Cluster Analysis for Investigating Road Recovery in Iwate Prefecture Following the 2011 Tohoku Earthquake

Jieling Wu, Noriaki Endo, *Member, IAENG,* and Mitsugu Saito

***Abstract*—The transport network in eastern Japan was severely damaged by the Tohoku Earthquake in 2011. The coast of Iwate Prefecture was severely affected by the tsunami. Because of the different topography, we think that the road recovery situation of Iwate Prefecture should be very different from the two prefectures studied previously. In this study, we analyzed the data of vehicles driving in Iwate Prefecture to classify the road recovery condition among municipalities in the first six months after the disaster. The results of the cluster analysis show that the road recovery condition is similar according to damage, recovery policy, importance of the road and population density.**

***Index Terms*—2011 Tohoku Earthquake; probe-car telematics data; vehicle-tracking map; Iwate Prefecture; cluster analysis; big data analysis**

I. Introduction

A. The 2011 Tohoku Earthquake

The Tohoku Earthquake of March 11th, 2011 and Tsunami caused serious damage throughout northeastern coast of Japan [1]. The tsunami was bigger than the 1896 and 1933 Sanriku earthquake tsunamis, and the 1960 Chilean earthquake tsunami, and the human and physical damage in coastal areas was particularly devastating.

In Iwate prefecture, the human toll was 5,794, including 4,672 dead and 1,122 missing. A total of 26,077 houses were destroyed or partially destroyed, most of which were damaged by the tsunami [2].

One of the main reasons for this is due to the rias (rocky) coast, which is characteristic of the coast of Iwate Prefecture. For example, at the end of a V-shaped bay, which is also common on a rias coast, tsunami forces can be concentrated and localized [3].

B. Road Clearance (Operation "Teeth of a Comb")

The Tohoku Earthquake of March 11th, 2011 caused major damage across a wide areas of transport routes in eastern Japan. Main roads and railways ceased to function for a long period of time, and the affected people were forced to lead very different lives from normal.

From the day after the disaster, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) carried out road clearance (Operation "Teeth of a Comb") [4] to open up as many routes as possible for vehicles to pass. Operation "Teeth of a Comb" was a road clearance operation to secure rescue and relief routes on a number of national highways extending from inland toward the Pacific coastal area of Tohoku. The operation was named after the shape of the road network being cleared, where the Tohoku Expressway and Route 4 run inland Tohoku from north to south, and a number of debris-covered roads to be cleared extended from the expressway and Route 4 toward the coast.

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C. Previous Study

In our previous study [5], we analyzed the data of vehicles driving in Fukushima Prefecture and Miyagi Prefecture to classify the road recovery condition among municipalities in the first six months after the disaster. The results of the cluster analysis show that the road recovery conditions are similar according to geographical location and topographical structure.

D. Purpose

Iwate Prefecture has a different topography from the other two prefectures, being rias coast, mostly mountainous with a small area of basin lowlands. We think that the road recovery situation should be very different from the two prefectures studied previously, and detailed research is needed. And the results of the study will provide a reference for road recovery in the event of future earthquakes and tsunamis in other parts of this terrain.

II. Concerning The Municipalities Of Iwate Prefecture

Before conducting a study of Iwate Prefecture, we compared the three prefectures in Tohoku. Iwate Prefecture has the largest area and the smallest number of municipalities [Table I, Fig.1]. Individual municipalities are generally larger in size than the previous two prefectures. In the existing data on administrative areas, there are 59 municipalities in Iwate Prefecture on the boundaries of the municipalities before they were merged in 1999 [6]. This does not affect the analysis of existing municipalities, but simply breaks down the existing municipalities more. In order to avoid mixing various road recovery speed within a large area as in the previous study [7], [8], we chose to study an area that is further subdivided than the existing municipal boundaries.

III. Methodology

A. Research area

59 municipalities in Iwate Prefecture [Fig.2].

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TABLE I
COMPARISON OF THREE PREFECTURES

Prefecture	Area(km^2)	Number of Municipalities
Fukushima	13,782.75	59
Miyagi	7,285.73	39
Iwate	15,278.77	33

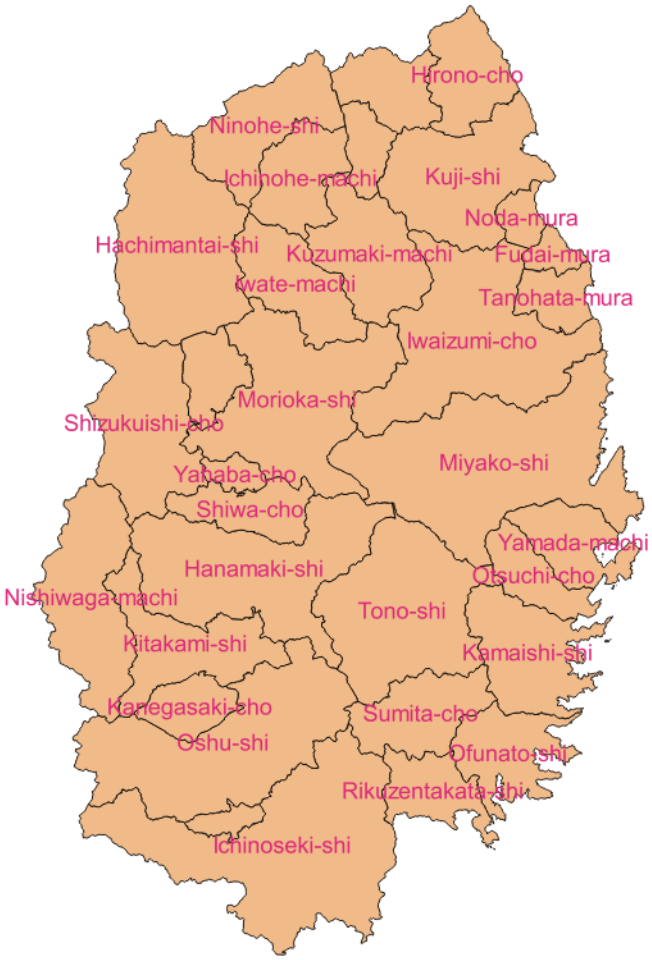

Fig. 1. 33 municipalities in Iwate Prefecture.

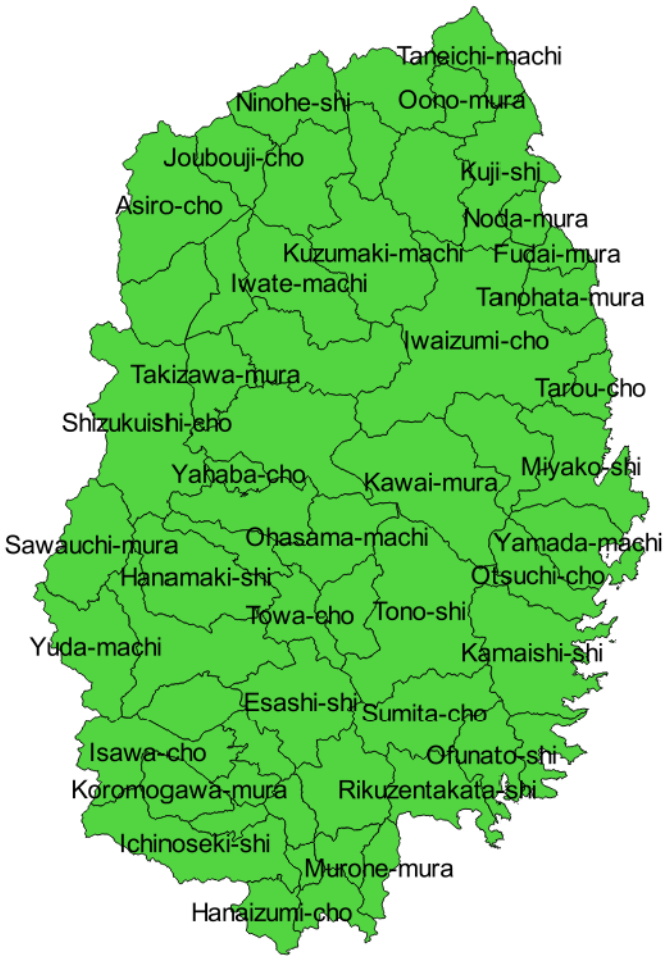

Fig. 2. 59 municipalities in Iwate Prefecture.

B. Research materials

In our current study, we have used the vehicle tracking maps built from the G-BOOK telematics data that is available on the Internet on March 18, 2011 following the 2011 Tohoku Earthquake [9]. The data used in this study have been collected between March 18 and September 30, 2011 (i.e., approximately six months following the 2011 Tohoku Earthquake).

C. System

1) Hardware: The computations have been performed on a standard PC laptop with a Core i7-6700U CPU (2.6 GHz) and 16 GB memory (Hasee Z7M-SL7D2).

2) Software: The software QGIS version 2.18.20, IBM SPSS Statistics 23, and Microsoft Excel 2010 running on the Windows 7 Professional operating system have been used in this study. It is well-known that QGIS is one of the most popular geographic information systems used worldwide.

D. Data Processing

1) The vehicle tracking maps constructed from the G-BOOK telematics data have been provided in the Google map KMZ format. For our analysis, we have first converted the KMZ files to SHP files (i.e., shape-files), which are compatible with ArcGIS using the ogr2ogr software.

2) Next, the data coordinates have been converted from the terrestrial latitude and longitude to the x and y coordinates in a rectangular coordinate system.

3) To reduce the computation time, the data file has been clipped to small files containing only the research area.

4) After merging daily data into weekly data and removing duplicate data, we have been able to calculate the exact usable road distance available for a given week.

In this context, a usable road is one on which at least one vehicle has been tracked during the observation period.

The purpose of converting the daily data to weekly data was to smooth the daily fluctuations in the traffic flows.

5) Next, we have calculated the proportion of the cumulative distance up to the specified date. Note that the cumulative

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TABLE II
FIVE CLUSTERS OF MUNICIPALITIES WITH SIMILAR ROAD RECOVERIES OF IWATE PREFECTURE

Cluster	Municipality	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	Asiro-cho	26	81	82	82	83	83	90	95	97	97	100
1	Fudai-mura	0	86	97	97	97	97	97	99	99	99	100
1	Yuda-machi	15	85	86	86	86	90	97	99	100	100	100
1	Tarou-cho	0	93	93	93	100	100	100	100	100	100	100
2	Kitakami-shi	54	79	83	87	91	92	95	98	98	99	100
2	Kawai-mura	58	82	90	93	93	93	93	93	93	95	100
2	Otsuchi-cho	43	87	88	92	92	97	97	97	97	100	100
2	Oono-mura	67	83	86	87	90	90	90	100	100	100	100
2	Maesawa-cho	53	76	86	93	95	95	95	96	97	98	100
2	Yamada-machi	77	83	91	97	97	98	98	100	100	100	100
2	Morioka-shi	72	84	88	89	92	94	96	97	99	100	100
2	Ishidoriya-cho	53	74	86	90	93	95	95	97	98	100	100
2	Yahaba-cho	53	81	88	91	92	94	95	96	98	100	100
2	Takizawa-mura	51	83	87	91	94	95	96	97	98	98	100
2	Mizuzawa-shi	72	89	94	96	97	99	100	100	100	100	100
2	Taneichi-machi	73	88	88	91	91	94	97	98	98	100	100
2	Sumita-cho	72	85	87	88	88	88	91	99	100	100	100
3	Kawasaki-mura	52	58	76	77	77	83	84	99	99	99	100
3	Ofunato-shi	54	75	81	86	86	89	91	99	100	100	100
3	Towa-cho	44	55	65	76	87	92	95	98	98	100	100
3	Higasiyama-cho	43	69	79	79	80	82	85	91	93	93	100
3	Ninohe-shi	51	63	75	78	89	90	93	95	97	97	100
3	Kamaishi-shi	48	63	77	79	81	85	87	94	94	94	100
3	Miyako-shi	54	63	79	84	84	87	87	95	96	100	100
3	Miyamori-mora	65	70	76	76	76	84	85	87	100	100	100
3	Hanamaki-shi	53	75	80	85	86	88	94	96	98	99	100
3	Hanaizumi-cho	56	69	75	80	90	94	95	99	99	100	100
3	Esashi-shi	52	62	71	75	83	85	87	90	96	97	100
3	Kanegasaki-cho	60	76	81	84	87	91	91	96	96	97	100
3	Kunohe-mura	43	71	79	82	82	82	82	82	82	90	100
3	Shizukuishi-cho	48	66	77	83	87	88	90	95	98	100	100
3	Nishine-cho	48	68	73	77	91	91	96	96	98	100	100
3	Ichinohe-machi	32	63	74	82	84	85	85	87	90	94	100
3	Tamayama-mura	56	66	79	84	85	86	87	94	95	100	100
3	Sawauchi-mura	69	69	69	69	69	69	88	88	99	99	100
3	Shiwa-cho	52	72	79	80	83	86	92	97	98	100	100
4	Daitou-cho	49	67	88	90	93	96	98	100	100	100	100
4	Kuzumaki-machi	38	47	94	94	94	95	95	97	99	99	100
4	Rikuzentakata-shi	49	64	82	88	90	93	95	96	99	99	100
4	Hiraizumi-cho	41	64	83	85	89	89	89	91	97	97	100
4	Senmaya-cho	43	71	80	88	91	93	95	99	99	100	100
4	Karumai-machi	34	69	81	82	87	91	96	96	100	100	100
4	Sanriku-cho	34	69	85	93	94	94	95	99	100	100	100
4	Murone-mura	20	56	56	97	97	97	97	100	100	100	100
4	Fujisawa-cho	46	70	82	86	90	94	96	97	98	98	100
4	Niisato-mura	40	44	87	87	87	87	87	100	100	100	100
4	Ichinoseki-shi	44	63	82	83	88	90	96	99	99	100	100
5	Ohasama-machi	37	41	47	47	54	54	85	90	90	99	100
5	Isawa-cho	44	55	71	74	75	79	82	93	99	100	100
5	Joubouji-cho	21	62	70	70	70	72	97	97	97	97	100
5	Kuji-shi	46	57	60	65	78	81	84	89	89	99	100
5	Yamagata-mura	27	47	61	68	74	88	91	91	96	97	100
5	Matsuo-mura	25	59	62	72	73	75	94	94	96	100	100
5	Tanohata-mura	10	55	57	57	69	93	96	97	98	98	100
5	Iwaizumi-cho	22	42	63	63	71	72	80	86	86	100	100
5	Iwate-machi	41	46	60	61	75	78	78	98	99	99	100
5	Noda-mura	4	48	48	70	70	70	70	70	70	100	100
5	Koromogawa-mura	18	30	64	76	78	80	85	88	95	100	100
5	Tono-shi	37	55	73	75	76	79	82	88	98	99	100

TABLE III
NUMBER OF ROAD RECOVERY PERCENTAGES IN FIVE CLUSTERS OF IWATE PREFECTURE

Cluster	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	10	86	**90**	90	92	93	96	98	99	99	100
2	61	83	88	**91**	93	94	95	97	98	99	100
3	52	67	76	80	83	86	89	**94**	96	98	100
4	40	62	82	89	**91**	92	95	98	99	99	100
5	28	50	61	66	72	77	85	**90**	93	99	100

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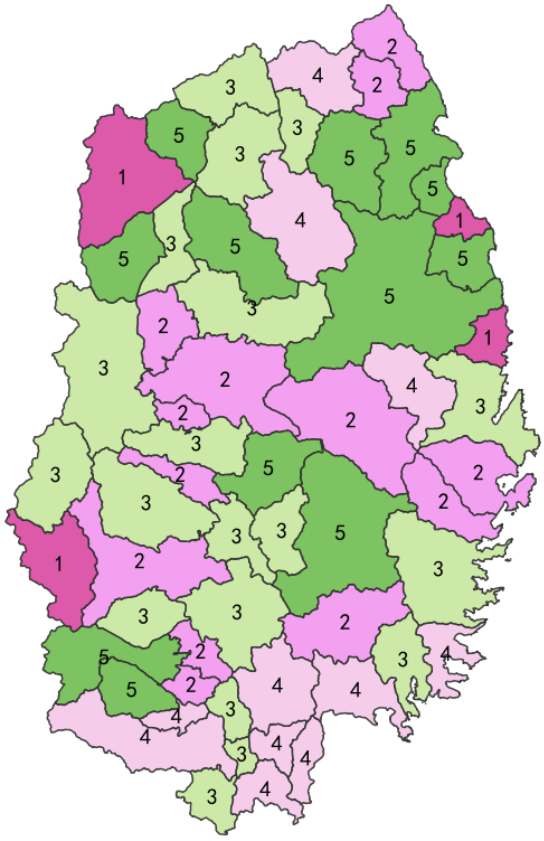

Fig. 3. Each municipality in Iwate Prefecture belongs to a cluster. Municipalities with similar road recoveries were divided into 5 clusters.

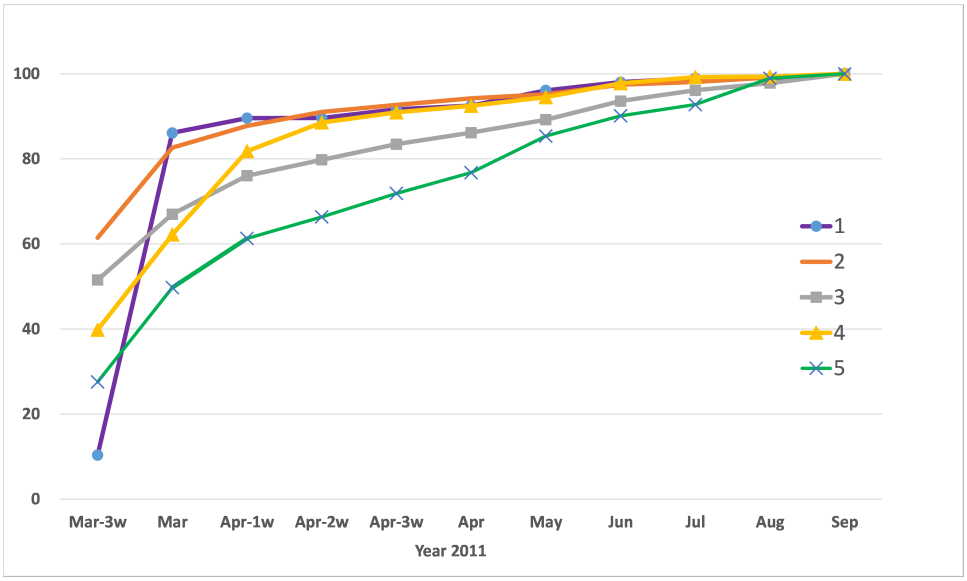

Fig. 4. Road recovery conditions of the five clusters in Iwate Prefecture. This chart shows the road recovery percentages for each group in the first six months after the 2011 Tohoku Earthquake. It is based on Table III.

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distance up to September 30th, 2011 was considered 100%.

6) Using this data, we obtained the percentage of road use recovery in each municipality.

Then, we introduced the number of percentages into the software SPSS and use the function of SPSS analysis to get the result of cluster analysis.

IV. Results

1) According to the results of the cluster analysis, municipalities with similar road recoveries were divided into five clusters [Table II].

2) Each municipalities cluster is shown on the map [Fig.3].

3) The date order of the recovery reaching 90%, averaged for each cluster, is $1 > 2 > 4 > 3 > 5$ [Table III, Fig.4].

V. Discussion

Consider the order and characteristics of each cluster recovery:

Cluster 1: Recovery was the fastest, with the least damage and considered to have the fewest roads.

Cluster 2: Second fastest recovery, concentrated in the larger cities (Morioka, Kitakami); in the municipalities that had priority recovery routes with "Teeth of a Comb" and few roads.

Cluster 4: Third in terms of recovery, but concentrated in municipalities with many routes, relatively high levels of road damage.

Cluster 3: Slow recovery concentrated in coastal municipalities where there was a lot of tsunami damage. In inland areas, municipalities in the south with many routes that had suffered a lot of earthquake damage were slow to recover; slow recovery time in municipalities in the north was due to snow.

Cluster 5: Slowest recovery, mainly in the mountains, non-main routes, relatively low population density. It was considered that the recovery of road use was delayed due to snow and the restriction of traffic until the road closures in urban areas of the prefecture were lifted.

VI. Conclusion

This study applied cluster analysis to find the similarity of road recovery after the earthquake in Iwate Prefecture's municipalities. Similar road recovery conditions of Iwate Prefecture were found according to damage, recovery policy, importance of the road and population density.

We think that the unique topographical features of Iwate Prefecture affect elements of road recovery differently from those previously studied in Fukushima and Miyagi prefectures.

Analysis of vehicle travel data from Iwate Prefecture during the second half year of the 2011 Tohoku Earthquake are used to identify regional characteristics and factors affecting road recovery. Mie Prefecture in the Tokai region has the same rais coast as Iwate Prefecture, where the Nankai Trough earthquake and resulting tsunami are expected to cause significant damage in the future. We think that the recovery of regional roads in Iwate Prefecture affected by the Tohoku Earthquake can be used to help promote the rapid recovery in Mie Prefecture in the Tokai region after the Nankai Trough earthquake in the future. Therefore, We will conduct a detailed study of the factors that affect road recovery and then create a relevant database. By using the database, we will develop a new forecasting model that can be applied to Mie Prefecture in the Tokai region by GIS mapping of regional characteristics and road recovery. We hope this model can be applied to other regions.

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