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Evaluating the Impact of Demographic Transition in the Context of the Tokai-Tonankai-Nankai Earthquake, Japan

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ABSTRACT

This study intends to adopt a geographical approach to building a region-type index associated with recovery, which aims to examine the impact of ongoing demographic transition in the context of the expected the Tokai-Tonankai-Nankai Earthquake. A great amount of population census data is applied in building the index that comprises 3 demographic transition patterns that represent the various degrees of regional self-sufficiency in a disaster. Applying the index to the population census data of 2005, with the anticipated seismicity in 4 appointed scenarios via GIS mapping, a place assessment is presented to examine the impact of a possible population demographic transition order issued in pre-disaster recovery planning.

Keyword: population decline, aging, self-sufficiency, Tokai-Tonankai-Nankai Earthquake, pre-disaster management

I. Background

1. Next catastrophe in a population decline period

The Tokai-Tonankai-Nankai Earthquake is regarded as a potential catastrophe in the first half of the century (see fig. 1). According to the estimation result,[1] the cumulative occurrence possibility for the coming 30 years reaches 60-70%, especially during the 2030s. The divergent core areas of the 3 metropolitan areas and their surrounding wide rural areas will be exposed to the disaster at the same time.[2]

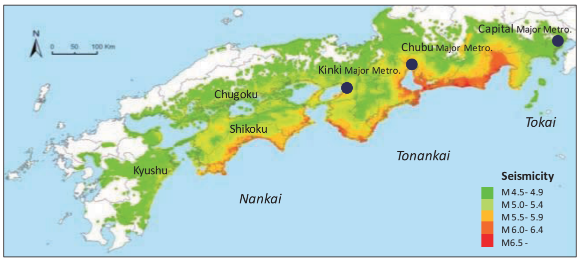


Figure 1. Anticipated seismicity of the Tokai-Tonankai-Nankai Earthquake[1]

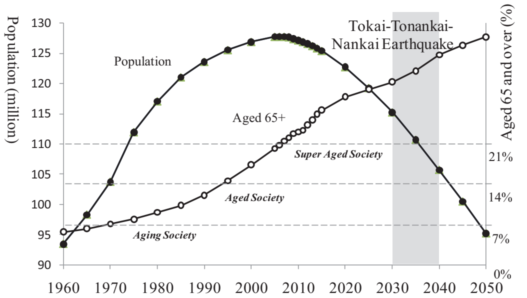


Figure 2. Transition and estimation of population in Japan (1960-2050), illustrated from IPPS.[3] Data since 2009 are estimated.

General population growth in Japan turned to minus in 2005, heralding the coming of the population decline period (see fig. 2). The National Institute of Population and Social Security Research (IPPS) estimates that the population in 2030 might remain at 90% of the current population and the elderly population of 65+ might go beyond 30%.[3] This reveals an age structure different from the current situation.

Yet Maki el al. [4] argued that no attempt has been made to examine population exposure in pre-disaster planning in the context of demographic transition. Seismicity simulation[5] is not sufficiently complete to reduce vulnerability of the population in advance. A general consideration of regional social characteristics is also suggested in disaster management.[6]

2. Demographic aspect in vulnerability assessment

To better connect hazards and the characteristics of the affected regions, Cutter suggests a spatial analysis to assess vulnerable places.[7] This implies the necessity of a geographic approach to integrating more regional information such as demographic factors.

Generally, population density, population growth rate, and aging rate are critical demographic factors in vulnerability assessment[8], [9], [10] especially while examining population exposure considering seismic intensity and amount of exposure [11]. Population exposure is based on physical calculation of numbers of casualties rather than recovery considerations. It may be appropriate to evaluate densely populated areas or population growth areas. Yet the calculation might lead to an opposite conclusion of a safer environment when it comes to a population decline period, e.g., as shown in isolated villages in the Niigata Chuetsu Earthquake 2004. Another issue is general population aging that might make the analysis result less discriminative. Thus, it is difficult to examine the impact of demographic transition in an ordinary vulnerability assessment.

The lessons learned show that sufficient numbers of participants of working age, amply serviced in employment, education, etc, are critical for independent and constant regional recovery.[12], [13], [14] This implies that, rather than the previously mentioned factors, demographic characteristics can represent place self-sufficiency that determines the continuity of an affected region in disaster recovery. Most of all, demographic characteristics provide a way of integrating disaster recovery with the ongoing demographic transition of this aging developed country.

In this research, instead of a numerical indicator such as population growth rate, aging rate, etc, a classification of demographic transition patterns in a token self-sufficiency index is built to visualize the impact of future demographic transition. Moreover, the self-sufficiency index and seismic intensity scale of the entire exposed areas in Japan are examined with the aim of providing essential information for pre-disaster recovery planning for the Tokai-Tonankai-Nankai Earthquake.

II. Methods

There have been studies that aim to classify region types concerning the population structure, e.g., [15], but none of them discusses the demographic transition of the concluded types. Therefore, these types are unable to represent a clear description of regional demographic transition. Also, a method of applying the classification standard to every time period is unavailable. This is because the classification is developed by the correlative difference in the collected samples from the census data. Another year's census data might lead to a completely different classification. Applying classification to different time periods of data leads to inexplicable results. To cope with this problem, we provide an approach to integrating several demographic classification results.

This study has 3 parts. We apply cluster analysis to the population statistics data of several time periods to acquire a regional classification for each period.

Then, discrimination analysis to integrate the series of regional classifications is undertaken, and to develop demographic transition patterns, a self-sufficiency index is developed. With mapping using the seismic intensity data of the Tokai-Tonankai-Nankai Earthquake, analysis is conducted using GIS to discuss the impact of demographic transition. The details of each part are given as follows.

1. Conducting regional classification

It is noted that detailed aging population proportion can provide more complete family structure information in the regions. [16] Cluster analysis is applied to a great amount of 1-km^2 mesh-based population data to acquire a regional classification.

Eighteen levels of 5-year population proportions (aged 0~4 to 80~84 and aged 85+) and the variables of each mesh are collected from the population census data. Repeating the same application to various population census time periods, a regional classification at every particular time period is obtained.

2. Developing demographic transition patterns

Discrimination analysis is conducted to adjust several sets of regional classifications and to integrate the adjusted sets into a demographic transition pattern. With the dendrogram graph of cluster analysis results, we can render clustered meshes in GIS. Based on the spatial distribution of regional classification, we can conclude which common regional types consistently exist. The meshes that remain stably classified at every time period are collected as “sample meshes” and are used as samples for discrimination analysis.

For one regional type, the meshes are ruled in mesh code and equally divided into the “experimental group” and the “control group.” The experimental group is made to be the discriminant. And the control group is used to test the reliability of the discriminant using a true positive rate test. And the discriminant with the best performance is applied to the study area to adjust the regional classification. Furthermore, transformation of the demographic transition patterns is discussed regarding self-sufficiency by a reference study.

Four methods of discrimination are applied here. The details and results of each are described in Chapter 3.

3. Application to place evaluation

The regional exposure characteristics and regional self-sufficiency are integrated in GIS in order to conduct spatial analysis in the affected area of the Tokai-Tonankai-Nankai Earthquake.

Regional exposure characteristics are determined by the exposure scenario numbers and the maximum seismicity intensity among these appointed scenarios. And regional self-sufficiency is based on the previous section. Discrimination analysis is applied in the latest Population Census 2005 to obtain the current situation. To reach a more accurate assessment, the above analysis is conducted on a 1-km^2 scale.

III. Building a classification of demographic transition patterns

Study area

Osaka Prefecture and Wakayama Prefecture are selected as study areas due to the variety of regional development, from the center of Osaka City to the mid-mountainous area of the Kii Peninsula. As the most aging metropolitan area, Osaka’s population increase has been slowing down since 1990. Meanwhile, population decline started to accelerate in Wakayama, one of the worst prefectures in 2005. Thus, the study area is representative of a near-future demographic transition. Another reason is that the study area is exposed to both the Nankai Earthquake and the Tokai-Tonankai Earthquake (see fig. 3).

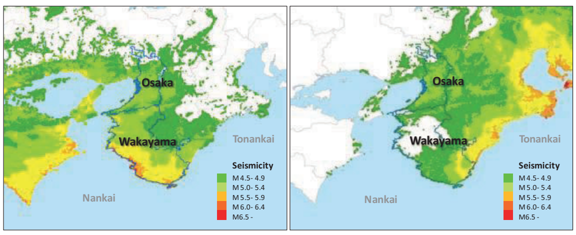


Figure 3. Osaka and Wakayama, both exposed in the scenario of the Nankai Earthquake (L) and the Tokai-Tonakai Earthquake (R)

TABLE I. COLLECTED MESH NUMBERS

Census	1990	1995	2000	2005
Collected Meshes*	3,521	3,450	3,495	3,862
Selected Meshes (N)	3,117	3,280	3,118	3,031

* For privacy protection, a few low-inhabited meshes are only collected in total numbers. As for the gendered 5-year aged populations, these meshes are combined into others.

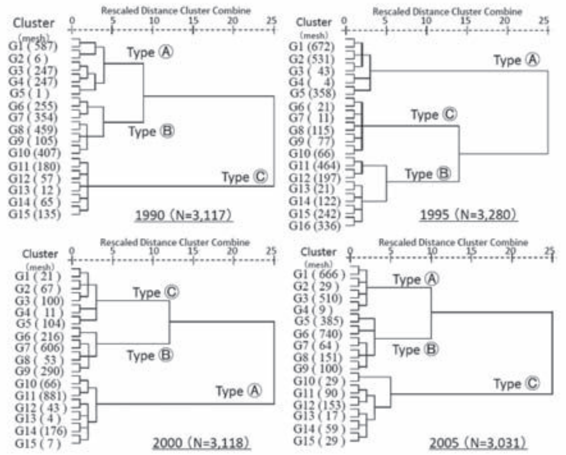


Figure 4. Cluster analysis result (1990, 1995, 2000, and 2005)

Regional classification

Following the previous demographic transition of Osaka and Wakayama Prefectures, the mesh-based Population Censuses of 1990, 1995, 2000, and 2005 are collected (see table 1). For each period of population census data, cluster analysis using Ward's method is applied to mesh 5-year population proportions. Based on the 4 dendrogram graphs (see fig. 4), 3 common regional types, A, B, and C, are found (see fig. 5).

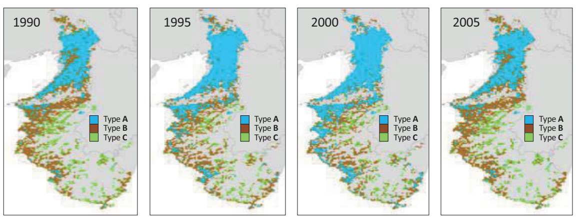


Figure 5. Distribution of region-type meshes from the cluster analysis result

Demographic transition patterns

As 2.2 described, cluster analysis is based on a relative difference among classified samples. In this way, while analyzing the difference among 4 maps in fig. 5, it is difficult to identify the difference resulting from the cluster analysis or the actual transition of the meshes. To deal with the first reason, "sample meshes" with the same classified result from 1990 to 2005 in fig. 5 are collected (N=1,223).

For each regional type, all of the selected meshes are individually separated by a ruled mesh code into the experimental group (N=612) and the control group (N=611). In this study, the following 4 methods, linear discrimination, multi-logistic regression, the nearest neighborhood method, and the weighted nearest neighborhood method, are applied to the experimental groups to develop an effective discriminant.

Linear discrimination: Eighteen classes of 5-year population proportions $P_m = \{P_1, P_2 \ldots P_{18}\}$ and regional type $Q = \{A, B, C\}$ of meshes are collected to build 3 sets of linear discrimination coefficients $X_{Qm} = \{X_{Q1}, X_{Q2} \ldots X_{Q18}\}$ and constant S_Q of function F_Q (see eq. 1). The highest score of F_Q determines Q of the discriminated mesh.

$$F_Q(P_1, P_2, \ldots P_{18}) = \sum_{m=1}^{18} P_m \qquad \text{(Eq. 1)}$$

Multi-logistic regression: While regional type A is a reference category, $P_m = \{P_1, P_2 \ldots P_{18}\}$ and regional type Q of meshes are applied for building 2 sets of coefficients $Y_{Qm} = \{Y_{Q1}, Y_{Q2} \ldots Y_{Q18}\}$ and constant T_Q of nonlinear function R_Q (see eq. 2). R_Q shows the probability, while regional type Q is discriminated as B or C. And eq. 3 shows the probability if regional type Q is discriminated as A, the appointed type at first. The highest R_Q leads to the result.

$$R_Q = \frac{exp\left(\sum_{m=1}^{18} P_m Y_{Qm} + T_Q\right)}{1 + exp\left(\sum_{m=1}^{18} P_m Y_{Bm} + T_B\right) + exp\left(\sum_{m=1}^{18} P_m Y_{Cm} + T_C\right)} \qquad \text{(Eq. 2)}$$

$$R_Q = \frac{1}{1 + exp\left(\sum_{m=1}^{18} P_m Y_{Bm} + T_B\right) + exp\left(\sum_{m=1}^{18} P_m Y_{Cm} + T_C\right)} \qquad \text{(Eq. 3)}$$

Nearest neighborhood method: In the experimental group, the gendered 18 classes of 5-year mesh population proportions $P_n = \{P_1, P_2 \ldots P_{36}\}$ are collected by type Q to calculate the average $P_{Qn} = \{P_{Q1}, P_{Q2} \ldots P_{Q36}\}$. Collective distance D_Q represents the similarity between the population pyramid of regional type Q and the pyramid of the discriminated mesh (see eq. 4). The smallest D_Q determines the result.

$$D_Q = \sum_{n=1}^{36} \sqrt[2]{\left(P_{Qn} - P_n\right)^2} \qquad \text{(Eq. 4)}$$

Weighted nearest neighborhood method: M_n is mid-age number of P_n. It aims to give different weights while discriminating places with large numbers of juveniles or elderly people. Equation 5 shows the calculation of weighted distance D'_q.

$$D'_q = \sum_{n=1}^{36} \sqrt[2]{M_n^2\left(P_{Qn} - P_n\right)^2} \quad \text{(Eq. 5)}$$

For one time period, we can obtain one discriminant using every method. Thus, 4 discriminants are applied to the meshes of the control group. Comparing the original classified result with the discriminated result, we can measure the true positive rate (TP rate) of each discriminant using these 4 methods.

Table 2 shows the TP rate of the 4 discrimination methods in 4 time periods. Linear discrimination and the nearest neighborhood method perform the best. Yet no linear relationship is found in $X_{Qm}= \{X_{Q1}, X_{Q2}\ldots X_{Q18}\}$ among the 4 periods. In this case, it is difficult to characterize the patterns from the discriminants. Also, when it comes to estimation, there is insufficient information to predict new sets of variables X_{Qm}.

In multiple logistic regressions, 18 explanatory variables P_m cannot be imported at once. To render the function ultimate, certain variables are selected. Thus, the combination is different between any 2 time periods, which is difficult to explain demographically.

TABLE II. FOUR METHODS OF DISCRIMINATION AND THEIR TP RATE APPLIED TO THE CONTROL GROUP IN 4 PERIODS

Method	Variables	Discrimination	Year	TP Rate	Note
Linear Discrimination (F_Q)	Dependent: $Q= \{A, B, C\}$ Explanatory: $P_m= \{P_1, P_2\ldots P_{18}\}$	The discriminant function result determines the classification result.	1990 1995 2000 2005	99.0% 99.5% 99.0% 96.7%	A sample mesh must be used for estimation.
Multiple Logistic Regression (R_Q)		The regression function result is the classification probability between any 2 types.	1990 1995 2000 2005	*92.1% *95.3% *95.2% *93.9%	Certain variables can be selectively integrated for optimizing the TP rate.
Nearest Neighborhood (D_Q)	$P_{Qn}=\{P_{Q1}, P_{Q2}\ldots P_{Q36}\}$ $Q= \{A, B, C\}$	There is similarity to each type of population pyramid, by the calculated distance.	1990 1995 2000 2005	99.5% 99.7% 99.0% 96.7%	The pyramid can be connected with cohort analysis for estimation.
Weighted Nearest Neighborhood (D'_Q)	$P_{Qn}=\{P_{Q1}, P_{Q2}\ldots P_{Q36}\}$ $M_{Qn}=\{M_{Q1}, M_{Q2}\ldots M_{Q36}\}$ $Q= \{A, B, C\}$	Based on the above, distance is defined as distance in N and the number of N.	1990 1995 2000 2005	99.3% 98.9% 97.9% 96.9%	The TP rate is lower than in the NN method.

* The functions of multi-logistic regression analysis in 4 time periods are all built with 2 different variables among 18.

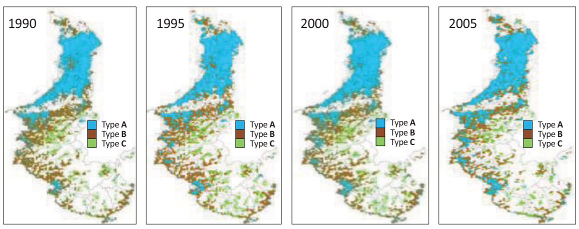


Figure 6. Distribution of region-type meshes after adjustment

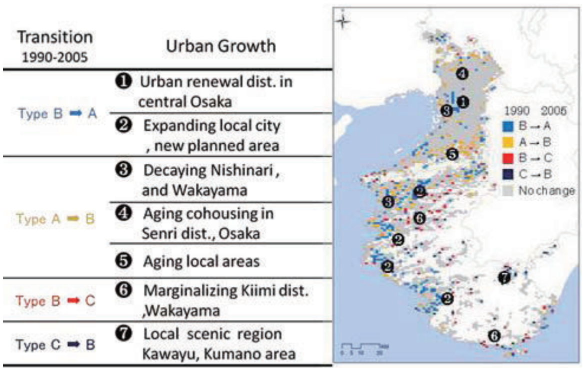


Figure 7. Comparison of adjusted results of 1990 and 2005: It is found that that the identified meshes listed below correspond to actual regional development during the period.

Despite 2005, the nearest neighborhood method constantly has a TP rate of over 99%, almost the same as linear discrimination. Because the discriminant itself is the population pyramid of one regional type, connecting to the idea of cohort analysis while examining the demographic transition from 4 pyramids (1990-2005) is clearly desirable.

Yet the weighted distance is not found to improve the TP rate of the nearest neighborhood method in general. We believe that the weighted distance might increase the difficulty in discriminating the less aging areas.

Above all, the pyramids of each regional type are applied to the whole meshes of Osaka and Wakayama Prefecture to adjust the original cluster result (see fig. 5) using the nearest neighborhood method. Figure 6 shows the adjusted distribution of the 3 regional types in 4 periods.

Examining the adjusted result

While the rescheduled distance of 4 cluster analysis is generated, another factor associated with the difference between the 4 time periods (fig. 6) is the transition of the study area itself. In this way, the actual urban development of Osaka and Wakayama is given in order to examine whether the regional type in the 4 periods can be regarded as one demographic transition.

Comparing the adjusted result in 1990 with the result of 2005 in fig. 6, we can collect meshes with different regional types (see fig. 7). Remarkably, it is found that the distribution of these meshes can correspond to certain events in urban development (see legend in fig. 7).

Those transformed from regional type B to A are inclined to experience urban renewal (central Osaka) or expanding local cities (Arida). By contrast, meshes from type A to B cover the first large-scale cohousing (Senri New Town) in Japan, decaying areas, urban areas (Nishinari district) and certain aging local areas. And the distribution of meshes from type B to C is also found to correspond to the marginalization of Wakayama's mountainous areas such as the Kiimi district.

Ultimately, it is proved that the 3 concluded demographic transition patterns can clearly correspond to one specific demographic transition. And these patterns constantly exist. With the nearest neighborhood method, the discrimination can effectively identify transformation at the local scale.

IV. examining self-sufficiency in demographic transition patterns

Based on Chapter 3, the pyramids of 3 regional types are collected to analyze the characteristics of the main demographic transition patterns. Referring to studies related to disaster recovery, demographic transition patterns are analyzed to discuss the self-sufficiency that they represent.

Pyramids of 1990, 1995, 2000, and 2005 are shown in table 3. Following the idea of cohort analysis, 5-year aged population P_m in one pyramid and 5-year older aged population P_{m+1} in the pyramid 5 years later are considered to be the same cohort. Also, the red line in table 3 marks the most aging cohort of the current population in 2030.

1. Pattern A—Sustainable pattern

Baby boomers (those born in 1947-1949) and baby boom juniors (those born in 1971-1974) lead the transition in the pyramid of pattern A. Accompanying the aging of these generations, there is no apparent decrease in the population of those 20-35 years old. It implies that, although the fertility decline since 1980 has contributed to a general decrease in the young population, the young working population has still constantly emigrated. As life step theory[17] notes, sufficient employment and higher education are connected to the emigration of the young labor population. Additionally, the fertility of the next generation can be secured. That is, the young labor population and new birth rate are stable enough to support the population structure.

As the white papers [13] and [14] note, with the two critical factors of well-equipped facilities and sufficient human resources, pattern A presents the places likely to be sustainable in recovery.

2. Pattern B—Dependent pattern

In pattern B, it is found that a more juvenile population occupies the base of the pyramid in the 1990s. However, the abundant number of juveniles does not contribute to the growth of the young working-age population in the next pyramid. This represents constant and severe emigration of the young labor population. Eventually, the decrease in the population of those aged 20-35 has contributed to an apparent decrease in new births (bottom of the pyramid) since 2000.

Accompanying population aging and the decrease in the juvenile population, population aging is expected to accelerate gradually. Insufficient advanced service and a lower proportion of the working-age population reveal less capability of the 2 noted factors in disaster recovery.[13], [14] In contrast to the sustainable pattern, pattern B shows a dependent characteristic.

3. Pattern C—Marginal pattern

In pattern C, an extremely aging and unstable pyramid is shown in table 3. The collective amount in every pyramid is 100%. In this case, while a great amount of the most senior cohorts gradually disappears, the rest of the cohorts, the middle part of the pyramid, should become wider in the next pyramid. In contrast, no increase in the proportion of juveniles and working-age population is found. It clearly represents a social decrease in population in the non-aging population. Following cohort analysis, a more unstable pyramid with a wider top and a narrower bottom is formed.

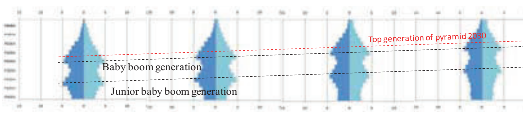
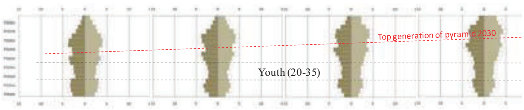
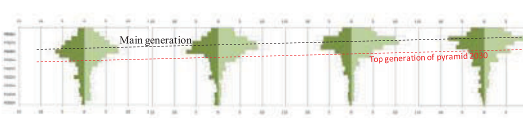
Compared with the dependent pattern, a low proportion of working people with social decrease shows that not only advanced services but also basic services for living might hardly be provided. The pattern refers to regions that have less capability to support themselves and that are more likely to become isolated in a disaster.[12] Also, it implies that limited human resources are available for recovery. Accompanying the demographic transition, a more unstable population pyramid is expected. Based on the severe population decline and decaying services, this marginal demographic transition represents places where energy might be insufficient to continue their recovery.

Above all, the characteristics of the 3 demographic transition patterns are observed in the context of disaster recovery. Based on the self-sufficiency that each pattern represents, this index is provided to analyze the demographic transition of exposed areas.

Application to the exposed areas of TTNN Eq.

Applying the 2005 pyramid of demographic transition patterns to the mesh-based Population Census 2005, discrimination analysis using the nearest neighborhood method is conducted in 151,558 meshes of the whole of Japan. Figure 8 shows the result of TTNN Earthquake-affected areas (over M4.5).

TABLE III. Characteristics of Demographic Transition patterns associated with self-sufficiency

Patterns	1990	1995	2000	2005	Characteristics of Self-sufficiency
Sustainable Pattern					• Young working population and fertility of the next generation are secured. • There are well-equipped facilities and sufficient human resources for recovery.
Dependent Pattern					• Ongoing population aging and emigration of the young working are expected. • Unsatisfactory advanced services and fewer human resources weaken region capability.
Marginal Pattern					• More unstable pyramid • Basic services might hardly be maintained and sufficiency in recovery is unlikely. • Human resources and service from outside are required.

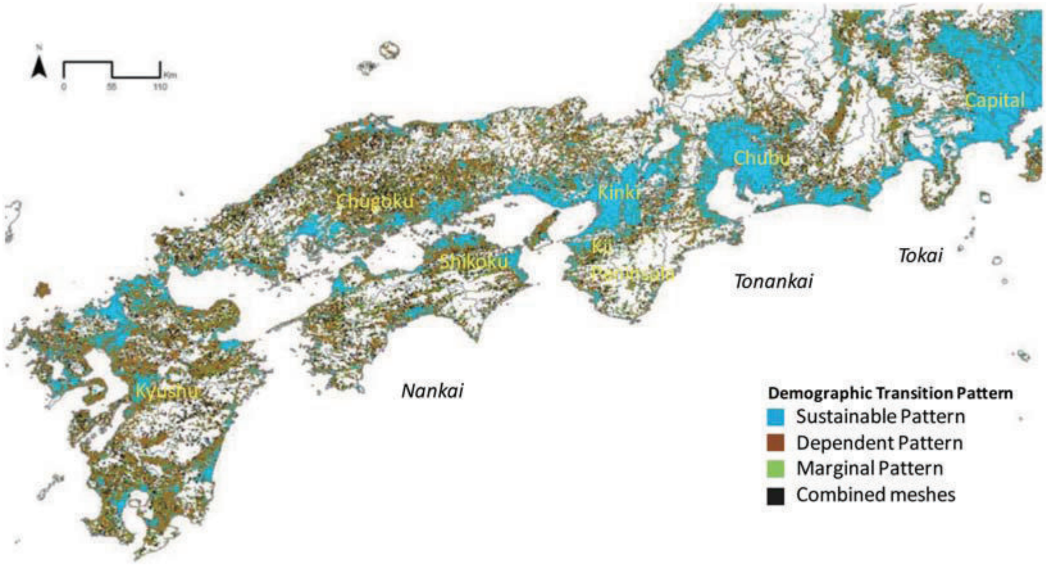


Figure 8. Distribution of the sustainable pattern (blue), dependent pattern (brown), and marginal pattern (green): The combined meshes (black) are the extremely lowly populated areas where the 5-year aged population from the census data is unvailable. According to the population census of 2005, metropolitan cities are marked in red. Also, the captical cities of the prefecture are marked in orange.

It is found that the sustainable-patterned meshes (blue) comprise wide areas in 3 major metropolitan cities in the Kinki, Chubu, and capital regions. And the metropolitan cities (e.g., Fukuoka, Kita Kyushu, Hiroshima, Okayama, Hamamatsu, and Shizuoka) are also covered by sustainable-patterned meshes. Meanwhile, besides the areas surrounding themajor metropolitan cities, a great amount of dependent-patterned meshes (brown) cover vast areas in the Chugoku region, Shikoku region, and Shikoku region, even most of the area of the prefectural capital cities (e.g., Miyazaki, Oita, and Kochi). And the marginal-patterned (green) and combined meshes (black) share a similarity of distribution. Most of these meshes apply to part of the coastline and mountainous areas in the Kii Peninsula, Shikoku region, Chugoku region, and Kyushu region.

V. Place evaluation

Scenario settings

The Tokai-Tonankai-Nankai Earthquake (see table 4; fig. 9) includes several scenarios as stated by the Central Disaster Prevention Council.[2] Additionally, a month's time delay between the Tokai-Tonankai Earthquake and the Nankai Earthquake is likely to occur and result in severe damage.[18] Considering the areas affected by the Nankai (N), Tokai-Tonankai (TTN), and Tokai-Tonankai-Nankai Earthquake (TTNN), and days of delay (Delay), 4 scenarios are examined in this paper.

TABLE IV. Setting the scenario of the TTNN Earthquake

Scenario	N	TN	TTN	TTNN	Delay
Mechanism	Individual	Individual	Linkage	Linkage	Linkage
Magnitude	M8.4	M8.1	M8.4	M8.5	M8.4;M8.4
Possibility[1)]	50%	60-70%	No Data	No Data	No Data
Exposure[2)]	50,413	36,970	48,171	89,315	84,536
Sea Area	N	TN	T+TN	T+TN+N	T+TN;N

1) Probability in the coming 30 yrs (Headquarters for Earthquake Research Promotion, 2009)
2) Exposure: Areas (km^2) exposed above M4.5

Regional seismicity exposure

To analyze the characteristics of regional exposure, it is essential to consider the intensity as well as the probability of each scenario at the same time. The meshes are collected using the rule of maximum intensity (intensity scale) and exposure scenarios (scenario numbers). Note that the number of exposure scenarios here is not representative of the times of occurrence but of the concept of potential.

The TTNN Earthquake will affect the entire plate of the Nankai Trough. Yet some of the affected areas are exposed to stronger seismicity than individually in the N or TTN Earthquake.[19] In this case, it is necessary to take another count of TTNN, apart from the N and TTN Earthquakes. As for the scenario of "Delay," the N and the TTN Earthquake are 2 individual events; thus, the calculation is the same as a double count of the 2 scenarios. Therefore, whichever place is exposed to the 3 scenarios, it is certain that the meshes are also exposed in the "Delay" scenario.

Figure 9 shows that 2,347 1-km^2 meshes among the inhabited areas are exposed to all scenarios with a maximum intensity above M5.5~. The meshes mostly cover the Kii Peninsula, Awaji Island, and part of Osaka Prefecture. A total of 4,177 meshes are also exposed to all scenarios with a maximum intensity of M4.5~5.4. Considering the impact of the "Delay" scenario, Osaka City, the core area of the Kinki region, is exposed to twice the impact.

It is also remarkable that 11,893 meshes are exposed to 2 scenarios with a maximum intensity above M5.5. Despite the TTNN Earthquake, these areas are exposed to either the strong seismicity of the N Earthquake, e.g., the southern coastline of the Shikoku region, or the TTN Earthquake, e.g., Nagoya, Hamamatsu, Shizuoka, and other coastal cities of the Chubu region.

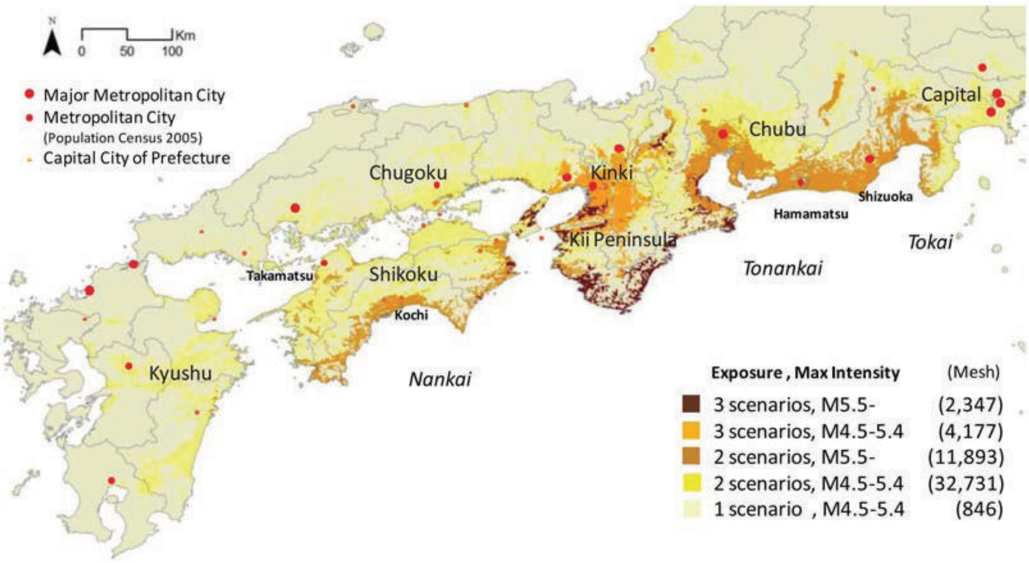


Figure 9. Overlapping seismicity intensity of TTNN Eq., TTN Eq., and N Eq., rendering the distribution of the inhabited meshes: Considering seismicity exposure, these meshes are classified separately in exposed scenario numbers and maximum intensity scale. Intensively multi-exposed meshes are marked in a strong color. Rather than a probability map, the figure integrates the information of several scenarios and presents the regional characteristics in exposure.

TABLE V. INTEGRATIVE PLACE EVLUATION

Exposure (Scenario Numbers)	Demographic (Maximum Seismicity[2])	Demographic Transition (mesh number, population)[1]: Sustainable Pattern	Independent Pattern	Marginal Pattern	Combined Mesh	Total	Main Distribution
3 Time Delay	M5.5~	728 (1,733)	1,091 (625)	215 (19)	313	2,347 (2,377)	Kii Peninsula, Awaji Island, part of Osaka Pref.
3 Time Delay	M4.5~5.4	2,597 (13,693)	1,092 (974)	168 (20)	320	4,177 (14,686)	Core area of the Kinki region
2	M5.5~	5,412 (10,116)	4,517 (2,284)	549 (62)	1,415	11,893 (12,462)	Southern Shikoku region, coastal area of the Chubu region
2	M4.5~5.4	10,350 (21,960)	14,934 (6,088)	2,580 (240)	4,867	32,731 (28,287)	Coast of Kyushu and Chugoku, northern Shikoku, inner land of Chubu, partial capital region
1	M4.5~5.4	243 (251)	426 (133)	44 (6)	133	846 (390)	
Population Density[3]		*2,470*	*458*	*79*	*9*	*1,119*	

1) Population: 1,000 persons

2) Seismicity: M4.5~5.4 refers to scale 5 (Japan Meteorological Agency, JMA); M 5.5~ refers to scale 6 and 7 (JMA).

3) Population Density: persons/ 1-km^{2}mesh

Also, there are 32,781 meshes exposed to 2 scenarios with a maximum intensity of M4.5~5.4. And 846 meshes are only exposed to the TTNN Earthquake with an intensity of M4.5~5.4. These wide areas are spread along the coastline of the Kyushu region and the Chugoku region, the northern Shikoku region, inner land of the Chubu region, and part of the capital region.

Integrative place evaluation

To integrate the above 5 regional exposure characteristics with the 3 demographic transition patterns associated with self-sufficiency, fig. 8 and fig. 9 are mapped in order to conduct a place assessment. Instead of a complicated legend, we collect mesh numbers classified into patterns (sustainable, independent, and marginal; uninhabited and combined meshes) as well as the exposure characteristics (scenario numbers with maximum intensity) in table 5.

It is found that more than 500 km^2 (around 19,000 inhabitants) spread over the Kii Peninsula are exposed to a severe intensity of every scenario, but are constructed by the marginal-patterned and combined meshes. Based on their demographic characteristics and the exposure, these meshes are considered to be the most vulnerable regions. More human resource and service support from outside is necessary in disaster recovery.

In the Chubu region, the vast industrial district along the coast is mostly classified as having a sustainable pattern. Yet these areas are also exposed to strong intensity in the TTN and TTNN Earthquake. Although sufficient social services and a large working-age population are highly cumulative and beneficial to recovery, devastating damage is also expected. In this sense, a damage evaluation is suggested.

Southern Shikoku shares similar characteristics of seismicity exposure to the Chubu region. But few sustainable-patterned meshes are found in this region. Apart from Kochi City, dependent- and marginal-patterned meshes occupy the long coastal areas and the mountainous inner land. Exposed to the strong intensity of the N and TTNN Earthquakes, it is believed that, as an issue affecting the Kii Peninsula, wide-area management is necessary in disaster recovery.

In the Kinki region, the core areas and suburban areas are both exposed to all scenarios with seismicity of M4.5~5.4. Also, large sustainable-patterned meshes are found in this area. Generally speaking, severe direct damage of casualties or physical damage to buildings is rarely of concern. Yet, as the secondary major metropolitan area, indirect damage is expected when the TTN and the N Earthquake occur individually with a time delay. Thus, business continuity planning (BCP) is very important in relieving the impact and adjusting effectively in recovery.

Unlike the capital region, the coastal areas of Kyushu and Chugoku, Northern Shikoku, and the inner land of Chubu Region are mostly covered by sustainable- and dependent-patterned meshes. Vast areas are exposed to either the N or the TTN Earthquake with seismicity of M4.5~5.4. Excluding certain sustainable-patterned meshes in prefectural cities, many local areas (around 15,000 km^2, 30% of the affected areas) are covered by independent transition-patterned meshes. This represents the necessity of reinforcing the capability of local government.

VI. Conclusion

In this study, we aimed to build a self-sufficiency index based on demographic transition patterns in order to examine the impact of demographic transition in the context of the Tokai-Tonankai-Nankai Earthquake, in contrast to previous concerns regarding exposed populations.

This study observed the past 15 years of demographic transition and analyzed a great amount of mesh-based population census data of 1990-2005 to develop 3 demographic transition patterns based on cluster analysis and a series of discrimination analyses. And the transition of each pattern reveals the capability of social services and human resources concerning the self-sufficiency. Applying the patterns developed to entire affected areas, an integrative place evaluation with scenario setting is presented to reinforce disaster management in the Tokai-Tonankai-Nankai Earthquake. The findings are as follows.

1) Sustainable pattern: This was constructed by the baby boom and baby boom junior generation. A constant young working population and stable fertility of the next generation result in well-equipped social services and sufficient human resources that are beneficial to disaster recovery.
2) Dependent pattern: Ongoing population aging and the emigration of young working people are

expected to accelerate. Unsatisfactory advanced services and fewer human resources will likely weaken region capability.

3) Marginal pattern: Severe natural and social decrease in population result in a highly aging population pyramid. In contrast to the dependent pattern, even basic services are barely maintained. More support from outside is required.
4) Kii Peninsula: The fewer human resources and poor social services are unable to cope with disaster recovery in the severely and most multi-exposed district.
5) Chubu region: Vast sustainable-patterned areas imply stably working immigrants in recovery. Yet the devastating damage from the TTN and TTNN Earthquake reveals the necessity of damage evaluation.
6) Southern Shikoku region: Under the strong intensity of the N and the TTNN Earthquake, outside the only prefectural capital city, the distribution of vast dependent - and marginal-patterned meshes stresses the importance of wide-area management.
7) Kinki region: This area is exposed to all scenarios but with a seismicity scale under M5.5. Severe physical damage and casualties are not expected, yet BCP is suggested to relieve the impact while in the time-delay scenario and for effective adjustment.
8) Coastal areas of the Kyushu region and Chugoku region, northern Shikoku region, and inner land of the Chubu region: These areas are exposed to either the N or the TTN Earthquake with seismicity of M4.5~5.4. However, vast independent transition-patterned meshes imply the necessity of reinforcing the capability of local government.

Additional work could usefully infer these findings for further comprehensive place evaluation with other information required such as infrastructure.

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