Cluster Analysis for Studying Road Recovery of Fukushima 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. In order to understand the road recovery conditions after the widespread disaster, a lot of time is needed to collect information on the extent of damage and road usage. In this study, we analyzed the data of vehicles driving in Fukushima Prefecture to classify the road recovery conditions among regions 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.**

***Index Terms*—2011 Tohoku Earthquake, big data analysis, cluster analysis, Fukushima Prefecture, telematics data, vehicle tracking map.**

I. Introduction

THE Tohoku Earthquake of March 11, 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 [1].

From the day after the disaster, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) carried out "road reclamation" (Operation "comb's tooth") to open up as many routes as possible for vehicles to pass [2].

In Fukushima Prefecture, most of the coastal area experienced a seismic intensity of over 6 on the Richter scale, the coast was hit by a massive tsunami, and the aftershocks caused a series of collapses of infrastructure and buildings. Furthermore, the Fukushima Daiichi nuclear power plant accident triggered by the earthquake shocked the whole world.

In the event of a disaster, the collection and aggregation of road information is a time-consuming process for various emergency, rescue and recovery operations. Therefore, we thought of analyzing the driving data of vehicles traveling in the disaster area in order to quickly understand the road conditions during the disaster [3].

In this study, we focused on the 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 Fukushima Prefecture. The objective of the study is to reflect the situation of local road use from objective data and to support disaster prevention measures according to the recovery situation.

J. Wu is a PhD candidate of Design and Media Technology, Graduate School of Engineering, Iwate University, Morioka, Iwate, Japan (e-mail: s3320002@iwate-u.ac.jp/wujl0612@yahoo.co.jp).

N. Endo is a Professor of Regional Innovation and Management, Graduate School of Arts and Sciences, Iwate University, Morioka, Iwate, Japan (e-mail: endo@iwate-u.ac.jp).

M. Saito is an Associate Professor of Design and Media Technology, Graduate School of Engineering, Iwate University, Morioka, Iwate, Japan (e-mail: mitsugu@iwate-u.ac.jp).

II. Previous Study

In our previous study [4], [5], Fukushima Prefecture was divided into seven regions [Fig.1] in the six months following the 2011 Tohoku Earthquake, the speed of road use recovery in inland areas was slower than coastal areas. It concluded that the roads in the two regions where recovery was much slower were narrow, steep-walled and mountainous.

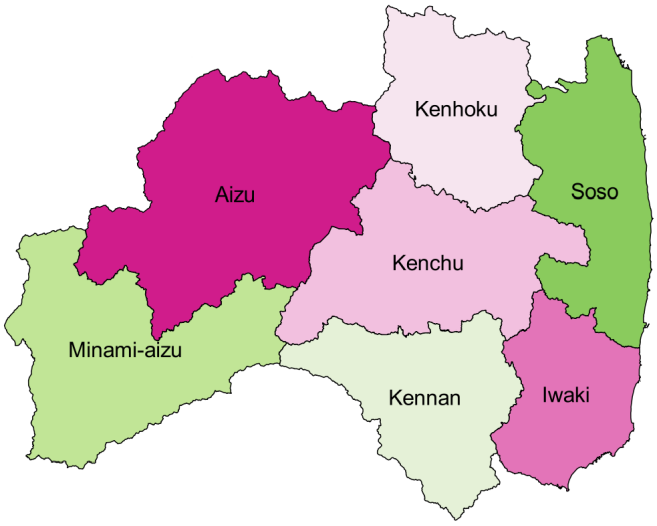

Fig. 1. Fukushima Prefecture divided into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions.

It is considered that the classification of the agreed maturity has an effect on the result and the road recovery speed is not the same depending on the municipalities in the same region. Therefore, it is necessary to divide into smaller areas and analyze in detail.

III. Methodology

A. Research Area

All municipalities in Fukushima Prefecture (excluding municipalities located in the no-go zone due to the Fukushima Daiichi nuclear power plant accident) [Fig.2].

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Fig. 2. Municipalities of Fukushima Prefecture. There're 59 municipalities in Fukushima Prefecture. The five municipalities of Namie-machi, Futaba-machi, Okuma-machi, Tomioka-machi, Naraha-machi were in the no-go zone due to the Fukushima Daiichi nuclear power plant accident.

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. 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 [6], IBM SPSS Statistics 23 [7], 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 Googlemap KMZ format. For our analysis, we have first convertedthe KMZ files to SHP files (i.e., shape-files), which are compatible with ArcGIS using the ogr2ogr software [8] on the Linux operating system [9].

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 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 [Table I].

IV. Results And Discussion

A. Results of Cluster Analysis

According to the results of the cluster analysis, municipalities with similar road recoveries were divided into seven groups [Table I]. The group of each municipality is shown on the map [Fig.3] . (0 is a closed area due to the Fukushima Daiichi nuclear power plant accident.) The date order of the recovery reaching 90%, averaged for each group, is $3 > 5 > 1, 4 > 6 > 2 > 7$ [Table II] [Fig.4]. The location of each group and its recovery:

Group 1: West side 1a (Echigo Mountains), due to snow; east side 1b (coastal lowlands), due to tsunami; roads recovered gradually after the disaster road closure was lifted.

Group 2: In the mountains (Ou Mountains, Abukuma Highlands), road recovery was slow.

Group 3: Roads in the Nakadori basin were the fastest to recover.

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TABLE I
SEVEN GROUPS OF MUNICIPALITIES WITH SIMILAR ROAD RECOVERIES

Group	Municipality	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	Hirono-machi	38.0	69.4	71.4	88.2	92.4	92.9	96.8	97.5	99.4	99.7	100.0
1	Minamisoma-shi	33.5	71.0	83.2	88.9	92.6	93.0	95.3	96.6	98.2	98.8	100.0
1	Shinchi-machi	43.9	64.4	76.8	85.6	88.2	94.0	97.1	97.8	98.0	99.1	100.0
1	Kunimi-machi	32.8	70.7	79.4	87.7	88.6	88.8	98.0	98.3	98.3	98.3	100.0
1	Tamura-shi	43.0	70.7	80.2	87.5	90.8	93.6	95.9	95.9	97.9	98.6	100.0
1	Aizubange-machi	40.7	69.5	80.8	84.9	89.0	91.6	95.6	96.7	96.7	100.0	100.0
1	Nishiaizu-machi	38.7	67.5	80.9	87.6	88.4	88.4	98.6	100.0	100.0	100.0	100.0
2	Iitate-mura	54.6	63.3	66.9	75.6	81.6	86.3	92.8	92.8	100.0	100.0	100.0
2	Kawamata-machi	56.1	70.5	71.0	76.3	85.4	89.7	94.8	96.3	97.9	100.0	100.0
2	Tenei-mura	49.0	62.9	72.5	75.7	80.3	85.1	96.7	97.2	97.6	99.2	100.0
2	Furudono-machi	56.9	58.4	58.5	72.6	85.6	93.3	93.3	93.3	98.8	100.0	100.0
2	Samegawa-mura	72.0	72.2	72.8	75.6	77.8	94.9	97.5	97.5	97.5	100.0	100.0
2	Inawashiro-machi	51.6	68.4	71.0	72.3	76.8	84.7	94.9	96.9	98.0	100.0	100.0
2	Yugawa-mura	59.4	68.0	68.8	77.7	77.7	82.8	89.0	95.7	95.7	97.8	100.0
3	Katsurao-mura	60.0	74.5	95.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3	Kawauchi-mura	40.3	94.5	97.8	97.8	99.1	99.1	99.2	99.2	100.0	100.0	100.0
3	Kori-machi	56.5	86.3	93.1	95.0	96.0	96.0	99.8	100.0	100.0	100.0	100.0
3	Kagamiishi-machi	56.6	84.7	89.5	94.9	97.7	97.7	97.7	98.0	99.0	100.0	100.0
3	Motomiya-shi	69.4	87.1	93.1	95.2	97.5	98.4	98.7	99.1	99.9	100.0	100.0
3	Ono-machi	50.7	88.0	95.3	95.3	96.6	97.0	98.4	98.4	98.4	98.4	100.0
3	Hirata-mura	57.2	81.5	89.6	95.4	95.9	96.4	97.1	97.1	100.0	100.0	100.0
3	Nakajima-mura	57.8	81.3	88.1	91.5	97.1	97.2	97.2	97.2	98.1	98.1	100.0
3	Tamakawa-mura	51.7	78.3	84.5	93.1	98.3	100.0	100.0	100.0	100.0	100.0	100.0
3	Yabuki-machi	62.6	89.6	90.7	94.4	95.7	98.1	98.1	99.5	99.5	99.8	100.0
4	Soma-shi	53.6	76.7	84.4	86.3	91.8	94.6	95.6	96.3	96.4	99.4	100.0
4	Date-shi	54.7	71.4	81.0	88.3	93.3	95.1	95.7	96.9	97.7	100.0	100.0
4	Nihonmatsu-shi	58.6	74.5	79.9	84.2	87.1	91.0	93.7	95.0	96.7	98.6	100.0
4	Otama-mura	46.5	74.8	84.0	89.2	91.2	93.5	93.5	93.5	93.8	99.9	100.0
4	Hanawa-machi	59.7	65.3	74.6	85.0	87.1	87.9	87.9	87.9	87.9	87.9	100.0
4	Ishikawa-machi	57.2	69.5	88.9	91.7	92.8	96.7	97.0	97.0	100.0	100.0	100.0
4	Izumizaki-mura	55.1	77.8	87.4	89.4	91.1	95.3	96.2	96.5	99.0	100.0	100.0
4	Nishigo-mura	53.2	71.1	82.3	91.1	92.2	99.0	99.9	99.9	100.0	100.0	100.0
4	Aizuwakamatsu-shi	55.3	69.4	80.1	83.5	85.7	92.4	94.9	96.8	98.1	99.6	100.0
4	Kitakata-shi	54.9	61.4	74.4	86.3	90.5	91.6	93.7	95.3	96.9	98.2	100.0
5	Iwaki-shi	60.3	80.9	87.5	90.5	92.9	94.5	97.2	98.3	98.9	99.3	100.0
5	Fukushima-shi	66.0	80.1	84.5	87.6	90.2	94.8	96.0	97.9	98.9	99.4	100.0
5	Koriyama-shi	66.2	84.2	88.9	91.1	94.1	95.8	97.0	97.6	98.6	99.5	100.0
5	Miharu-machi	60.1	79.7	83.1	84.5	90.3	96.7	98.9	98.9	100.0	100.0	100.0
5	Sukagawa-shi	63.8	79.7	84.7	90.4	91.7	94.6	96.5	97.4	98.5	99.8	100.0
5	Asakawa-machi	67.3	76.3	79.0	86.2	94.8	98.0	99.0	99.0	99.0	99.0	100.0
5	Shirakawa-shi	66.8	80.4	85.6	89.4	92.1	92.3	96.6	98.0	98.5	99.2	100.0
5	Tanagura-machi	81.6	86.0	89.4	94.0	97.8	97.8	99.0	99.0	100.0	100.0	100.0
5	Yamatsuri-machi	80.8	83.0	89.5	93.1	93.4	93.4	93.4	100.0	100.0	100.0	100.0
6	Aizumisato-machi	38.8	51.3	70.8	75.3	80.6	93.1	93.5	95.9	98.3	98.8	100.0
6	Mishima-machi	15.9	54.3	80.2	80.2	81.9	82.0	83.7	97.7	97.7	97.7	100.0
6	Yanaizu-machi	29.2	49.6	87.2	91.5	91.7	94.1	97.8	99.6	100.0	100.0	100.0
7	Bandai-machi	27.7	51.6	55.9	58.6	58.6	70.2	95.3	96.9	97.5	98.0	100.0
7	Kaneyama-machi	0.0	13.0	60.7	60.7	64.1	64.4	64.9	96.8	100.0	100.0	100.0
7	Kitashiobara-mura	39.3	44.4	48.1	54.4	71.2	82.3	96.7	97.8	98.5	98.5	100.0
7	Showa-mura	0.0	32.7	46.4	47.4	70.4	73.1	95.1	95.1	95.1	95.1	100.0
7	Hinoemata-mura	0.0	0.0	0.0	0.0	0.0	30.6	61.1	100.0	100.0	100.0	100.0
7	Minamiaizu-machi	32.1	47.1	59.2	63.6	64.0	77.3	84.4	88.3	99.1	99.1	100.0
7	Shimogo-machi	41.2	56.8	59.1	62.3	75.3	85.2	93.4	93.7	99.3	99.3	100.0
7	Tadami-machi	4.3	4.4	27.0	37.8	53.2	54.8	78.0	89.8	93.9	94.9	100.0

TABLE II
NUMBER OF ROAD RECOVERY PERCENTAGES IN SEVEN GROUPS OF FUKUSHIMA

Group	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	38.7	69.0	79.0	87.2	**90.0**	91.8	96.8	97.6	98.4	99.2	100.0
2	57.1	66.2	68.8	75.1	80.7	88.1	**94.1**	95.7	97.9	99.6	100.0
3	56.3	84.6	**91.8**	95.3	97.4	98.0	98.6	98.9	99.5	99.6	100.0
4	54.9	71.2	81.7	87.5	**90.3**	93.7	94.8	95.5	96.7	98.4	100.0
5	68.1	81.2	85.8	**89.6**	93.0	95.3	97.1	98.5	99.2	99.6	100.0
6	28.0	51.7	79.4	82.3	84.7	**89.7**	91.7	97.7	98.7	98.8	100.0
7	18.1	31.2	44.5	48.1	57.1	67.2	83.6	**94.8**	97.9	98.1	100.0

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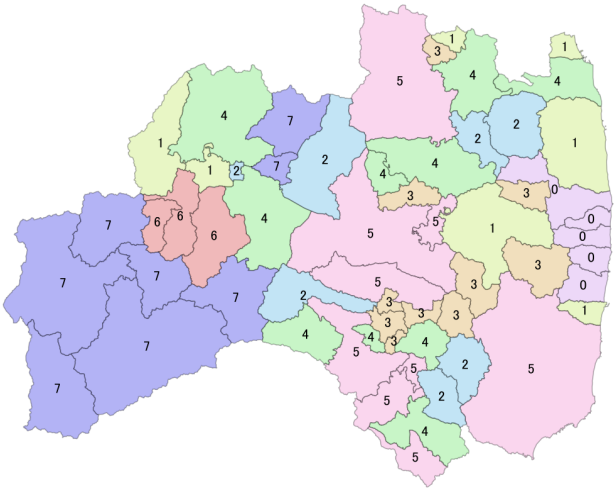

Fig. 3. Each municipality in Fukushima Prefecture belongs to a group. Municipalities with similar road recoveries were divided into seven groups.

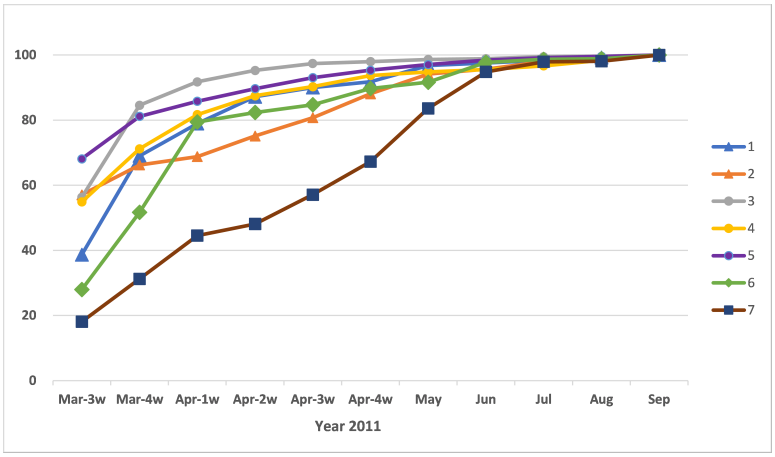

Fig. 4. Road recovery conditions of the seven groups in Fukushima Prefecture. This chart shows the road recovery percentages for each group in the first six months after the 2011 Tohoku Earthquake. It is based on Table II.

Group 4: Located in the mountains and also in the basin, urban to other groups, the speed of road recovery was middling compared to other groups.

Group 5: Roads located in basins, lowlands and large cities, the speed of road recovery was the second fastest.

Group 6: Recovery was slow due to some mountains (Echigo Mountains) and snow.

Group 7: Heavy snowfall areas and mountain (Echigo Mountains) locations, slowest recovery.

In the disaster areas, similar recovery conditions were observed depending on geographical location and topography. Recovery in lowland areas seemed to be faster than in mountainous areas.

Each group was divided into four areas according to its geographical shape and proximity to the recovery [Fig.5]. The order of area recovery is $(b) > (d) > (c) > (a)$.

(a) Aizu Inland Region

This area is mainly located in the Aizu region and is characterised by groups 1a, 2, 4, 6 and 7. This area is located in the Ou and Echigo mountain ranges and in a region of heavy snowfall. The Aizu region has always had a problem with the lack of high standard roads, and due to the snow and mountainous terrain, the order of recovery is $1a, 4 > 6 > 2 > 7$.

(b) Nakadori Inland Region

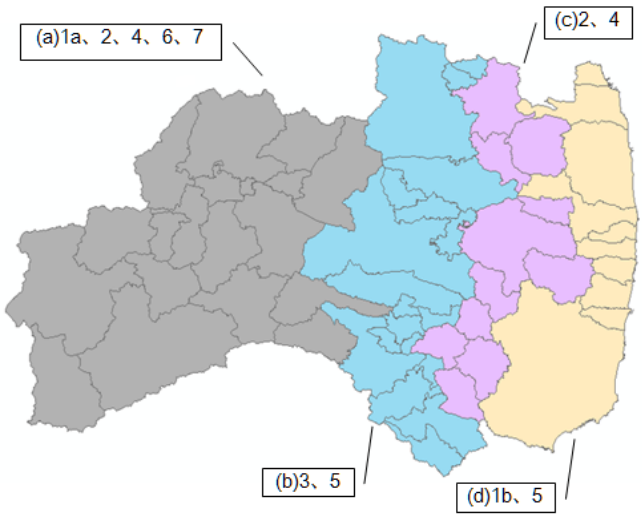

Fig. 5. Four zones of Fukushima. Fukushima Prefecture was divided into four zones based on the proximity of the road recovery conditions and the location of the municipalities.

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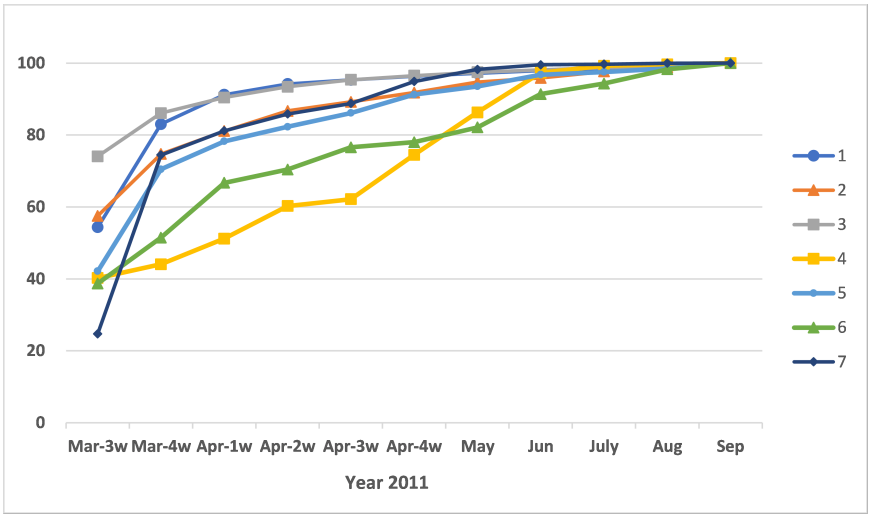

Fig. 6. Road recovery conditions of the seven groups in Miyagi Prefecture. This chart shows the road recovery percentages for each group in the first six months after the 2011 Tohoku Earthquake. It is based on Table III.

TABLE III
NUMBER OF ROAD RECOVERY PERCENTAGES IN SEVEN GROUPS OF MIYAGI

Group	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	54.4	83.0	**91.2**	94.2	95.3	96.4	97.2	97.9	98.6	98.9	100.0
2	57.5	74.7	81.1	86.7	89.2	**91.8**	94.7	95.9	97.7	98.8	100.0
3	74.1	86.1	**90.4**	93.4	95.4	96.5	97.5	98.1	98.7	99.4	100.0
4	40.2	44.0	51.2	60.2	62.2	74.5	86.3	**97.3**	99.2	99.7	100.0
5	42.1	70.5	78.2	82.3	86.1	**91.2**	93.5	96.8	97.5	98.5	100.0
6	38.7	51.5	66.7	70.4	76.6	78.0	82.1	**91.4**	94.3	98.3	100.0
7	24.7	74.5	81.2	85.8	88.8	**94.9**	98.2	99.5	99.7	100.0	100.0

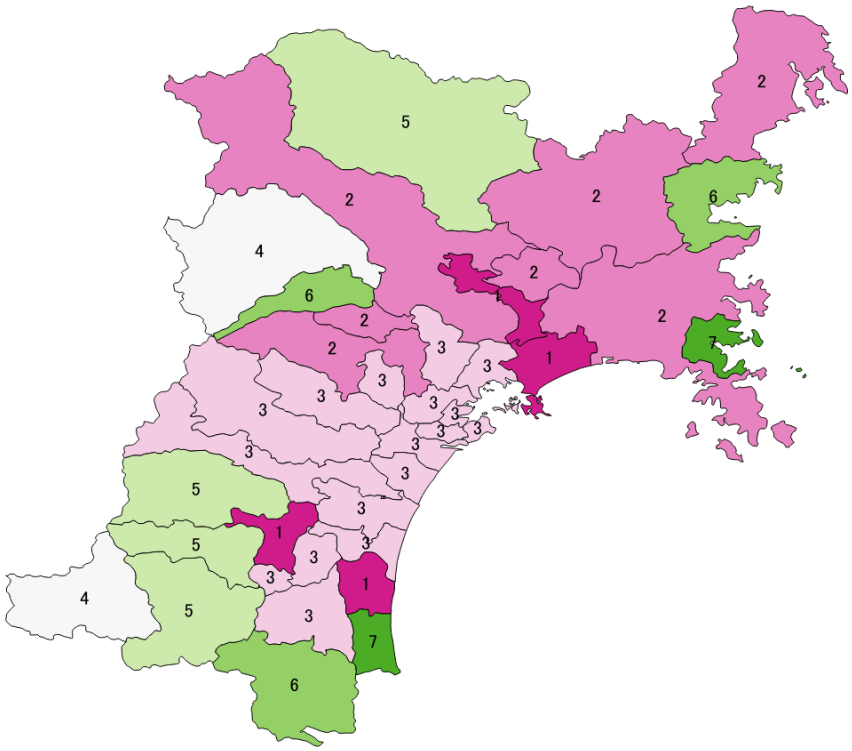

Fig. 7. Each municipality in Miyagi Prefecture belongs to a group. Municipalities with similar road recoveries were divided into seven groups.

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This area is mainly located in the central part of Fukushima, and the characteristics are group 3 and 5. This area is mainly in the basin, where the road density is high and the main roads are concentrated, so the road recovery is the fastest. The order of recovery of the groups is $3 > 5$, and the time difference of reaching 90% is 1 week. Group 3 has a motorway and an airport. Group 5 has highways, but the rest of the road network is more complex than Group 3, so it is thought that Group 3 recovered a little faster than Group 5 due to the early relief efforts.

(c) Abukuma Highlands

This area is located mainly in the Abukuma Highlands between Nakadori and Hamadori, and is characterized by Groups 2 and 4. Group 2 is mainly mountainous, while Group 4 has both mountain and basin features. The order of group recovery is $4 > 2$.

(d) Hamadori Coastal Region

This zone is mainly located in the Hamadori area and is characterized by Groups 1b and 5. As this area is located in a coastal lowland, the tsunami caused by the 2011 Tohoku Earthquake has caused more damage and recovery is slower than in a basin topography such as zone (b). Once the debris from the earthquake is removed, the road itself can be restored to use relatively quickly compared to mountainous terrain if it is less damaged. The order of group recovery is $5 > 1b$.

B. Verification in Miyagi Prefecture

In order to verify the effectiveness of the cluster classification method, the same method was conducted by using Miyagi Prefecture as a sample, a disaster-stricken area in Tohoku, Japan. The municipalities in Miyagi Prefecture were also divided into seven groups and the results were as Table III. The date order of the recovery reaching 90%, averaged for each group, is $1, 3 > 2, 5, 7 > 4, 6$ [Fig.6]. Match order and topography of each group recovery [Fig.7].

Groups 1,3: recovery is the fastest, mainly in the plains.

Groups 2,5,7: second fastest recovery, but 2,5 are in the mountains and plains, 7 in the coastal lowlands.

Groups 4,6: slowest to recover, mainly in mountainous areas. Obviously, similar recovery conditions were observed depending on the topography.

V. Conclusion

1) Using cluster analysis, similar road recovery conditions of Fukushima Prefecture were found according to geographical location and topography.

2) The cluster analysis was similarly applied for the road recovery of Miyagi Prefecture to verify the effectiveness of that. Similar recovery conditions were observed depending on the topography. The results were almost the same as Fukushima Prefecture.

This study applied cluster analysis to find the similarity of road recovery after the earthquake in Fukushima Prefecture's municipalities. And its effectiveness was also verified for Miyagi Prefecture. In the near future, we would like to conduct a research to predict the road recovery in various areas with disaster risk for the suggestions after the disasters.

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