Doctoral Thesis

Study on Statistical Analysis of Post-Earthquake Road Use Recovery Characteristics and Its Application

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Abstract

The Tohoku Earthquake of March 11, 2011, and the consequent tsunami caused severe damage throughout the northeastern coast of Japan. The transport network in the Tohoku region was severely damaged by this disaster. A huge earthquake and tsunami are predicted to occur in the Nankai Trough in the future. Furthermore, the three prefectures (Fukushima, Miyagi, and Iwate prefectures) on the Pacific side of the Tohoku region, are relatively similar to the three prefectures (Shizuoka, Aichi, and Mie prefectures) in the Tokai region in terms of the topographical environment. I think that the recovery of regional roads in the three prefectures affected by the Tohoku Earthquake can be studied to help promote the rapid recovery of the three prefectures in the Tokai region after the Nankai Trough earthquake that will almost certainly occur in the future.

Concerning post-earthquake road recovery research, many research reports on the recovery of motorways and general national roads after the 2011 Tohoku Earthquake are available. However, few studies have examined the road recovery of prefectural and municipal roads that play an important role in the daily lives of residents.

In previous related studies, the G-BOOK telematics data of the Toyota Motor Corporation were used to survey road recovery after the Tohoku earthquake. The affected prefectures in the Tohoku region were divided into several large areas, and the authors concluded that road restoration varied between these areas. However, the road recovery in these large areas was affected by the overbroad classification of road types and it was found that road restoration speed differed between municipalities in the same area. Hence, I investigated municipalities in

Fukushima and Miyagi prefectures using cluster analysis to classify municipalities with similar road recovery rates. Additionally, I visualized cluster analysis results on a map and observed that road restoration in municipalities was related to the geographical location and topography. In another one of my previous studies, the same cluster analysis was performed to analyze the road recovery conditions in Iwate prefecture, which has a rias coast unlike the coastal conditions of the other studied prefectures. The result showed that the road recovery conditions are similar according to damage, recovery policy, the importance of the road, and population density. However, these cluster analysis studies did not illustrate how cluster analysis selects the optimal classification and did not validate the classification results after obtaining the cluster analysis results regarding road restoration. Furthermore, studying the three prefectures together will help identify regional commonalities, which will be important for regional resource deployment after the disaster. Therefore, it is necessary to study three prefectures in the Tohoku region following the Tohoku Earthquake to provide a reference for future road recovery in the Tokai region in the event of a Nankai Trough earthquake.

In this study, I applied cluster analysis to examine the driving data in the Tohoku region to classify the road recovery condition among municipalities in the first six months after the disaster. The cluster analysis classifications were chosen according to the dendrogram and the agglomeration coefficients. In addition, I utilized ANOVA to check the significance of the differences between the clusters and selected five clusters. The results of this cluster analysis can be successfully tested with discriminant functions. I visualized the five clusters' results, and then gained insights into road recovery characteristics through a geographic information system (GIS). Furthermore, my analysis of objective data reflecting regional characteristics showed that the road recovery conditions are similar from the viewpoints of topography, the importance of the road, snow, population density, damage, and geographical location.

In order to simulate the recovery of local roads in the Tokai region (Shizuoka, Aichi, and Mie prefectures), after the Nankai Trough earthquake, which is expected to occur in the near future, I analyzed and quantified these six factors in each pattern of road recovery in the Tohoku region and applied discriminant analysis to construct a road recovery prediction model. Firstly, I collected twenty data points reflecting topography, the importance of the road, snow, population density, damage, and geographical location to build a database of the Tohoku region. Secondly, I used Pearson correlation analysis and multiple covariance analysis to screen and determine the parameters. Thirdly, I applied discriminant analysis and adjusted the parameters to determine which combinations of parameters produced the highest accuracy. The following eight parameters were chosen for the model with 72.4% accuracy: percentage of terrain, percentage of area above 100m elevation, percentage of area below 500m elevation, measured seismicity, percentage of important roads (such as highways and national roads), percentage of area at a distance from roads, minimum temperature, and employee density. Finally, I created the eight parameters for a database of the Tokai region to predict municipal road recovery in the Tokai region after the expected Nankai Trough earthquake and mapped the recovery on a geographic information system. The predicted results for the Tokai region match the results of the previous classification of the Tohoku region. In practice, however, most municipal roads will be restored in Cluster 1, and they may not be restored simultaneously in the event of a severe earthquake and a major tsunami. To address this issue, I need to improve my predictive model. Concerning the examination of other influencing factors, the previous cluster analysis of the Tohoku region as a whole has revealed that the characteristics of coastal and inland municipalities within the same category are different. At the same time, to avoid an overconcentration of a single cluster in the predicted results for the three Tokai prefectures, I attempted to subdivide the predictive model into several more clusters. Furthermore, Stepwise discriminant analysis can make the process of filter parameters simpler. Hence, I considered re-clustering the three Tohoku prefectures separately based on coastal or inland and attempted to use Stepwise discriminant analysis with the intention of simplifying the process and improving accuracy. The results showed that the accuracy of the model improved from 72.4% to 80.0% along the coast and 77.8% inland. In addition, the overall condition of the Tokai region was better matched to the actual situation by increasing the number of clusters from the previous four to six.

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Finally, I would like to thank my family and friends. Especially my husband, thank you for being there all the way.

Overview

This study is divided into 7 chapters.

Chapter 1 introduces the background and the purpose of the study. I investigated the conditions of local road use from the Tohoku region after the 2011 Tohoku Earthquake to find the shared characteristics of local road recovery, and to simulate the recovery of local roads in the Tokai region (Shizuoka, Aichi, and Mie prefectures) after the predicted Nankai Trough earthquake. The transport network in eastern Japan was severely damaged by the 2011 Tohoku Earthquake. In the future, a huge earthquake and tsunami are predicted to occur in the Nankai Trough. The three prefectures (Fukushima, Miyagi, and Iwate prefectures) on the Pacific side of the Tohoku region are relatively similar to the three prefectures (Shizuoka, Aichi, and Mie prefectures) in the Tokai region in terms of the topographical environment. I think that the recovery of regional roads in the three prefectures affected by the Tohoku Earthquake can be studied to help promote the rapid recovery of the three prefectures in the Tokai region after a possible Nankai Trough earthquake in the future.

Chapter 2 reviews previous research related to the vehicle tracking map data to study road recovery. It first describes the initial construction of a vehicle tracking map by Honda Company to reflect actual road conditions after an earthquake. Then it is followed by analyses of a vehicle tracking map for a six-month period after the 2011 Tohoku earthquake to investigate road recovery in the wider region. This is followed by a description of the road recovery in Tohoku municipalities on the coast using the same data source and cluster analysis. Previous studies have left much to be desired in terms of methodology, for example the process of cluster analysis was not described in detail and the results were not adequately validated. Therefore, it is necessary to study the municipalities of the Tohoku region using cluster analysis in detail.

Chapter 3 briefly describes the data and operating systems used in this study.

Chapter 4 is about how I used cluster analysis to investigate vehicle driving data in the Tohoku region after the 2011 Tohoku earthquake. This chapter describes in detail how this study derived five patterns of road recovery in the Tohoku region. I also explored the factors affecting road recovery through GIS and then categorized my insights into six common characteristics of road recovery patterns using objective data. In the Tohoku region, the road recovery conditions were found to be similar depending on topography, the importance of the road, snow, population density, damage, and geographical location.

Chapter 5 describes how I have used the data from the Tohoku region to predict road recovery in the Tokai region, where a major Nankai Trough earthquake could occur. I used general discriminant analysis to construct a road recovery prediction model. The predicted results for the Tokai region matched the results of the previous classifications of the Tohoku region. However, the cluster classification of the three Tokai prefectures resulted in an overconcentration in Cluster 1, where recovery is the fastest. It is unlikely that most municipal roads will be able to recover at the same time, suggesting that other parameters should be considered in the forecasting of the three Tokai prefectures.

Chapter 6 describes how I re-clustered the coastal and inland areas and applied Stepwise discriminant analysis to improve the accuracy of the prediction model. I found that municipalities with high coastal breakwaters, which were not hit by the tsunami, suffered less damage to their roads and recovered the fastest. In addition, a comparison of previous studies shows that it is the coastal clusters that were severely affected by the tsunami that recovered most slowly, rather than the inland heavy snowfall areas, which was more in line with reality. The predicted results of the Tokai region were better matched to the actual condition by increasing the number of clusters from the previous four to six. In addition, the accuracy of the model improved from 72.4% to 80.0% along the coast and 77.8% inland.

Chapter 7 summarizes the whole paper and what to expect in the future.

Contents

Chapter 1

Introduction

The Tohoku earthquake of March 11, 2011, and the tsunami triggered by it had devastating effects throughout the northeastern coast of Japan [1]. The transport network in eastern Japan was severely damaged by this disaster. In the Tohoku region, the main roads and railways ceased to function for a long period of time, and the lives of the people in these areas drastically altered.

From the day after the disaster, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) performed road clearance (Operation "Teeth of a Comb", Fig. 1) [2] to open up as many routes as possible for vehicles to pass. This operation involved road clearance to secure rescue and relief routes on many national highways, extending from inland areas toward the Pacific coastal area of Tohoku. The main routes in the Tohoku region were restored in the first week after the serious earthquake at a speed that surprised the whole world. Studying road recovery in the Tohoku region will provide a reference for road recovery in the event of future earthquakes and tsunamis in other areas.

A large earthquake and tsunami are predicted to occur in the Nankai Trough in Japan by 2050 with a probability of 70%–80% [3]. This disaster is predicted to cause significant damage, and hence, it is essential that measures be taken in advance. The three prefectures (Fukushima, Miyagi, and Iwate prefectures) on the Pacific side of the Tohoku region are relatively similar to the three prefectures (Shizuoka, Aichi, and Mie prefectures) in the Tokai region in terms of their topographical environments (rias coast, sandy coast, plain and mountainous area, etc.). Hence, I think that knowledge of the recovery of regional roads in the three prefectures affected by the Tohoku earthquake can be used to help promote the rapid recovery of the three prefectures in the Tokai region in the event of a large Nankai Trough earthquake in the future.

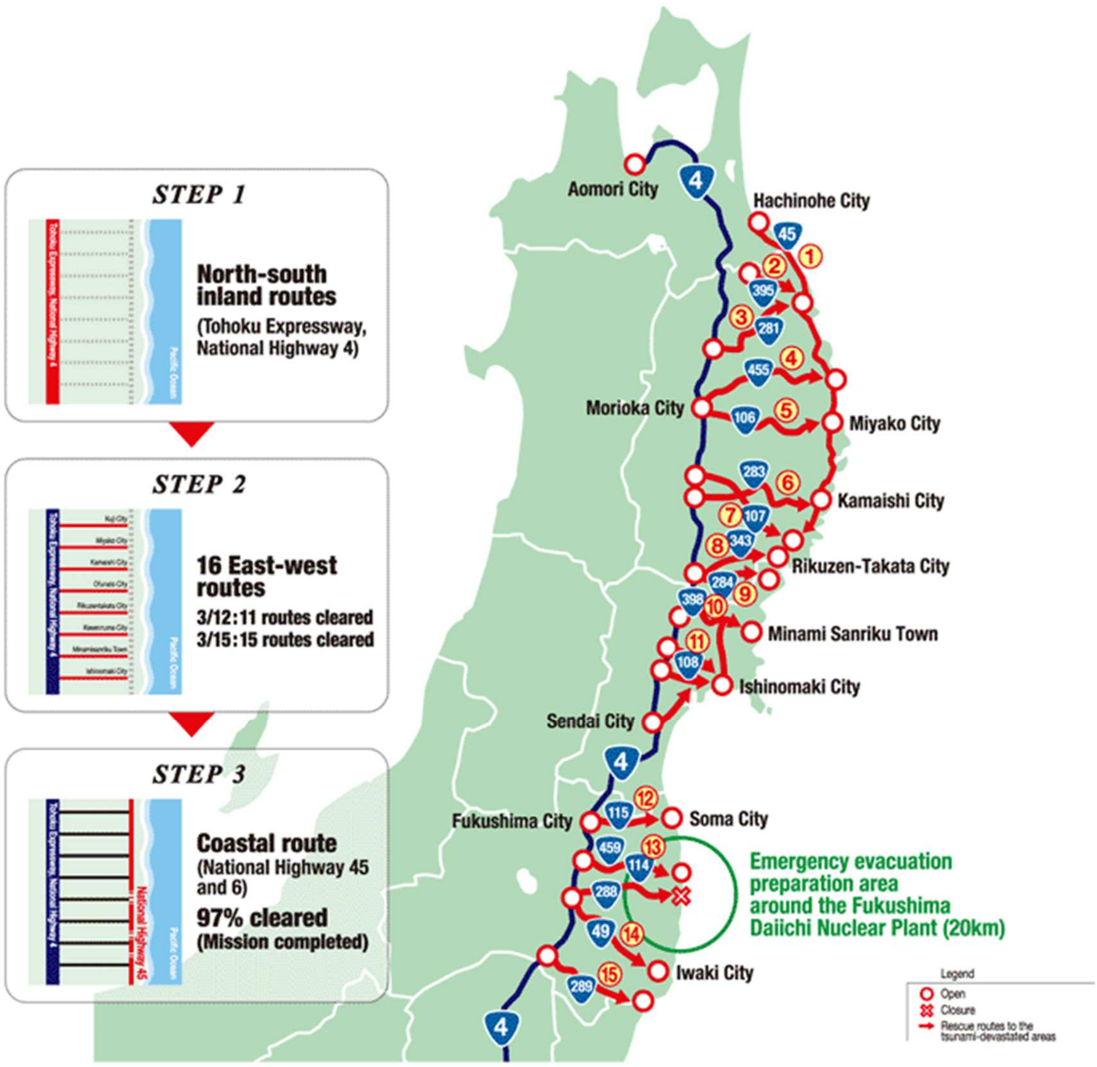

Fig. 1 The routes of “road clearance” (Operation “Teeth of a Comb”).

Concerning post-earthquake road recovery research, many research reports on the recovery of motorways and general national roads after the 2011 Tohoku earthquake are available [4],

[5]. However, few studies have examined the road recovery of prefectural and municipal roads that play an important role in the daily lives of residents. In addition, although some studies predict the damage of roads and propose priority orders of road restoration for the expected Nankai Trough earthquake [6], [7], [8], limited works exist that predict the recovery of road use in the region. In this study, I focused on the local road network, which is one of the most important factors in rescuing victims and supplying them with daily commodities, and surveyed the situation of roads accessible to motor vehicles in the first six months after the disaster and their recovery process in the municipalities of the Tohoku region. The purpose of this study was to investigate the conditions of local road use from objective data, to find the shared characteristics of local road recovery, and to simulate the recovery of local roads in the Tokai region (Shizuoka, Aichi, and Mie prefectures) after the Nankai Trough earthquake, which is predicted to occur in the near future. To this end, I proposed the following framework (Fig. 2). Firstly, the vehicular driving data were processed to derive the recovery conditions of each municipality at each time period in the first six months after the earthquake. Secondly, cluster analysis and discriminant analysis were used to identify clusters with similar road recovery rates. Thirdly, the clusters were observed on a map using GIS to detect their common characteristics and verify them with objective data. Finally, a prediction model was constructed by a database for road recovery and regional characteristics in the Tohoku region and discriminant analysis to predict road recovery in the Tokai region.

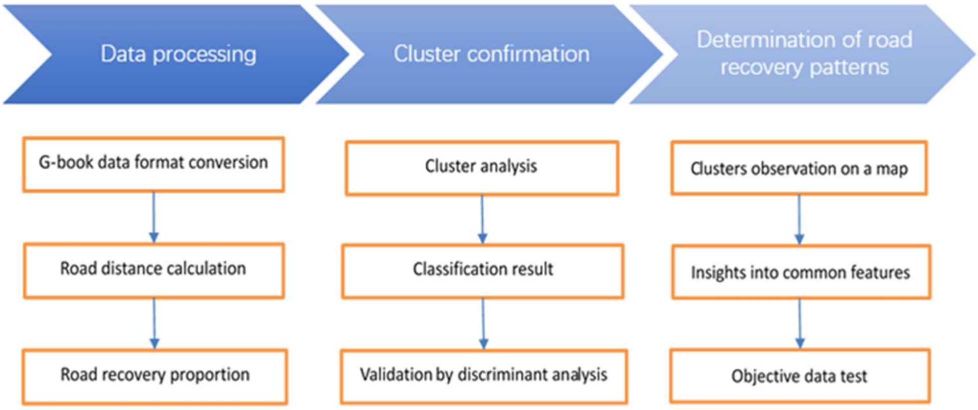

Fig. 2 Research flowchart.

Chapter 2

Related Works

In the event of a disaster, the collection and consolidation of road information is a time-consuming process for various emergency, rescue, and recovery operations. Therefore, a vehicle tracking map was built by Honda Motor Company, Ltd., Japan to quickly determine the road conditions after the 2007 Niigata-ken Chuetsu-oki earthquake [9]. This system can be used to obtain reference information to support evacuation and rescue operations in disaster areas based on actual vehicular traffic data, showing the traffic routes that are accessible after a major earthquake. After the Tohoku earthquake, on 19 March, ITS (Intelligent Transport Systems) Japan began to integrate probe-car telematics data from private automakers (e.g., Honda, Toyota) to provide information on traffic records and road closures in the affected areas [10].

In the field of post-earthquake road recovery research, there are many research reports on the recovery of motorways and general national roads after the 2011 Tohoku Earthquake [11], [12]. However, there are few reports on municipal road recovery related to the daily lives of residents. In previous related studies [13], [14], [15], [16], [17], [18], the G-BOOK telematics data of the Toyota Motor Corporation were used to survey road recovery after the Tohoku earthquake. The affected prefectures in the Tohoku region were divided into several large areas, and the authors concluded that road restoration varied between these areas. In two of my previous studies [19], [20], the same vehicular driving data from the Toyota Motor Corporation in the Fukushima prefecture (Fig. 3) were divided into seven regions (Fig. 4), and it was found that in the six months following the 2011 Tohoku earthquake, the speed of road use recovery in inland areas was slower than that in coastal areas. I concluded that the recovery of roads was much slower in areas that were narrow, steep-walled, and mountainous. In addition, studies [19], [20], compared regions in different prefectures, coastal and inland, that reached

90% recovery rates. These areas had similar recovery dates, which illustrate similar rates of recovery between regions.

However, the recovery in these seven regions was affected by local consensus [21], which I believe was caused by broad classification, road restoration speed differs between municipalities in the same region. Moreover, the similarity of road restoration between regions should not be seen in terms of similarity at one time alone, but should instead be considered in terms of the similarity of the entire restoration process. Hence, I investigated municipalities in Fukushima prefecture using cluster analysis to classify municipalities into seven clusters (Fig. 5) with similar road recovery rates [22]. Additionally, I visualized cluster analysis results on a map and observed that road restoration in municipalities was related to the geographical location and topography (Fig. 6). The study concluded with the same cluster analysis method used in Miyagi prefecture (Fig. 7) and was visualized on a map to draw conclusions related to the topography.

Fig. 3 Municipalities of Fukushima Prefecture. There're 59 municipalities in Fukushima Prefecture.

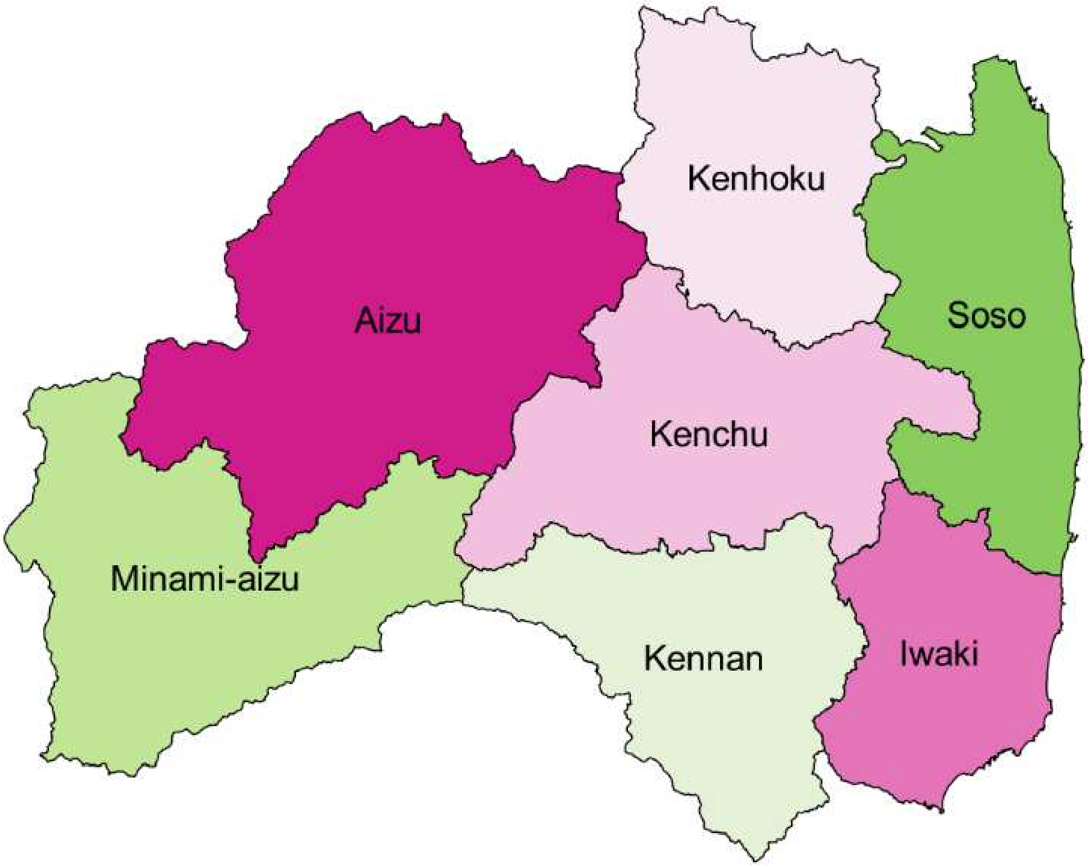

Fig. 4 Fukushima Prefecture divided into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions.

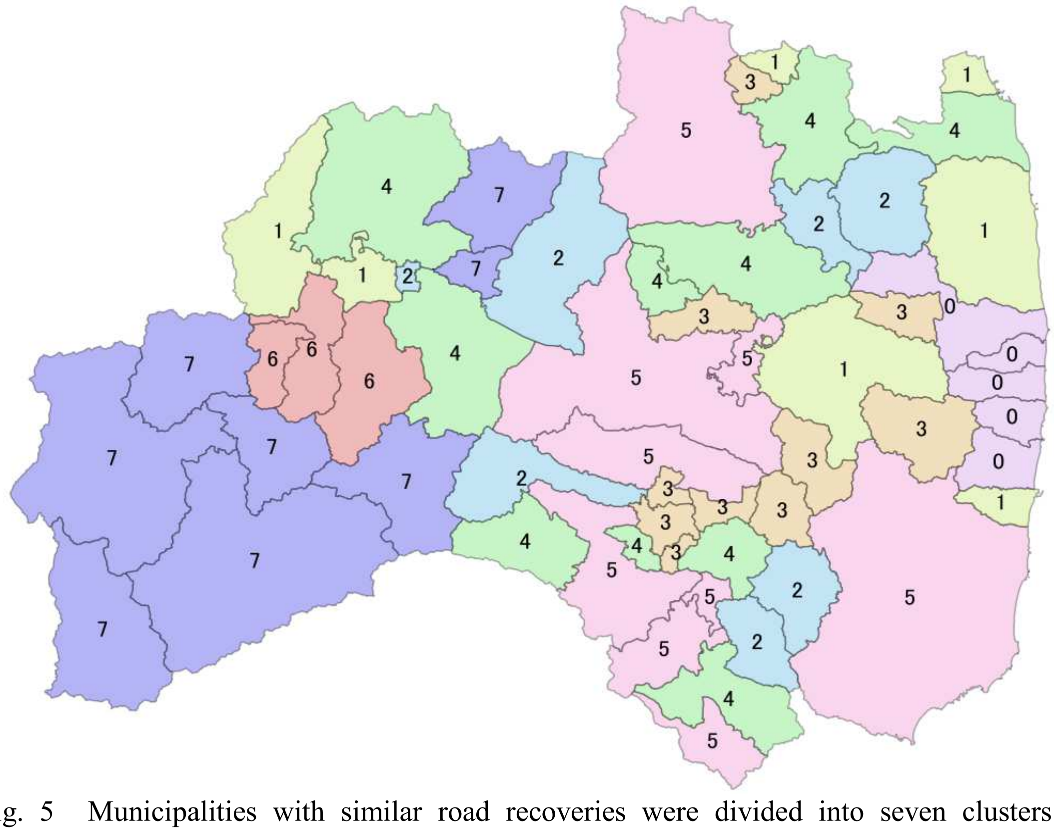

Fig. 5 Municipalities with similar road recoveries were divided into seven clusters. The five municipalities were in the no-go zone due to the Fukushima Daiichi nuclear power plant accident.

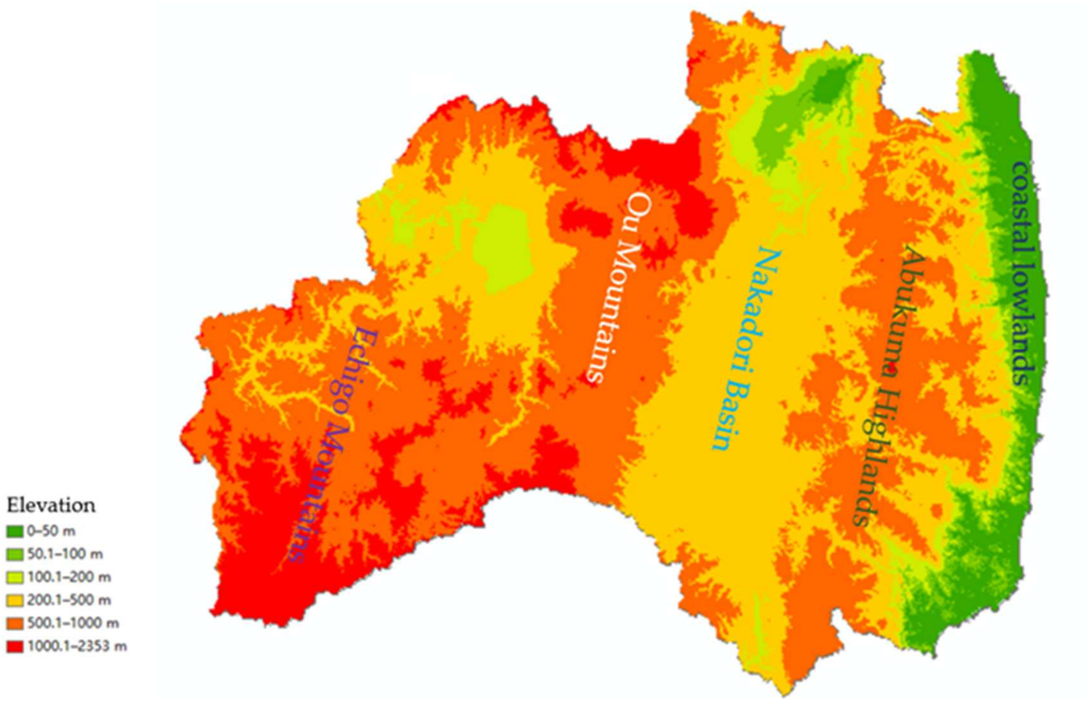

Fig. 6 Topographical map of Fukushima prefecture.

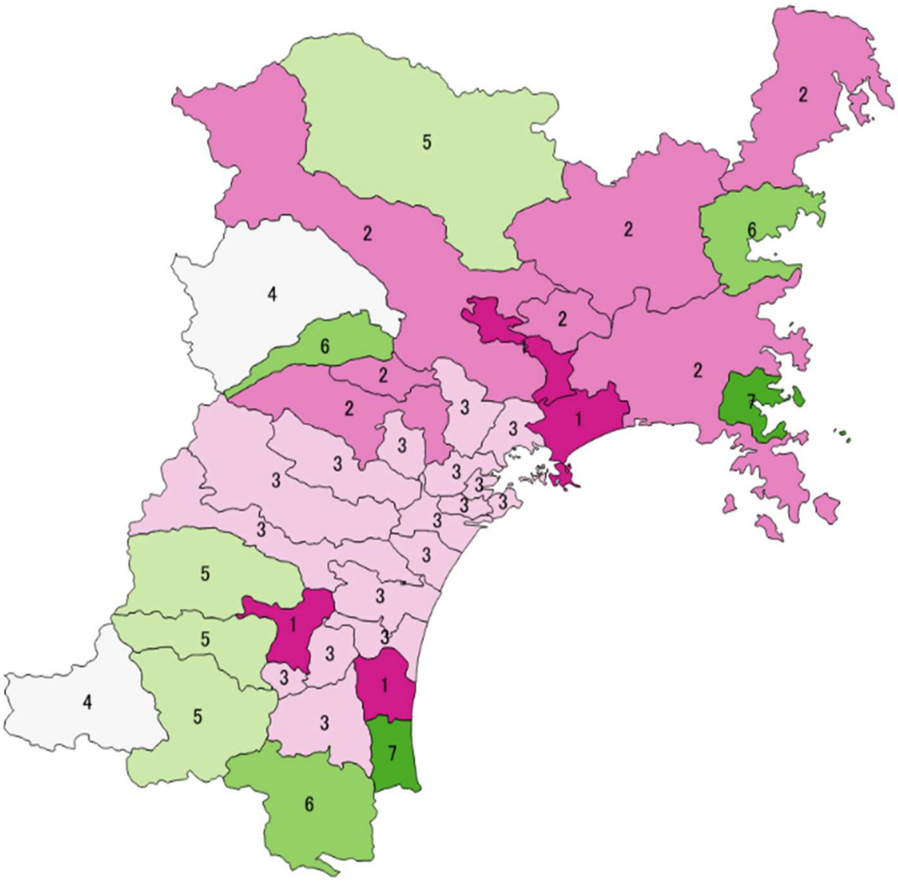

Fig. 7 Each municipality in Miyagi Prefecture belongs to a cluster. Municipalities with similar road recoveries were divided into seven clusters in Miyagi Prefecture.

In another one of my previous studies [23], the same cluster analysis was performed to analyze the road recovery conditions in Iwate prefecture, which has a rias coast unlike the coastal conditions of the other studied prefectures. Since the existing 33 municipalities in Iwate prefecture (Fig. 8) are relatively large in area, I have chosen to study the 59 municipal boundaries of Iwate prefecture (Fig. 9) in 1999 in order to avoid the inaccurate results that would have resulted from previous analyses by concentrating on one large classification. The results of this study are divided into five clusters to show that the road recovery conditions are similar according to damage, recovery policy, the importance of the road, and population density.

The visual results of my previous studies, as shown on the map, showed that similar road recovery areas in the two studies [22], [23] have different influencing factors; however, I think that road recovery after earthquakes can be expected to differ based on regional characteristics, which can be verified by objective data. In a related study [24], I analyzed road recovery in the Fukushima prefecture regarding not only the geographical location and topography but also the population density. In addition, I divided each cluster into four zones (Fig. 10) and used road closure information to verify the results of the road use recovery. With one exception, the order of these zones in terms of road use recovery was the same as that of road closures being lifted. The cluster analysis results of road recovery in the Tohoku region have not yet been fully validated. Moreover, the visualization on a map has not been tested with objective data to draw conclusions related to geographical location, topography, and population density. I wanted to explore other factors, besides these three, that influence road restoration. The most important and essential thing is that the three previous studies [22], [23], [24] did not illustrate how cluster analysis selects the optimal classification. I hope to analyze the methodology in detail in this study. Furthermore, studying the three prefectures together will help identify regional commonalities, which will be important for regional resource deployment after the disaster. Therefore, it is necessary to study three prefectures in the Tohoku region following the Tohoku earthquake to provide a reference for future road recovery in the Tokai region in the event of a Nankai Trough earthquake.

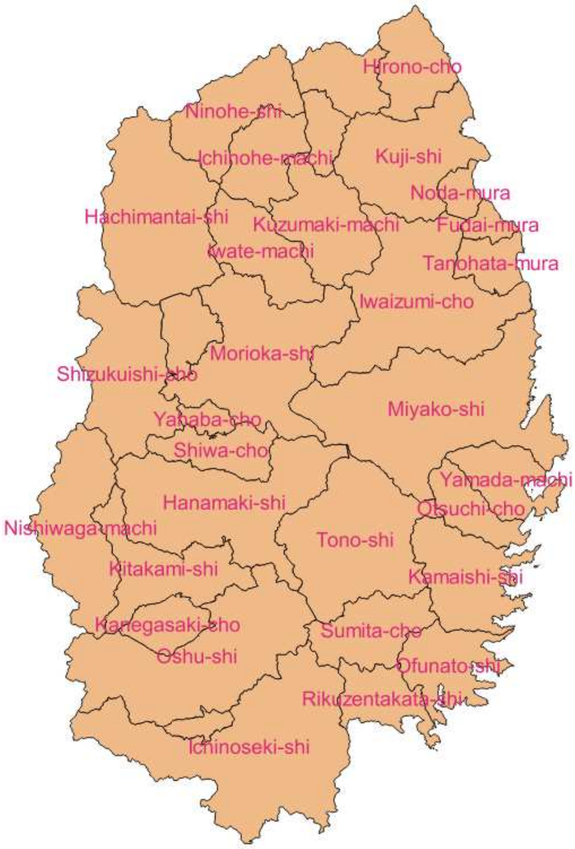

Fig. 8　33 municipalities in Iwate Prefecture.

Fig. 9　59 municipalities in Iwate Prefecture.

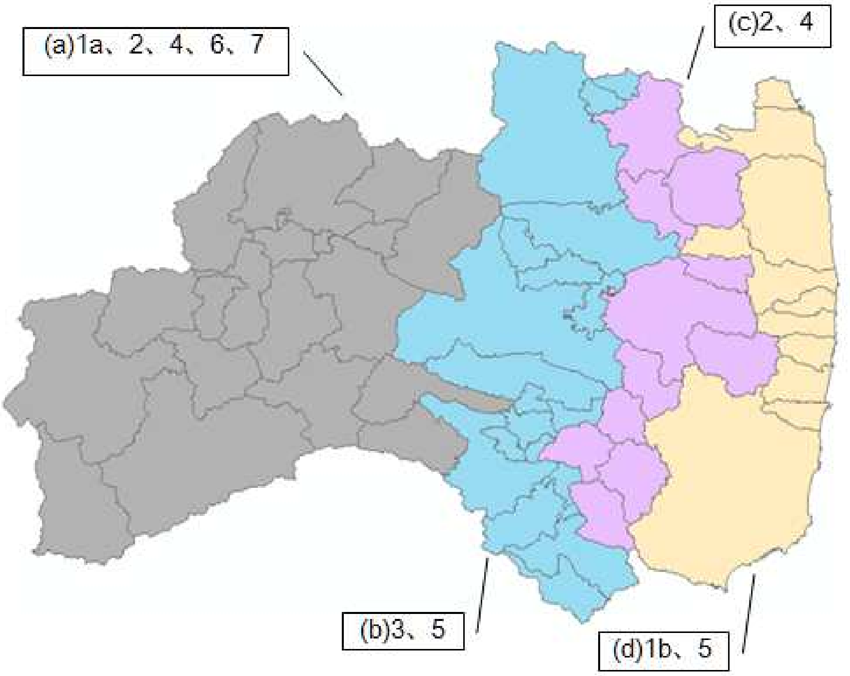

Fig. 10 Four zones of Fukushima. Fukushima Prefecture was divided into four zones based on the proximity of the road recovery conditions and the location of the municipalities.

Chapter 3

Materials and System

3.1 Vehicle Tracking Map

The vehicle tracking map (Fig. 11) was built from the G-BOOK telematics data from the Toyota Motor Corporation, which has been available on the internet since 18 March 2011 following the 2011 Tohoku earthquake [25]. Toyota is the largest car manufacturer in Japan, and its vehicle driving data reflect the road conditions after the Tohoku earthquake. The data used in this study were collected in 152 municipalities in three prefectures (Fukushima, Miyagi, and Iwate prefectures) of the Tohoku region (Fig. 12) between 18 March and 30 September 2011 (i.e., approximately six months following the 2011 Tohoku earthquake), excluding municipalities located in the no-go zone due to the accident at the Fukushima Daiichi nu-clear power plant.

3.2 System

3.2.1. Hardware

The computations were performed on a standard PC laptop with a Core i7–10510U CPU (1.8 GHz) and 16 GB memory (ASUS Expert Book B9450FA: Taiwan).

3.2.2. Software

This study used QGIS version 2.18.20 [26], IBM SPSS Statistics 23 [27], and Microsoft Excel 2019 software running on the Windows 10 Professional operating system.

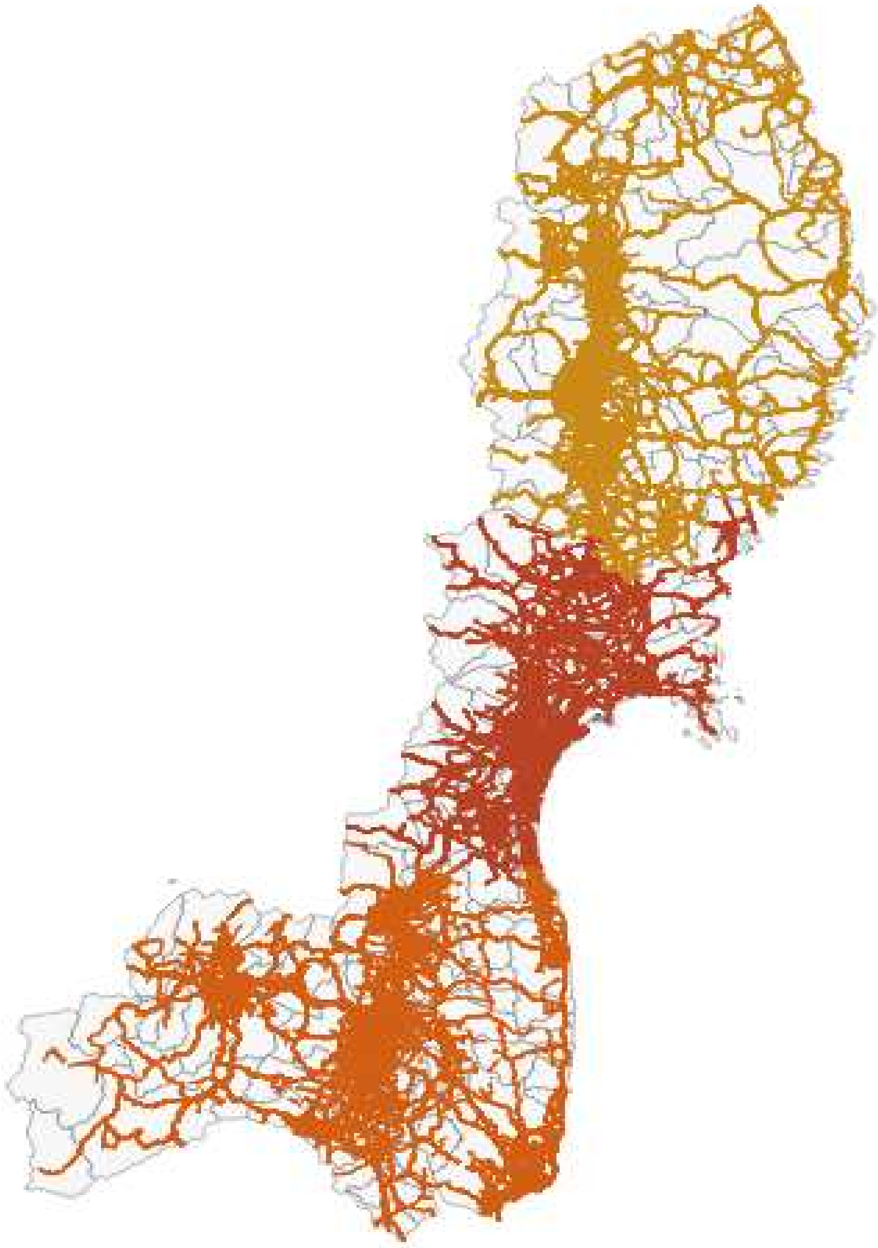

Fig. 11 Vehicle tracking map of the Tohoku region on 30 September 2011.

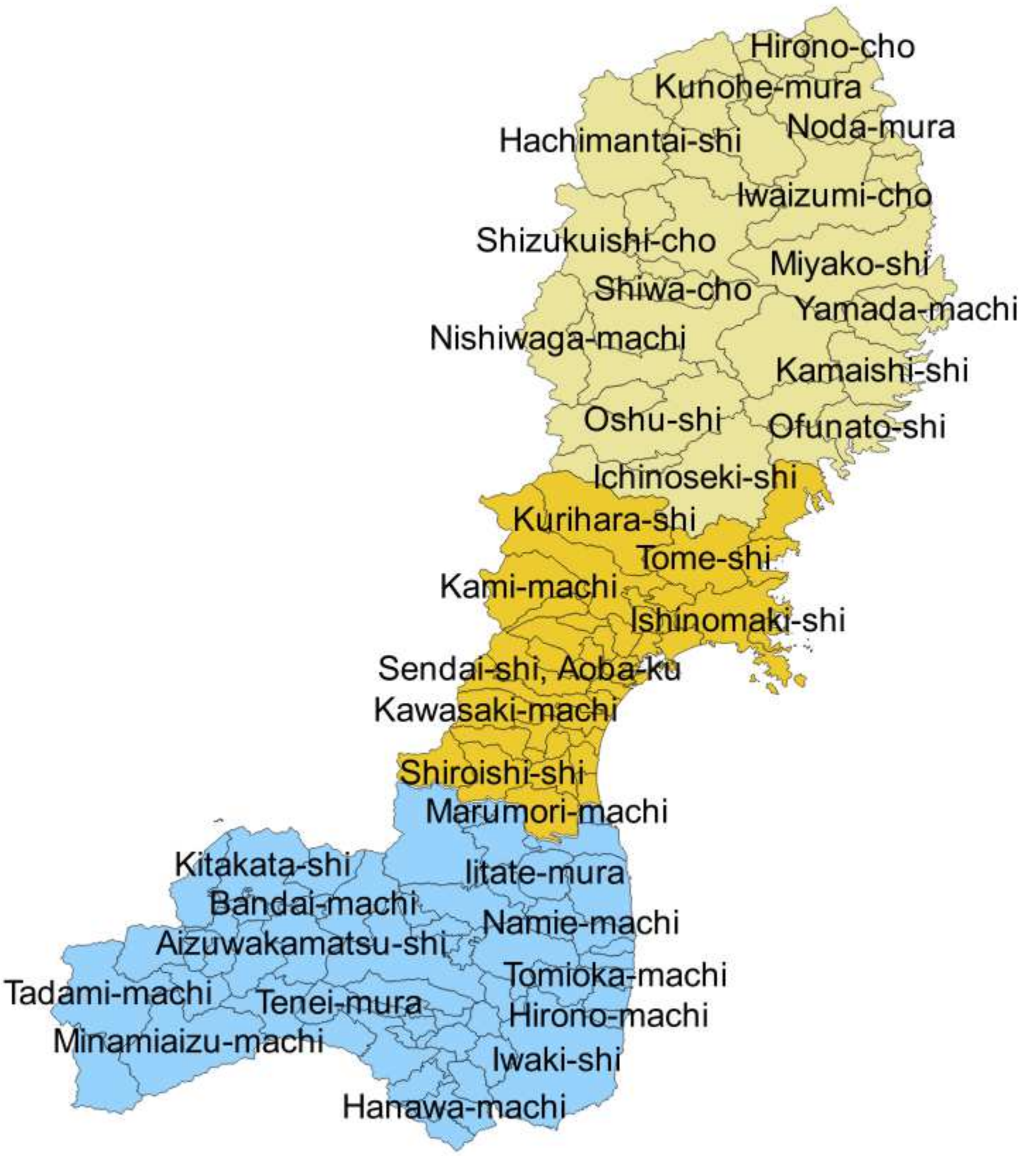

Fig. 12 152 municipalities in three prefectures (Fukushima, Miyagi, and Iwate prefectures) of the Tohoku region.

Chapter 4

Study on Road Recovery Characteristic in the Tohoku Region Following the 2011 Tohoku Earthquake

4.1 Data Processing

1) The vehicle-tracking maps constructed from the G-BOOK telematics data were provided in the Google Map KMZ format in a geographical coordinate system. For my analysis, I first converted the KMZ files to SHP files in a rectangular coordinate system.
2) After merging daily data into weekly data and removing duplicate data, I calculated the exact usable road distance available for a given week. In this context, a usable road is one on which at least one vehicle was tracked during the observation period. The daily data were converted to weekly data to smoothen the daily fluctuations in the traffic flows.
3) Next, I calculated the proportion of the cumulative distance up to the specified date. Note that the cumulative distance up to September 30, 2011, was considered 100%.

4.2 Cluster Confirmation

4.2.1 Specific Methods for Cluster Analysis

Cluster analysis is the task of clustering a set of objects such that all objects in a cluster are similar to one another and at the same time are distinctly different from all objects outside of this cluster. It is a major task of exploratory data analysis, in which observations are divided into meaningful groups whose members share common characteristics. It is a common technique for statistical data analysis and is used in many fields, including pattern recognition, image analysis, information retrieval, bioinformatics, data compression, computer graphics, and machine learning [28].

Using this method, I decided to classify all municipalities in the Tohoku region using cluster analysis to determine the common characteristics shared by municipalities with similar road recovery conditions.

There are various methods of cluster analysis, of which k-means clustering and hierarchical clustering analysis are more commonly used. K-means clustering requires the number of clusters to be specified in advance and is suitable for large data, while hierarchical clustering analysis determines the number of clusters based on the output results and is suitable for small data types. As my analysis sample is only 152 municipalities with small data, I chose unsupervised hierarchical clustering analysis.

The basic logic of hierarchical clustering analysis is that each case (or variable) is first considered as a class, then grouped into smaller classes based on the distance or similarity between the cases (or variables), and then gradually grouped upwards based on the distance or similarity between the classes, until all the cases are aggregated into one large class.

In the hierarchical cluster analysis, I employed Ward's method [29], which is also the most commonly used. As a procedure for grouping similar objects, Ward's method aims to minimize the sum of squared errors between two groups for all variables.

The squared Euclidean distance between each pair of observations is used to measure the similarity between groups, with shorter distances indicating greater similarity. If there are n attribute variables measuring the "distance" and the "distance" between No. j case and No. k case, the squared Euclidean distance can be expressed by the Equation (1):

$$e_{jk} = \sum_{i=1}^{n}\left(X_{ij} - X_{jk}\right)^2 \quad (1)$$

Using the cumulative data from Section 3.3, I obtained the percentage of road use recovery in each municipality. Then, I introduced the percentages into SPSS Statistics software and used Ward's method with the squared Euclidean distance as the measurement interval in hierarchical cluster analysis to produce a classification dendrogram (Fig. 13).

4.2.2 Clusters Selection

According to the results of the cluster analysis (Fig. 13), municipalities with similar road recoveries were divided into two to nine clusters (Table 1). To test the validity of these clusters, I used the means and analysis of variance (ANOVA) methods to test the differences between the clusters in terms of road recovery. It is well-known that ANOVA is one of the most popular statistical methods to test the differences between groups. If the differences are significant, the classification results can be considered reliable.

First, I used the means method in the analysis function of SPSS to calculate the mean of each cluster classification. An example of 5 cluster classifications is provided in Table 2.

Second, I used the One-Way ANOVA of SPSS to examine the significance of the differences between eight classification results. For example, in the case of five clusters (Table 3), the difference between groups in each recovery period was less than 0.05. The significance of the differences between groups for eight classifications is summarized in Table 4, refer to the Appendix for details.

The column of significance shows that all the indicators are significant, except for one, which is greater than 0.05, in 9, 4, and 2 clusters (Table 4). This table indicates that this classification is relatively valid. No significant differences in this indicator were seen in August. As the date of 100% recovery in the data is set as September 30, the differences between regions become less consequential as the road recovery is prolonged. Nevertheless, compared to 9, 4, and 2 clusters, more significant differences are seen in the case of eight, seven, six, five, and three clusters. Further, according to the agglomeration coefficient line shown in Fig. 14, there is a large drop in the aggregation coefficient between one and four clusters, and then, the coefficient starts to plateau at four to five clusters. When there are 4 or 5 clusters, the distance between the clusters becomes manageable; hence, the most useful number of classifications can be set as four or five clusters. Between these, the most statistically significant information can be obtained using 5 clusters. Therefore, five clusters were chosen in this study.

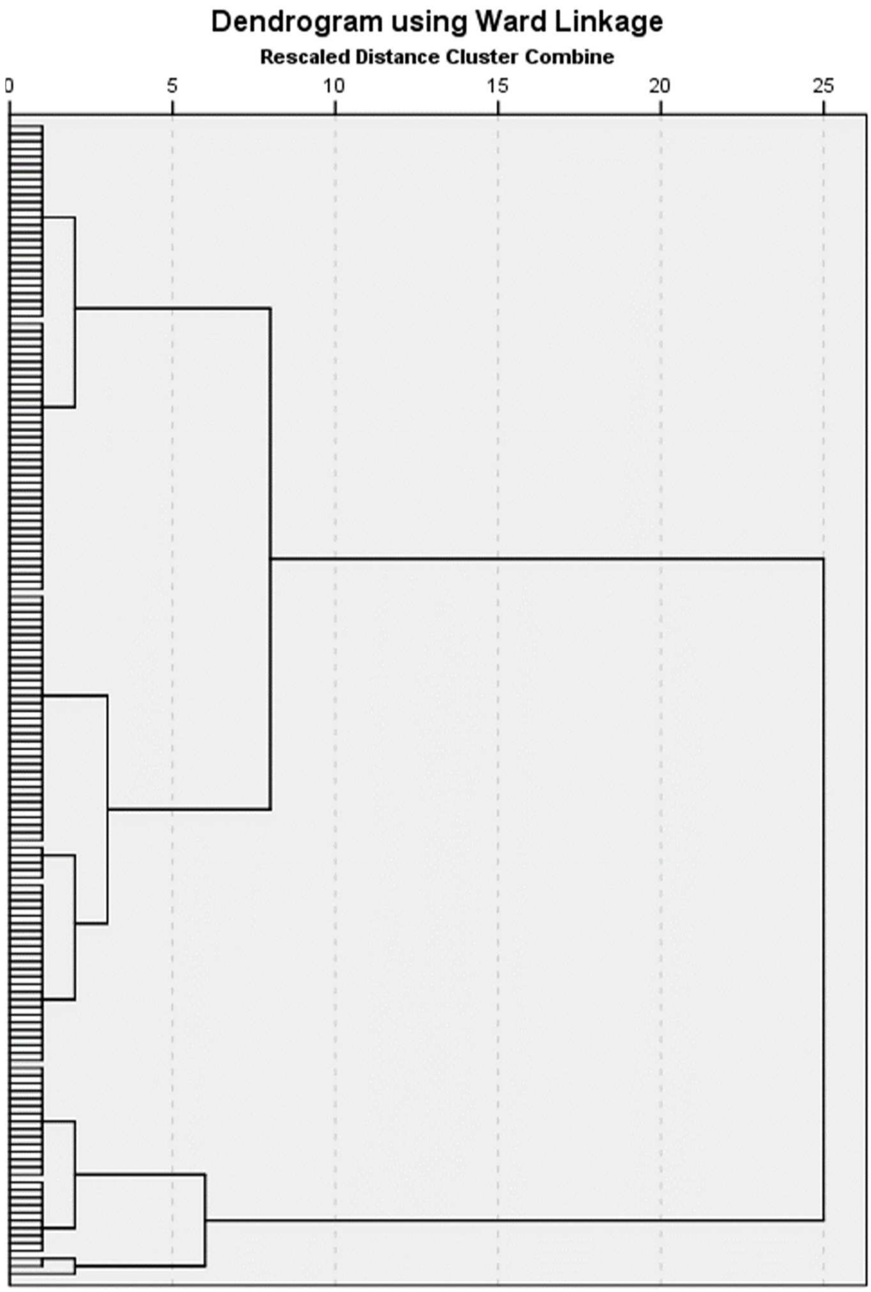

Fig. 13 Classification dendrogram.

Table 1 Number of municipalities in 2-9 clusters after cluster analysis.

Cluster	9 clusters	8 clusters	7 clusters	6 clusters	5 clusters	4 clusters	3 clusters	2 clusters
1	36	36	36	62	62	62	62	124
2	33	33	33	33	33	62	62	28
3	26	26	26	25	25	25	28	
4	10	25	25	29	29	3		
5	24	24	29	2	3			
6	15	5	2	1				
7	5	2	1					
8	2	1						
9	1							
Total	152	152	152	152	152	152	152	152

Table 2 Mean of the clusters when divided into 5 clusters.

Cluster	N		Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	July	Aug	Sep
1	62	Mean	63.81	82.40	88.53	92.15	94.40	95.99	97.03	98.07	98.76	99.38	100.00
		Std. Deviation	10.36	5.67	4.26	3.37	2.71	2.43	2.17	1.66	1.53	1.10	0.00
2	33	Mean	53.93	68.20	75.41	79.82	83.41	87.54	91.17	94.17	96.46	98.06	100.00
		Std. Deviation	7.51	5.09	5.25	4.78	4.97	4.99	4.24	4.14	3.77	2.99	0.00
3	25	Mean	30.66	49.33	60.92	65.85	72.23	78.38	87.22	92.56	95.13	98.73	100.00
		Std. Deviation	13.26	7.76	8.94	8.83	7.87	8.68	7.50	6.16	6.44	1.27	0.00
4	29	Mean	34.44	68.80	81.88	87.71	90.18	92.02	95.11	97.45	98.56	99.21	100.00
		Std. Deviation	12.86	10.80	7.25	4.03	3.70	3.75	3.19	2.20	1.56	0.99	0.00
5	3	Mean	1.42	5.78	29.22	32.81	39.10	49.96	68.01	95.54	97.96	98.29	100.00
		Std. Deviation	2.46	6.60	30.39	30.63	34.30	17.42	8.88	5.21	3.54	2.96	0.00
Total	152	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
		Std. Deviation	18.72	16.34	13.89	13.30	12.04	9.86	6.61	4.11	3.63	1.79	0.00

Table 3 Analysis of variance (ANOVA) of 5 clusters.

		Sum of Squares	df	Mean Square	F	**Sig.**
Mar-3w	Between Groups	35729.165	4	8932.291	76.286	**.000**
	Within Groups	17212.211	147	117.090		
	Total	52941.377	151			
Mar-4w	Between Groups	32726.416	4	8181.604	158.484	**.000**
	Within Groups	7588.747	147	51.624		
	Total	40315.163	151			
Apr-1w	Between Groups	21883.872	4	5470.968	111.261	**.000**
	Within Groups	7228.355	147	49.172		
	Total	29112.227	151			
Apr-2w	Between Groups	21079.779	4	5269.945	137.712	**.000**
	Within Groups	5625.369	147	38.268		
	Total	26705.148	151			
Apr-3w	Between Groups	16415.318	4	4103.830	110.446	**.000**
	Within Groups	5462.050	147	37.157		
	Total	21877.368	151			
Apr-4w	Between Groups	10706.468	4	2676.617	99.218	**.000**
	Within Groups	3965.640	147	26.977		
	Total	14672.108	151			
May	Between Groups	3950.316	4	987.579	54.683	**.000**
	Within Groups	2654.833	147	18.060		
	Total	6605.149	151			
Jun	Between Groups	730.879	4	182.720	14.779	**.000**
	Within Groups	1817.442	147	12.364		
	Total	2548.321	151			
July	Between Groups	306.103	4	76.526	6.682	**.000**
	Within Groups	1683.479	147	11.452		
	Total	1989.582	151			
Aug	Between Groups	41.597	4	10.399	3.445	**.010**
	Within Groups	443.741	147	3.019		
	Total	485.338	151			
Sep	Between Groups	0.000	4	0.000		
	Within Groups	0.000	147	0.000		
	Total	0.000	151			

Table 4 Significant differences between groups in the recovery period for each classification.

	9 clusters	8 clusters	7 clusters	6 clusters	5 clusters	4 clusters	3 clusters	2 clusters
Mar-3w	.000	.000	.000	.000	.000	.000	.000	.000
Mar-4w	.000	.000	.000	.000	.000	.000	.000	.000
Apr-1w	.000	.000	.000	.000	.000	.000	.000	.000
Apr-2w	.000	.000	.000	.000	.000	.000	.000	.000
Apr-3w	.000	.000	.000	.000	.000	.000	.000	.000
Apr-4w	.000	.000	.000	.000	.000	.000	.000	.000
May	.000	.000	.000	.000	.000	.000	.000	.000
Jun	.000	.000	.000	.000	.000	.000	.000	.000
July	.001	.001	.000	.000	.000	.000	.000	.000
Aug	.054	**.033**	**.018**	**.012**	**.010**	.082	**.038**	.413
Sep								

Fig. 14 Agglomeration coefficient with the number of clusters.

4.2.3 Discriminant Analysis for Validation of the Cluster Analysis Results

(1) Canonical Discriminant Analysis

Canonical discriminant analysis is a classification model that works by identifying a projection hyper plane in k-dimensional space such that the projections of the same categories on that hyper plane are as close as possible to each other while the projections of different categories are as far apart as possible. If the results obtained from the cluster analysis can be fitted with the discriminant analysis equation, this classification result is considered valid [30].

(2) Canonical Discriminant Function Determination

Therefore, I used the five-clusters as the dependent variable and the date of recovery as the independent variable and chose “enter independent together” for the discriminant analysis in the SPSS statistics software. The larger the eigenvalue is, the better the linear discriminant function obtained. According to Table 5, the canonical correlations of the first two functions derived from SPSS both reach 85% or more, with the two functions together explaining 96.1% of the variance. Furthermore, the closer the Wilks’ lambda value is to 0, the better the group is identified, and the significance of the first two functions was 0.000 in Wilks’ lambda test (Table 6). Therefore, I believe that the results of the cluster analysis are successfully captured by using the first two functions.

Table 5 Eigenvalues.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	8.992[a]	88.6	88.6	.949
2	.760[a]	7.5	96.1	.657
3	.317[a]	3.1	99.2	.491
4	.083[a]	.8	100.0	.277

Table 6 Wilks’ lambda.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1	.040	462.405	40	.000
2	.398	132.102	27	.000
3	.701	50.954	16	.000
4	.923	11.424	7	.121

4.2.4 Validated Results of Discriminant Analysis on Classification

(1) Standardized Canonical Discriminant Function

Regarding the standardized canonical discriminant function coefficients, the larger the absolute value of the coefficient is, the greater the contribution to the discriminant function. As shown in Table 7, for

Function 1, the order according to the coefficients is Mar—3 w > Apr—2 w > Mar—4 w > May > Jul > Apr—3 w > Apr—4 w > Apr—1 w > Jun > Aug. It is clear that the recovery rates in the 3rd week of March, the 2nd week of April, and the 4th week of March contribute the most to the discriminant function; that is, the recovery rates in the 1th, 3rd, and 2nd weeks after the Tohoku earthquake are the most important factor in the classification of the recovery cluster. Similarly, the recovery rates in weeks 1 of March, 2 and 4 weeks of April contribute the most for Function 2.

Pooled within-group correlations between discriminating variables and standardized canonical discriminant functions are shown in Table 8. The variables ordered by the absolute size of correlation within Function 1 are Mar—4 w > Apr—2 w > Apr—1 w > Apr—3 w > Apr—4 w > May > Mar—3 w> Jun > Jul > Aug. Similarly, the order of function 2 is Mar—3 w > Apr—2 w > Apr—3 w > Apr—1 w > Apr—4 w > May > Jun > Jul > Aug> Mar—4 w. Standardized function 1 was associated with higher recovery rates in week 4 of March and standardized function 2 was associated with higher recovery rates in week 3 of March.

Table 7 Standardized canonical discriminant function coefficients.

Independent Variable	Function	
	1	2
Mar-3w	.516	-.749
Mar-4w	.437	-.128
Apr-1w	.067	-.067
Apr-2w	.492	.737
Apr-3w	-.142	.029
Apr-4w	.118	-.323
May	.435	.225
Jun	.051	.252
July	-.330	.106
Aug	.012	.123

Although the correlations with the two functions are shown in Table 8, the variables for Apr—2 w are both more advanced. As the previous results (Table 5) show that the first discriminant function carries most of the discriminant information, this suggests that the variable for Mar—4 w may play a major role in the discriminant analysis. I believe that this is linked to the government's road recovery policy, namely "road clearance", prioritizing the restoration of the Tohoku Expressway and major national highways and opening up the roads to the affected areas along the coast.

Table 8 Structure matrix.

Independent Variable	Function	
	1	2
Mar-3w	.428	-.723*
Mar-4w	.692*	.036
Apr-1w	.570*	.366
Apr-2w	.627*	.524
Apr-3w	.563*	.446
Apr-4w	.537*	.352
May	.391*	.345
Jun	.150	.312
July	.094	.218
Aug	.053	.181

*. Largest absolute correlation between each variable

(2) Unstandardized Canonical Discriminant

Canonical discriminant function coefficients are shown in Table 9. I can obtain the unstandardized canonical discriminant functions evaluated as group means. The centroids of the discriminant functions for each cluster are given in Table 10

$$F1 = 0.048 \times X_1 + 0.061 \times X_2 + 0.010 \times X_3 + 0.080 \times X_4 - 0.023 \times X_5 + 0.023 \times X_6 + 0.102 \times X_7 + 0.014 \times X_8 - 0.098 \times X_9 + 0.007 \times X_{10} - 16.065 \quad (2)$$

$$F2 = -0.069 \times X_1 - 0.018 \times X_2 - 0.010 \times X_3 + 0.119 \times X_4 + 0.005 \times X_5 - 0.062 \times X_6 + 0.053 \times X_7 + 0.072 \times X_8 + 0.031 \times X_9 + 0.071 \times X_{10} - 21.208 \quad (3)$$

Table 9 Canonical discriminant function coefficients.

Independent Variable		Function	
		1	2
Mar-3w	X_1	.048	-.069
Mar-4w	X_2	.061	-.018
Apr-1w	X_3	.010	-.010
Apr-2w	X_4	.080	.119
Apr-3w	X_5	-.023	.005
Apr-4w	X_6	.023	-.062
May	X_7	.102	.053
Jun	X_8	.014	.072
July	X_9	-.098	.031
Aug	X_{10}	.007	.071
(Constant)		-16.1	-21.2

Table 10 Functions at group centroids.

Cluster	Function	
	1	2
1	2.54	-.195
2	-.279	-.884
3	-4.03	-.268
4	-.285	1.68
5	-13.1	-.240

The unstandardized discriminant function and the clustering centers are represented in the following diagram (Fig. 15). Based on the use of these two discriminant functions to predict the classification, the correct rate was 95.4% (Table 11). This shows that the results of the cluster analysis can be successfully tested with discriminant functions.

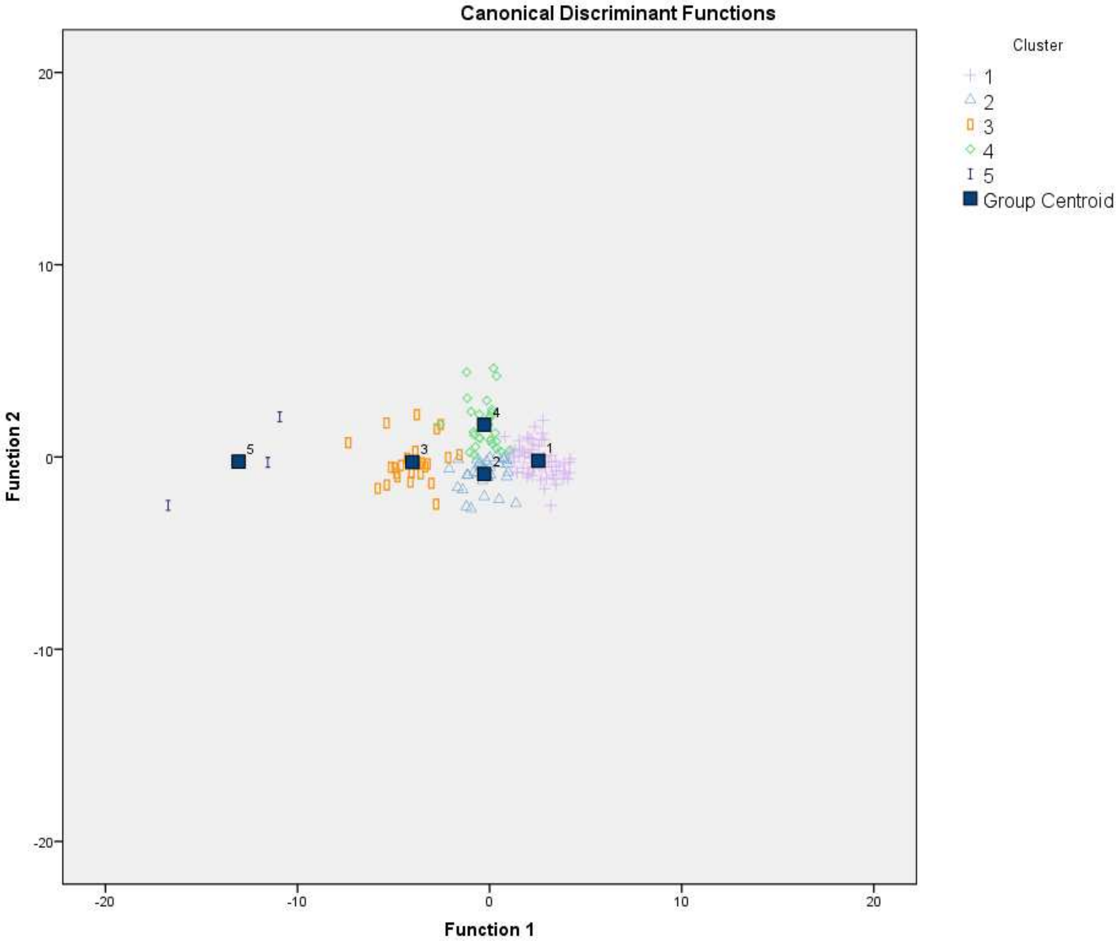

Fig. 15 Canonical discriminant functions.

Table 11 Classification results.

Cluster			Predicted Group Membership 1	2	3	4	5	Total
Original	Count	1	61	0	0	1	0	62
		2	0	33	0	0	0	33
		3	0	1	23	1	0	25
		4	1	3	0	25	0	29
		5	0	0	0	0	3	3
	%	1	98.4	0.0	0.0	1.6	0.0	100.0
		2	0.0	100.0	0.0	0.0	0.0	100.0
		3	0.0	4.0	92.0	4.0	0.0	100.0
		4	3.4	10.3	0.0	86.2	0.0	100.0
		5	0.0	0.0	0.0	0.0	100.0	100.0

95.4% of original grouped cases correctly classified.

From the results of the discriminant analysis prediction shown in Table 11, it can be seen that Cluster 1 and Cluster 4 each predicted the wrong set for one another. The two discriminant functions are relatively close in the distribution in Fig 15. Additionally, three of Cluster 4 were misclassified as Cluster 2 and one of Cluster 3 was misclassified as Cluster 2. The misclassified municipalities are all bordering each other in Table 11. In contrast, Clusters 2 and 5 have a 100% discrimination rate.

4.3 Determination of Road Recovery Patterns

4.3.1 Visualized Clusters on a Map and Gained Insights into Common Features

According to the results of the cluster analysis, municipalities with similar road recoveries were divided into five clusters. The cluster for each municipality is shown on the map (Fig. 16).

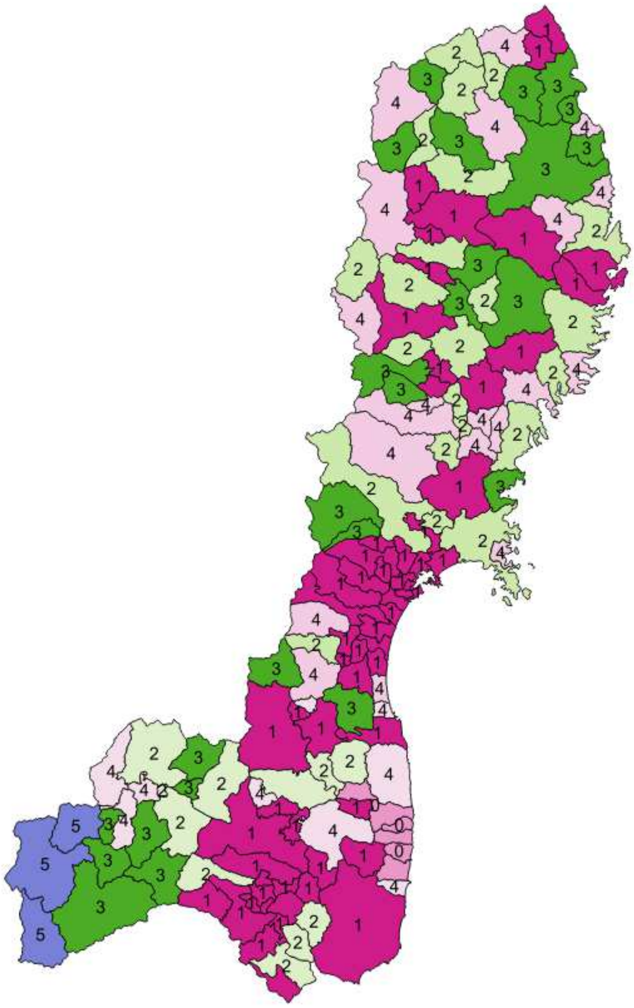

Fig. 16 Each municipality in the Tohoku region belongs to a cluster.

The order of the recovery reaching 90%, averaged for each cluster is 1 > 4 > 2 > 3 > 5 (Table 12, Fig. 17).

Table 12 Road recovery percentages in five clusters of the Tohoku region.

Cluster	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	July	Aug	Sep
1	64	82	89	**92**	94	96	97	98	99	99	100
2	54	68	75	80	83	88	**91**	94	96	98	100
3	31	49	61	66	72	78	87	**93**	95	99	100
4	34	69	82	88	**90**	92	95	97	99	99	100
5	1	6	29	33	39	50	68	**96**	98	98	100

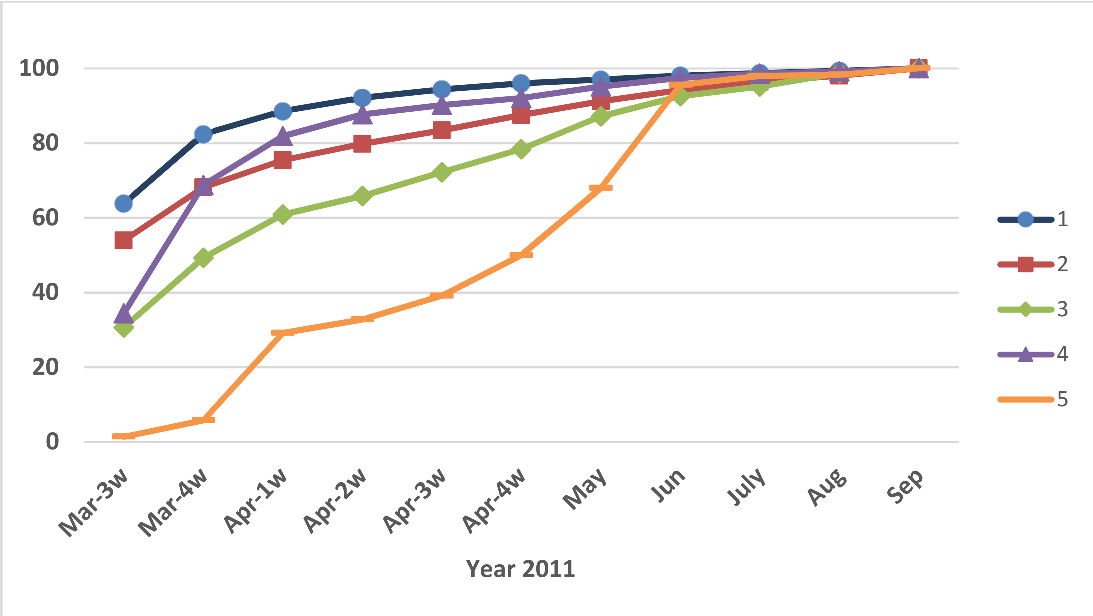

Fig. 17 Road recovery conditions of the five clusters in the Tohoku region.

Consider the order and characteristics of recovery of each cluster:

Cluster 1: The fastest recovery occurred in the major cities in the plains, where there are more main roads, followed by municipalities with fewer roads, which benefited from the “Teeth of a Comb” recovery policy.

Cluster 4: The second-fastest recovery is mainly concentrated in the coastal lowlands affected by the tsunami and in inland mountains affected by snow; roads recovered gradually after the road closures necessitated by the disaster were lifted.

Cluster 2: The speed of road recovery was intermediate compared to other clusters, and the distribution was similar to that of Cluster 4 but was mainly concentrated on the northern ria coast, which was more severely affected than the region in Cluster 4. In the inland areas, this cluster included municipalities in the plains with many routes that had suffered extensive earthquake damage; the road recovery was slow in municipalities in the mountains because of snow.

Cluster 3: The slowest recovery was observed for this cluster, mainly in the mountains, minor routes with relatively low population density. The recovery of road use was delayed possibly because of the restriction of traffic until the road closures in urban areas of the prefecture were lifted.

Cluster 5: The slowest recovery was observed in locations with heavy snowfall areas and mountainous locations. Note that in the inland Tohoku region, especially in the mountainous areas, roads are closed from the previous winter until June this year because of snow [31].

4.3.2 Objective Data Test

To prove my hypothesis, I collected data reflecting geographic location, topography, damage, recovery policy, the importance of roads, population density, and snow to examine their relationship with road recovery (Table 13). A total of 152 municipalities exists, 15 of which are shown here for reference. Refer to the Appendix for full data.

Table 13 Collection of actual data affecting road recovery factors.

Cluster	Municipality	Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
1	Takizawa-mura	1	1	5.6	0.02	0.04	295	0
1	Sumita-cho	2	3	5.1	0.03	0.08	18	2
2	Ishinomaki-shi	2	2	5.3	0.02	0.03	289	0
2	Osaki-shi	2	3	5.3	0.01	0.04	170	2
3	Iwaizumi-cho	1	4	4.2	0.04	0.06	11	2
3	Iwate-machi	2	3	4.7	0.02	0.02	42	0
3	Noda-mura	2	3	4.9	0.02	0.02	57	1
3	Tono-shi	2	3	5.3	0.02	0.04	37	4
4	Kawasaki-machi	1	2	6.2	0.00	0.09	37	1
4	Kurihara-shi	2	2	5.38	0.02	0.04	93	3
4	Onagawa-cho	2	3	5.38	0.06	0.06	153	0
4	Ichinoseki-shi	2	2	5.8	0.02	0.05	127	1
5	Kaneyama-machi	2	3	3.3	0.00	0.10	8	4
5	Hinoemata-mura	2	3	3.5	0.00	0.13	2	4
5	Tadami-machi	2	3	3.8	0.00	0.13	7	4

The individual factors are described as follows.

Type of municipality: In terms of geographic location, roads in major municipalities were generally prioritized for rehabilitation over other municipalities as seen in Cluster 1. Major municipalities are generally the principal cities and surrounding municipalities, denoted by 1 in the dataset, and other cities are denoted by 2.

Type of terrain: For topography, I classified the type of terrain to which the municipality belongs into four categories, with 1 in the database indicating that more than three-quarters of the terrain is plains, 2 indicating that it is half plains and half mountainous, 3 indicating that three quarters is mountainous, and 4 indicating that it is entirely mountainous.

Measuring seismic intensity: For damage, earthquake seismicity is often used as a criterion for predicting damage [32]. I collected measured seismic intensities from the Japan Meteorological Agency for each municipality in the Tohoku region for the 2011 Tohoku Earthquake [33].

Priority road restoration occupancy: For recovery policy, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) implemented a road opening policy called “Teeth of a Comb” [2] on the second day after the Tohoku earthquake, as the Tohoku coast was severely hit by the tsunami. The main roads were National Routes 4, 6, and 45 in the vertical direction and National Routes 395, 281, 455, 106, 283, 107, 343, 284, 398, 108, 115, 459, 114, 288, 49, and 289 in the horizontal direction. I calculated the ratio of road distances to total road distances for each municipality participating in the recovery policy via GIS.

Proportion of important roads: For the importance of roads, I calculated the distances of highways and national roads that were given priority for restoration after the disaster as a percentage of the total distance of roads in the municipality.

Population density: For population density, it can be obtained using census data [34]. Here I used data from 2010, the year before the Tohoku earthquake as a reference.

Roads closed due to snow: For the snow factor, I calculated the closed roads in each municipality from the information on winter closure routes in the Tohoku region [31].

I imported Table 13 into SPSS Statistics software and used Pearson correlation analysis to see how these seven factors specifically influenced the recovery of each cluster. From Table 14, all factors are significantly correlated with clusters, except for priority road restoration occupancy whose significance is greater than 0.05. In terms of the absolute value of Pearson's correlation coefficient, the order of correlation for each factor and cluster is type of terrain, proportion of important roads, roads closed due to snow, population density, seismic intensity, and type of municipality. This shows the relationship between the influences of these six factors on road recovery patterns.

Table 14 Correlations

		Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
Cluster	Pearson Correlation	.264**	.520**	-.328**	.080	.419**	-.344**	.405**
	Sig.	**.001**	**.000**	**.000**	.326	**.000**	**.000**	**.000**
	N	152	152	152	152	152	152	152

Chapter 5

Predicted Road Recovery in the Tokai Region Based on Data from the 2011 Tohoku Earthquake

In this section, I analyzed and quantified the various influencing factors of each pattern of road recovery. By using a database, I developed a new forecasting model that can be applied to other regions by geographic information system (GIS) mapping of regional characteristics and road recovery in the Tokai region. My research flow of predictive model construction is shown in Fig. 18.

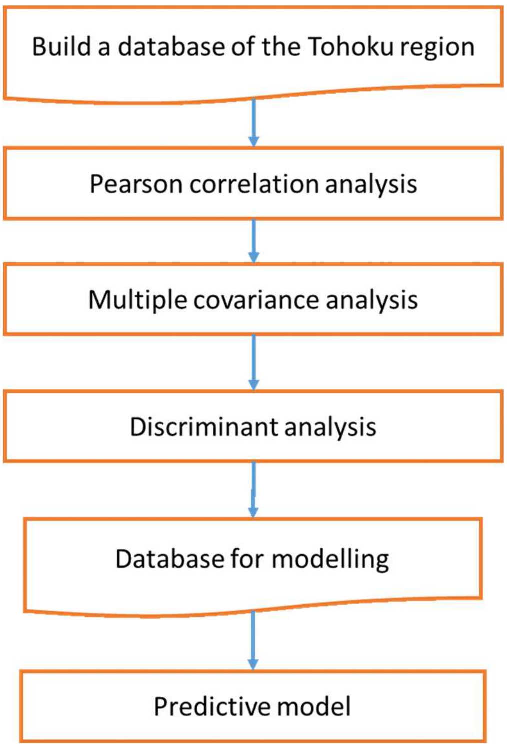

Fig. 18 Flowchart of predictive model construction.

5.1 Building of Database of the Tohoku Region

To quantify the influencing factors of each pattern of road recovery, I collected geographic location, topography, damage, recovery policy, road importance, population density, and snow data (Table 15, Table 16, and Table 17). Although the influencing factors reflect the results of previous studies in the three prefectures in the Tohoku region, they can be applied to the three prefectures in the Tokai region, which is my main consideration. Cases of 152 municipalities in the Tohoku region were found; however, only 10 are shown here for reference. Refer to the Appendix for full data. The data were conceived, collected, and calculated as follows:

Table 15 Database of the Tohoku region (1).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
1	Iwanuma-shi	2	4.18	340	12.74	60.71	1	0.80
1	Kakuda-shi	2	4.17	329	7.80	147.58	2	0.67
1	Misato-machi	2	5.03	396	10.62	75.06	2	1.00
1	Murata-machi	1	4.20	344	9.40	78.41	3	0.23
1	Natori-shi	1	4.25	345	13.43	100.07	1	0.66
1	Ohira-mura	2	4.85	391	7.83	60.19	2	0.42
1	Osato-cho	2	4.67	380	7.13	82.02	2	0.66
1	Rifu-cho	1	4.52	368	12.93	44.75	2	0.42
1	Shibata-machi	2	4.33	343	14.13	53.98	2	0.70
1	Shiogama-shi	2	4.57	365	19.88	17.86	1	0.81

Table 16 Database of the Tohoku region (2).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
1	Iwanuma-shi	0.06	0.86	0.10	0.03	0.00	5.9
1	Kakuda-shi	0.12	0.79	0.17	0.04	0.00	5.8
1	Misato-machi	0.00	1.00	0.00	0.00	0.00	5.5
1	Murata-machi	0.18	0.41	0.37	0.21	0.00	5.4
1	Natori-shi	0.09	0.75	0.21	0.05	0.00	6.1
1	Ohira-mura	0.42	0.84	0.15	0.01	0.00	6
1	Osato-cho	0.30	0.96	0.04	0.00	0.00	5.6
1	Rifu-cho	0.44	0.86	0.14	0.00	0.00	5.6
1	Shibata-machi	0.12	0.83	0.13	0.04	0.00	5.4
1	Shiogama-shi	0.17	0.98	0.02	0.00	0.00	6

Table 17 Database of the Tohoku region (3).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
1	Iwanuma-shi	0.00	0.01	0.01	727.80	367.06	1.72
1	Kakuda-shi	0.00	0.00	0.02	212.30	103.45	1.72
1	Misato-machi	0.00	0.01	0.02	335.60	120.86	1.72
1	Murata-machi	0.00	0.02	0.03	153.00	76.23	1.72
1	Natori-shi	0.00	0.01	0.02	730.80	313.73	3.36
1	Ohira-mura	0.00	0.02	0.04	88.60	79.08	1.04
1	Osato-cho	0.00	0.00	0.00	108.80	48.35	1.72
1	Rifu-cho	0.00	0.00	0.05	759.60	273.21	1.72
1	Shibata-machi	0.00	0.01	0.01	728.80	294.00	1.72
1	Shiogama-shi	0.00	0.02	0.02	3162.90	1302.30	4.26

5.1.1 Dependent Variable

As shown by cluster analyses of vehicle driving data in the Tohoku region (Fukushima, Miyagi, and Iwate prefectures) during the second half of the 2011 Tohoku earthquake, regional characteristics and other factors affected road recovery at section 4.3.1 [35]. To facilitate statistical analysis, I have reordered the clusters. (Fig. 19).

In case the recovery speed reached 90%, the average recovery speed for each cluster is as follows: 1 > 2 > 3 > 4 > 5 (Fig. 20). The order and characteristics of the clusters' recoveries are as follows:

Cluster 1: The fastest recovery was performed in the major cities in the plains, which had many main roads, followed by municipalities, which had fewer roads. This cluster benefited from the "Teeth of a Comb" recovery policy. This operation involved road clearance to secure, rescue, and relief routes on many national highways, extending from inland areas toward the Pacific coastal area of Tohoku. The road is shaped like the teeth of a comb, hence the name.

Cluster 2: The second fastest recovery was mainly concentrated in the coastal lowlands affected by the tsunami and inland mountains affected by snow. The roads recovered gradually after the disaster road closures were lifted.

Cluster 3: The speed of road recovery was moderate compared with that in other clusters, and the distribution was similar to that of Cluster 2. However, the recovery in Cluster 3 was mainly concentrated in the northern rias coast, which was more severely affected than Cluster 2. Many routes in the municipalities in the inland plains suffered considerable earthquake damage. The road recovery in municipalities in the mountains was slowed by snow.

Cluster 4: This cluster exhibited slow recovery. The areas in this cluster are mainly in the mountains, had non-main routes, and had relatively low population densities. The delay in the recovery of road use may have been due to the restriction of traffic, which remained until the road closures in the urban areas of the prefectures were lifted.

Cluster 5: Consisting of heavy-snowfall areas and mountain locations, this cluster exhibited the slowest recovery.

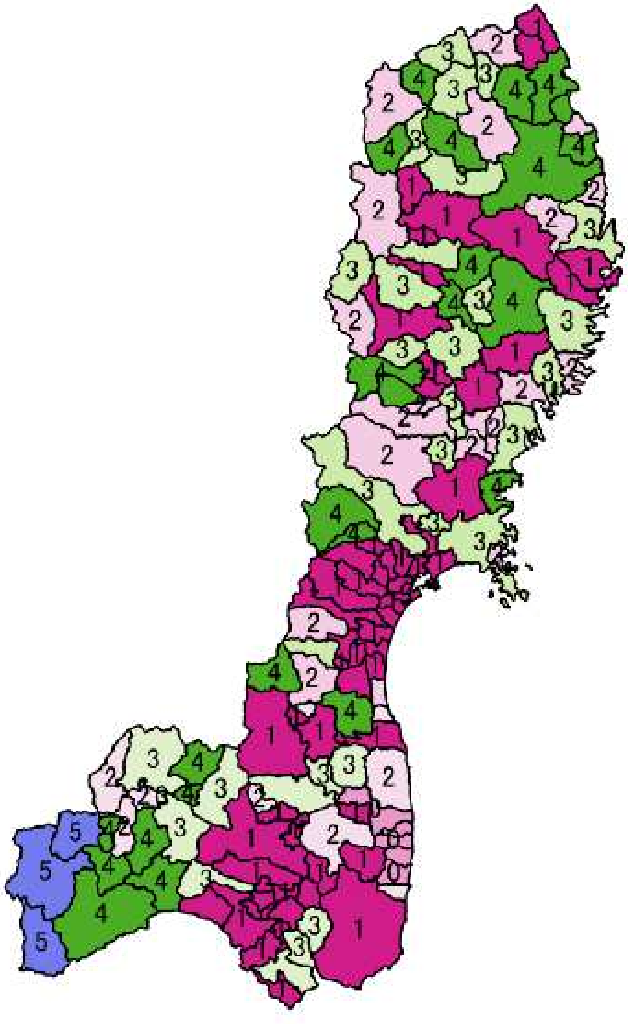

Fig. 19 Road recovery speed in the five clusters in the Tohoku region.

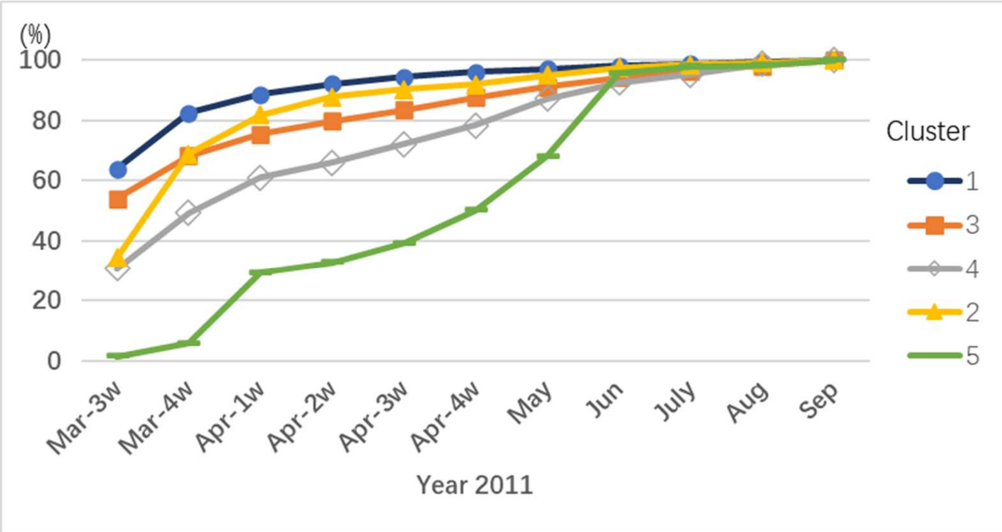

Fig. 20 Road recovery conditions in the five clusters in the Tohoku region.

5.1.2 Independent Variable

(i) Geographic location

Type of municipality: According to previous studies [22], [23], roads in major municipalities are generally prioritized for rehabilitation over other municipalities. Major municipalities are typically principal cities and their surrounding municipalities. Principal cities are denoted as 1 in the dataset, and other cities are denoted as 2.

Time and distance to Tokyo: The distance and time taken to travel from Tokyo to the municipal office of each Tohoku city after the Tohoku earthquake were also used as a reference.

Area: The area of each municipality was calculated using a GIS software.

Distance area ratio: The ratio of road distance and area in the municipality was also used as an indicator affecting road rehabilitation. For the road distances, I used road centerline data from 2006 [36] for calculation.

(ii) Topography

Type of terrain: I classified the type of terrain of each municipality into four categories. In the database, 1 indicates that more than three quarters of the terrain is plains, 2 means half plains and half mountainous, 3 indicates that three quarters is mountainous, and 4 means all mountainous.

Area share of elevation range: One quarter of Japan's area and 80% of its population are below 100 m in elevation [37]. In the Tohoku region, Iwate and Fukushima prefectures are more mountainous, whereas Miyagi prefecture has more plains. The three studied prefectures in the Tokai region are similar to those in the Tohoku region in terms of elevation; Mie and Shizuoka prefectures have more mountains, whereas Aichi prefecture has more plains. To show the characteristics of each municipality, I divided the elevations into six ranges: <50 m, 50≤100 m, 100≤200 m, 200≤500 m, and ≥500 m. I used digital elevation model data [36] to calculate the percentage of area occupied by each municipality at each elevation using the GIS.

(iii) Damage

Measured seismic intensity: Earthquake seismicity is often used as a criterion for predicting damage [32]. I collected measured seismic intensities of the 2011 Tohoku earthquake from the Japan Meteorological Agency for each municipality in the Tohoku region [33].

Damage rate: Related studies used road damage rates for evaluating road recovery [38], [39]. These rates are derived from information provided by prefectural office road management departments on road closures due to earthquakes. In my previous study [24], I calculated the road damage rate of each municipality in Fukushima prefecture. In the current work, I also calculated the road damage rate in Iwate and Miyagi prefectures using the following equation:

$$\mathrm{R} = \frac{X}{L} \tag{4}$$

The damage rate R (cases per kilometer) is calculated by dividing the number of cases of damage to road structures X for a given seismic intensity by the distance of the road extension L (kilometers).

(iv) Recovery policy

Priority road restoration occupancy: On the following day of the Tohoku earthquake, the Ministry of Land, Infrastructure, Transport, and Tourism implemented a road clearance policy called "Teeth of a Comb" [2], as the Tohoku coast was severely hit by the tsunami. The main roads were National Routes

4, 6, and 45 in the vertical direction and National Routes 395, 281, 455, 106, 283, 107, 343, 284, 398, 108, 115, 459, 114, 288, 49, and 289 in the horizontal direction. I calculated the ratio of the affected road distances to the total road distances of each municipality participating in the recovery policy via the GIS.

(v) Road importance

Proportion of important roads: The highways and national roads were prioritized for restoration after the disaster, and I calculated their distances as a percentage of the total distance of the roads in the municipalities for reference.

(vi) Population density

Population density and employee density: These were used as indicators for major cities. Roads in dense municipalities should be prioritized for restoration. These indicators can be obtained from the national situation survey [34]. Here, I used data from 2010, the year before the Tohoku earthquake, as reference.

(vii) Snow

Minimum temperature: According to my previous studies [22], [23], most roads with slow recovery are in mountainous and snowy areas. Therefore, snow-related parameters are important; I initially considered the average snowfall per municipality. However, the Tokai region is in southern Japan, where snow is scarce. Considering the data available for the prediction model, I shifted the snowfall to the average monthly minimum temperature. These data are also available from the Japan Meteorological Agency [40]. Here, I used data from 2010 as reference.

5.2 Parameter Screening and Determination

The database contains 19 independent variables, but not all of them were required to be entered into my prediction model. I selected the parameters that are relevant to the impact of the recovery speed. Therefore, I analyzed the specific relationships affecting the recovery factors and speed.

5.2.1 Pearson Correlation Analysis

I used Pearson correlation analysis, the factors affecting road recovery as the independent variables, and road recovery patterns as the dependent variable. The significance probability between the independent and dependent variables was less than 0.05, indicating statistical significance. The SPSS correlation test showed that four independent variables were not significantly correlated with the dependent variable and were not statistically significant, so these independent variables were eliminated (Table 18). An absolute value of the Pearson's correlation coefficient over 0.5 indicates a strong correlation, between 0.3 and 0.5 a medium correlation, and below 0.3 a weak correlation.

The magnitude of the correlation between each independent variable and the dependent variable is summarized in Table 19.

Table 18 Independent variables that are not significantly correlated with the dependent variable.

Parameter	Sig.
Elevation 100m-200m	.823
Elevation 200m-500m	.769
Priority road restoration occupancy	.658
Damage rate	.754

Table 19 Correlation between independent and dependent variables.

Parameter	Pearson Correlation	Relevance
Type of terrain	.671**	Strong
Measured seismic intensity	-.560**	
Distance area ratio	-.546**	
Minimum temperature	-.507**	
Elevation >500m	.443**	Medium
Population density	-.358**	
Elevation <100m	-.352**	
Elevation <50m	-.343**	
Proportion of important roads	.341**	
Employee density	-.327**	
Area	.256**	Weak
Time to Tokyo	.246**	
Type of municipality	.222**	
Elevation 50m-100m	-.195*	
Distance to Tokyo	.192*	

5.2.2 Multiple Covariance Analysis

Correlation was also observed between the independent variables. Pearson correlation coefficients with absolute values greater than 0.5 indicate a possible covariance; multiple covariance analysis was performed to identify independent variables with covariance (Table 20). The collinearity diagnostics between each independent variable was tested using SPSS (Table 21) and excluded based on independent variables that were weakly correlated with the dependent variable. Four independent variables, namely, time to Tokyo, distance to Tokyo, population density, and employee density, exhibited a variance inflation factor (VIF) over 10. Collinearity was found between time to Tokyo and distance to Tokyo and between population density and employee density. Moreover, their correlations with the dependent variable were similar (Table 19). Hence, I entered them into my model separately and determined which one demonstrated a high prediction accuracy before selecting which independent variable to keep.

Table 20 Breakdown of Pearson correlation coefficients between independent variables with absolute values greater than 0.5.

	Time to Tokyo	Distance area ratio	Type of terrain	Elevation <50m	Elevation 50m-100m	Elevation <100m	Elevation >500m	Population density
Distance to Tokyo	.991**							
Type of terrain		-.751**						
Elevation <50m		.625**						
Elevation <100m		.617**		.953**	.614**			
Elevation >500m		-.624**				-.571**		
Measuring seismic intensity		.506**	-.513**					
Proportion of important roads		-.502**					.544**	
Population density		.727**		.606**		.547**		
Employee's density		.649**		.540**				.954**
Minimum temperature							-.523**	

Table 21 Collinearity statistics

Parameter	VIF
Time to Tokyo	87.779
Distance to Tokyo	85.473
Type of terrain	2.162
Elevation <50m	2.084
Elevation 50m-100m	1.494
Elevation >500m	2.724
Measured seismic intensity	1.948
Proportion of important roads	1.730
Population density	13.389
Employee density	11.716
Minimum temperature	1.754

5.3 Application of General Discriminant Analysis for Construction of Road Recovery Prediction Model

I integrated the model through general discriminant analysis in SPSS, which produced the analysis directly (Table 22). For cases with low accuracy, I adjusted the added parameters to determine which combinations of parameters produced the highest accuracy (Table 23). Additionally, the cross-validation rate changed as different parameters were added.

Table 22 Classification Results of the Predictive Model.

Cluster		Predicted Group Membership					Total
		1	2	3	4	5	
Count	1	47	6	6	3	-	62
	2	3	20	6	-	-	29
	3	4	6	22	1	-	33
	4	-	1	4	18	2	25
	5	-	-	-	-	3	3
Accuracy (%)	1	75.8	9.7	9.7	4.8	-	100.0
	2	10.3	69.0	20.7	-	-	100.0
	3	12.1	18.2	66.7	3.0	-	100.0
	4	-	4.0	16.0	72.0	8.0	100.0
	5	-	-	-	-	100.0	100.0

Table 23 Experimental results of discriminant analysis with different combinations of parameters.

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Type of municipality	✓	✓	✓					
Minimum temperature	✓	✓	✓	✓	✓	✓	✓	✓
Time to Tokyo		✓	✓	✓	✓	✓		
Distance to Tokyo	✓							
Area	✓	✓	✓	✓	✓	✓	✓	
Type of terrain	✓	✓	✓	✓	✓	✓	✓	✓
Elevation <50m	✓	✓	✓	✓	✓	✓		
Elevation 50m-100m	✓	✓	✓	✓	✓	✓	✓	
Elevation <100m								✓
Elevation >500m	✓	✓	✓	✓	✓	✓	✓	✓
Measuring seismic intensity	✓	✓	✓	✓	✓	✓	✓	✓
Population density	✓	✓		✓				
Employee density			✓		✓	✓	✓	✓
Proportion of important roads	✓	✓	✓	✓	✓	✓		✓
Distance area ratio	✓	✓	✓	✓	✓	✓	✓	✓
Total	12	12	12	11	11	11	8	8
Accuracy(%)	69.1	69.1	69.1	71.1	71.1	72.4	72.4	72.4
Cross-validation(%)	59.9	60.5	60.5	60.5	61.2	61.8	63.2	64.5

5.4 Confirmation of Model Parameters, Creation of Database for Tokai Region, and Prediction of Recovery

After all the independent variables to be used in the simulation model were identified (Table 24), data on these variables for each municipality in the study area were collated into a database and were used in the prediction of recovery (Table 25). The data collection sources for the Tokai region were essentially the same as in Section 3.1 except for three differences. First, the road distance for the Tokai region was calculated using the 2020 version of the road centerline. Second, the measured seismic intensity was derived from the predicted seismicity distribution for the Tokai region by the Cabinet Office, Government of Japan [41]. Third, the population and employee densities of the Tokai region were obtained from the 2015 national situation survey [34].

Table 24 Database for modeling.

Cluster	Municipality	Minimum temperature	Type of terrain	Elevation <100m	Elevation >500m	Employee density	Measured seismic intensity	Proportion of significant roads	Distance area ratio
1	Natori-shi	3.36	1	0.75	0.00	313.73	6.1	0.02	13.43
1	Rifu-cho	1.72	2	0.86	0.00	273.21	5.6	0.05	12.93
1	Tome-shi	0.77	2	0.71	0.00	66.08	5.5	0.04	5.94
1	Soma-shi	3.15	2	0.55	0.15	89.71	5.7	0.04	7.99
1	Iwaki-shi	5.37	2	0.35	0.29	124.70	5.5	0.04	6.11
1	Date-shi	1.90	1	0.27	0.06	96.35	5.5	0.03	7.65
3	Shiwa-cho	-0.48	2	0.08	0.15	45.88	4.9	0.03	6.72
4	Towa-cho	-0.64	3	0.01	0.04	16.59	5.3	0.03	8.88
4	Kuji-shi	0.43	4	0.26	0.11	48.00	4.6	0.04	4.30
4	Tono-shi	-1.58	3	0.00	0.64	14.64	5.3	0.04	2.80
2	Otama-mura	0.61	3	0.00	0.46	32.83	5.38	0.02	6.29
2	Tamura-shi	-0.41	3	0.00	0.55	33.07	5.38	0.03	5.39
2	Asiro-cho	-2.54	3	0.00	0.64	4.82	5.38	0.09	2.11
2	Fudai-mura	-0.02	3	0.16	0.03	12.98	5.3	0.05	4.91
2	Sanriku-cho	0.61	3	0.25	0.15	14.53	5.38	0.04	4.08

Table 25 Predicted results of the road recovery pattern in the Tokai region.

Cluster	1	2	3	4	5	Total
Number of municipalities	122	3	15	1	-	141
Percentage (%)	86.5	2.1	10.6	0.7	-	100.0

The accuracy rate of my model was 72.4%. The following parameters were chosen for the model: percentage of terrain, percentage of area above 100 m elevation, percentage of area below 500 m elevation, measured seismicity, percentage of important roads, percentage of area at a distance from roads, minimum temperature, and employee density. According to my results (Table 22 and Fig. 21), the prediction accuracy for Clusters 2 and 3 was relatively low. These clusters may be similar in terms of recovery speed and distribution in some areas. Their existing regional characteristics are not sufficient to fully distinguish them. By contrast, Cluster 1 is a major city in the plains, and Clusters 4 and 5 are in the mountains; these features can be clearly distinguished in the model.

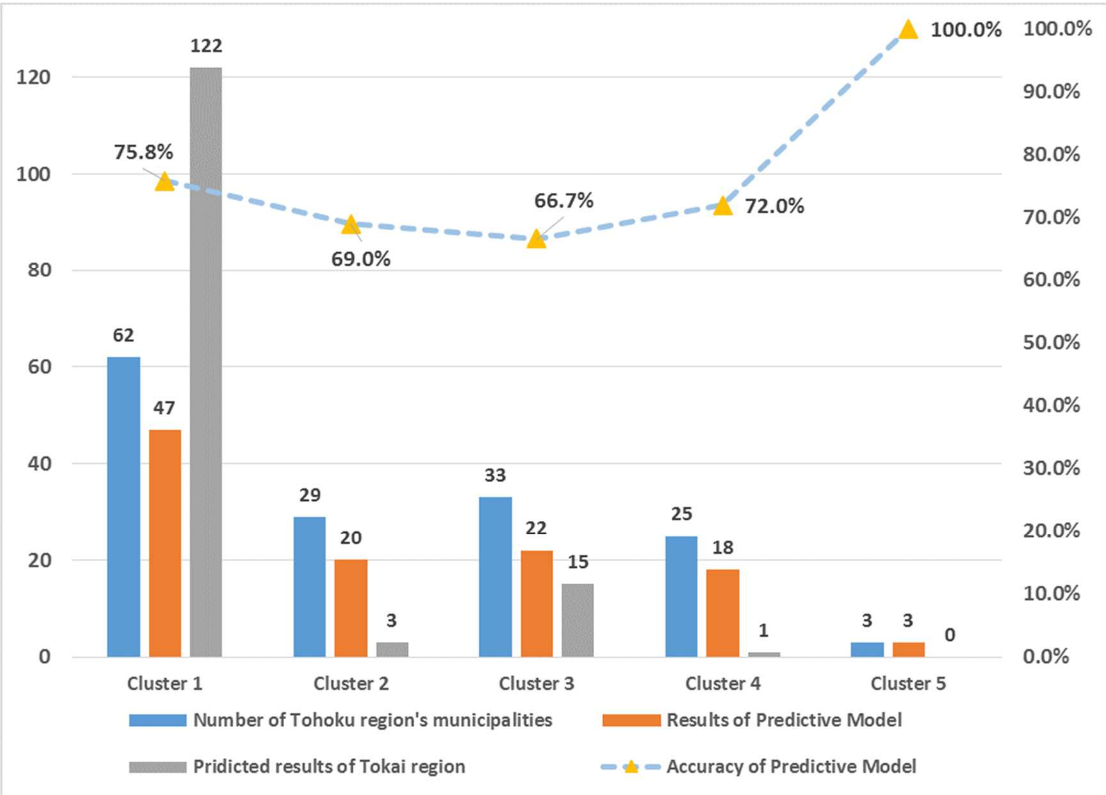

Fig. 21 Comparison of the Tohoku region, predictive models, and the Tokai Region in clusters.

I employed this model to predict municipal road recovery in the Tokai region after the expected Nankai Trough earthquake, and the recovery was mapped using a GIS software (Fig. 22).Only four types of municipal road recovery exist in the Tokai region (Table 25). The distribution characteristics are as follows:

Cluster 1: Most of the municipalities fall into the fast-recovery cluster. The main roads and developed areas of the Tokai region are concentrated in Cluster 1 (Fig. 22).

Cluster 2: This cluster has three municipalities that are located in areas with strong predicted seismicity.

Cluster 3: This cluster is mainly concentrated in the mountainous areas in Shizuoka prefecture. It also lies on the coast of Mie prefecture, which also has a ria coast.

Cluster 4: Only one municipality exists in this slow-recovery cluster. This is the location of Mt. Fuji, and it exhibits the highest latitude and lowest temperature.

The predicted results for the Tokai region match the results of the previous classification of the Tohoku region. In practice, however, most municipal roads will be restored in Cluster 1, and they may not be restored simultaneously in the event of a severe earthquake and a major tsunami.

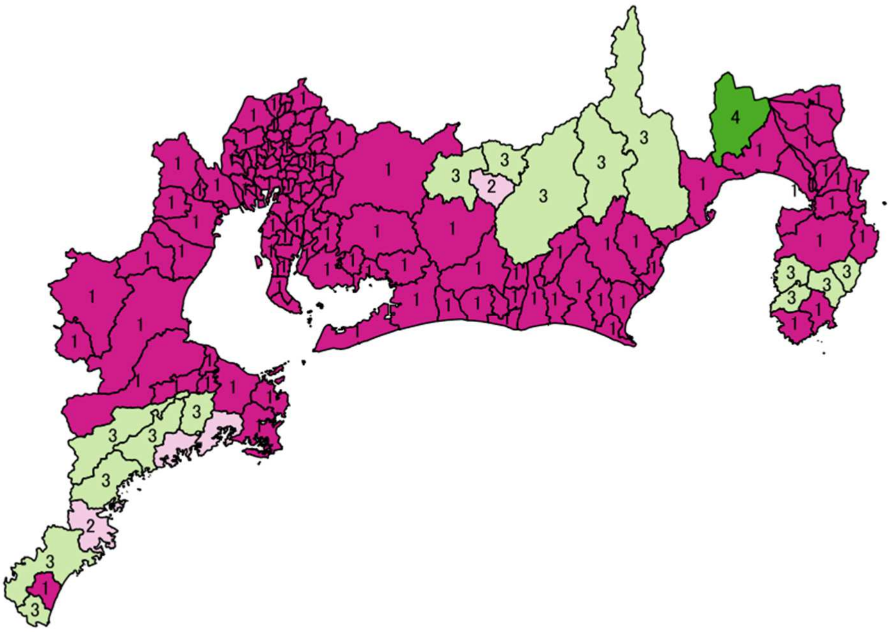

Fig. 22 Predicted results for road recovery in the Tokai region.

Chapter 6

Re-clustering the Three Tohoku Prefectures Separately Based on Coastal or Inland

Concerning the examination of other influencing factors, the previous cluster analysis of the Tohoku region as a whole has revealed that the characteristics of coastal and inland municipalities within the same category are different. In particular, coastal municipalities were hit hard by the tsunami, and road recovery was slower than inland. Previous studies on Fukushima prefecture have also shown that recovery is not the same in coastal and inland areas [19]. At the same time, to avoid an overconcentration of a single cluster in the forecast results for the three Tokai prefectures, I subdivided the forecast model into several more clusters. Hence, I considered re-clustering the three Tohoku prefectures separately based on coastal or inland.

The research materials and areas were the same as in section 3.1, namely the vehicle tracking maps that were collected in the three Tohoku regions following the 2011 Tohoku earthquake. However, this study is for 35 municipalities along the coast and 117 municipalities inland respectively. Their road restoration rates were analyzed separately in clusters.

6.1 Data Processing

The first three steps are the same as outlined in section 4.1. Using these cumulative distance data, I obtained the percentage of road use recovery in each municipality. I introduced the percentages into SPSS Statistics software and used Ward's method with the Squared Euclidean distance as the measurement interval in hierarchical cluster analysis to produce a classification dendrogram. The number of clusters was chosen according to the stopping rule (a large percentage drop in the agglomeration coefficients followed by a plateau). The best clustering result for coastal municipalities was four clusters (Fig. 23), while for inland municipalities it was three clusters (Fig. 24). The results were also confirmed by visual inspection of the dendrogram.

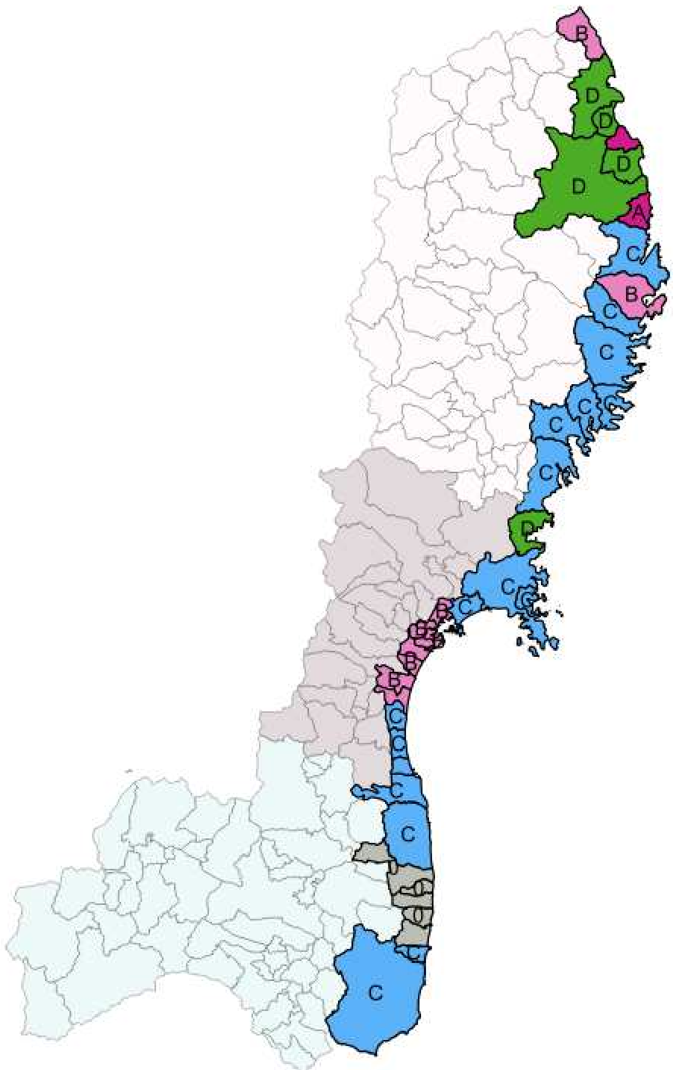

Fig. 23 The four coastal clusters in the Tohoku region.

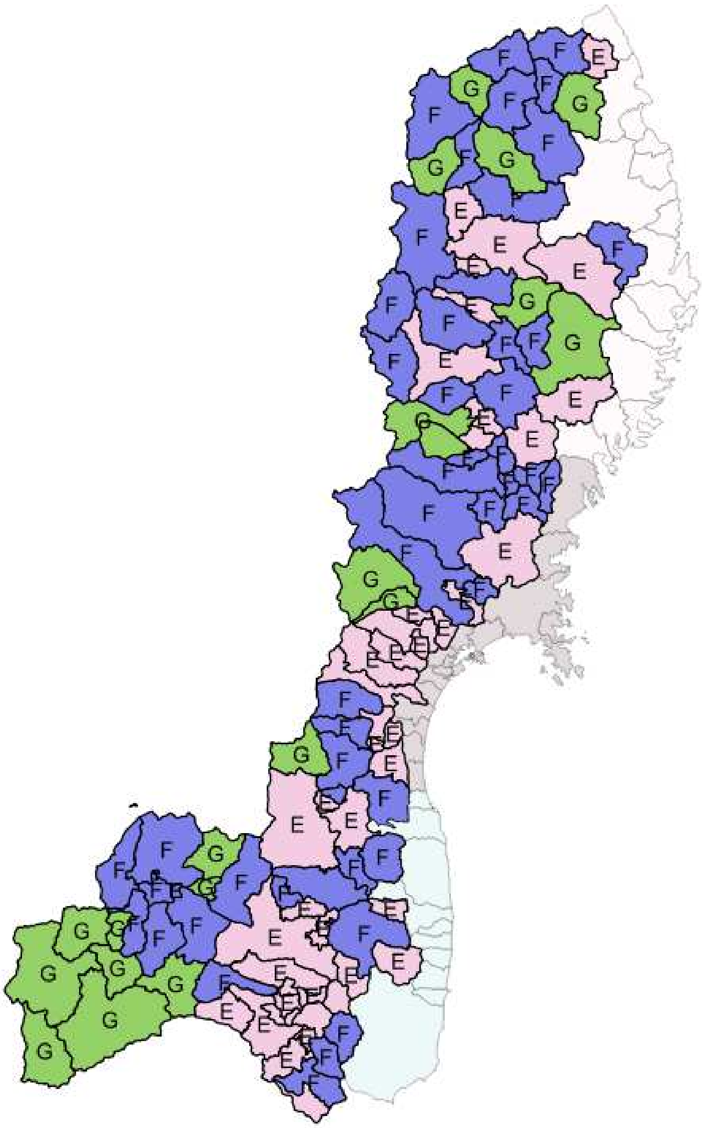

Fig. 24 The three inland clusters in the Tohoku region.

6.2 Results and Discussion

In addition, I examined the clustering results by visualizing them on a map through GIS.

1) For the four clusters in the coastal area (Fig. 23), ranked by road restoration rates reaching 90%, I observed the following:

Cluster A: Only two municipalities along the coast had their roads recovered as a part of this fastest cluster. The reason for this is that the breakwaters are high in those municipalities, and they did not receive the full effects of the tsunami.

Cluster B: Municipalities in Cluster B are mainly concentrated in densely populated areas in the coastal lowlands of Miyagi prefecture and municipalities with high breakwaters in Iwate prefecture. Densely populated main roads are considered to be in need of priority restoration.

Cluster C: Mainly concentrated in the areas more severely affected by the tsunami. The impact of the tsunami had slowed the recovery of this cluster.

Cluster D: Municipalities in Cluster D are mainly concentrated in mountainous areas more severely affected by the tsunami. I think the effects of the tsunami and geographical location made this cluster the slowest to recover.

2) For the three clusters in the inland area (Fig. 24), ranked by road restoration rates reaching 90%, I observed the following:

Cluster E: Municipalities that generally have major roads. This fits in well with the government restoration policy "Teeth of a Comb". The main inland roads were given priority for restoration followed by the national roads linking the coast.

Cluster F: Mainly municipalities in mountainous areas with low population density. Roads with less concentrated populations are not considered to have recovered so quickly.

Cluster G: Municipalities in Cluster G are mainly concentrated in mountainous areas with heavy snowfall. Roads were slow to recover due to residual snow.

I also ranked the overall restoration rates for all coastal and inland municipal roads in the order that they reached 90% (Fig. 25). The overall order was found to be Clusters A, B, E, C, F, G, and D. After comparing the results for the whole Tohoku region about re-clustering (Fig. 26) and the original clusters, the order changed. In my previous cluster analysis of the road

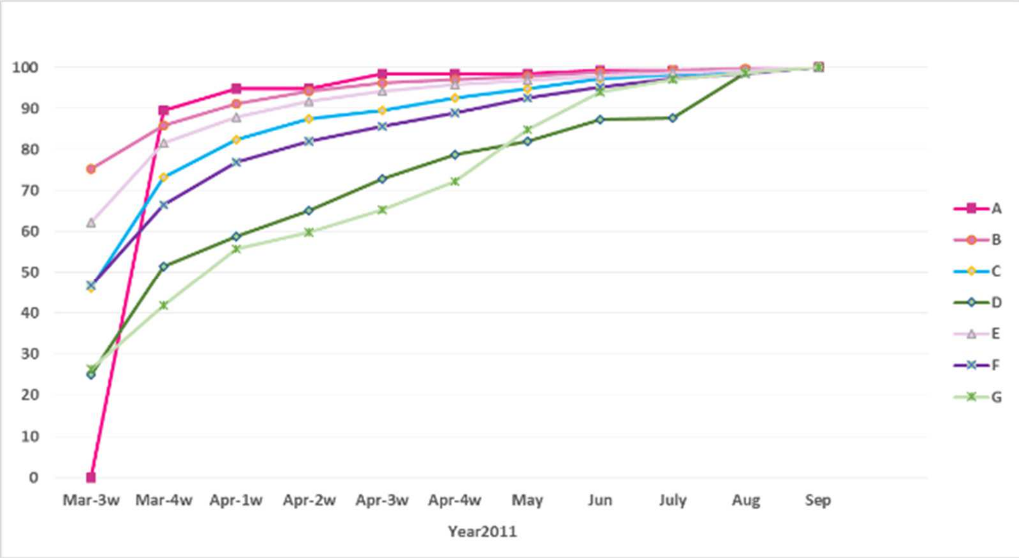

Fig. 25　The road recovery speed of the seven clusters in the Tohoku region.

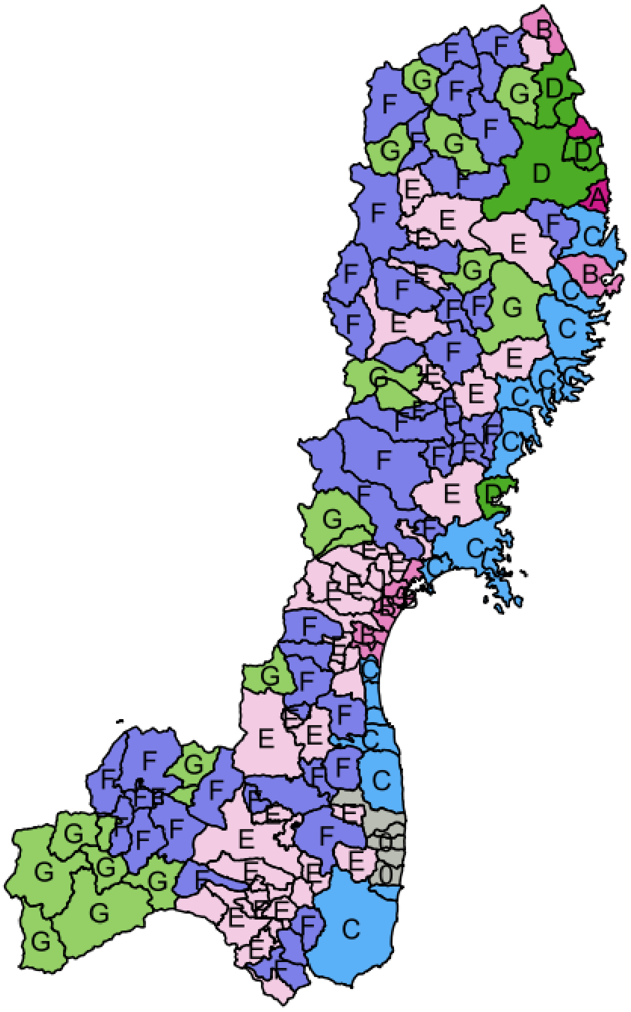

Fig. 26　The seven clusters in the Tohoku region.

recovery in municipalities throughout Tohoku, the slowest recovery was in the heavy snowfall areas. Now that the clustering analysis has been conducted separately for coastal and inland areas, the slowest recovery overall has been in the higher terrain areas along the coast.

In addition, with this new classification, I found previously ignored influences such as breakwaters. Apparently, even within the same cluster, the characteristics of the coastal and inland areas were different. This is more in line with the reality that the coast was heavily affected by the tsunami. Separating the coastal and inland analyses to capture the different features and explore the different influences would help improve the accuracy of the prediction as a model.

My previous research framework as described in section 5 used Pearson correlation analysis, multiple covariance analysis, and general discriminant analysis to screen variables (Fig. 18). The process is more complex, and the accuracy is only 72.4%. Stepwise discriminant analysis can also automatically filter variables. In this study, I attempted to use Stepwise discriminant analysis with the intention of simplifying the process and improving accuracy.

6.3 Predicted Road Restoration in the Tokai Region

Next, I used the previous database (Table 15, Table 16, and Table 17) which I had compiled a total of 19 variables representing the factors of geographic location, topography, damage, recovery policy, road importance, population density, and snow data for the Tohoku region and used it to predict road restoration in the three Tokai prefectures. The difference is that I have separated the coastal and inland forecasts in this study. For my Tokai study, however, I separated coastal and inland forecasts in order to obtain a more accurate picture of road recovery.

In the coastal municipalities, Stepwise discriminant analysis filtered the three remaining variables of road density, topography and measured seismicity. Data on these three variables were also collected by coastal municipalities in the Tokai region for prediction purposes.

The prediction accuracy for the coastal area is 80% (Table 26). And the predictions along the coast are shown in Fig.8. The distribution characteristics are as follows:

Cluster B: It is mainly concentrated in the lowlands of Aichi prefecture and other areas with dense roads.

Cluster C: These are expected to be areas affected by a tsunami.

Cluster D: These are expected to be areas affected by a tsunami while on higher ground.

Table 26 Predicted results for the coast in the Tokai region.

Cluster			Predicted Group Membership				Total
			A	B	C	D	
Original	Count	A	2	0	0	0	2
		B	1	8	1	1	11
		C	2	1	14	0	17
		D	1	0	0	4	5
		Tokai coastal	0	25	24	9	58
	%	A	100.0	0.0	0.0	0.0	100.0
		B	9.1	72.7	9.1	9.1	100.0
		C	11.8	5.9	82.4	0.0	100.0
		D	20.0	0.0	0.0	80.0	100.0
		Tokai coastal	0.0	43.1	41.4	15.5	100.0
Cross-validated	Count	A	1	0	1	0	2
		B	1	7	2	1	11
		C	2	2	12	1	17
		D	1	0	1	3	5
	%	A	50	0	50	0	100
		B	9.1	63.6	18.2	9.1	100.0
		C	11.8	11.8	70.6	5.9	100.0
		D	20.0	0.0	20.0	60.0	100.0

a. 80.0% of original grouped cases correctly classified.

b. 65.7% of cross-validated grouped cases correctly classified.

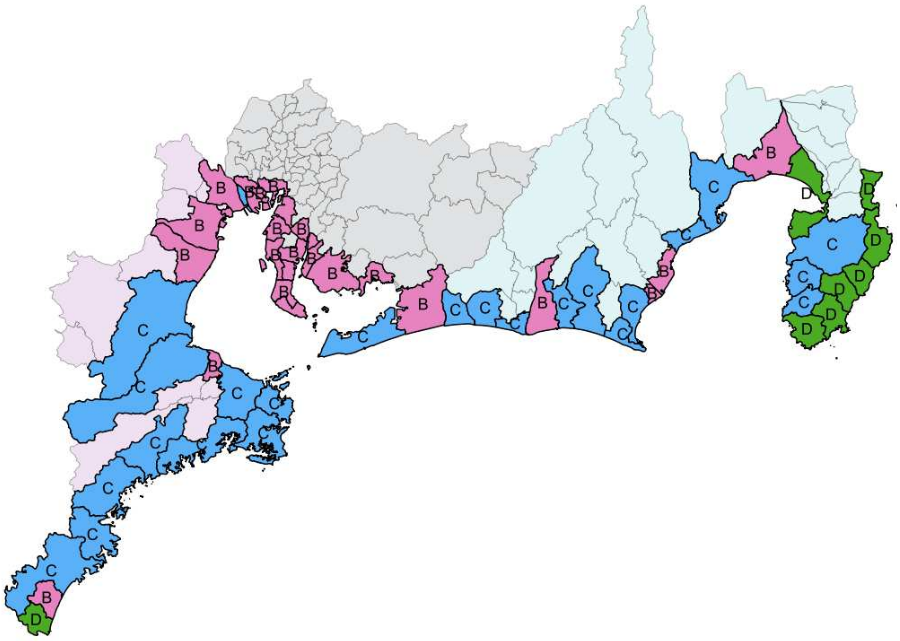

Fig. 27　The three coastal clusters in the Tokai region.

The coastal predictions resulted in only three clusters, with no fastest cluster A. In my Tohoku study, Cluster A was characterized by a high coastal breakwater, however this information was not available in my database. This indicates that I need to update my database to consider this new feature to make more accurate predictions. Additionally, regarding the coastal features, data relating to the tsunami were not included. The previous Tohoku earthquake was compounded by a tsunami like no other. There are also many predictions of tsunami heights for the future Nankai Trough earthquake, a feature not previously considered in my models. Looking at the maps of coastal municipalities in the Tohoku and Tokai regions, there are some cities that are so large and have such a short coastline that they need to be reconsidered as to whether they can be treated as inland cities. Alternatively, I should again review the scale of the coastal roads.

With regards to the inland municipalities, Stepwise discriminant analysis screened the remaining three variables of topography, population density and minimum temperature. Data on these four variables were also collected from inland municipalities in the Tokai region for prediction purposes.

The prediction accuracy for the inland area is 77.8% (Table 27, Fig. 28). I observed the following:

Cluster E: This cluster contains the largest number of municipalities in the cluster. It is mainly concentrated in municipalities with major roads.

Cluster F: This cluster is expected to be concentrated in mountainous areas with low population density.

Cluster G: Only one municipality is predicted for this cluster, and this is where Mt Fuji is located. This is the area with the highest altitude and lowest temperature in the Tokai region.

Table 27 Predicted results for the inland in the Tokai region.

Cluster			Predicted Group Membership			Total
			E	F	G	
Original	Count	E	39	5	2	46
		F	6	35	10	51
		G	0	3	17	20
		Tokai inland	77	5	1	83
	%	E	84.8	10.9	4.3	100.0
		F	11.8	68.6	19.6	100.0
		G	0.0	15.0	85.0	100.0
		Tokai inland	92.8	6.0	1.2	100.0
Cross-validated	Count	E	39	5	2	46
		F	6	35	10	51
		G	0	4	16	20
	%	E	84.8	10.9	4.3	100.0
		F	12	69	20	100.0
		G	0.0	20.0	80.0	100.0

a. 77.8% of original grouped cases correctly classified.
b. 76.9% of cross-validated grouped cases correctly classified.

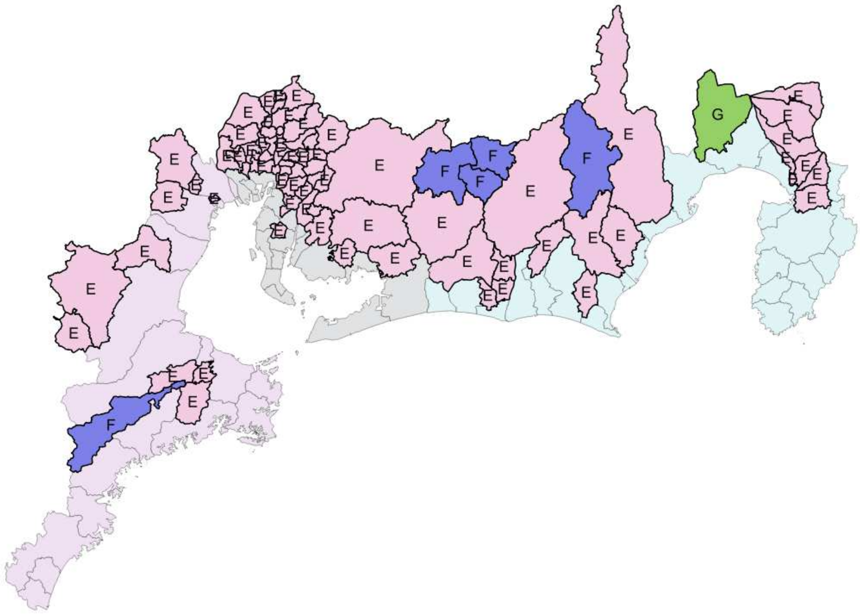

Fig. 28　The three inland clusters in the Tokai region.

I have also combined the coastal and inland results together (Fig. 29) in my analysis. Although Cluster E is still more concentrated inland, there are six clusters in this overall forecast compared to the previous forecast of only four clusters (Fig. 22). It is of note that there is no concentration of the fastest recoveries along the coast in the Tokai region.

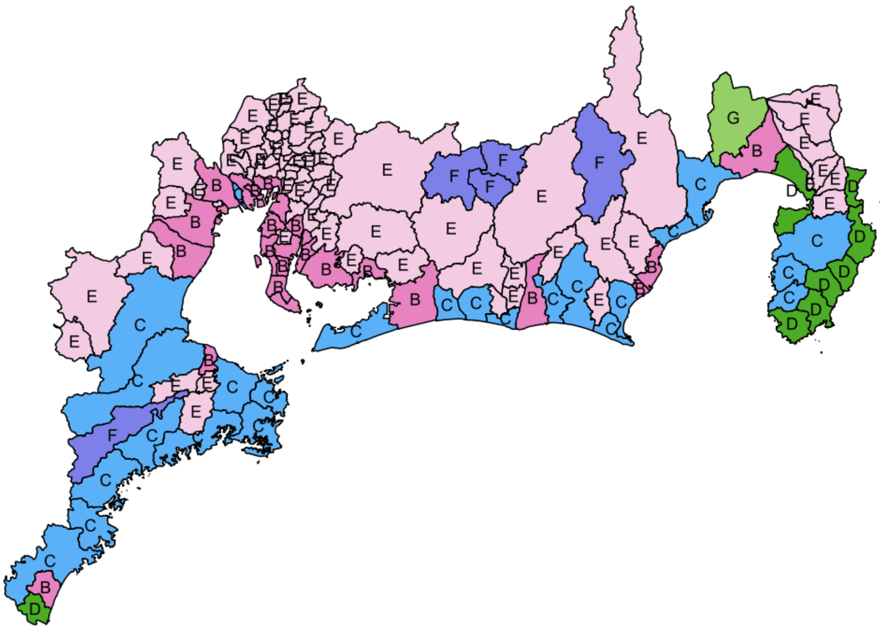

Fig. 29　The six clusters in the Tokai region.

Chapter 7

Conclusion

In this study, cluster analysis was applied to find the similarities in road recovery after the earthquake in the Tohoku region. In the research methodology, the classification results obtained after cluster analysis were examined to select the best classification cluster. Moreover, I examined the recovery clusters on a map taking into account their regional characteristics and validating them with objective data. In the Tohoku region, the road recovery conditions were found to be similar depending on topography, the importance of the road, snow, population density, damage, and geographical location.

Analysis of vehicle travel data for the six months following the 2011 Tohoku Earthquake was used to identify regional characteristics and factors affecting road recovery. I observed that six of the seven impact factors thought of by the clusters represented on the map were significantly correlated with the recovery clusters. Surprisingly, I found that the government's recovery policy of prioritization of certain roads did not show a significant correlation with all of the recovery clusters.

In addition, I constructed a database by correlating previous road recovery in the Tohoku region with regional characteristics. Using this database, I employed discriminant analysis to construct a prediction model, and the accuracy of the model prediction was 72.4%. I applied this model to predict municipal road recovery in the Tokai region (Shizuoka, Aichi, and Mie prefectures) after the predicted Nankai Trough earthquake and map the predicted recovery in a

GIS. The cluster classification of the three Tokai prefectures resulted in an overconcentration in Cluster 1, where recovery is the fastest. It is unlikely that most municipal roads will be able to recover at the same time, suggesting that other parameters should be considered in the forecasting of the three Tokai prefectures.

To address this issue, I re-clustered the road recovery of municipalities in the Tohoku region by separating coastal areas and inland areas. I found that municipalities with high coastal breakwaters, which were not hit by the tsunami, suffered less damage to their roads and recovered the fastest. In addition, a comparison of previous studies shows that it is the coastal clusters that were severely affected by the tsunami that recovered most slowly, rather than the inland heavy snowfall areas, which was more in line with reality. Furthermore, I used stepwise discriminant analysis to simplify the flow of the model. The road recovery of municipalities in coastal and inland areas of the Tokai region were predicted separately. The accuracy of the model improved from 72.4% to 80.0% along the coast and 77.8% inland. Furthermore, the overall condition of the Tokai region was better matched to the actual situation by increasing the number of clusters from the previous four to six.

I found characteristics that affect road recovery by classifying vehicle tracking maps in municipalities after an earthquake. In addition, I identified the influencing factors to create a database to apply to future predicted post-earthquake road recovery clusters. Based on the predicted road recovery, I hope to make recommendations for disaster mitigation, such as where it would be better to set up logistical centers in the event of a disaster. It is hoped that the results of my research will contribute to future disaster areas.

Appendix

Table 28 Mean of the clusters when divided into 9 clusters.

Clusters9		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	56.52	79.80	87.30	91.49	94.11	96.03	97.09	97.77	98.55	99.22	100.00
	N	36	36	36	36	36	36	36	36	36	36	36
	Std. Deviation	6.467	5.666	4.547	3.485	2.474	1.983	1.713	1.537	1.454	1.204	.000
2	Mean	53.93	68.20	75.41	79.82	83.41	87.54	91.17	94.17	96.46	98.06	100.00
	N	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	7.506	5.087	5.254	4.780	4.971	4.987	4.244	4.139	3.767	2.992	.000
3	Mean	73.92	85.99	90.22	93.07	94.80	95.94	96.96	98.49	99.05	99.59	100.00
	N	26	26	26	26	26	26	26	26	26	26	26
	Std. Deviation	4.531	3.233	3.187	3.025	3.018	2.985	2.709	1.756	1.602	.912	.000
4	Mean	27.16	45.39	52.45	57.88	65.57	74.65	87.31	92.81	94.52	98.58	100.00
	N	10	10	10	10	10	10	10	10	10	10	10
	Std. Deviation	16.531	6.238	5.473	6.896	6.525	10.133	9.062	8.829	9.122	1.444	.000
5	Mean	39.05	65.46	80.65	87.46	90.07	91.64	94.78	97.26	98.44	99.21	100.00
	N	24	24	24	24	24	24	24	24	24	24	24
	Std. Deviation	6.941	8.346	6.814	3.665	2.663	2.716	3.025	2.203	1.630	.978	.000
6	Mean	33.00	51.95	66.57	71.16	76.66	80.86	87.16	92.39	95.55	98.82	100.00
	N	15	15	15	15	15	15	15	15	15	15	15
	Std. Deviation	10.540	7.734	5.674	5.244	5.113	6.833	6.607	3.861	4.128	1.190	.000
7	Mean	12.31	84.85	87.80	88.90	90.70	93.81	96.68	98.39	99.14	99.20	100.00
	N	5	5	5	5	5	5	5	5	5	5	5
	Std. Deviation	11.849	5.115	6.963	5.878	7.396	7.150	3.832	2.169	1.166	1.156	.000
8	Mean	2.13	8.66	43.82	49.21	58.65	59.63	71.48	93.31	96.93	97.44	100.00
	N	2	2	2	2	2	2	2	2	2	2	2
	Std. Deviation	3.012	6.081	23.818	16.195	7.684	6.793	9.251	4.948	4.338	3.624	.000
9	Mean	.00	.00	.00	.00	.00	30.62	61.08	100.00	100.00	100.00	100.00
	N	1	1	1	1	1	1	1	1	1	1	1
	Std. Deviation	.	.	.	.	.	.	.	.	.	.	.
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 29 Analysis of variance (ANOVA) of 9 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	43467.929	8	5433.491	82.018	.000
	Within Groups	9473.447	143	66.248		
	Total	52941.377	151			
Mar4w	Between Groups	35170.644	8	4396.330	122.203	.000
	Within Groups	5144.519	143	35.976		
	Total	40315.163	151			
Apr1w	Between Groups	24701.688	8	3087.711	100.111	.000
	Within Groups	4410.538	143	30.843		
	Total	29112.227	151			
Apr2w	Between Groups	23797.627	8	2974.703	146.304	.000
	Within Groups	2907.521	143	20.332		
	Total	26705.148	151			
Apr3w	Between Groups	19454.699	8	2431.837	143.541	.000
	Within Groups	2422.669	143	16.942		
	Total	21877.368	151			
Apr4w	Between Groups	11518.057	8	1439.757	65.276	.000
	Within Groups	3154.051	143	22.056		
	Total	14672.108	151			
May	Between Groups	4037.705	8	504.713	28.111	.000
	Within Groups	2567.444	143	17.954		
	Total	6605.149	151			
Jun	Between Groups	775.044	8	96.881	7.813	.000
	Within Groups	1773.277	143	12.401		
	Total	2548.321	151			
July	Between Groups	324.498	8	40.562	3.484	.001
	Within Groups	1665.084	143	11.644		
	Total	1989.582	151			
Aug	Between Groups	48.301	8	6.038	1.976	.054
	Within Groups	437.036	143	3.056		
	Total	485.338	151			
Sep	Between Groups	.000	8	.000	.	.
	Within Groups	.000	143	.000		
	Total	.000	151			

Table 30 Mean of the clusters when divided into 8 clusters.

Clusters8		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	56.52	79.80	87.30	91.49	94.11	96.03	97.09	97.77	98.55	99.22	100.00
	N	36	36	36	36	36	36	36	36	36	36	36
	Std. Deviation	6.467	5.666	4.547	3.485	2.474	1.983	1.713	1.537	1.454	1.204	.000
2	Mean	53.93	68.20	75.41	79.82	83.41	87.54	91.17	94.17	96.46	98.06	100.00
	N	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	7.506	5.087	5.254	4.780	4.971	4.987	4.244	4.139	3.767	2.992	.000
3	Mean	73.92	85.99	90.22	93.07	94.80	95.94	96.96	98.49	99.05	99.59	100.00
	N	26	26	26	26	26	26	26	26	26	26	26
	Std. Deviation	4.531	3.233	3.187	3.025	3.018	2.985	2.709	1.756	1.602	.912	.000
4	Mean	30.66	49.33	60.92	65.85	72.23	78.38	87.22	92.56	95.13	98.73	100.00
	N	25	25	25	25	25	25	25	25	25	25	25
	Std. Deviation	13.259	7.762	8.938	8.827	7.870	8.681	7.501	6.162	6.435	1.273	.000
5	Mean	39.05	65.46	80.65	87.46	90.07	91.64	94.78	97.26	98.44	99.21	100.00
	N	24	24	24	24	24	24	24	24	24	24	24
	Std. Deviation	6.941	8.346	6.814	3.665	2.663	2.716	3.025	2.203	1.630	.978	.000
6	Mean	12.31	84.85	87.80	88.90	90.70	93.81	96.68	98.39	99.14	99.20	100.00
	N	5	5	5	5	5	5	5	5	5	5	5
	Std. Deviation	11.849	5.115	6.963	5.878	7.396	7.150	3.832	2.169	1.166	1.156	.000
7	Mean	2.13	8.66	43.82	49.21	58.65	59.63	71.48	93.31	96.93	97.44	100.00
	N	2	2	2	2	2	2	2	2	2	2	2
	Std. Deviation	3.012	6.081	23.818	16.195	7.684	6.793	9.251	4.948	4.338	3.624	.000
8	Mean	.00	.00	.00	.00	.00	30.62	61.08	100.00	100.00	100.00	100.00
	N	1	1	1	1	1	1	1	1	1	1	1
	Std. Deviation	.	.	.	.	.	.	.	.	.	.	.
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 31 Analysis of variance (ANOVA) of 8 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	43263.246	7	6180.464	91.959	.000
	Within Groups	9678.130	144	67.209		
	Total	52941.377	151			
Mar4w	Between Groups	34912.356	7	4987.479	132.930	.000
	Within Groups	5402.806	144	37.519		
	Total	40315.163	151			
Apr1w	Between Groups	23504.402	7	3357.772	86.222	.000
	Within Groups	5607.825	144	38.943		
	Total	29112.227	151			
Apr2w	Between Groups	22740.749	7	3248.678	118.003	.000
	Within Groups	3964.400	144	27.531		
	Total	26705.148	151			
Apr3w	Between Groups	18717.450	7	2673.921	121.853	.000
	Within Groups	3159.918	144	21.944		
	Total	21877.368	151			
Apr4w	Between Groups	11286.998	7	1612.428	68.591	.000
	Within Groups	3385.110	144	23.508		
	Total	14672.108	151			
May	Between Groups	4037.561	7	576.794	32.349	.000
	Within Groups	2567.588	144	17.830		
	Total	6605.149	151			
Jun	Between Groups	773.972	7	110.567	8.973	.000
	Within Groups	1774.349	144	12.322		
	Total	2548.321	151			
July	Between Groups	318.130	7	45.447	3.915	.001
	Within Groups	1671.452	144	11.607		
	Total	1989.582	151			
Aug	Between Groups	47.961	7	6.852	2.256	.033
	Within Groups	437.377	144	3.037		
	Total	485.338	151			
Sep	Between Groups	.000	7	.000	.	.
	Within Groups	.000	144	.000		
	Total	.000	151			

Table 32 Mean of the clusters when divided into 7 clusters.

Ward Method		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	56.52	79.80	87.30	91.49	94.11	96.03	97.09	97.77	98.55	99.22	100.00
	N	36	36	36	36	36	36	36	36	36	36	36
	Std. Deviation	6.467	5.666	4.547	3.485	2.474	1.983	1.713	1.537	1.454	1.204	.000
2	Mean	53.93	68.20	75.41	79.82	83.41	87.54	91.17	94.17	96.46	98.06	100.00
	N	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	7.506	5.087	5.254	4.780	4.971	4.987	4.244	4.139	3.767	2.992	.000
3	Mean	73.92	85.99	90.22	93.07	94.80	95.94	96.96	98.49	99.05	99.59	100.00
	N	26	26	26	26	26	26	26	26	26	26	26
	Std. Deviation	4.531	3.233	3.187	3.025	3.018	2.985	2.709	1.756	1.602	.912	.000
4	Mean	30.66	49.33	60.92	65.85	72.23	78.38	87.22	92.56	95.13	98.73	100.00
	N	25	25	25	25	25	25	25	25	25	25	25
	Std. Deviation	13.259	7.762	8.938	8.827	7.870	8.681	7.501	6.162	6.435	1.273	.000
5	Mean	34.44	68.80	81.88	87.71	90.18	92.02	95.11	97.45	98.56	99.21	100.00
	N	29	29	29	29	29	29	29	29	29	29	29
	Std. Deviation	12.856	10.796	7.254	4.034	3.702	3.749	3.186	2.202	1.565	.988	.000
6	Mean	2.13	8.66	43.82	49.21	58.65	59.63	71.48	93.31	96.93	97.44	100.00
	N	2	2	2	2	2	2	2	2	2	2	2
	Std. Deviation	3.012	6.081	23.818	16.195	7.684	6.793	9.251	4.948	4.338	3.624	.000
7	Mean	.00	.00	.00	.00	.00	30.62	61.08	100.00	100.00	100.00	100.00
	N	1	1	1	1	1	1	1	1	1	1	1
	Std. Deviation	.	.	.	.	.	.	.	.	.	.	.
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 33 Analysis of variance (ANOVA) of 7 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	40304.849	6	6717.475	77.081	.000
	Within Groups	12636.527	145	87.148		
	Total	52941.377	151			
Mar4w	Between Groups	33355.670	6	5559.278	115.827	.000
	Within Groups	6959.493	145	47.997		
	Total	40315.163	151			
Apr1w	Between Groups	23292.884	6	3882.147	96.731	.000
	Within Groups	5819.342	145	40.133		
	Total	29112.227	151			
Apr2w	Between Groups	22732.175	6	3788.696	138.275	.000
	Within Groups	3972.973	145	27.400		
	Total	26705.148	151			
Apr3w	Between Groups	18715.801	6	3119.300	143.062	.000
	Within Groups	3161.567	145	21.804		
	Total	21877.368	151			
Apr4w	Between Groups	11267.624	6	1877.937	79.983	.000
	Within Groups	3404.484	145	23.479		
	Total	14672.108	151			
May	Between Groups	4022.665	6	670.444	37.644	.000
	Within Groups	2582.484	145	17.810		
	Total	6605.149	151			
Jun	Between Groups	768.608	6	128.101	10.437	.000
	Within Groups	1779.713	145	12.274		
	Total	2548.321	151			
July	Between Groups	316.120	6	52.687	4.565	.000
	Within Groups	1673.463	145	11.541		
	Total	1989.582	151			
Aug	Between Groups	47.960	6	7.993	2.650	.018
	Within Groups	437.377	145	3.016		
	Total	485.338	151			
Sep	Between Groups	.000	6	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	151			

Table 34 Mean of the clusters when divided into 6 clusters.

Ward Method		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	63.81	82.40	88.53	92.15	94.40	95.99	97.03	98.07	98.76	99.38	100.00
	N	62	62	62	62	62	62	62	62	62	62	62
	Std. Deviation	10.362	5.674	4.259	3.367	2.713	2.431	2.167	1.658	1.525	1.098	.000
2	Mean	53.93	68.20	75.41	79.82	83.41	87.54	91.17	94.17	96.46	98.06	100.00
	N	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	7.506	5.087	5.254	4.780	4.971	4.987	4.244	4.139	3.767	2.992	.000
3	Mean	30.66	49.33	60.92	65.85	72.23	78.38	87.22	92.56	95.13	98.73	100.00
	N	25	25	25	25	25	25	25	25	25	25	25
	Std. Deviation	13.259	7.762	8.938	8.827	7.870	8.681	7.501	6.162	6.435	1.273	.000
4	Mean	34.44	68.80	81.88	87.71	90.18	92.02	95.11	97.45	98.56	99.21	100.00
	N	29	29	29	29	29	29	29	29	29	29	29
	Std. Deviation	12.856	10.796	7.254	4.034	3.702	3.749	3.186	2.202	1.565	.988	.000
5	Mean	2.13	8.66	43.82	49.21	58.65	59.63	71.48	93.31	96.93	97.44	100.00
	N	2	2	2	2	2	2	2	2	2	2	2
	Std. Deviation	3.012	6.081	23.818	16.195	7.684	6.793	9.251	4.948	4.338	3.624	.000
6	Mean	.00	.00	.00	.00	.00	30.62	61.08	100.00	100.00	100.00	100.00
	N	1	1	1	1	1	1	1	1	1	1	1
	Std. Deviation	.	.	.	.	.	.	.	.	.	.	.
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 35 Analysis of variance (ANOVA) of 6 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	35732.190	5	7146.438	60.629	.000
	Within Groups	17209.187	146	117.871		
	Total	52941.377	151			
Mar4w	Between Groups	32776.467	5	6555.293	126.955	.000
	Within Groups	7538.696	146	51.635		
	Total	40315.163	151			
Apr1w	Between Groups	23164.241	5	4632.848	113.718	.000
	Within Groups	5947.986	146	40.740		
	Total	29112.227	151			
Apr2w	Between Groups	22694.492	5	4538.898	165.230	.000
	Within Groups	4010.656	146	27.470		
	Total	26705.148	151			
Apr3w	Between Groups	18708.634	5	3741.727	172.401	.000
	Within Groups	3168.734	146	21.704		
	Total	21877.368	151			
Apr4w	Between Groups	11267.489	5	2253.498	96.637	.000
	Within Groups	3404.619	146	23.319		
	Total	14672.108	151			
May	Between Groups	4022.432	5	804.486	45.477	.000
	Within Groups	2582.717	146	17.690		
	Total	6605.149	151			
Jun	Between Groups	760.690	5	152.138	12.425	.000
	Within Groups	1787.631	146	12.244		
	Total	2548.321	151			
July	Between Groups	312.376	5	62.475	5.438	.000
	Within Groups	1677.206	146	11.488		
	Total	1989.582	151			
Aug	Between Groups	45.975	5	9.195	3.056	.012
	Within Groups	439.363	146	3.009		
	Total	485.338	151			
Sep	Between Groups	.000	5	.000	.	.
	Within Groups	.000	146	.000		
	Total	.000	151			

Table 36 Mean of the clusters when divided into 4 clusters.

Ward Method		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	63.81	82.40	88.53	92.15	94.40	95.99	97.03	98.07	98.76	99.38	100.00
	N	62	62	62	62	62	62	62	62	62	62	62
	Std. Deviation	10.362	5.674	4.259	3.367	2.713	2.431	2.167	1.658	1.525	1.098	.000
2	Mean	44.81	68.48	78.44	83.51	86.58	89.63	93.01	95.71	97.44	98.60	100.00
	N	62	62	62	62	62	62	62	62	62	62	62
	Std. Deviation	14.194	8.195	7.016	5.934	5.555	4.956	4.246	3.734	3.113	2.340	.000
3	Mean	30.66	49.33	60.92	65.85	72.23	78.38	87.22	92.56	95.13	98.73	100.00
	N	25	25	25	25	25	25	25	25	25	25	25
	Std. Deviation	13.259	7.762	8.938	8.827	7.870	8.681	7.501	6.162	6.435	1.273	.000
4	Mean	1.42	5.78	29.22	32.81	39.10	49.96	68.01	95.54	97.96	98.29	100.00
	N	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	2.459	6.597	30.395	30.635	34.295	17.424	8.880	5.210	3.542	2.959	.000
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 37 Analysis of variance (ANOVA) of 4 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	29869.708	3	9956.569	63.869	.000
	Within Groups	23071.668	148	155.890		
	Total	52941.377	151			
Mar4w	Between Groups	32720.916	3	10906.972	212.560	.000
	Within Groups	7594.247	148	51.312		
	Total	40315.163	151			
Apr1w	Between Groups	21237.919	3	7079.306	133.058	.000
	Within Groups	7874.307	148	53.205		
	Total	29112.227	151			
Apr2w	Between Groups	20118.697	3	6706.232	150.692	.000
	Within Groups	6586.451	148	44.503		
	Total	26705.148	151			
Apr3w	Between Groups	15707.232	3	5235.744	125.587	.000
	Within Groups	6170.136	148	41.690		
	Total	21877.368	151			
Apr4w	Between Groups	10397.301	3	3465.767	119.990	.000
	Within Groups	4274.807	148	28.884		
	Total	14672.108	151			
May	Between Groups	3710.879	3	1236.960	63.253	.000
	Within Groups	2894.270	148	19.556		
	Total	6605.149	151			
Jun	Between Groups	564.650	3	188.217	14.043	.000
	Within Groups	1983.671	148	13.403		
	Total	2548.321	151			
July	Between Groups	237.680	3	79.227	6.693	.000
	Within Groups	1751.902	148	11.837		
	Total	1989.582	151			
Aug	Between Groups	21.390	3	7.130	2.274	.082
	Within Groups	463.948	148	3.135		
	Total	485.338	151			
Sep	Between Groups	.000	3	.000	.	.
	Within Groups	.000	148	.000		
	Total	.000	151			

Table 38 Mean of the clusters when divided into 3 clusters.

Clusters3		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	63.81	82.40	88.53	92.15	94.40	95.99	97.03	98.07	98.76	99.38	100.00
	N	62	62	62	62	62	62	62	62	62	62	62
	Std. Deviation	10.362	5.674	4.259	3.367	2.713	2.431	2.167	1.658	1.525	1.098	.000
2	Mean	44.81	68.48	78.44	83.51	86.58	89.63	93.01	95.71	97.44	98.60	100.00
	N	62	62	62	62	62	62	62	62	62	62	62
	Std. Deviation	14.194	8.195	7.016	5.934	5.555	4.956	4.246	3.734	3.113	2.340	.000
3	Mean	27.53	44.66	57.53	62.31	68.68	75.33	85.16	92.88	95.44	98.68	100.00
	N	28	28	28	28	28	28	28	28	28	28	28
	Std. Deviation	15.542	15.650	15.466	15.718	15.844	13.022	9.615	6.054	6.207	1.452	.000
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 39 Analysis of variance (ANOVA) of 3 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	27579.406	2	13789.703	81.014	.000
	Within Groups	25361.971	149	170.215		
	Total	52941.377	151			
Mar4w	Between Groups	27640.813	2	13820.407	162.473	.000
	Within Groups	12674.350	149	85.063		
	Total	40315.163	151			
Apr1w	Between Groups	18545.133	2	9272.566	130.747	.000
	Within Groups	10567.094	149	70.920		
	Total	29112.227	151			
Apr2w	Between Groups	17195.065	2	8597.533	134.703	.000
	Within Groups	9510.083	149	63.826		
	Total	26705.148	151			
Apr3w	Between Groups	12768.214	2	6384.107	104.426	.000
	Within Groups	9109.154	149	61.135		
	Total	21877.368	151			
Apr4w	Between Groups	8234.770	2	4117.385	95.302	.000
	Within Groups	6437.338	149	43.204		
	Total	14672.108	151			
May	Between Groups	2722.919	2	1361.459	52.253	.000
	Within Groups	3882.230	149	26.055		
	Total	6605.149	151			
Jun	Between Groups	540.771	2	270.385	20.068	.000
	Within Groups	2007.551	149	13.473		
	Total	2548.321	151			
July	Between Groups	216.357	2	108.178	9.090	.000
	Within Groups	1773.226	149	11.901		
	Total	1989.582	151			
Aug	Between Groups	20.884	2	10.442	3.350	.038
	Within Groups	464.454	149	3.117		
	Total	485.338	151			
Sep	Between Groups	.000	2	.000	.	.
	Within Groups	.000	149	.000		
	Total	.000	151			

Table 40 Mean of the clusters when divided into 2 clusters.

Clusters2		Mar3w	Mar4w	Apr1w	Apr2w	Apr3w	Apr4w	May	Jun	July	Aug	Sep
1	Mean	54.31	75.44	83.48	87.83	90.49	92.81	95.02	96.89	98.10	98.99	100.00
	N	124	124	124	124	124	124	124	124	124	124	124
	Std. Deviation	15.626	9.903	7.685	6.473	5.865	5.030	3.917	3.112	2.529	1.862	.000
2	Mean	27.53	44.66	57.53	62.31	68.68	75.33	85.16	92.88	95.44	98.68	100.00
	N	28	28	28	28	28	28	28	28	28	28	28
	Std. Deviation	15.542	15.650	15.466	15.718	15.844	13.022	9.615	6.054	6.207	1.452	.000
Total	Mean	49.38	69.77	78.70	83.13	86.47	89.59	93.21	96.15	97.61	98.93	100.00
	N	152	152	152	152	152	152	152	152	152	152	152
	Std. Deviation	18.724	16.340	13.885	13.299	12.037	9.857	6.614	4.108	3.630	1.793	.000

Table 41 Analysis of variance (ANOVA) of 2 clusters.

		Sum of Squares	df	Mean Square	F	Sig.
Mar3w	Between Groups	16387.787	1	16387.787	67.248	.000
	Within Groups	36553.590	150	243.691		
	Total	52941.377	151			
Mar4w	Between Groups	21639.777	1	21639.777	173.810	.000
	Within Groups	18675.386	150	124.503		
	Total	40315.163	151			
Apr1w	Between Groups	15389.693	1	15389.693	168.224	.000
	Within Groups	13722.534	150	91.484		
	Total	29112.227	151			
Apr2w	Between Groups	14881.112	1	14881.112	188.782	.000
	Within Groups	11824.036	150	78.827		
	Total	26705.148	151			
Apr3w	Between Groups	10868.718	1	10868.718	148.093	.000
	Within Groups	11008.649	150	73.391		
	Total	21877.368	151			
Apr4w	Between Groups	6981.395	1	6981.395	136.165	.000
	Within Groups	7690.712	150	51.271		
	Total	14672.108	151			
May	Between Groups	2221.557	1	2221.557	76.018	.000
	Within Groups	4383.592	150	29.224		
	Total	6605.149	151			
Jun	Between Groups	367.542	1	367.542	25.281	.000
	Within Groups	2180.779	150	14.539		
	Total	2548.321	151			
July	Between Groups	162.405	1	162.405	13.332	.000
	Within Groups	1827.177	150	12.181		
	Total	1989.582	151			
Aug	Between Groups	2.174	1	2.174	.675	.413
	Within Groups	483.164	150	3.221		
	Total	485.338	151			
Sep	Between Groups	.000	1	.000	.	.
	Within Groups	.000	150	.000		
	Total	.000	151			

Table 42 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (1).

Cluster	Municipality	Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
1	Higashimatsushima-shi	2	1	5.5	0.02	0.03	421	0
1	Iwanuma-shi	2	1	5.9	0.01	0.01	728	0
1	Kakuda-shi	2	2	5.8	0.00	0.02	212	0
1	Matsushima-machi	2	2	5.7	0.03	0.06	279	0
1	Misato-machi	2	2	5.5	0.01	0.02	336	0
1	Murata-machi	1	3	5.4	0.02	0.03	153	0
1	Natori-shi	1	1	6.1	0.01	0.02	731	0
1	Ogawara-machi	2	1	5.6	0.01	0.01	941	0
1	Ohira-mura	2	2	6	0.02	0.04	89	0
1	Osato-cho	2	2	5.6	0.00	0.00	109	0
1	Rifu-cho	1	2	5.6	0.00	0.05	760	0
1	Sendai-shi, Aoba-ku	1	2	5.5	0.00	0.03	964	0
1	Sendai-shi, Izumi-ku	1	2	5.8	0.01	0.02	1440	0
1	Sendai-shi, Miyagino-ku	1	1	5.5	0.01	0.02	3278	0
1	Sendai-shi, Taihaku-ku	1	3	5.4	0.01	0.03	967	0
1	Sendai-shi, Wakabayashi-ku	1	1	5.8	0.01	0.02	2735	0
1	Shibata-machi	2	2	5.4	0.01	0.01	729	0
1	Shichigahama-machi	1	1	5.4	0.00	0.00	1539	0
1	Shiogama-shi	2	1	6	0.02	0.02	3163	0
1	Tagajo-shi	1	1	5.3	0.01	0.02	3209	0
1	Taiwa-cho	1	3	5.5	0.01	0.02	110	0
1	Tome-shi	2	2	5.5	0.01	0.04	157	1
1	Tomiya-machi	1	2	5.5	0.02	0.04	958	0
1	Watari-cho	2	1	5.5	0.00	0.03	476	0
1	Katsurao-mura	2	3	5.4	0.00	0.04	18	0
1	Kawauchi-mura	1	3	5.5	0.00	0.04	14	0
1	Soma-shi	2	2	5.7	0.01	0.04	191	0

Table 43 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (2).

Cluster	Municipality	Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
1	Iwaki-shi	1	2	5.5	0.01	0.04	278	0
1	Date-shi	1	1	5.5	0.01	0.03	249	0
1	Fukushima-shi	1	2	5.5	0.02	0.04	381	0
1	Kori-machi	1	2	5.7	0.02	0.02	299	0
1	Kagamiishi-machi	2	1	6	0.03	0.04	410	0
1	Koriyama-shi	1	2	5.5	0.01	0.03	447	0
1	Miharu-machi	1	1	5.1	0.01	0.03	250	0
1	Motomiya-shi	1	1	5.5	0.01	0.02	358	0
1	Ono-machi	1	1	5.5	0.00	0.06	90	0
1	Sukagawa-shi	1	1	5.5	0.01	0.02	284	0
1	Asakawa-machi	2	1	5.6	0.00	0.02	184	0
1	Hirata-mura	1	1	5.3	0.02	0.03	74	0
1	Ishikawa-machi	2	1	5.1	0.00	0.01	154	0
1	Izumizaki-mura	2	1	5.3	0.02	0.02	192	0
1	Nakajima-mura	2	1	5.8	0.00	0.00	273	0
1	Nishigo-mura	2	2	5.5	0.01	0.03	103	0
1	Shirakawa-shi	2	2	5.5	0.02	0.03	212	0
1	Tamakawa-mura	2	2	5.5	0.00	0.01	155	0
1	Tanagura-machi	2	2	5.5	0.01	0.03	94	0
1	Yabuki-machi	2	1	5.6	0.01	0.01	305	0
1	Yamatsuri-machi	2	2	5.5	0.00	0.09	54	0
1	Kitakami-shi	1	1	5.4	0.02	0.03	213	2
1	Kawai-mura	1	4	4.7	0.05	0.08	6	0
1	Otsuchi-cho	2	3	5.5	0.02	0.02	76	0
1	Daitou-cho	2	2	5	0.03	0.05	55	1
1	Oono-mura	2	3	4.1	0.04	0.04	40	0
1	Maesawa-cho	2	1	5.5	0.02	0.02	201	0

Table 44 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (3).

Cluster	Municipality	Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
1	Yamada-machi	2	3	5.5	0.03	0.04	71	0
1	Morioka-shi	1	2	5.5	0.02	0.03	581	2
1	Ishidoriya-cho	2	2	5	0.01	0.02	132	0
1	Yahaba-cho	1	1	5.7	0.01	0.02	404	0
1	Takizawa-mura	1	1	5.6	0.02	0.04	295	0
1	Mizuzawa-shi	2	1	5.5	0.02	0.04	580	0
1	Taneichi-machi	2	3	4.2	0.03	0.03	74	0
1	Sumita-cho	2	3	5.1	0.03	0.08	18	2
2	Ishinomaki-shi	2	2	5.3	0.02	0.03	289	0
2	Kesennuma-shi	2	3	5.3	0.02	0.03	220	0
2	Osaki-shi	2	3	5.3	0.01	0.04	170	2
2	Wakuya-cho	2	2	6	0.02	0.03	213	0
2	Zao-machi	2	3	6	0.02	0.03	84	1
2	Iitate-mura	2	3	5.5	0.00	0.03	27	0
2	Kawamata-machi	1	3	5.5	0.04	0.06	122	0
2	Nihonmatsu-shi	1	2	5.3	0.02	0.03	174	0
2	Tenei-mura	1	3	6.2	0.00	0.06	28	0
2	Furudono-machi	1	3	5.3	0.00	0.04	37	0
2	Hanawa-machi	2	3	4.9	0.01	0.04	47	0
2	Samegawa-mura	1	3	4.7	0.05	0.09	30	0
2	Aizuwakamatsu-shi	1	2	5.3	0.00	0.04	330	0
2	Inawashiro-machi	1	3	5.3	0.00	0.05	40	0
2	Kitakata-shi	2	3	5.3	0.00	0.03	94	0
2	Yugawa-mura	2	1	5.4	0.00	0.05	206	0
2	Kawasaki-mura	2	3	5.1	0.03	0.03	97	0
2	Ofunato-shi	2	3	5.3	0.03	0.05	176	1
2	Higasiyama-cho	2	3	5.1	0.02	0.01	82	1
2	Ninohe-shi	2	3	5.3	0.02	0.02	102	0
2	Kamaishi-shi	2	3	5.3	0.04	0.05	90	2
2	Miyako-shi	2	3	5.3	0.02	0.03	142	0

Table 45 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (4).

Cluster	Municipality	Type of municip ality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
2	Miyamori-mora	2	3	5	0.06	0.10	30	0
2	Hanamaki-shi	1	2	5.2	0.01	0.02	177	2
2	Hanaizumi-cho	2	3	5.6	0.00	0.04	108	0
2	Esashi-shi	1	3	5.4	0.00	0.03	88	0
2	Kanegasaki-cho	1	2	5.2	0.01	0.01	91	0
2	Kunohe-mura	2	3	4.4	0.01	0.07	49	1
2	Nishine-cho	2	2	5.3	0.01	0.02	99	1
2	Ichinohe-machi	2	3	4.8	0.04	0.04	47	1
2	Tamayama-mura	1	3	5.3	0.03	0.03	36	0
2	Sawauchi-mura	1	3	5.3	0.00	0.00	11	1
2	Shiwa-cho	1	2	4.9	0.01	0.03	139	1
3	Kami-machi	2	4	4.77	0.00	0.03	55	0
3	Marumori-machi	2	3	4.77	0.00	0.03	57	0
3	Minamisanriku-cho	2	4	5.6	0.05	0.06	106	0
3	Shichikashuku-machi	2	4	5	0.00	0.08	6	2
3	Shikama-cho	2	3	5.4	0.00	0.01	68	0
3	Aizumisato-machi	2	3	4.77	0.00	0.03	82	3
3	Mishima-machi	2	4	3.4	0.00	0.12	21	3
3	Bandai-machi	2	3	5.2	0.00	0.02	63	3
3	Kitashiobara-mura	2	4	4.2	0.00	0.07	14	3
3	Showa-mura	2	4	3.7	0.00	0.16	7	3
3	Minamiaizu-machi	2	4	4.77	0.00	0.09	20	3
3	Shimogo-machi	2	4	4.77	0.00	0.08	20	3
3	Ohasama-machi	1	3	4.77	0.00	0.02	29	2
3	Isawa-cho	2	3	4.77	0.00	0.03	57	1
3	Towa-cho	1	3	5.3	0.01	0.03	67	0
3	Joubouji-cho	2	4	4.9	0.02	0.03	28	0

Table 46 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (5).

Cluster	Municipality	Type of municipality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
3	Kuji-shi	2	4	4.6	0.04	0.04	102	0
3	Yamagata-mura	2	4	3.9	0.04	0.04	11	1
3	Matsuo-mura	2	3	4.77	0.02	0.04	26	3
3	Tanohata-mura	2	4	4.77	0.04	0.05	25	0
3	Iwaizumi-cho	1	4	4.2	0.04	0.06	11	2
3	Iwate-machi	2	3	4.7	0.02	0.02	42	0
3	Noda-mura	2	3	4.9	0.02	0.02	57	1
3	Koromogawa-mura	2	3	5.5	0.01	0.00	32	0
3	Tono-shi	2	3	5.3	0.02	0.04	37	4
4	Kawasaki-machi	1	2	6.2	0.00	0.09	37	1
4	Kurihara-shi	2	2	5.38	0.02	0.04	93	3
4	Onagawa-cho	2	3	5.38	0.06	0.06	153	0
4	Shiroishi-shi	2	2	5.6	0.02	0.05	131	0
4	Yamamoto-cho	2	1	6	0.00	0.03	259	0
4	Hirono-machi	1	3	5.38	0.00	0.08	93	0
4	Minamisoma-shi	2	3	5.38	0.00	0.02	178	0
4	Shinchi-machi	2	3	6.1	0.00	0.04	177	0
4	Kunimi-machi	2	3	6.3	0.03	0.04	266	0
4	Otama-mura	1	3	5.38	0.02	0.02	108	0
4	Tamura-shi	1	3	5.38	0.01	0.03	88	0
4	Aizubange-machi	2	3	5.3	0.00	0.03	189	0
4	Nishiaizu-machi	2	3	4.7	0.00	0.08	25	0
4	Yanaizu-machi	2	3	5.38	0.00	0.04	23	0
4	Asiro-cho	2	3	5.38	0.04	0.09	13	0
4	Kuzumaki-machi	2	3	5.38	0.04	0.07	17	2
4	Rikuzentakata-shi	2	3	5.38	0.03	0.04	100	0
4	Shizukuishi-cho	1	2	4.6	0.00	0.01	30	3

Table 47 Collection of actual data on factors affecting road recovery with 152 municipalities in the Tohoku region (6).

Cluster	Municipality	Type of municip ality	Type of terrain	Measuring seismic intensity	Priority road restoration occupancy	Proportion of important roads	Population density	Roads closed due to snow
4	Hiraizumi-cho	2	2	5.3	0.02	0.03	132	0
4	Fudai-mura	2	3	5.3	0.04	0.05	44	1
4	Senmaya-cho	2	2	5.8	0.02	0.04	129	0
4	Karumai-machi	2	3	4.6	0.05	0.06	42	0
4	Sanriku-cho	2	3	5.38	0.03	0.04	58	0
4	Murone-mura	2	3	5.5	0.03	0.03	55	1
4	Yuda-machi	1	3	5.38	0.04	0.09	11	1
4	Fujisawa-cho	2	2	5.6	0.00	0.03	73	1
4	Tarou-cho	2	3	4.7	0.05	0.05	43	0
4	Niisato-mura	2	3	5.38	0.03	0.09	13	1
4	Ichinoseki-shi	2	2	5.8	0.02	0.05	127	1
5	Kaneyama-machi	2	3	3.3	0.00	0.10	8	4
5	Hinoemata-mura	2	3	3.5	0.00	0.13	2	4
5	Tadami-machi	2	3	3.8	0.00	0.13	7	4

Table 48 Full Database of the Tohoku region (1).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
1	Higashimatsushima-shi	2	4.80	394	11.75	101.86	1	0.97
1	Iwanuma-shi	2	4.18	340	12.74	60.71	1	0.80
1	Kakuda-shi	2	4.17	329	7.80	147.58	2	0.67
1	Matsushima-machi	2	4.65	377	9.23	54.04	2	0.80
1	Misato-machi	2	5.03	396	10.62	75.06	2	1.00
1	Murata-machi	1	4.20	344	9.40	78.41	3	0.23
1	Natori-shi	1	4.25	345	13.43	100.07	1	0.66
1	Ogawara-machi	2	4.27	340	14.35	25.01	1	0.72
1	Ohira-mura	2	4.85	391	7.83	60.19	2	0.42
1	Osato-cho	2	4.67	380	7.13	82.02	2	0.66
1	Rifu-cho	1	4.52	368	12.93	44.75	2	0.42
1	Sendai-shi, Aoba-ku	1	4.93	381	7.61	302.27	2	0.04
1	Sendai-shi, Izumi-ku	1	4.73	380	12.75	146.61	2	0.16
1	Sendai-shi, Miyagino-ku	1	4.45	359	18.45	58.1	1	0.93
1	Sendai-shi, Taihaku-ku	1	4.70	373	8.16	228.18	3	0.13
1	Sendai-shi, Wakabayashi-ku	1	4.33	354	17.49	48.38	1	1.00
1	Shibata-machi	2	4.33	343	14.13	53.98	2	0.70
1	Shichigahama-machi	1	4.60	368	16.86	13.27	1	1.00
1	Shiogama-shi	2	4.57	365	19.88	17.86	1	0.81
1	Tagajo-shi	1	4.45	362	22.25	19.65	1	1.00
1	Taiwa-cho	1	4.78	384	4.86	225.59	3	0.24
1	Tome-shi	2	4.40	434	5.94	536.38	2	0.62
1	Tomiya-machi	1	4.72	381	13.10	49.13	2	0.46
1	Watari-cho	2	4.18	331	12.84	73.21	1	0.89
1	Katsurao-mura	2	4.37	346	2.28	84.37	3	0.00
1	Kawauchi-mura	1	3.48	264	2.32	197.35	3	0.00
1	Soma-shi	2	3.78	303	7.99	197.79	2	0.49

Table 49 Full Database of the Tohoku region (2).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
1	Iwaki-shi	1	2.77	215	6.11	1232.02	2	0.22
1	Date-shi	1	3.87	309	7.65	265.12	1	0.11
1	Fukushima-shi	1	3.73	289	6.64	767.72	2	0.00
1	Kori-machi	1	3.82	306	11.00	42.97	2	0.09
1	Kagamiishi-machi	2	2.85	226	15.29	31.3	1	0.00
1	Koriyama-shi	1	3.15	248	7.67	757.2	2	0.00
1	Miharu-machi	1	3.30	266	11.68	72.76	1	0.00
1	Motomiya-shi	1	3.25	258	11.00	88.02	1	0.00
1	Ono-machi	1	3.05	244	4.98	125.18	1	0.00
1	Sukagawa-shi	1	2.93	231	10.64	279.43	1	0.00
1	Asakawa-machi	2	3.13	231	9.00	37.43	1	0.00
1	Hirata-mura	1	3.07	240	5.94	93.42	1	0.00
1	Ishikawa-machi	2	3.02	235	9.46	115.71	1	0.00
1	Izumizaki-mura	2	2.87	218	11.79	35.43	1	0.00
1	Nakajima-mura	2	2.92	227	12.97	18.92	1	0.00
1	Nishigo-mura	2	2.62	204	5.74	192.06	2	0.00
1	Shirakawa-shi	2	2.67	205	8.25	305.32	2	0.00
1	Tamakawa-mura	2	2.90	228	10.96	46.67	2	0.00
1	Tanagura-machi	2	3.10	226	4.21	159.93	2	0.00
1	Yabuki-machi	2	2.83	221	14.66	60.4	1	0.00
1	Yamatsuri-machi	2	2.72	183	2.89	118.27	2	0.00
1	Kitakami-shi	1	6.03	494	7.19	437.55	1	0.00
1	Kawai-mura	1	7.33	589	1.50	563.07	4	0.00
1	Otsuchi-cho	2	6.87	551	2.17	200.47	3	0.07
1	Daitou-cho	2	6.02	473	3.04	278.71	2	0.00
1	Oono-mura	2	8.13	655	3.08	134.65	3	0.00
1	Maesawa-cho	2	5.85	475	12.28	72.34	1	0.41

Table 50 Full Database of the Tohoku region (3).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
1	Yamada-machi	2	7.08	566	2.75	263.4	3	0.10
1	Morioka-shi	1	6.65	540	7.75	489.15	2	0.00
1	Ishidoriya-cho	2	6.37	517	9.43	118.57	2	0.00
1	Yahaba-cho	1	6.50	531	13.26	67.28	1	0.00
1	Takizawa-mura	1	6.65	544	7.21	182.32	1	0.00
1	Mizuzawa-shi	2	5.82	575	14.16	96.92	1	0.42
1	Taneichi-machi	2	8.28	666	4.74	168.51	3	0.10
1	Sumita-cho	2	6.37	510	2.17	334.83	3	0.00
2	Kawasaki-machi	1	4.42	358	3.55	270.8	2	0.00
2	Kurihara-shi	2	5.18	421	4.85	804.93	2	0.32
2	Onagawa-cho	2	5.27	416	4.70	65.8	3	0.27
2	Shiroishi-shi	2	4.17	326	5.18	286.47	2	0.06
2	Yamamoto-cho	2	4.07	323	12.01	64.48	1	0.75
2	Hirono-machi	1	3.00	241	3.44	58.69	3	0.21
2	Minamisoma-shi	2	3.63	290	7.38	398.58	3	0.46
2	Shinchi-machi	2	3.95	315	12.11	46.7	3	0.66
2	Kunimi-machi	2	3.85	309	12.19	37.95	3	0.08
2	Otama-mura	1	3.32	261	6.29	79.44	3	0.00
2	Tamura-shi	1	3.28	260	5.39	458.33	3	0.00
2	Aizubange-machi	2	3.90	308	9.65	91.59	3	0.00
2	Nishiaizu-machi	2	4.45	329	2.75	298.18	3	0.00
2	Yanaizu-machi	2	4.33	322	2.35	175.82	3	0.00
2	Asiro-cho	2	6.98	577	2.11	457.78	3	0.00
2	Kuzumaki-machi	2	7.72	609	1.79	434.99	3	0.00
2	Rikuzentakata-shi	2	6.13	494	5.78	232.19	3	0.17
2	Shizukuishi-cho	1	6.78	555	3.13	609.01	2	0.00
2	Hiraizumi-cho	2	5.68	459	9.80	63.39	2	0.32

Table 51 Full Database of the Tohoku region (4).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
2	Fudai-mura	2	8.00	638	4.91	69.65	3	0.06
2	Senmaya-cho	2	5.95	466	5.67	89.84	2	0.00
2	Karumai-machi	2	7.77	644	3.53	245.74	3	0.00
2	Sanriku-cho	2	6.48	519	4.08	137.13	3	0.10
2	Murone-mura	2	5.98	473	2.99	97.28	3	0.00
2	Yuda-machi	1	6.42	526	1.56	304.56	3	0.00
2	Fujisawa-cho	2	5.83	453	3.83	122.82	2	0.08
2	Tarou-cho	2	7.77	606	3.42	101.05	3	0.10
2	Niisato-mura	2	7.52	605	1.58	256.29	3	0.01
3	Ishinomaki-shi	2	4.98	402	7.55	555.78	2	0.52
3	Kesennuma-shi	2	5.95	480	6.96	333.37	3	0.23
3	Osaki-shi	2	5.03	405	5.59	796.76	3	0.37
3	Wakuya-cho	2	5.05	399	7.38	82.08	2	0.75
3	Zao-machi	2	4.23	339	5.56	152.85	3	0.04
3	Iitate-mura	2	3.92	307	2.77	230.13	3	0.00
3	Kawamata-machi	1	3.82	292	5.32	127.7	3	0.00
3	Nihonmatsu-shi	1	3.43	268	7.49	344.42	2	0.00
3	Tenei-mura	1	2.90	226	2.66	225.52	3	0.00
3	Furudono-machi	1	3.10	225	2.89	163.29	3	0.00
3	Hanawa-machi	2	2.93	194	2.99	211.41	3	0.00
3	Samegawa-mura	1	3.12	229	2.99	131.34	3	0.00
3	Aizuwakamatsu-shi	1	3.82	267	7.03	382.97	2	0.00
3	Inawashiro-machi	1	3.52	280	3.71	394.85	3	0.00
3	Kitakata-shi	2	4.07	314	3.77	554.63	3	0.00
3	Yugawa-mura	2	3.80	304	14.60	16.37	1	0.00
3	Kawasaki-mura	2	5.82	457	4.77	42.49	3	0.25
3	Ofunato-shi	2	6.33	508	5.23	186.02	3	0.13

Table 52 Full Database of the Tohoku region (5).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
3	Higasiyama-cho	2	5.83	466	5.15	87.72	3	0.07
3	Ninohe-shi	2	7.65	622	4.70	240.61	3	0.00
3	Kamaishi-shi	2	6.77	541	2.75	441.26	3	0.07
3	Miyako-shi	2	7.38	590	3.82	339.38	3	0.14
3	Miyamori-mora	2	6.60	536	2.90	165.24	3	0.00
3	Hanamaki-shi	1	6.23	509	7.60	385.4	2	0.00
3	Hanaizumi-cho	2	5.48	440	4.65	126.83	3	0.49
3	Esashi-shi	1	5.98	486	6.24	362.5	3	0.08
3	Kanegasaki-cho	1	5.92	484	7.35	179.77	2	0.03
3	Kunohe-mura	2	7.73	638	3.65	134.05	3	0.00
3	Nishine-cho	2	7.43	568	5.54	167.16	2	0.00
3	Ichinohe-machi	2	7.57	624	3.56	300.26	3	0.00
3	Tamayama-mura	1	7.05	571	3.44	397.32	3	0.00
3	Sawauchi-mura	1	6.87	546	1.66	286.22	3	0.00
3	Shiwa-cho	1	6.45	530	6.72	239.26	2	0.00
4	Kami-machi	2	5.12	405	3.02	460.82	4	0.08
4	Marumori-machi	2	4.18	329	4.48	273.34	3	0.15
4	Minamisanriku-cho	2	5.50	447	5.17	163.74	4	0.27
4	Shichikashuku-machi	2	4.28	330	1.48	263	4	0.00
4	Shikama-cho	2	5.07	399	4.90	109.23	3	0.19
4	Aizumisato-machi	2	3.83	269	3.99	276.33	3	0.00
4	Mishima-machi	2	4.28	271	1.73	90.81	4	0.00
4	Bandai-machi	2	3.67	294	6.35	59.77	3	0.00
4	Kitashiobara-mura	2	3.97	308	1.71	234.08	4	0.00
4	Showa-mura	2	3.77	274	1.39	209.46	4	0.00
4	Minamiaizu-machi	2	3.20	222	1.66	886.47	4	0.00
4	Shimogo-machi	2	3.17	236	1.82	317.04	4	0.00

Table 53 Full Database of the Tohoku region (6).

Cluster	Municipality	Type of municipality	Time to Tokyo	Distance to Tokyo	Distance area ratio	Area	Type of terrain	Elevation <50m
4	Ohasama-machi	1	6.60	531	2.89	246.61	3	0.00
4	Isawa-cho	2	6.25	495	4.44	298.02	3	0.00
4	Towa-cho	1	6.33	519	8.88	157.51	3	0.00
4	Joubouji-cho	2	7.40	610	3.22	179.55	4	0.00
4	Kuji-shi	2	8.35	671	4.30	327.5	4	0.12
4	Yamagata-mura	2	8.10	659	1.99	295.49	4	0.00
4	Matsuo-mura	2	7.47	617	2.97	234.85	3	0.00
4	Tanohata-mura	2	7.70	625	3.58	156.19	4	0.03
4	Iwaizumi-cho	1	7.98	629	1.58	992.9	4	0.01
4	Iwate-machi	2	7.12	580	3.48	360.55	3	0.00
4	Noda-mura	2	8.25	653	4.95	80.82	3	0.12
4	Koromogawa-mura	2	5.77	470	3.51	163.57	3	0.04
4	Tono-shi	2	6.70	529	2.80	660.38	3	0.00
2	Ichinoseki-shi	2	5.55	454	5.08	410.23	2	0.11
5	Kaneyama-machi	2	4.15	266	1.19	293.92	3	0.00
5	Hinoemata-mura	2	3.92	260	0.61	390.46	3	0.00
5	Tadami-machi	2	4.17	276	0.69	747.56	3	0.00

Table 54 Full Database of the Tohoku region (7).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
1	Higashimatsushima-shi	0.03	1.00	0.00	0.00	0.00	5.5
1	Iwanuma-shi	0.06	0.86	0.10	0.03	0.00	5.9
1	Kakuda-shi	0.12	0.79	0.17	0.04	0.00	5.8
1	Matsushima-machi	0.17	0.97	0.03	0.00	0.00	5.7
1	Misato-machi	0.00	1.00	0.00	0.00	0.00	5.5
1	Murata-machi	0.18	0.41	0.37	0.21	0.00	5.4
1	Natori-shi	0.09	0.75	0.21	0.05	0.00	6.1
1	Ogawara-machi	0.18	0.90	0.10	0.00	0.00	5.6
1	Ohira-mura	0.42	0.84	0.15	0.01	0.00	6
1	Osato-cho	0.30	0.96	0.04	0.00	0.00	5.6
1	Rifu-cho	0.44	0.86	0.14	0.00	0.00	5.6
1	Sendai-shi, Aoba-ku	0.07	0.11	0.22	0.37	0.30	5.5
1	Sendai-shi, Izumi-ku	0.26	0.42	0.24	0.24	0.10	5.8
1	Sendai-shi, Miyagino-ku	0.07	1.00	0.00	0.00	0.00	5.5
1	Sendai-shi, Taihaku-ku	0.07	0.20	0.21	0.27	0.31	5.4
1	Sendai-shi, Wakabayashi-ku	0.00	1.00	0.00	0.00	0.00	5.8
1	Shibata-machi	0.12	0.83	0.13	0.04	0.00	5.4
1	Shichigahama-machi	0.00	1.00	0.00	0.00	0.00	5.4
1	Shiogama-shi	0.17	0.98	0.02	0.00	0.00	6
1	Tagajo-shi	0.00	1.00	0.00	0.00	0.00	5.3
1	Taiwa-cho	0.20	0.44	0.16	0.23	0.17	5.5
1	Tome-shi	0.09	0.71	0.18	0.11	0.00	5.5
1	Tomiya-machi	0.52	0.98	0.02	0.00	0.00	5.5
1	Watari-cho	0.06	0.95	0.05	0.00	0.00	5.5
1	Katsurao-mura	0.00	0.00	0.00	0.25	0.75	5.4
1	Kawauchi-mura	0.00	0.00	0.00	0.29	0.71	5.5
1	Soma-shi	0.07	0.55	0.10	0.20	0.15	5.7

Table 55 Full Database of the Tohoku region (8).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
1	Iwaki-shi	0.12	0.35	0.10	0.27	0.29	5.5
1	Date-shi	0.16	0.27	0.28	0.39	0.06	5.5
1	Fukushima-shi	0.11	0.11	0.18	0.33	0.38	5.5
1	Kori-machi	0.31	0.40	0.15	0.30	0.15	5.7
1	Kagamiishi-machi	0.00	0.00	0.00	1.00	0.00	6
1	Koriyama-shi	0.00	0.00	0.00	0.58	0.42	5.5
1	Miharu-machi	0.00	0.00	0.00	1.00	0.00	5.1
1	Motomiya-shi	0.00	0.00	0.00	1.00	0.00	5.5
1	Ono-machi	0.00	0.00	0.00	0.51	0.49	5.5
1	Sukagawa-shi	0.00	0.00	0.00	0.80	0.20	5.5
1	Asakawa-machi	0.00	0.00	0.00	0.99	0.01	5.6
1	Hirata-mura	0.00	0.00	0.00	0.36	0.64	5.3
1	Ishikawa-machi	0.00	0.00	0.00	0.93	0.07	5.1
1	Izumizaki-mura	0.00	0.00	0.00	1.00	0.00	5.3
1	Nakajima-mura	0.00	0.00	0.00	1.00	0.00	5.8
1	Nishigo-mura	0.00	0.00	0.00	0.36	0.64	5.5
1	Shirakawa-shi	0.00	0.00	0.00	0.87	0.13	5.5
1	Tamakawa-mura	0.00	0.00	0.00	0.86	0.14	5.5
1	Tanagura-machi	0.00	0.00	0.00	0.67	0.33	5.5
1	Yabuki-machi	0.00	0.00	0.00	1.00	0.00	5.6
1	Yamatsuri-machi	0.00	0.00	0.13	0.58	0.28	5.5
1	Kitakami-shi	0.28	0.28	0.25	0.21	0.25	5.4
1	Kawai-mura	0.00	0.00	0.01	0.17	0.82	4.7
1	Otsuchi-cho	0.06	0.14	0.14	0.38	0.35	5.5
1	Daitou-cho	0.03	0.03	0.27	0.51	0.20	5
1	Oono-mura	0.00	0.00	0.24	0.76	0.01	4.1
1	Maesawa-cho	0.28	0.69	0.21	0.10	0.00	5.5

Table 56 Full Database of the Tohoku region (9).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
1	Yamada-machi	0.12	0.23	0.23	0.39	0.15	5.5
1	Morioka-shi	0.00	0.00	0.26	0.37	0.37	5.5
1	Ishidoriya-cho	0.31	0.31	0.31	0.25	0.14	5
1	Yahaba-cho	0.03	0.03	0.72	0.17	0.07	5.7
1	Takizawa-mura	0.00	0.00	0.18	0.67	0.15	5.6
1	Mizuzawa-shi	0.39	0.81	0.11	0.08	0.01	5.5
1	Taneichi-machi	0.13	0.22	0.56	0.21	0.02	4.2
1	Sumita-cho	0.01	0.01	0.07	0.45	0.47	5.1
2	Kawasaki-machi	0.00	0.00	0.13	0.52	0.35	6.2
2	Kurihara-shi	0.17	0.50	0.16	0.21	0.14	5.38
2	Onagawa-cho	0.22	0.48	0.28	0.24	0.00	5.38
2	Shiroishi-shi	0.11	0.17	0.19	0.40	0.24	5.6
2	Yamamoto-cho	0.12	0.86	0.09	0.05	0.00	6
2	Hirono-machi	0.21	0.42	0.12	0.32	0.14	5.38
2	Minamisoma-shi	0.13	0.59	0.11	0.25	0.04	5.38
2	Shinchi-machi	0.16	0.82	0.11	0.07	0.00	6.1
2	Kunimi-machi	0.32	0.40	0.22	0.31	0.07	6.3
2	Otama-mura	0.00	0.00	0.00	0.54	0.46	5.38
2	Tamura-shi	0.00	0.00	0.00	0.45	0.55	5.38
2	Aizubange-machi	0.00	0.00	0.53	0.47	0.00	5.3
2	Nishiaizu-machi	0.00	0.00	0.13	0.62	0.25	4.7
2	Yanaizu-machi	0.00	0.00	0.01	0.49	0.49	5.38
2	Asiro-cho	0.00	0.00	0.00	0.36	0.64	5.38
2	Kuzumaki-machi	0.00	0.00	0.00	0.13	0.87	5.38
2	Rikuzentakata-shi	0.10	0.27	0.16	0.44	0.13	5.38
2	Shizukuishi-cho	0.00	0.00	0.03	0.50	0.47	4.6
2	Hiraizumi-cho	0.24	0.55	0.29	0.15	0.00	5.3

Table 57 Full Database of the Tohoku region (10).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
2	Fudai-mura	0.09	0.16	0.36	0.46	0.03	5.3
2	Senmaya-cho	0.05	0.05	0.65	0.28	0.02	5.8
2	Karumai-machi	0.00	0.00	0.11	0.87	0.01	4.6
2	Sanriku-cho	0.14	0.25	0.23	0.37	0.15	5.38
2	Murone-mura	0.01	0.01	0.20	0.71	0.08	5.5
2	Yuda-machi	0.00	0.00	0.00	0.56	0.44	5.38
2	Fujisawa-cho	0.14	0.22	0.51	0.27	0.00	5.6
2	Tarou-cho	0.15	0.24	0.34	0.40	0.02	4.7
2	Niisato-mura	0.02	0.03	0.07	0.35	0.55	5.38
3	Ishinomaki-shi	0.15	0.67	0.19	0.14	0.00	5.3
3	Kesennuma-shi	0.17	0.39	0.27	0.30	0.03	5.3
3	Osaki-shi	0.13	0.50	0.10	0.21	0.19	5.3
3	Wakuya-cho	0.11	0.85	0.14	0.01	0.00	6
3	Zao-machi	0.11	0.15	0.18	0.36	0.31	6
3	Iitate-mura	0.00	0.00	0.01	0.47	0.52	5.5
3	Kawamata-machi	0.00	0.00	0.03	0.53	0.44	5.5
3	Nihonmatsu-shi	0.00	0.00	0.05	0.76	0.20	5.3
3	Tenei-mura	0.00	0.00	0.00	0.24	0.76	6.2
3	Furudono-machi	0.00	0.00	0.00	0.34	0.66	5.3
3	Hanawa-machi	0.00	0.00	0.03	0.42	0.55	4.9
3	Samegawa-mura	0.00	0.00	0.00	0.30	0.70	4.7
3	Aizuwakamatsu-shi	0.00	0.00	0.10	0.33	0.57	5.3
3	Inawashiro-machi	0.00	0.00	0.00	0.00	1.00	5.3
3	Kitakata-shi	0.00	0.00	0.12	0.45	0.43	5.3
3	Yugawa-mura	0.00	0.00	1.00	0.00	0.00	5.4
3	Kawasaki-mura	0.19	0.44	0.40	0.16	0.00	5.1
3	Ofunato-shi	0.10	0.23	0.19	0.42	0.16	5.3

Table 58 Full Database of the Tohoku region (11).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
3	Higasiyama-cho	0.13	0.20	0.44	0.35	0.01	5.1
3	Ninohe-shi	0.04	0.04	0.27	0.66	0.03	5.3
3	Kamaishi-shi	0.08	0.15	0.16	0.33	0.37	5.3
3	Miyako-shi	0.14	0.28	0.22	0.36	0.14	5.3
3	Miyamori-mora	0.00	0.00	0.03	0.66	0.31	5
3	Hanamaki-shi	0.18	0.18	0.27	0.35	0.21	5.2
3	Hanaizumi-cho	0.35	0.84	0.16	0.00	0.00	5.6
3	Esashi-shi	0.16	0.24	0.27	0.38	0.11	5.4
3	Kanegasaki-cho	0.19	0.22	0.34	0.32	0.13	5.2
3	Kunohe-mura	0.00	0.00	0.00	0.79	0.21	4.4
3	Nishine-cho	0.00	0.00	0.00	0.74	0.26	5.3
3	Ichinohe-machi	0.00	0.00	0.05	0.74	0.21	4.8
3	Tamayama-mura	0.00	0.00	0.03	0.32	0.66	5.3
3	Sawauchi-mura	0.00	0.00	0.00	0.51	0.49	5.3
3	Shiwa-cho	0.08	0.08	0.41	0.36	0.15	4.9
4	Kami-machi	0.11	0.19	0.18	0.40	0.23	4.77
4	Marumori-machi	0.09	0.24	0.20	0.49	0.06	4.77
4	Minamisanriku-cho	0.24	0.51	0.27	0.22	0.00	5.6
4	Shichikashuku-machi	0.00	0.00	0.00	0.25	0.75	5
4	Shikama-cho	0.24	0.43	0.18	0.27	0.12	5.4
4	Aizumisato-machi	0.00	0.00	0.03	0.49	0.49	4.77
4	Mishima-machi	0.00	0.00	0.00	0.48	0.52	3.4
4	Bandai-machi	0.00	0.00	0.00	0.35	0.65	5.2
4	Kitashiobara-mura	0.00	0.00	0.00	0.06	0.94	4.2
4	Showa-mura	0.00	0.00	0.00	0.05	0.95	3.7
4	Minamiaizu-machi	0.00	0.00	0.00	0.01	0.99	4.77
4	Shimogo-machi	0.00	0.00	0.00	0.06	0.94	4.77

Table 59 Full Database of the Tohoku region (12).

Cluster	Municipality	Elevation 50m-100m	Elevation <100m	Elevation 100m-200m	Elevation 200m-500m	Elevation >500m	Measured seismic intensity
4	Ohasama-machi	0.00	0.00	0.07	0.47	0.46	4.77
4	Isawa-cho	0.11	0.11	0.17	0.19	0.53	4.77
4	Towa-cho	0.01	0.01	0.41	0.54	0.04	5.3
4	Joubouji-cho	0.00	0.00	0.02	0.67	0.31	4.9
4	Kuji-shi	0.14	0.26	0.31	0.31	0.11	4.6
4	Yamagata-mura	0.00	0.00	0.01	0.55	0.45	3.9
4	Matsuo-mura	0.00	0.00	0.00	0.29	0.71	4.77
4	Tanohata-mura	0.05	0.08	0.23	0.60	0.09	4.77
4	Iwaizumi-cho	0.01	0.02	0.05	0.27	0.66	4.2
4	Iwate-machi	0.00	0.00	0.00	0.55	0.45	4.7
4	Noda-mura	0.10	0.22	0.15	0.52	0.10	4.9
4	Koromogawa-mura	0.08	0.12	0.24	0.48	0.16	5.5
4	Tono-shi	0.00	0.00	0.00	0.36	0.64	5.3
2	Ichinoseki-shi	0.17	0.28	0.28	0.27	0.17	5.8
5	Kaneyama-machi	0.00	0.00	0.00	0.33	0.67	3.3
5	Hinoemata-mura	0.00	0.00	0.00	0.00	1.00	3.5
5	Tadami-machi	0.00	0.00	0.00	0.10	0.90	3.8

Table 60 Full Database of the Tohoku region (13).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
1	Higashimatsushima-shi	0.00	0.02	0.03	421.20	129.85	2.54
1	Iwanuma-shi	0.00	0.01	0.01	727.80	367.06	1.72
1	Kakuda-shi	0.00	0.00	0.02	212.30	103.45	1.72
1	Matsushima-machi	0.00	0.03	0.06	279.10	104.83	1.18
1	Misato-machi	0.00	0.01	0.02	335.60	120.86	1.72
1	Murata-machi	0.00	0.02	0.03	153.00	76.23	1.72
1	Natori-shi	0.00	0.01	0.02	730.80	313.73	3.36
1	Ogawara-machi	0.00	0.01	0.01	940.80	472.33	1.72
1	Ohira-mura	0.00	0.02	0.04	88.60	79.08	1.04
1	Osato-cho	0.00	0.00	0.00	108.80	48.35	1.72
1	Rifu-cho	0.00	0.00	0.05	759.60	273.21	1.72
1	Sendai-shi, Aoba-ku	0.00	0.00	0.03	964.20	843.46	-0.48
1	Sendai-shi, Izumi-ku	0.00	0.01	0.02	1440.40	504.11	1.72
1	Sendai-shi, Miyagino-ku	0.00	0.01	0.02	3278.40	2054.37	1.72
1	Sendai-shi, Taihaku-ku	0.00	0.01	0.03	966.70	256.62	1.72
1	Sendai-shi, Wakabayashi-ku	0.00	0.01	0.02	2734.70	1549.86	1.72
1	Shibata-machi	0.00	0.01	0.01	728.80	294.00	1.72
1	Shichigahama-machi	0.00	0.00	0.00	1538.50	252.60	1.72
1	Shiogama-shi	0.00	0.02	0.02	3162.90	1302.30	4.26
1	Tagajo-shi	0.00	0.01	0.02	3209.20	1288.70	1.72
1	Taiwa-cho	0.00	0.01	0.02	110.40	59.56	1.72
1	Tome-shi	0.00	0.01	0.04	156.50	66.08	0.77
1	Tomiya-machi	0.00	0.02	0.04	957.50	245.41	1.72
1	Watari-cho	0.00	0.00	0.03	476.00	142.32	2.86
1	Katsurao-mura	0.00	0.00	0.04	18.20	4.35	1.72
1	Kawauchi-mura	0.00	0.00	0.04	14.30	5.07	-1.44
1	Soma-shi	0.02	0.01	0.04	191.30	89.71	3.15

Table 61 Full Database of the Tohoku region (14).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
1	Iwaki-shi	0.02	0.01	0.04	277.90	124.70	5.37
1	Date-shi	0.02	0.01	0.03	249.10	96.35	1.90
1	Fukushima-shi	0.01	0.02	0.04	381.10	194.91	4.37
1	Kori-machi	0.02	0.02	0.02	299.10	125.44	1.72
1	Kagamiishi-machi	0.01	0.03	0.04	410.10	171.92	1.72
1	Koriyama-shi	0.01	0.01	0.03	447.40	238.85	1.53
1	Miharu-machi	0.01	0.01	0.03	250.00	83.48	1.72
1	Motomiya-shi	0.02	0.01	0.02	358.10	188.33	1.72
1	Ono-machi	0.00	0.00	0.06	89.50	36.38	-0.47
1	Sukagawa-shi	0.04	0.01	0.02	283.60	114.09	1.72
1	Asakawa-machi	0.00	0.00	0.02	184.00	61.85	1.72
1	Hirata-mura	0.00	0.02	0.03	74.00	26.54	1.72
1	Ishikawa-machi	0.01	0.00	0.01	153.60	62.27	1.58
1	Izumizaki-mura	0.02	0.02	0.02	192.10	109.77	1.72
1	Nakajima-mura	0.00	0.00	0.00	272.60	84.51	1.72
1	Nishigo-mura	0.01	0.01	0.03	102.80	56.54	1.72
1	Shirakawa-shi	0.02	0.02	0.03	211.90	98.97	1.78
1	Tamakawa-mura	0.04	0.00	0.01	155.30	74.97	1.44
1	Tanagura-machi	0.03	0.01	0.03	94.20	47.45	1.72
1	Yabuki-machi	0.02	0.01	0.01	304.90	128.97	1.72
1	Yamatsuri-machi	0.00	0.00	0.09	53.70	25.00	1.72
1	Kitakami-shi	0.00	0.02	0.03	212.86	118.70	2.11
1	Kawai-mura	0.01	0.05	0.08	6.23	1.73	0.83
1	Otsuchi-cho	0.06	0.02	0.02	76.20	26.52	1.10
1	Daitou-cho	0.01	0.03	0.05	55.18	16.44	1.72
1	Oono-mura	0.00	0.04	0.04	40.00	11.17	1.72
1	Maesawa-cho	0.01	0.02	0.02	201.06	92.62	1.72

Table 62 Full Database of the Tohoku region (15).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
1	Yamada-machi	0.02	0.03	0.04	70.68	22.46	1.61
1	Morioka-shi	0.00	0.02	0.03	581.04	327.68	0.83
1	Ishidoriya-cho	0.03	0.01	0.02	132.39	40.78	1.72
1	Yahaba-cho	0.00	0.01	0.02	404.35	223.72	1.72
1	Takizawa-mura	0.00	0.02	0.04	295.40	93.77	1.72
1	Mizuzawa-shi	0.02	0.02	0.04	579.91	301.58	1.52
1	Taneichi-machi	0.03	0.03	0.03	74.34	19.57	0.68
1	Sumita-cho	0.00	0.03	0.08	18.49	6.81	1.22
2	Kawasaki-machi	0.00	0.00	0.09	36.80	14.13	0.61
2	Kurihara-shi	0.00	0.02	0.04	93.10	38.10	0.15
2	Onagawa-cho	0.00	0.06	0.06	152.80	87.19	2.38
2	Shiroishi-shi	0.00	0.02	0.05	130.60	51.07	2.51
2	Yamamoto-cho	0.00	0.00	0.03	259.10	73.40	0.61
2	Hirono-machi	0.01	0.00	0.08	92.80	49.84	3.83
2	Minamisoma-shi	0.04	0.00	0.02	177.90	76.85	0.61
2	Shinchi-machi	0.04	0.00	0.04	177.40	64.86	4.40
2	Kunimi-machi	0.03	0.03	0.04	266.10	87.85	1.11
2	Otama-mura	0.01	0.02	0.02	107.90	32.83	0.61
2	Tamura-shi	0.01	0.01	0.03	88.20	33.07	-0.41
2	Aizubange-machi	0.00	0.00	0.03	189.40	74.05	0.61
2	Nishiaizu-machi	0.00	0.00	0.08	24.70	8.93	0.77
2	Yanaizu-machi	0.00	0.00	0.04	22.80	7.64	0.61
2	Asiro-cho	0.00	0.04	0.09	13.13	4.82	-2.54
2	Kuzumaki-machi	0.00	0.04	0.07	16.79	5.11	-2.63
2	Rikuzentakata-shi	0.07	0.03	0.04	100.35	33.33	2.53
2	Shizukuishi-cho	0.00	0.00	0.01	29.61	13.18	-2.03
2	Hiraizumi-cho	0.00	0.02	0.03	131.65	54.08	0.61

Table 63 Full Database of the Tohoku region (16).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
2	Fudai-mura	0.04	0.04	0.05	44.34	12.98	-0.02
2	Senmaya-cho	0.00	0.02	0.04	128.85	65.55	0.55
2	Karumai-machi	0.00	0.05	0.06	41.54	15.03	-2.30
2	Sanriku-cho	0.00	0.03	0.04	57.86	14.53	0.61
2	Murone-mura	0.00	0.03	0.03	55.47	16.76	0.61
2	Yuda-machi	0.00	0.04	0.09	11.28	5.84	-0.54
2	Fujisawa-cho	0.01	0.00	0.03	72.66	31.17	0.61
2	Tarou-cho	0.05	0.05	0.05	42.73	10.21	0.61
2	Niisato-mura	0.00	0.03	0.09	13.45	3.73	0.61
3	Ishinomaki-shi	0.00	0.02	0.03	289.40	128.67	3.89
3	Kesennuma-shi	0.00	0.02	0.03	220.40	90.69	2.54
3	Osaki-shi	0.00	0.01	0.04	169.60	76.31	1.12
3	Wakuya-cho	0.00	0.02	0.03	213.10	85.10	1.82
3	Zao-machi	0.00	0.02	0.03	84.30	38.97	1.38
3	Iitate-mura	0.00	0.00	0.03	27.00	8.18	-2.23
3	Kawamata-machi	0.01	0.04	0.06	122.00	49.50	0.73
3	Nihonmatsu-shi	0.01	0.02	0.03	173.70	72.04	1.98
3	Tenei-mura	0.04	0.00	0.06	27.90	10.19	-2.56
3	Furudono-machi	0.02	0.00	0.04	36.90	13.85	-0.13
3	Hanawa-machi	0.01	0.01	0.04	46.70	18.60	1.76
3	Samegawa-mura	0.01	0.05	0.09	30.40	9.63	0.73
3	Aizuwakamatsu-shi	0.00	0.00	0.04	329.50	175.16	0.73
3	Inawashiro-machi	0.01	0.00	0.05	40.00	16.71	0.65
3	Kitakata-shi	0.00	0.00	0.03	94.40	37.27	0.45
3	Yugawa-mura	0.00	0.00	0.05	205.60	55.65	0.73
3	Kawasaki-mura	0.03	0.03	0.03	97.05	31.80	0.73
3	Ofunato-shi	0.03	0.03	0.05	176.34	94.55	2.66

Table 64 Full Database of the Tohoku region (17).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
3	Higasiyama-cho	0.02	0.02	0.01	82.45	34.29	0.73
3	Ninohe-shi	0.00	0.02	0.02	102.46	48.98	-1.72
3	Kamaishi-shi	0.04	0.04	0.05	89.68	42.33	2.92
3	Miyako-shi	0.09	0.02	0.03	141.90	62.69	1.83
3	Miyamori-mora	0.00	0.06	0.10	29.98	10.79	0.73
3	Hanamaki-shi	0.00	0.01	0.02	176.80	88.36	-0.53
3	Hanaizumi-cho	0.03	0.00	0.04	107.74	34.59	0.73
3	Esashi-shi	0.01	0.00	0.03	88.12	31.69	0.94
3	Kanegasaki-cho	0.01	0.01	0.01	90.81	50.83	0.73
3	Kunohe-mura	0.00	0.01	0.07	48.54	16.53	0.73
3	Nishine-cho	0.00	0.01	0.02	99.33	38.63	0.73
3	Ichinohe-machi	0.00	0.04	0.04	47.25	18.94	0.73
3	Tamayama-mura	0.00	0.03	0.03	35.57	13.56	0.73
3	Sawauchi-mura	0.00	0.00	0.00	11.07	3.77	-1.78
3	Shiwa-cho	0.01	0.01	0.03	139.13	45.88	-0.48
4	Kami-machi	0.00	0.00	0.03	55.40	24.22	-0.64
4	Marumori-machi	0.00	0.00	0.03	56.70	16.76	1.11
4	Minamisanriku-cho	0.00	0.05	0.06	106.40	38.77	2.63
4	Shichikashuku-machi	0.00	0.00	0.08	6.40	2.56	-0.64
4	Shikama-cho	0.00	0.00	0.01	68.00	27.30	0.78
4	Aizumisato-machi	0.00	0.00	0.03	82.30	21.43	-0.64
4	Mishima-machi	0.00	0.00	0.12	21.20	8.48	-0.64
4	Bandai-machi	0.00	0.00	0.02	63.00	33.61	-0.64
4	Kitashiobara-mura	0.00	0.00	0.07	13.60	7.60	-4.49
4	Showa-mura	0.00	0.00	0.16	7.20	2.11	-0.23
4	Minamiaizu-machi	0.00	0.00	0.09	20.20	9.36	-0.64
4	Shimogo-machi	0.00	0.00	0.08	20.40	8.02	-2.89

Table 65 Full Database of the Tohoku region (18).

Cluster	Municipality	Damage rate	Priority road restoration occupancy	Proportion of important roads	Population density	Employee density	Minimum temperature
4	Ohasama-machi	0.00	0.00	0.02	28.66	7.47	-0.53
4	Isawa-cho	0.00	0.00	0.03	56.66	15.94	-0.64
4	Towa-cho	0.00	0.01	0.03	66.88	16.59	-0.64
4	Joubouji-cho	0.00	0.02	0.03	28.12	8.27	-0.64
4	Kuji-shi	0.01	0.04	0.04	102.48	48.00	0.43
4	Yamagata-mura	0.00	0.04	0.04	11.20	3.10	-2.03
4	Matsuo-mura	0.00	0.02	0.04	25.82	11.29	-2.23
4	Tanohata-mura	0.04	0.04	0.05	24.60	7.77	0.33
4	Iwaizumi-cho	0.01	0.04	0.06	10.88	4.44	0.40
4	Iwate-machi	0.00	0.02	0.02	41.56	14.64	-0.64
4	Noda-mura	0.10	0.02	0.02	57.31	17.20	-0.64
4	Koromogawa-mura	0.00	0.01	0.00	31.59	7.57	-0.64
4	Tono-shi	0.01	0.02	0.04	36.91	14.64	-1.58
2	Ichinoseki-shi	0.01	0.02	0.05	127.44	78.24	2.53
5	Kaneyama-machi	0.00	0.00	0.10	8.40	2.93	1.49
5	Hinoemata-mura	0.00	0.00	0.13	1.60	1.24	-2.98
5	Tadami-machi	0.00	0.00	0.13	6.60	2.72	0.91

References

[1] The 2011 Tohoku Earthquake Tsunami Joint Survey Group: Results of Tsunami Surveys (Jul.5, 2011)
http://www.coastal.jp/tsunami2011/index.php?Field (viewed on April 12, 2018)

[2] Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Information related to the Tohoku Earthquake, Operation "Teeth of a Comb".
http://infra-archive311.jp/s-kushinoha.html (viewed on December 13, 2019)

[3] MLIT: Information related to the Nankai Trough Mega Earthquake
https://www.mlit.go.jp/hakusyo/mlit/r01/hakusho/r02/html/n1222000.html

[4] Noujima Shouro, and Kato Hiroki, "Spatio-Temporal Analysis of Traffic Volumes on Highway Networks - Comparison of the Great East Japan Earthquake Disaster and the Great Hanshin-Awaji Earthquake Disaster," Civil Engineering Society Paper Series A1 (Structural and Seismic Engineering), Vol.69, No.4, 2013, pp. I_121-I_133 (In Japanese)

[5] Masahiro Kishida, "The Great East Japan Earthquake: Damage and Restoration on Expressway," 2012, Concrete journal 50(1), 45-48

[6] Satoshi Nakao, Tetsuya Onodera, Shintaro Katayama, Tetsu Higashi, Yuichiro Kawabata, and Satoshi Fujii, "Developing A Model for Prediction of Road Shut-Down Caused by Large Earthquakes," Proceedings of the Civil Engineering Society D3 (Civil Engineering Design) 75(5), I_407-I_417, 2019

[7] Kuanyo Hattori, Hideo Oishi, Makoto Nakamura, Kazuya Makoshi, and Seiji Shinohara," Reproduction Simulation and Damage Prediction by Earthquake Damage Simulations in

Expressway Network," Proceedings of the Civil Engineering Society A1 (Structural and Seismic Engineering) 76(4), I_516-I_528, 2020

[8] Takeshi Ishibashi, Takayuki Kojima, Masayoshi Akiyama, and Shunichi Koshimura, "Road Network Retrofitting Prioritization Under Seismic and Tsunami Hazards Caused by The Anticipated Nankai Trough Earthquake Based on The Probabilistic Risk And Resilience," Proceedings of the Civil Engineering Society A1 (Structural and Seismic Engineering) 76(4), I_32-I_46, 2020

[9] Hada, Y.; Suzuki, T.; Shimora, H.; Meguro, K.; Kodama, N. Issues and Future Prospect on Practical Use of Probe Vehicle Data for Disaster Reduction—Provision of the for Disaster Reduction—Provision of the Vehicle Tracking Map in the 2007 Niigata-Ken Chuetsu-Oki Earthquake. J. Jpn. Assoc. Earthq. Eng. 2009, 9, 148–159. Available online: http://www.jaee.gr.jp/stack/submit-j/v09n02/090211 paper.pdf (accessed on 12 April 2018). (In Japanese)

[10] ITS JAPAN Traffic Information Map. Available online: https://www.its-jp.org/saigai/(accessed on 13 December 2019).

[11] Shouro, N.; Hiroki, K. Spatio-Temporal Analysis of Traffic Volumes on Highway Networks—Comparison of the Great East Japan Earthquake Disaster and the Great Hanshin-Awaji Earthquake Disaster; Civil Engineering Society: Tokyo, Japan, 2013; Volume 69, pp. I_121–I_133. (In Japanese)

[12] Kishida, M. The Great East Japan Earthquake: Damage and Restoration on Expressway. Concr. J. 2012, 50, 45–48.

[13] Komori, H; Endo, N. Road Distance Traveled by Vehicles Following the 2011 Tohoku

Earthquake, Calculated by G-BOOK Telematics Data, In Proceedings of the 9th International Conference on Signal-Image Technology & Internet-Based Systems, SITIS 9, Kyoto, Japan, 2–5 December 2013, pp. 870–874.

[14] Endo, N.; Komori, H. Analysis of Vehicle Tracking Maps in Iwate Prefecture Following the 2011 Tohoku Earthquake. Lecture Notes in Engineering and Computer Science. In Proceedings of the International MultiConference of Engineers and Computer Scientists 2015, IMECS 2015, Hong Kong, China, 18–20 March 2015; pp. 124–128.

[15] Endo, N.; Komori, H. Regional Difference on Road Recovery in Iwate Prefecture Following the 2011 Tohoku Earthquake. Lecture Notes in Engineering and Computer Science. In Proceedings of the World Congress on Engineering and Computer Science 2015, WCECS 2015, Berkeley, CA, USA, 21–23 October 2015; pp. 162–167.

[16] Endo, N.; Komori, H. Municipal Difference on Road Recovery in Iwate Prefecture Following the 2011 Tohoku Earthquake. In IAENG Transactions on Engineering Sciences—Special Issue for the International Association of Engineers Conferences, San Francisco, CA, USA, 21–23 October 2015; World Scientific: Singapore, 2016; pp. 226–235.

[17] Endo, N.; Komori, H. Regional Differences in Iwate Prefecture Road Usage Recovery Following the 2011 Tohoku Earthquake, Transactions on Engineering Technologies—World Congress on Engineering and Computer Science 2015; Springer: Berlin/Heidelberg, Germany, 2017; pp. 219–231. https://doi.org/10.1007/978-981-10-2717-8.

[18] Endo, N. Road Usage Recovery in Miyagi Prefecture Following the 2011 Tohoku Earthquake, IAENG Transactions on Engineering Sciences—Special Issue for the

International Association of Engineers Conferences 2016, Singapore, 5–7 January 2016; World Scientific: Singapore, 2017, pp. 111–125.

[19] Wu, J. Endo, N. Regional Differences in Fukushima Prefecture Road Recovery Following the 2011 Tohoku Earthquake, Lecture Notes in Engineering and Computer Science. In Proceedings of The International Multi Conference of Engineers and Computer Scientists 2019, Hong Kong, China, 13–15 March 2019, pp. 164–169.

[20] Wu, J.; Endo, N. Road Usage Recovery in Fukushima Prefecture Following the 2011 Tohoku Earthquake, IAENG Transactions on Engineering Sciences—Special Issue for the International Association of Engineers Conferences 2019, Hong Kong, China, 13–15 March 2019; World Scientific: Singapore, 2020; pp. 48–62.

[21] Information on 59 Municipalities in Fukushima Prefecture. Available online: https://www.pref.fukushima.lg.jp/site/iju-tokyo/city-town-vill.html (accessed on 12 April 2018).

[22] Wu, J.; Endo, N.; Saito, M. Cluster Analysis for Studying Road Recovery of Fukushima Prefecture Following the 2011 Tohoku Earthquake, Lecture Notes in Engineering and Computer Science. In Proceedings of the World Congress on Engineering 2021, London, UK, 7–9 July 2021, pp. 107–112.

[23] Wu, J.; Endo, N.; Saito, M. Cluster Analysis for Investigating Road Recovery in Iwate Prefecture Following the 2011 Tohoku Earthquake, Proceedings of The International Multi Conference of Engineers and Computer Scientists 2021, pp.65-69

[24] Wu, J.; Endo, N.; Saito, M. Cluster Analysis for Investigating Road Recovery in Fukushima Prefecture Following the 2011 Tohoku Earthquake. Eng. Lett. 2021, 29, 1636–

1642.

[25] TOYOTA CONNECTED Big Data, Passable Road Map. Available online: https://www.toyotaconnected.co.jp/service/bigdata.html (accessed on 13 December 2019)

[26] Official Website of QGIS, A Free and Open Source Geographic Information System. Available online: http://www.qgis.org/en/site/ (accessed on 13 December 2019).

[27] Official Website of IBM SPSS Statistics. Available online: https://www.ibm.com/products/spss-statistics (accessed on 13 December 2019).

[28] Edwards, A.W.; Cavalli-Sforza, L.L. A Method for Cluster Analysis. Biometrics 1965, 21, 362–375.

[29] Ward, Jr.; Joe, H. Hierarchical Grouping to Optimize an Objective Function. J. Am. Stat. Assoc. 1963, 58, 236–244.

[30] Klecka, W.R.; Iversen, G.R.; Klecka, W.R. Discriminant Analysis; Sage: New York, NY, USA, 1980; Volume 19.

[31] MLIT: Information on winter closure routes in the Tohoku region https://www.thr.mlit.go.jp/road/koutsu/heisa/index.html (viewed on June 13, 2021)

[32] Japan Meteorological Agency seismic intensity table https://www.jma.go.jp/jma/kishou/know/shindo/kaisetsu.html

[33] Japan Meteorological Agency, Seismic intensity of the 2011 off the Pacific coast of Tohoku earthquake https://www.data.jma.go.jp/svd/eqev/data/2011_03_11_tohoku/index.html

[34] Statistics Bureau Japan: https://www.stat.go.jp/data/index.html

[35] Wu, J.; Endo, N.; Saito, M. Cluster Analysis to Extract Municipal Road Recovery

Features in the Tohoku Region Following the 2011 Tohoku Earthquake, IAENG International Journal of Computer Science, vol. 49, no. 1, pp232-240, 2022

[36] Conservation GIS-consortium Japan, GIS data download, road center line (2006) and Dem data: http://cgisj.jp/download_typeJist.php

[37] Japan Institute of Country-ology and Engineering: Demographics by land shape and its analysis: https://www.jice.or.jp/knowledge/japan/commentary06

[38] Kaku S, Kazushin T, Tomoharu N and Toshiaki S 2012 Damage Assessment on Road Structures Due to Ground Excitation in the 2011 Off the Pacific Coast of Tohoku earthquake Civil Engineering Society Paper Series A1 (Structural and Seismic Engineering) 68-4 L1186 (In Japanese) https://www.jstage.jst.go.jp/article/jscejseee/68/4/6^_^_1186^article/-char/ja/

[39] Itagaki Osamu, and Maruyama Kikyu 2016 Damage Ratio of Regional Road Due to the 2011 Off the Pacific Coast of Tohoku earthquake Tsunami Civil Engineering Society Paper Series A1 (Structural and Seismic Engineering) 72-4 I_82 https://www.jstage.jst.go.jp/article/jscejseee/68/4/6^L1186^article/-char/ja/

[40] Japan Meteorological Agency, Historical weather data: https://www.data.jma.go.jp/gmd/risk/obsdl/#

[41] Cabinet Office, Government of Japan, Disaster Prevention Information: http://www.bousai.go.jp/kaigirep/hakusho/h19/bousai2007/html/zu/z^^^24.htm