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MAPPING OF EXPECTED INCONVENIENCE IN RESIDENTS' DAILY LIVING IN EARTHQUAKE-INDUCED SUSPENSION OF UTILITY LIFELINES

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ABSTRACT

A method for the mapping of inconvenience posed on residents' daily living in the suspension of utility services was developed and utilized in a case study. The method includes 1) relative vulnerability of a household to the suspension of power, water, and gas supply and 2) terms of disorder of the lifeline services. For the evaluation of the vulnerability in daily living, a questionnaire survey by household was carried out, while the terms of disorder were given as the result from conventional damage estimation on lifeline facility and function.

KEYWORDS

Earthquake disaster; living in disasters; inconvenience in daily living; utility lifelines; suspension of lifeline services; damage estimation; disaster mapping.

INTRODUCTION

While social attention has long been paid to inconvenience posed on residents' daily living by the suspension of lifeline services, technical achievement in this problem is extremely limited. Studies on lifeline users, of which support is eventually the objective of lifelines, are far behind those on the facility damage and functional disorder of lifeline systems.

A considerable number of case studies have been done, but systematic approach to this problem has been seldom attempted. Findings from the past studies are largely descriptive rather than analytical and, consequently, are not applicable to the practice of disaster reduction.

In this study, the authors developed a method to draw maps that illustrate the spatial distribution, or area-to-area difference, of expected inconvenience in the suspension of lifeline services. In this development, they tried to find a key toward the construction of a technically systematized procedure to handle the problem.

METHOD

Scoring Index

Extent of inconvenience was measured in terms of 1) the degree to which daily living at home was restricted and 2) the period for which daily living was restricted (Shiono, 1988; Shiono and Shumuta, 1994).

A formula as follows was defined so as to include the two factors mentioned above:

$$DI=\sum_{i=1}^{5}[c_i\,(DOR)_i\,(TOR)_i] \qquad (1)$$

where,

DI (Difficulty Index): The numerical evaluate that measures the extent of inconvenience posed on a household in the suspension of lifeline services.

DOR (Degree of Restriction): The score that measures the extent of restriction in living activities. A DOR was assigned with a score between 0 (no effect) and 10 (completely restricted).

TOR (Term of Restriction): The period for which living activity is restricted.

i: The suffix that indicates a type of living activity among the five as follows: 1) cooking meals, 2) using the toilet, 3) using a washbasin, 4) taking a bath, and 5) washing clothes. These are ordinarily carried out with a great dependency on utility services and are essential for maintaining daily living at home even in the aftermath of an earthquake.

c: The weighting coefficient that indicates the relative significance of living activity. In this study, a weight of 1.0 was tentatively used for every sort of living activity. Determination of c_i's is among topics for further investigation.

In Fig. 1 is a schematic expression of the Difficulty Index. The bold lines in the figure show how the level of living activity changes with time. The living activity suddenly goes down when utility services are disrupted and, then, goes up by stages with the recovery of services. The area of the shaded part corresponds to a score of the Difficulty Index.

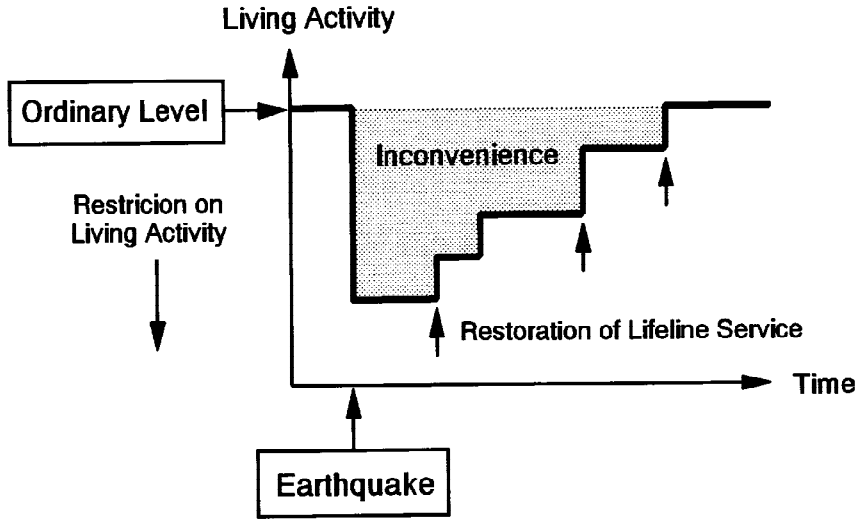

Fig.1. Schematic expression of the Difficulty Index.

Estimation Formula

Terms of Restriction. Expected terms of restriction by activity type were given in Table 1. The equations were first given through analytical examination on the dependency of living activity on utility services and, subsequently, confirmed in a post-event survey of the 1987 Chiba-Ken Toho-Oki earthquake (Shiono and Shumuta, 1994).

The equations shown in Table 1, g's, give the terms of restriction, TOR's in Eq. (1), with the terms of lifeline suspension, E, W, and G, as explanatory variables.

Degree of Restriction (DOR). There are two factors that significantly affect DOR's. Those are: 1) suspension pattern, or the combination of suspended lifelines and 2) the living type of an affected household. The living type, in other words, is the dependency of daily living on lifeline services in ordinary living. Among the two, the lifeline suspension can be regarded as an "external" factor, while the living type can be regarded as an "internal" factor, or the vulnerability.

Living type of a household was classified in terms of the dependency on lifeline services. In the classification, four aspects as follows were examined: 1) possession of a well as an alternative of piped water (possessed or not), 2) type of heat source for cooking (piped gas or other), 3) type of heat source for bathing (piped gas, electricity, or other), 4) type of toilet (flash or dipping-up).

Table 1. Terms of restriction as functions of the period of lifeline suspension

Living Activity	Expected Terms of Restriction (g)
Cooking Meals	
Completely restricted	g=min[E, G]
Partly restricted	g=max[E, W, G]
Using the Toilet	g=W
Using a Washbasin	g=W
Taking a Bath	g=max[W, G]
Washing Clothes	g=W

E: Term of the suspension of power supply
W: Term of the suspension of water supply
G: Term of the suspension of piped-gas supply

Among the 24 possible living types, or the combination of the classification categories, seven types shown in Table 2 are common as present living types in Japan.

Table 2. Major living types

Living Type	Well	Heat Source for Cooking	Heat Source for Bathing	Toilet
1	Possessed	LPG[1)]	LPG[1)]	Flush
2	Possessed	Piped Gas	Piped Gas	Flush
3	Unpossessed	LPG[1)]	LPG[1)]	Dipping-up
4	Unpossessed	LPG[1)]	LPG[1)]	Flush
5	Unpossessed	Piped Gas	Electricity	Flush
6	Unpossessed	Piped Gas	Piped Gas	Dipping-up
7	Unpossessed	Piped Gas	Piped Gas	Flush

[1)] Private storage of Liquefied Propane Gas

Shiono and Shumuta (1994) investigated residents' inconvenience in the 1987 Chiba-Ken Toho-Oki earthquake to determine DOR's. A questionnaire survey was carried out, where DOR's for the five living activities were investigated together with the living type of the responded households. Sets of the DOR's for each living type were derived by suspension pattern. An example of the set of DOR's, which is for washing clothes, for example, is shown in Table 3.

Table 3. A set of DOR's determined for washing clothes

	Suspension Pattern (Combination of Suspended Services)							
Living Type	Power Water Gas	Power Water –	Power – Gas	– Water Gas	Power – –	– Water –	– – Gas	– – –
1	0	1.1	0	0	0	1.1	0	0
2	4.7	0.6	2.7	4.7	0	0.6	2.7	0
3	0	3.4	0	0	0	3.4	0	0
4	0	3.4	0	0	0	3.4	0	0
5	3.4	3.4	0	3.4	0	3.4	0	0
6	5.8	3.6	3.6	5.8	0	3.6	3.6	0
7	5.8	3.6	3.6	5.8	0	3.6	3.6	0

Remark: See Table 2 for "Living Type."

Estimation Formula. A formula as follows was obtained for the estimation of a score of the Difficulty Index for a single household:

$$E(DI)=\sum_{i=1}^{5}[f_i(LT, SP)\, g_i(E, W, G)] \quad (2)$$

where,
E(DI): An estimated score of the Difficulty Index for a household
f: An estimated score of the DOR, which can be found in a table of DOR's, such as seen in Table 3, for given categories of living type (LT) and suspension pattern (SP).
g: An estimated term of restriction, which can be obtained with the equations in Table 2, g's, with input variables of the terms of suspension for power (E), water (W), and gas (G) services.
i: The suffix that indicates a sort of living activity (i=1 to 5).

CASE STUDY

Study Area

A city in the Tokyo metropolitan area was chosen as a case study area for the pre-event assessment of the inconvenience. The city has a geographical area of 56 km^2 and a population of 433,000 in 175,000 households.

The city is divided into 12 administrative districts, which were used as regional units in the assessment. Among the districts, natural, built, and social environment are distinctive to each other, and, accordingly, expected earthquake damage, including lifeline suspension and its effects on residents' living, differs by district.

Living Type

A questionnaire survey was carried out for the classification of households by living type. Five thousand survey forms were mailed, and 2,251 (46.2%) were successfully corrected.

Rates of households by living type in each district were clarified as shown in Table 4.

Table 4. Rates of household by living type (%)

	Living Type							
District	1	2	3	4	5	6	7	Other
1	12.0	3.2	1.9	20.3	5.1	1.3	51.1	5.1
2	11.0	6.6	3.3	23.1	0.0	3.3	45.0	7.7
3	3.9	7.0	7.8	24.2	2.3	3.1	43.1	8.6
4	4.0	4.8	2.4	7.9	4.0	7.1	63.4	6.4
5	0.0	1.0	1.9	1.0	2.9	2.9	83.6	6.7
6	0.7	2.2	0.7	9.6	3.0	0.0	78.7	5.1
7	2.8	5.5	2.8	9.9	3.3	6.1	64.6	5.0
8	0.0	1.2	0.0	12.4	2.9	1.7	78.1	3.7
9	0.6	0.0	0.6	16.3	3.8	1.3	69.3	8.1
10	2.1	0.0	3.5	24.5	1.4	1.4	67.1	0.0
11	0.0	0.0	4.1	8.2	6.8	0.5	76.3	4.1
12	0.2	0.5	1.2	19.0	3.5	0.5	70.9	4.2
Entire City	2.0	1.9	2.1	14.7	3.5	1.9	68.9	5.0

Remark: See Table 2 for "Living Type."

Suspension Pattern – Combination of Suspended Services

Damage assessment on lifeline facility and function, in which conventional methods were employed, was carried out. In Table 5 are the results, which were used as input information, together with the survey results on living type, in the assessment of residents' inconvenience.

Table 5. Lifeline suspension given to the case study area

(a) Affected households

District	Lifelines		
	Power	Water	Gas
1	737 (7.5%)	532 (5.4%)	285 (3.9%)
2	766 (13.4%)	298 (5.2%)	75 (1.8%)
3	1,321 (15.3%)	1,422 (16.5%)	237 (4.6%)
4	677 (8.2%)	743 (9.0%)	125 (1.8%)
5	500 (5.4%)	104 (1.12%)	192 (1.8%)
6	590 (5.9%)	93 (0.9%)	191 (1.8%)
7	938 (6.5%)	450 (3.1%)	517 (3.6%)
8	1,148 (5.6%)	50 (0.2%)	350 (1.8%)
9	1,951 (13.8%)	2,814 (19.9%)	1,098 (8.8%)
10	2,895 (27.3%)	2,711 (25.6%)	1,508 (19.0%)
11	4,953 (27.1%)	14,603 (79.9%)	15,279 (75.5%)
12	8,430 (22.8%)	18,512 (50.1%)	12,181 (36.0%)

(b) Terms of suspension (Days needed for restoration work)

District	Lifelines		
	Power	Water	Gas
1	3	3	1
2	3	1	1
3	4	5	1
4	3	3	1
5	1	1	1
6	1	1	1
7	2	1	1
8	1	1	1
9	5	6	2
10	5	8	3
11	6	17	4
12	6	16	4

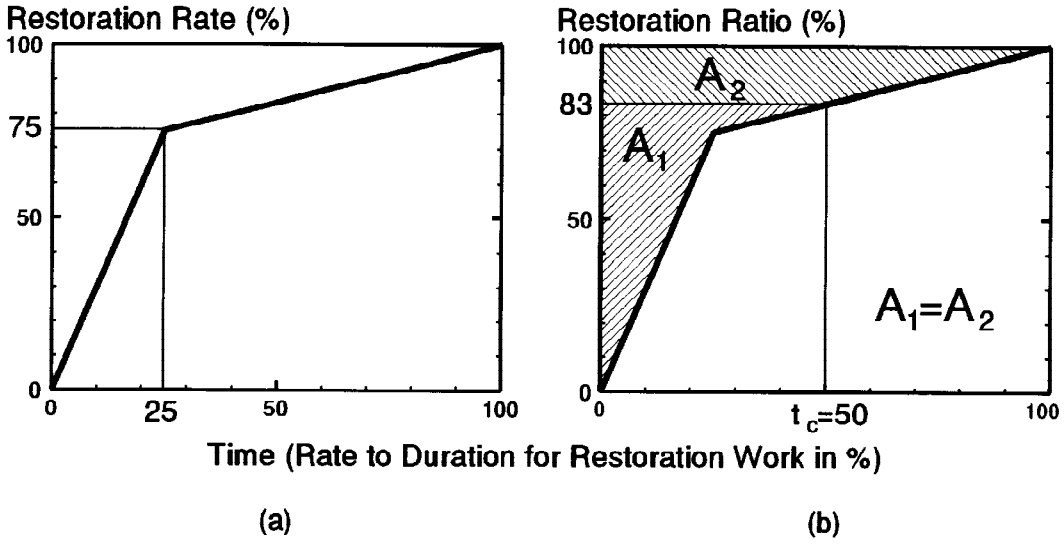

Fig. 2. Representative term of lifeline suspension for an area, t_c.

For the evaluation of a "representative" term of suspension for an area, an assumption for the recovery process (Fig. 2) was employed. The assumption was used with no distinction of the sort of lifelines. For an area, a representative term, t_c, was determined so that the total term for households in which service is restored before t_c is the same with that for households in which service is restored after t_c. The representative period was obtained at a half of the total restoration term. Representative periods for power, water, and gas were employed as E, W, and G required in equation g's in Table 1 as explanatory variables.

Since damage estimation for each lifeline service was done independently, it was necessary to assume spatial distribution of suspended services for the evaluation of the number of households by suspension pattern. A simple assumption as shown in Fig. 3 (a) was employed for this evaluation. More general patterns of the spatial distribution, such as shown in Fig. 3 (b), were not employed in this study, since there was not any appropriate reasons that determine a specific pattern.

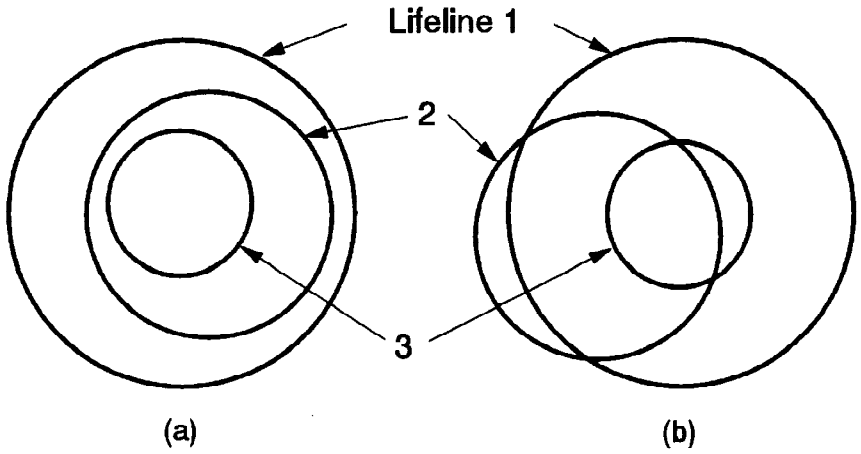

Fig. 3. Distribution of the areas of lifeline suspension.

Table 6. Distribution of households in each district by suspension pattern

	Suspension Pattern (Combination of Suspended Services)							
District	Power Water Gas	Power Water –	Power – Gas	– Water Gas	Power – –	– Water –	– – Gas	– – –
1	234	262	0	0	99	0	0	9,297
2	62	230	0	0	365	0	0	5,063
3	188	649	0	0	0	425	0	7,359
4	261	236	0	0	0	173	0	7,636
5	158	0	7	0	228	0	0	8,932
6	144	0	13	0	270	0	0	9,519
7	347	0	71	0	266	0	0	13,753
8	44	0	243	0	544	0	0	19,541
9	1,063	838	0	0	0	1,019	0	11,223
10	1,262	878	0	0	0	235	0	8,234
11	3,797	0	0	8,756	0	456	0	5,263
12	6,265	0	0	3,730	0	6,468	0	20,503

Classification of households by living type and suspension pattern

On the basis of the data shown in Tables 4 and 6, the number of households classified by both suspension pattern and living type were determined for each district. A few examples of the result are shown in Table 7. Among households having the same suspension pattern, the rates of households by living type were given in proportion with those for the entire households in the district.

Table 7. Distribution of households in a district classified by suspension pattern and living type – a few examples

District 1

Living Type	Suspended Services						
	Power Water Gas	Power Water –	Power – Gas	– Water Gas	Power – –	– Water –	– – Gas
1	34	38	0	0	14	0	0
2	9	10	0	0	4	0	0
3	4	5	0	0	2	0	0
4	49	54	0	0	21	0	0
5	12	14	0	0	5	0	0
6	3	3	0	0	1	0	0
7	122	137	0	0	52	0	0

District 12

Living Type	Suspended Services						
	Power Water Gas	Power Water –	Power – Gas	– Water Gas	Power – –	– Water –	– – Gas
1	13	0	0	7	0	13	0
2	31	0	0	19	0	32	0
3	81	0	0	48	0	84	0
4	1,240	0	0	739	0	1,281	0
5	232	0	0	138	0	239	0
6	31	0	0	19	0	32	0
7	4,636	0	0	2,760	0	4,786	0

Remark: See Table 2 for "Living Type."

Mapping

An estimation formula for an area was given as follows on the basis of that for a single household, Eq. (1):

$$E(DI\text{-}A)=\sum_{k=1}^{q}\sum_{j=1}^{p} n_{jk}\left[\sum_{i=1}^{5} f_{ijk}\, g_i(E, W, G)\right] \quad (3)$$

where,
E(DI–A): A total of estimated Difficulty Indexes for an area
k: Suspension pattern (k_{max}=q=7; See Table 3)
j: Living type (j_{max}=p=7; See Table 2)
i: Type of living activity (i_{max}=5)
n_{jk}: Number of households with the j–th living type and the k–th suspension pattern
f_{ijk}: DOR for the i–th activity in a household with the j–th living type and the k–th suspension pattern
g_i: Expected term of restriction for the i–th living activity (See Table 1)
E, W, and G: Representative terms of suspension for an area for power, water, and gas, respectively.

Total scores of the Difficulty Index were calculated by district, and their logarithms were depicted in Fig. 4 (a), while averages, or total scores normalized by the number of households, were shown in Fig. 4 (b). Fig. 4 (a) is a map that shows the "size" of inconvenience by district, while Fig.4 (b) is a map that shows the "level."

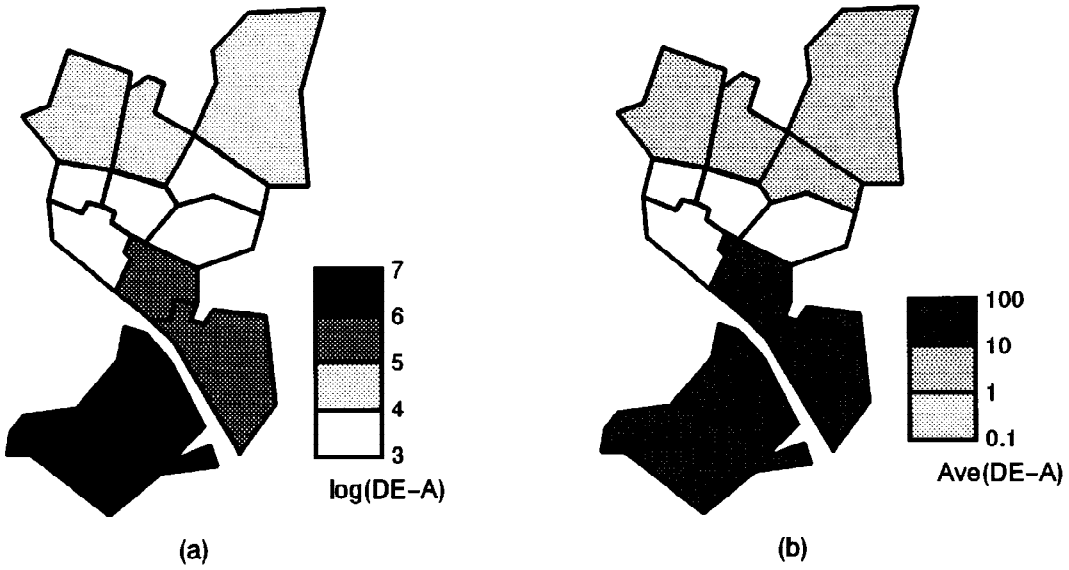

Figure 4. Map showing the district-to-district estimation of residents' inconvenience in the suspension of lifeline services.

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