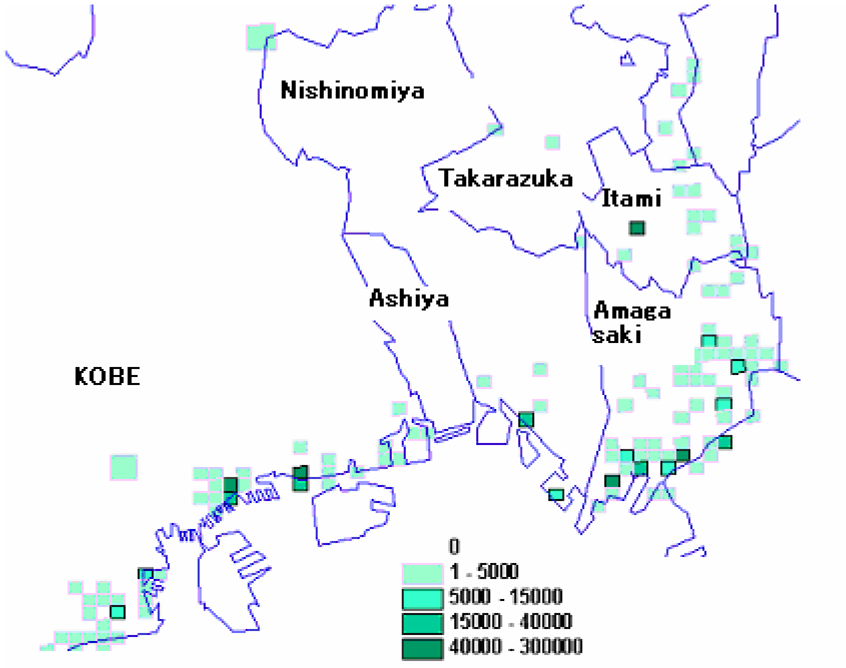
Miller, R. E. 1998. ″Chapter 3 Regional and interregional input–output analysis,″ in W. Isard et al. Methods of Interregional and Regional Analysis, Ashgate.

Okuyama, Y., G. J.D. Hewings and M. Sonis. 1999. "Economic Impacts of an Unscheduled, Disruptive Event: A Miyazawa Multiplier Analysis," in Geoffrey J.D. Hewings, Michael Sonis, Moss Madden and Yoshio Kimura (eds), Understanding and Interpreting Economic Structure, Advances in Spatial Sciences, Springer–Verlag, Heidelberg, Germany .

Okuyama, Y., 2004. "Sequential Interindustry Model(SIM) and Impact Analysis: Application for Measuring Economic Impact of Unscheduled Events" in Okuyama, Y. and S. Chang eds. Modeling Spatial and Economic Impacts of Disasters. Springer–Verlag, Heidelberg, Germany .

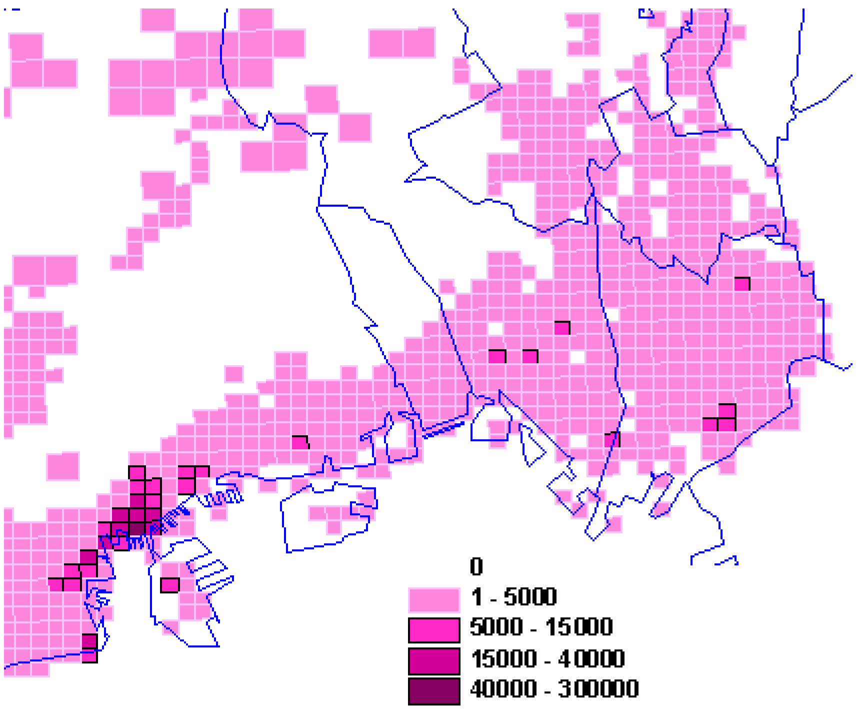
Rose, A., J. Benavides, S.E. Chang, P. Szczesniak, and D. Lim. 1997. "The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions," Journal of Regional Science, 37 (3), 437–458.

Yamano, N. 2002. ″The effect of Highway Openings on Interregional Trade Structure,″ Denryoku Keizai Kenkyu, No.47 (In Japanese).



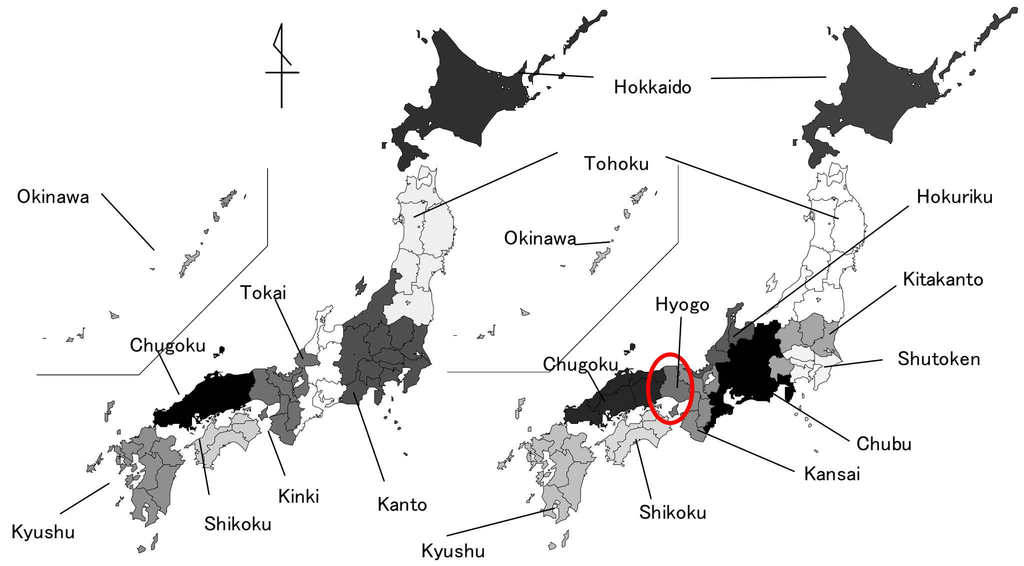
(Steel Output in Hyogo prefecture = 1.95 Trillion Yen)

Figure 1: Distribution of Steel Manufacturer Output (Million Yen / Grid, 1995)



(Business Services Output in Hyogo prefecture = 1.99 Trillion Yen)

Figure 2: Distribution of Business Services Output (Million Yen / Grid, 1995)



(METI original IRIO) (Regional Division in this paper)

Figure 3: Regional Divisions of interregional Input Output Table

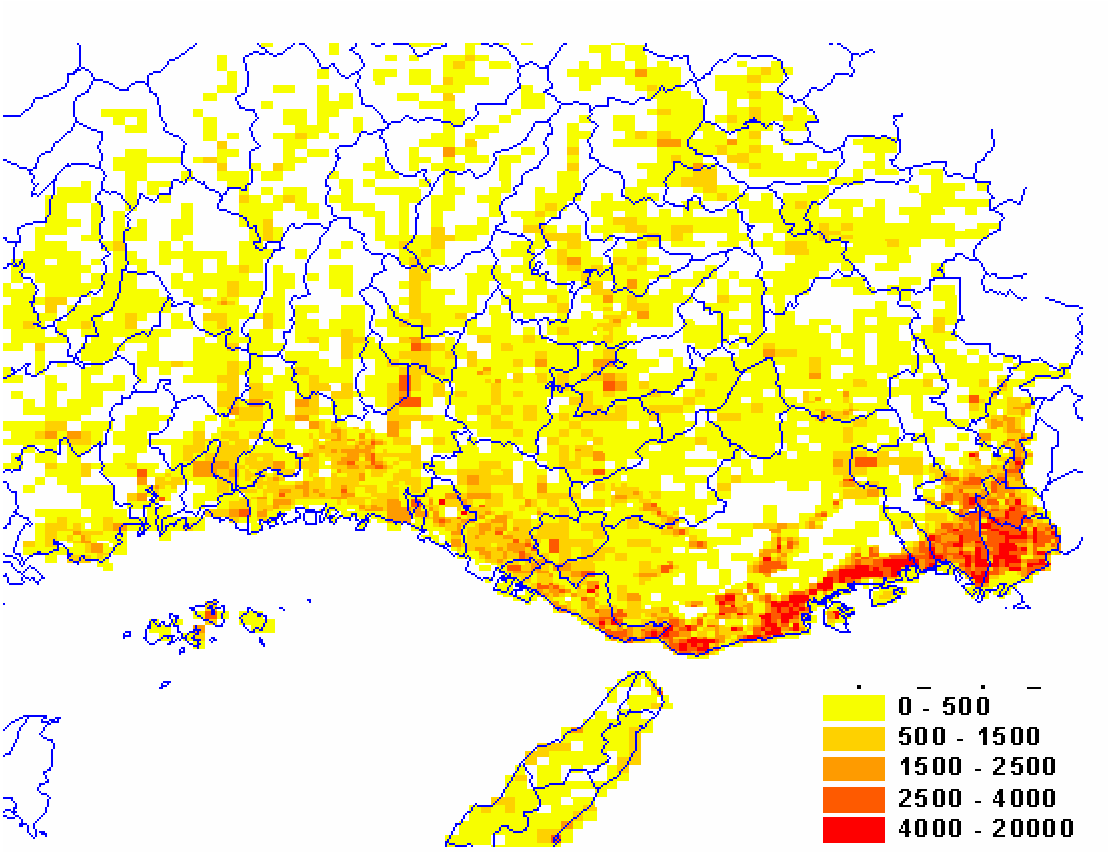


Figure 4: Population distribution (Population / Grid, 1995)

Table 1: Published and Estimated Data in Different Spatial Scale

Spatial Scales	Published/Available Data	Developed in this paper
1 Grid (500mx500m)	Employment by sectors Population	Production by sectors
2 Power substations area	Locations of power substation	Boundaries Production by sectors
3 Prefecture	substation Input-Output table	Production by sectors (constant price)
4 Region	Interregional IO table (9regions)	Power supply regions + Target region (12 regions) Multiregional IO Model

Table 2: Sectors in Interregional Input Output Model

Primary	Manufacturing	Tertiary
1 Agriculture, Forestry & Fishery	3 Food	14 Construction
2 Mining	4 Textile & Apparel	15 Electricity, Gas & Water
Cement, Clay & Stone	5 Paper & Pulp	16 Wholesale & Retail
	6 Chemical Products	17 Financial & Insurance
	7 Refinery	18 Real Estates
	8 Cement, Clay & Stone	19 Transportation & Communication
	9 Steel and Iron Products	20 Government
	10 Nonferrous Metal	21 Educational Services
	11 Metal Products	22 Medical Services
	12 Machinery	23 Other Public Services
	13 Other MA	24 Business Services
		25 Personal Services
		26 Miscellaneous

Table 3: Result of Economic Loss Simulation by Grid

Grid ID#	Power Station ID#	Population	Direct Production Loss *	Economic Loss in Hyogo *	Total Economic Loss *
1	1	302	216	51,478	68,759
2	1	431	1,496	263,804	495,404
3	1	410	4,693	50,548	67,593
4	2	144	485	9,761	14,210
5	2	0	591	1,342	1,872
…	…	…	…	…	…
7126	141	1210	14,718	284,923	523,971
7127	141	1269	7,405	315,556	578,241
7128	142	200	160	221,759	440,343
7129	142	1001	5,108	315,540	578,238
7130	142	124	121	9,035	13,208

*: Million Yen
The base year is 1995

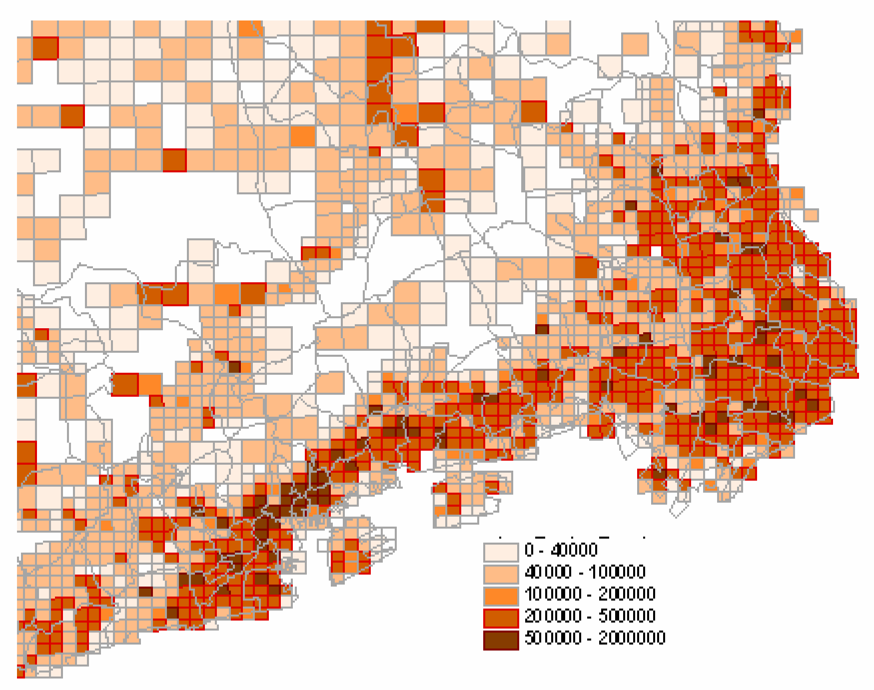


Figure 5: Hazard Map (Economic Loss Induced by the Damage of Grid, Million Yen)

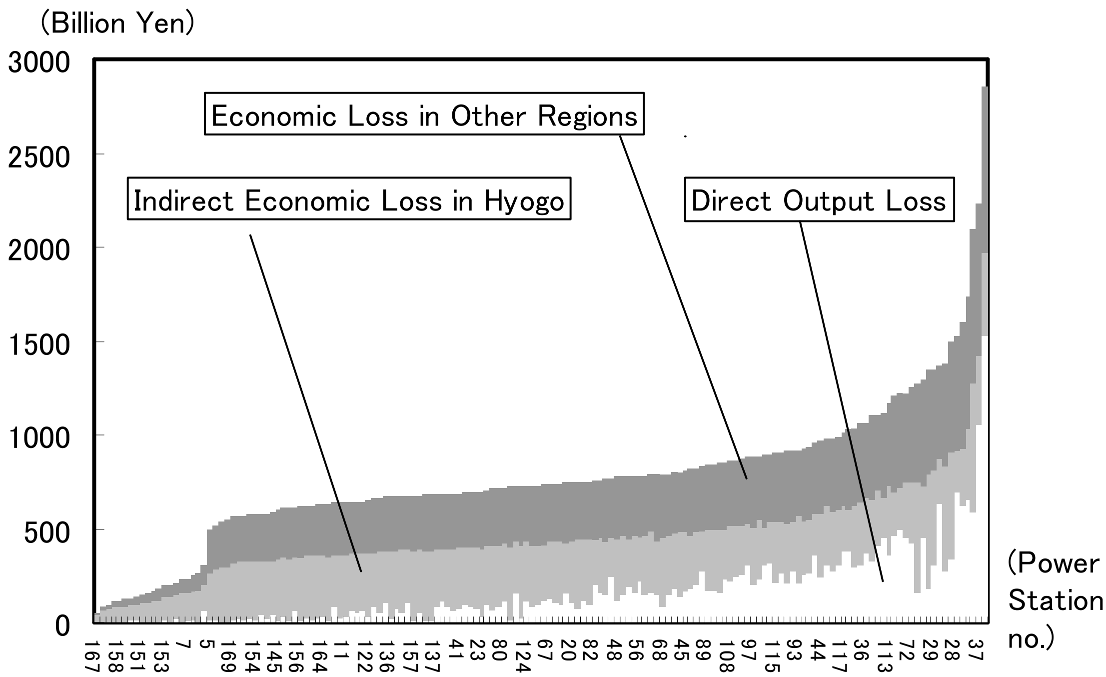


Figure 6: Economic Loss Induced by Power Outage by 172 Power Substation Areas

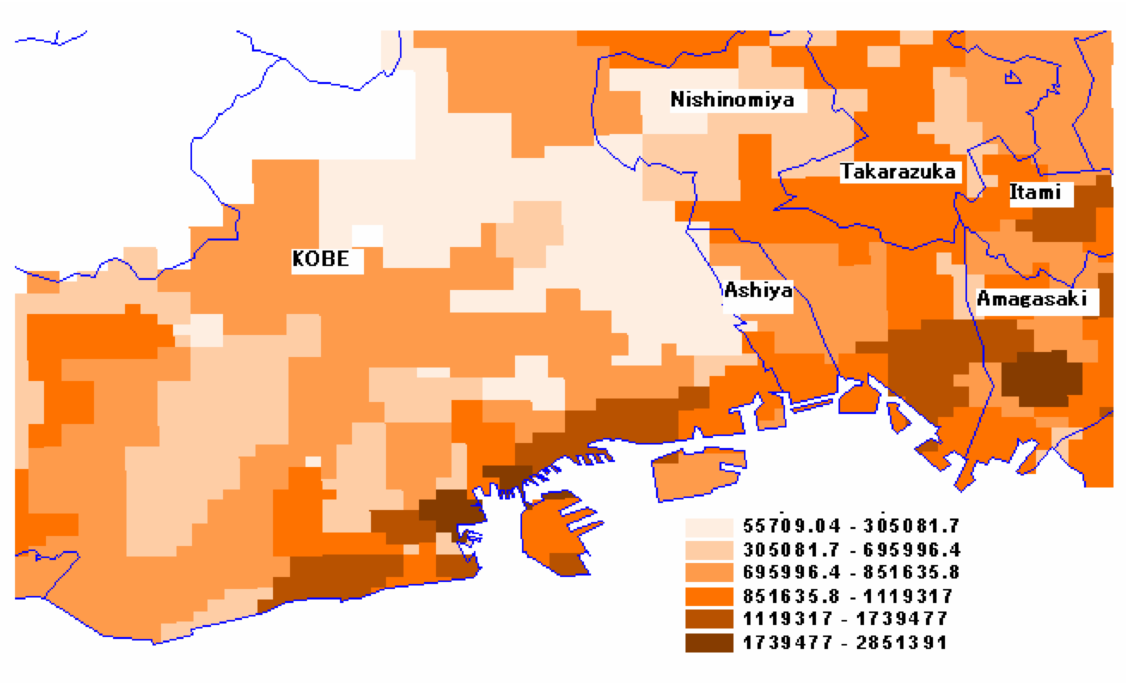


Figure 7: Hazard Map (Loss Induced by Damages of Power Substations Area, Million Yen)

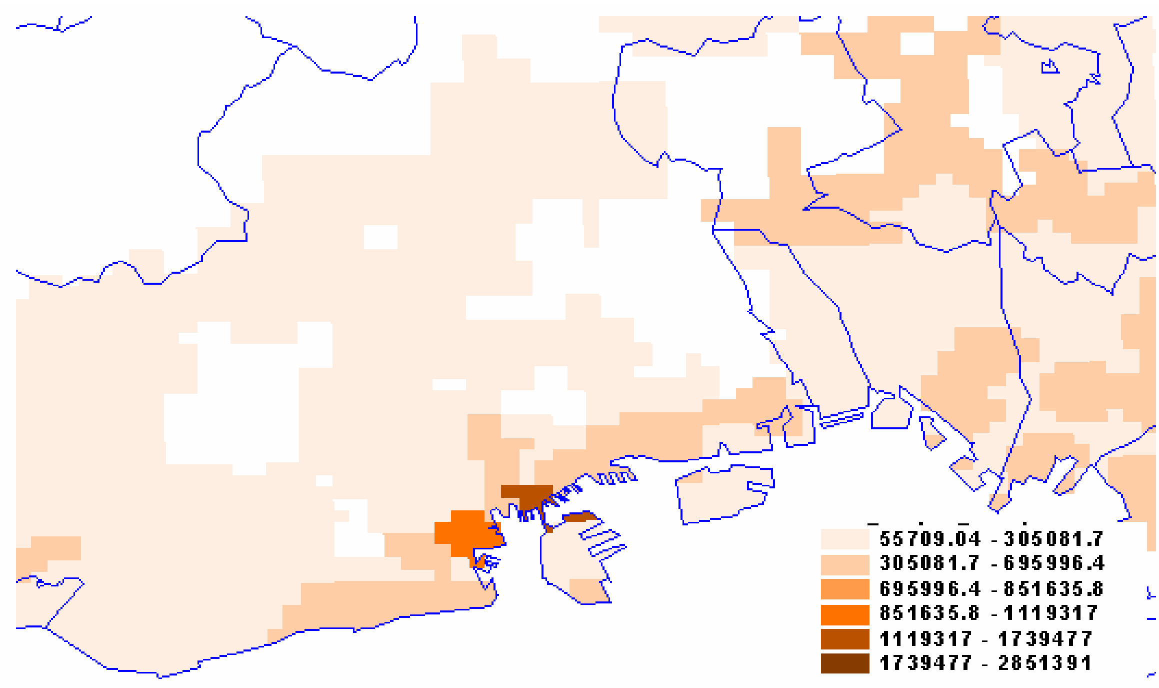


Figure 8: Direct Output Loss Estimates by Power Outage (Million Yen)