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

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***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 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, topography and population density. In addition, according to its geographical shape and proximity to the recovery, we divided each cluster into four zones and used road closure information to verify the results of the road use recovery.**

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

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. Big data is important in disaster management applications due to its ability to visualize, analyze and predict disasters [3]. It is necessary to research using big data to monitor and detect natural hazards, mitigate their effects, assist in relief efforts, and contribute to the recovery and reconstruction processes [4]. 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 [5].

In the area of post-earthquake road recovery research, there are many research reports on road recovery of motorway and general national roads after the 2011 Tohoku Earthquake [6], [7]. However, there are few studies on road recovery of prefectural and municipal roads related to the daily lives of local residents. In this study, we 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 Fukushima Prefecture. The purpose of this study is to reflect the situation of local road use from objective data and to support disaster mitigation measures according to the recovery conditions.

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II. Previous Study

In our previous study [8], [9], 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.

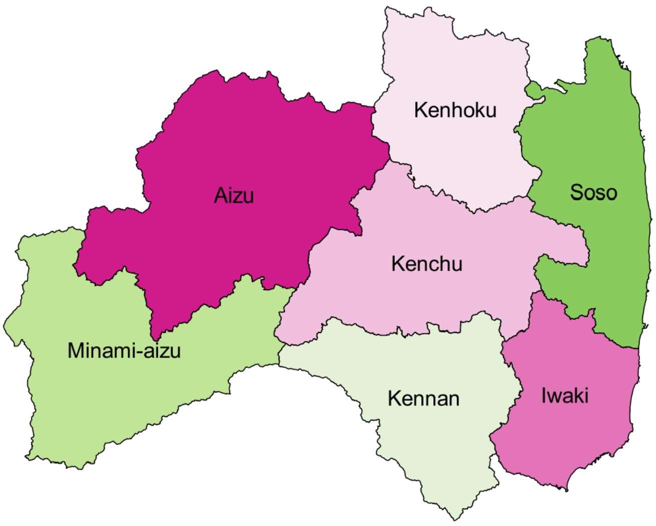

Fig. 1. Fukushima Prefecture divided into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions.

Seven regions were decided by local consensus [10]. It was considered that the broad classification had an effect

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.

on the result and the road recovery speed was not the same despite municipalities being in the same region. Therefore, it was necessary to divide the larger areas into smaller municipalities and analyze them in detail.

Moreover, we think that the extent of road damage affects the speed of road recovery. The previous studies have not analyzed road recovery in terms of actual road damage, and we hope to analyze that in detail in this study. In relation to road damage, there have been related studies that have used damage rates for evaluation [11], [12]. The damage rate is defined as the damage rate R (cases/km), which 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 (km), as shown in the following equation. It is calculated using the following formula:

$$R = \frac{X}{L}$$

We employed this formula to calculate the damage rates and analyzed the relationship between road damage and road recovery.

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].

B. 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 [13], IBM SPSS Statistics 23 [14], 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.

C. Research Materials and Data Processing

1.Vehicles driving data

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).

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 [15] on the Linux operating system [16].

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%.

TABLE I
SEVEN CLUSTERS OF MUNICIPALITIES WITH SIMILAR ROAD RECOVERIES

Cluster	Municipality	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	Hirono-machi	38	69	71	88	92	93	97	98	99	100	100
1	Minamisoma-shi	34	71	83	89	93	93	95	97	98	99	100
1	Shinchi-machi	44	64	77	86	88	94	97	98	98	99	100
1	Kunimi-machi	33	71	79	88	89	89	98	98	98	98	100
1	Tamura-shi	43	71	80	87	91	94	96	96	98	99	100
1	Aizubange-machi	41	69	81	85	89	92	96	97	97	100	100
1	Nishiaizu-machi	39	67	81	88	88	88	99	100	100	100	100
2	Iitate-mura	55	63	67	76	82	86	93	93	100	100	100
2	Kawamata-machi	56	71	71	76	85	90	95	96	98	100	100
2	Tenei-mura	49	63	72	76	80	85	97	97	98	99	100
2	Furudono-machi	57	58	59	73	86	93	93	93	99	100	100
2	Samegawa-mura	72	72	73	76	78	95	98	98	98	100	100
2	Inawashiro-machi	52	68	71	72	77	85	95	97	98	100	100
2	Yugawa-mura	59	68	69	78	78	83	89	96	96	98	100
3	Katsurao-mura	60	74	96	100	100	100	100	100	100	100	100
3	Kawauchi-mura	40	95	98	98	99	99	99	99	100	100	100
3	Kori-machi	57	86	93	95	96	96	100	100	100	100	100
3	Kagamiishi-machi	57	85	89	95	98	98	98	98	99	100	100
3	Motomiya-shi	69	87	93	95	97	98	99	99	100	100	100
3	Ono-machi	51	88	95	95	97	97	98	98	98	98	100
3	Hirata-mura	57	82	90	95	96	96	97	97	100	100	100
3	Nakajima-mura	58	81	88	92	97	97	97	97	98	98	100
3	Tamakawa-mura	52	78	85	93	98	100	100	100	100	100	100
3	Yabuki-machi	63	90	91	94	96	98	98	100	100	100	100
4	Soma-shi	54	77	84	86	92	95	96	96	96	99	100
4	Date-shi	55	71	81	88	93	95	96	97	98	100	100
4	Nihonmatsu-shi	59	75	80	84	87	91	94	95	97	99	100
4	Otama-mura	46	75	84	89	91	93	94	94	94	100	100
4	Hanawa-machi	60	65	75	85	87	88	88	88	88	88	100
4	Ishikawa-machi	57	69	89	92	93	97	97	97	100	100	100
4	Izumizaki-mura	55	78	87	89	91	95	96	97	99	100	100
4	Nishigo-mura	53	71	82	91	92	99	100	100	100	100	100
4	Aizuwakamatsu-shi	55	69	80	83	86	92	95	97	98	100	100
4	Kitakata-shi	55	61	74	86	91	92	94	95	97	98	100
5	Iwaki-shi	60	81	88	90	93	95	97	98	99	99	100
5	Fukushima-shi	66	80	85	88	90	95	96	98	99	99	100
5	Koriyama-shi	66	84	89	91	94	96	97	98	99	99	100
5	Miharu-machi	60	80	83	85	90	97	99	99	100	100	100
5	Sukagawa-shi	64	80	85	90	92	95	97	97	98	100	100
5	Asakawa-machi	67	76	79	86	95	98	99	99	99	99	100
5	Shirakawa-shi	67	80	86	89	92	92	97	98	99	99	100
5	Tanagura-machi	82	86	89	94	98	98	99	99	100	100	100
5	Yamatsuri-machi	81	83	90	93	93	93	93	100	100	100	100
6	Aizumisato-machi	39	51	71	75	81	93	93	96	98	99	100
6	Mishima-machi	16	54	80	80	82	82	84	98	98	98	100
6	Yanaizu-machi	29	50	87	92	92	94	98	100	100	100	100
7	Bandai-machi	28	52	56	59	59	70	95	97	98	98	100
7	Kaneyama-machi	0	13	61	61	64	64	65	97	100	100	100
7	Kitashiobara-mura	39	44	48	54	71	82	97	98	98	98	100
7	Showa-mura	0	33	46	47	70	73	95	95	95	95	100
7	Hinoemata-mura	0	0	0	0	0	31	61	100	100	100	100
7	Minamiaizu-machi	32	47	59	64	64	77	84	88	99	99	100
7	Shimogo-machi	41	57	59	62	75	85	93	94	99	99	100
7	Tadami-machi	4	4	27	38	53	55	78	90	94	95	100

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

Then, we introduced the percentages into the software SPSS, and used Ward's method with the Squared Euclidean distance as the measurement interval in hierarchical cluster analysis to get the result [Table I].

2. Road closure information

For subsequent analysis, the "Road closure information due to the 2011 Tohoku Earthquake" [Table II] which is managed by the Road Management Division, Civil Engineering Department, Fukushima Prefecture [17] was used to calculate the road damage rate and the traffic closure release location ratio. There are 146 cases, only 18 are shown here for reference.

1) The data does not indicate which municipality the road belongs to, so we used the location of the closed area to get the coordinates and overlapped them with the administrative boundaries on QGIS.

2) Then we used QGIS's "Count points in polygon" function to get the number of closed roads in each municipality. The number of road closures is defined as the number of incidents of damage to roads.

3) Next, we used QGIS's "Sum lines lengths" function to calculate the regional road distance from the road centerline GIS data [18].

4) To collate the traffic closure release location ratio in each area, we used an Excel pivot table.

TABLE II
ROAD CLOSURE INFORMATION DUE TO THE 2011 TOHOKU EARTHQUAKE

No.	Route	Location	Reason	Start time	Release time
1	Yabuki Ten'ei Line	Shirakawa City Oshinkumado - County border	Slope collapse	3/11	4/25
2	Naganuma-Kikuda Line	Sukagawa City, near Sukinoko Bridge	Total collapse of road	3/11	3/24
3	National highway No.118	Tenei Village	Sinking	3/11	3/13
4	Haobata-Shirakawa line	Shirakawa City Honuma (Jigame Bridge)	Sink (step)	3/11	3/15
5	Kudano Stopping Place Line	Kudano, Shirakawa City (Kudano Bridge)	Sinking	3/11	3/17
6	Shirakawa-Ishikawa line	Shirakawa City Oorenome (near Rorenome Bridge)	Rock fall	3/11	5/25
7	Nakoso Asakawa Line	Furudono Town Mikabu	Slope collapse	3/11	5/2
8	Onahama Ono line	Iwaki City Yata River Bridge	Sinking	3/11	3/12
9	Onahama Yotsukura Line	Iwaki City Nametsu Bridge	Sinking	3/11	3/14
10	Kami-Misaka Line	Iwaki City Kawamae-cho Unejiri	Sinking	3/11	3/14
11	National Road No.459	Inawashiro-cho (Mitsuya crossing) - Akimoto-ko crossing	Sinking	3/11	3/30
12	Tsuboyage Honmachi Line	Inawashiro Town, Nishidate (near Nishidate Bridge)	Sinking	3/11	3/26
13	Kawajikaishichiba Katada Line	Inawashiro Town Small and Medium Pine	Sinking	3/11	3/26
14	Nakanosawa Atami Line	Koriyama City Atami Town Ishimata	Sinking	3/11	4/4
15	Hitachi-Iwaki Line	Iwaki City Ueda (Ueda crossing bridge)	Damaged central pier	3/11	9/26
16	Joban Nakoso Line	Iwaki City (Samegawa Bridge)	Tsunami threat	3/11	3/12
17	Koriyama Yabuki Line	Sukagawa City (Yatano Bypass)	Cracks	3/12	3/13
18	Yabuki Horigome Line	Sukagawa City, Hokotsuki (Yamashita Bridge)	Sinking	3/11	3/14

TABLE III
NUMBER OF ROAD RECOVERY PERCENTAGES IN SEVEN CLUSTERS OF FUKUSHIMA

Cluster	Mar-3w	Mar-4w	Apr-1w	Apr-2w	Apr-3w	Apr-4w	May	Jun	Jul	Aug	Sep
1	39	69	79	87	**90**	92	97	98	98	99	100
2	57	66	69	75	81	88	**94**	96	98	100	100
3	56	85	**92**	95	97	98	99	99	99	100	100
4	55	71	82	87	**90**	94	95	96	97	98	100
5	68	81	86	**90**	93	95	97	98	99	100	100
6	28	52	79	82	85	**90**	92	98	99	99	100
7	18	31	45	48	57	67	84	**95**	98	98	100

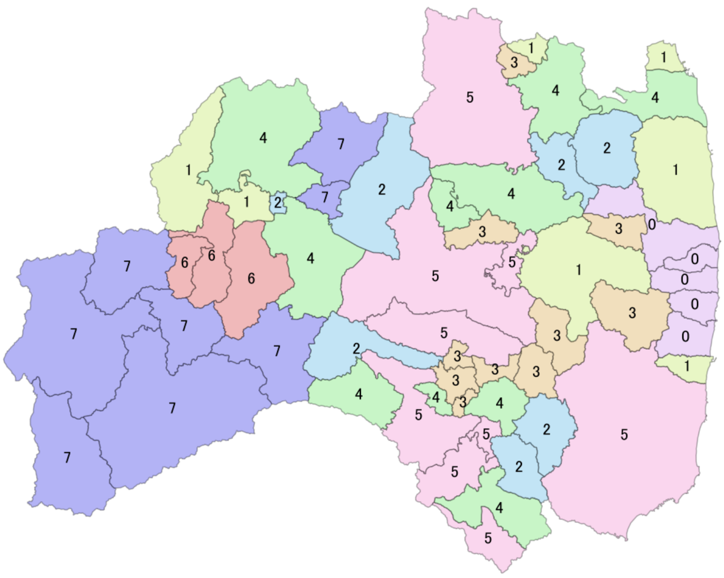

Fig. 3. Each municipality in Fukushima Prefecture belongs to a cluster. Municipalities with similar road recoveries were divided into seven clusters.

IV. Results And Discussion

A. Cluster Analysis

According to the results of the cluster analysis, municipalities with similar road recoveries were divided into seven clusters [Table I]. The cluster 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 cluster, is $3 > 5 > 1, 4 > 6 > 2 > 7$ [Table III] [Fig.4].

The location of each cluster and its recovery:

Cluster 1: Located in the west side and east side. The west side 1a (Echigo Mountains) was affected by lingering snow, while the east side 1b was recovering from the tsunami damage. Roads recovered gradually after the disaster road closure was lifted.

Cluster 2: Located in the mountains (Ou Mountains, Abukuma Highlands). Road recovery here was slow.

Cluster 3: Municipalities located adjacent to Koriyama, the largest city in Fukushima Prefecture. Roads leading from the Nakadori basin to the city center tended to show the fastest recovery in road use.

Cluster 4: Municipalities located in the northern part adjacent to Fukushima City and in the Aizu region. Urban areas are relatively populous and have mountainous or basin

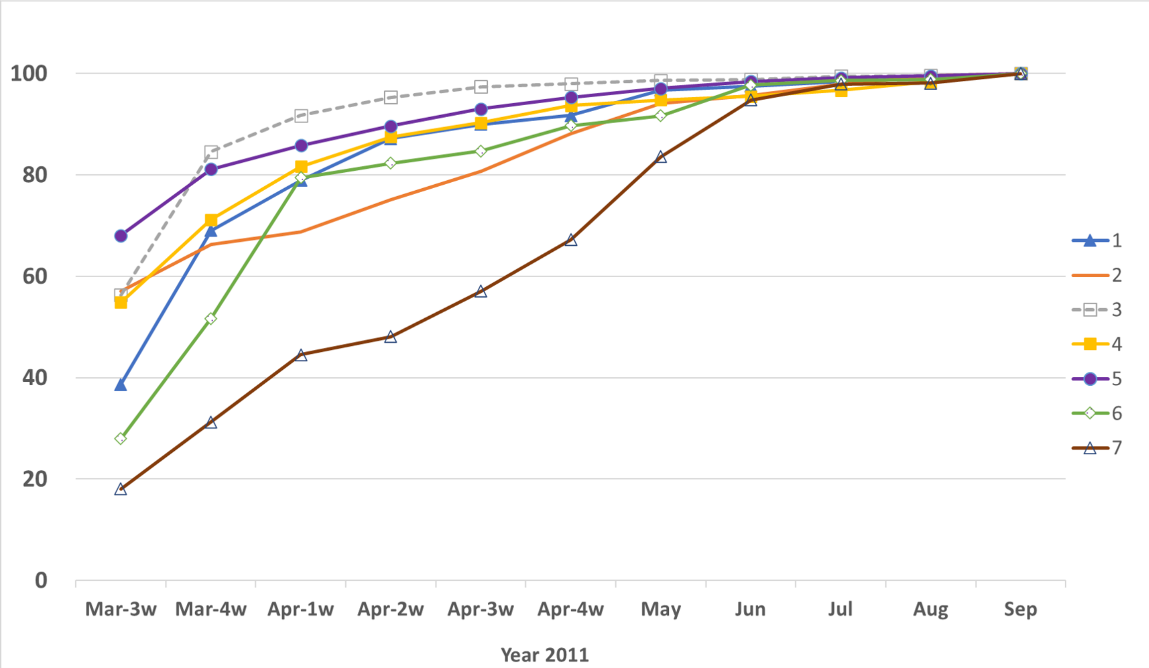

Fig. 4. Road recovery conditions of the seven clusters in Fukushima Prefecture. This chart shows the road recovery percentages for each cluster in the first six months after the 2011 Tohoku Earthquake. It is based on Table III.

topography, but the speed of road use recovery was middling.

Cluster 5: The most populous cities in our study were Fukushima City, Koriyama and Iwaki. Urban areas and low-lying areas are spread out, and road use tended to recover quickly.

Cluster 6: Three towns in the Aizu region. Recovery was slow due to some mountains (Echigo Mountains) and snow. Similar to Cluster 2 they were affected by lingering snow, but due to their location by the Ban-Etsu Expressway, road use recovery tended to be faster than Cluster 2.

Cluster 7: These areas had the slowest recovery. Located in mountainous areas with heavy snowfall (Echigo Mountains).

In the disaster areas, similar recovery conditions were observed depending on geographical location, topography [19] and population density. Recovery in lowland areas seemed to be faster than in mountainous areas. In addition, each cluster was divided into four zones according to its geographical shape and proximity to the recovery [Fig.5]. The order of area recovery is Zone $(b) > (d) > (c) > (a)$.

(a) Aizu Inland Area

This area is mainly located in the Aizu region and is characterised by clusters 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 [20], the order of recovery was $1a, 4 > 6 > 2 > 7$.

(b) Nakadori Inland Area

This area is mainly located in the central part of Fukushima and contained Cluster 3 and 5. The characteristics of this area are mainly in the basin, where the road density is high and the main roads are concentrated, so the road recovery was the fastest. The order of recovery of the clusters was $3 > 5$, and the time difference of reaching 90% was 1 week. Cluster 3 has a motorway and an airport. Cluster 5 has highways, but the rest of the road network is more complex than cluster 3, so it was thought that Cluster 3 recovered a little faster than Cluster 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 Clusters 2 and 4. Cluster 2 is mainly mountainous, while cluster 4 has both mountain and basin features. The order of cluster recovery was $4 > 2$.

(d) Hamadori Coastal Area

This area is mainly located in the Hamadori region and contained clusters 1b and 5. As this area is located in a coastal lowland, the tsunami caused by the 2011 Tohoku Earthquake caused more damage and recovery was slower than in a basin topography such as Zone (b). Once the debris from the earthquake was removed, the road itself could be restored to use relatively quickly compared to less damaged mountainous terrain. The order of cluster recovery was $5 > 1b$.

B. Relationship between road recovery, damage and topography

1) Recovery and damage in the four zones

In order to analyze the relationship between the recovery conditions of local roads, damage and topography, we calculated the damage rate of the four zones [Table IV].

TABLE IV
DAMAGE RATES IN THE FOUR ZONES OF FUKUSHIMA

Zone	Number of damages	Road length (km)	Damage rate
a	11	15,791	0.0007
b	71	26,753	0.0027
c	10	9,603	0.0010
d	54	12,819	0.0042

The order of area recovery is Zone $(b) > (d) > (c) > (a)$, where Zone (a) and (c) are mountainous areas, Zone (b) and

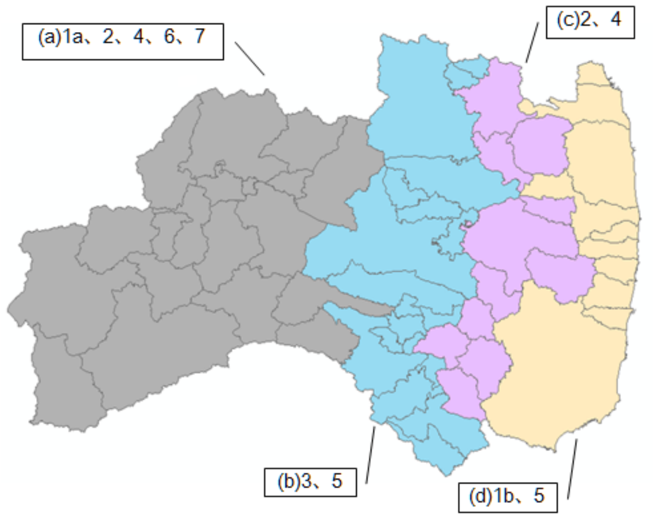

Fig. 5. Four zones of Fukushima. Fukushima Prefecture was divided into four zones based on the proximity of the road recovery conditions and the location of the municipalities.

(d) are lowland areas. Damage is concentrated in zones (b) and (d). The damage rate is Zone $(d) > (b) > (c) > (a)$. Even though the damage rate was high, recovery was fast. Lowland areas were more damaged, but recovered faster.

2) Road recovery and road closures in the four zones

The percentage of road closures that had been lifted was calculated using the "Road closure information due to earthquakes" [Fig.6].

The order of recovery was Zone $(b) > (d) > (c) > (a)$. And the order of the 90% road closures lifted was Zone $(a) > (b) > (d) > (c)$. Zone (a) was not affected by the tsunami and the relatively low level of radiation in Fukushima Prefecture is thought to have contributed to the speed with which the road closure was lifted. Even if the road closure was lifted in Zone (a), there was no use of the road. The reason for this is that there was a situation in Zone (a) where high quality roads were not being built due to snow, so it was thought that there was not much use of the roads. In the other zones (b), (d) and (c), the order of recovery of road use was the same as that of road closures lifted.

V. Conclusion

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

2) The relationship between road recovery, damage and topography was examined. Lowland areas were more damaged, but recovered faster.

3) The results of the road use recovery were verified by using the "Road closure information due to earthquakes". The order of other zones road use recovery was the same as that of road closures lifted except Zone (a).

This study applied cluster analysis to find the similarity of road recovery after the earthquake in Fukushima Prefecture's municipalities. Although this study focused on the influence of natural characteristics such as topography or climate, and did not focus on social characteristics such as population density, it is thought that the actual recovery of road use is influenced by various characteristics of the area's roads. For example, the type of road (emergency transport road, main road or not), the importance of the road for the recovery of the area (high traffic volume), the connectivity of the road network (priority given to isolated areas). In the future, we will add elements of other characteristics and consider them comprehensively to quantify models that influence road use recovery.

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References

[1] Nobuhito Mori, Tomoyuki Takahashi, Tomohiro Yasuda, and Hideaki Yanagisawa, "Survey of 2011 Tohoku earthquake tsunami inundationand run-up," *Geophysical Research Letters*, Vol.38, No.7, April, 2011.http://dx.doi.org/10.1029/2011GL049210

[2] Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Information related to the Tohoku Earthquake, "Operation Combs' Teeth". (In Japanese): http://infra-archive311.jp/s-kushinoha.html

[3] Akter, Shahriar and Fosso Wamba, Samuel, "Big data and disaster management: a systematic review and agenda for future research," 2017, *The University of Wollongong Faculty of Business* - Papers. 1282. https://ro.uow.edu.au/buspapers/1282

[4] Manzhu Yu, Chaowei Yang, and Yun Li, "Big Data in Natural Disaster Management: A Review," 2018, *Geosciences* 8(5), 165, https://doi.org/10.3390/geosciences8050165

[5] Yasunori Hada, Takeyasu Suzuki, Hiroki Shimora, Kimiro Meguro, and Noriko Kodama, "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 Niigataken Chuetsu-oki Earthquake-" (In Japanese), *Journal of Japan Association for Earthquake Engineering*, 9(2), 148-159, 2009. Available at http://www.jaee.gr.jp/stack/ submit-j/v09n02/090211 paper.pdf (2018) April 12, 2018)

[6] 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)

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

[8] Jieling Wu, and Noriaki Endo," Regional Differences in Fukushima Prefecture Road Recovery Following the 2011 Tohoku Earthquake," *Lecture Notes in Engineering and Computer Science: Proceedings of The International Multi Conference of Engineers and Computer Scientists 2019*, March 13-15, 2019, Hong Kong, pp164-169. http://www.iaeng.org/publication/IMECS2019/IMECS2019_pp164-169.pdf

[9] Jieling Wu, and Noriaki Endo, "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, *World Scientific*, 2020, pp.48-62.[Revised and extended version of the paper[4]] https://doi.org/10.1142/9789811215094_0004

[10] Information on 59 municipalities in Fukushima prefecture: https://www.pref.fukushima.lg.jp/site/iju-tokyo/city-town-vill.html

[11] Shoji Kaku, Takahashi Kazushin, Nakamura Tomoharu, and Sakurai Toshiaki, "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)*, Vol.68, No.4, 2012, pp.I_1186-I_1193 (In Japanese): https://www.jstage.jst.go.jp/article/jscejseee/68/4/68_I_1186/_article/-char/ja/

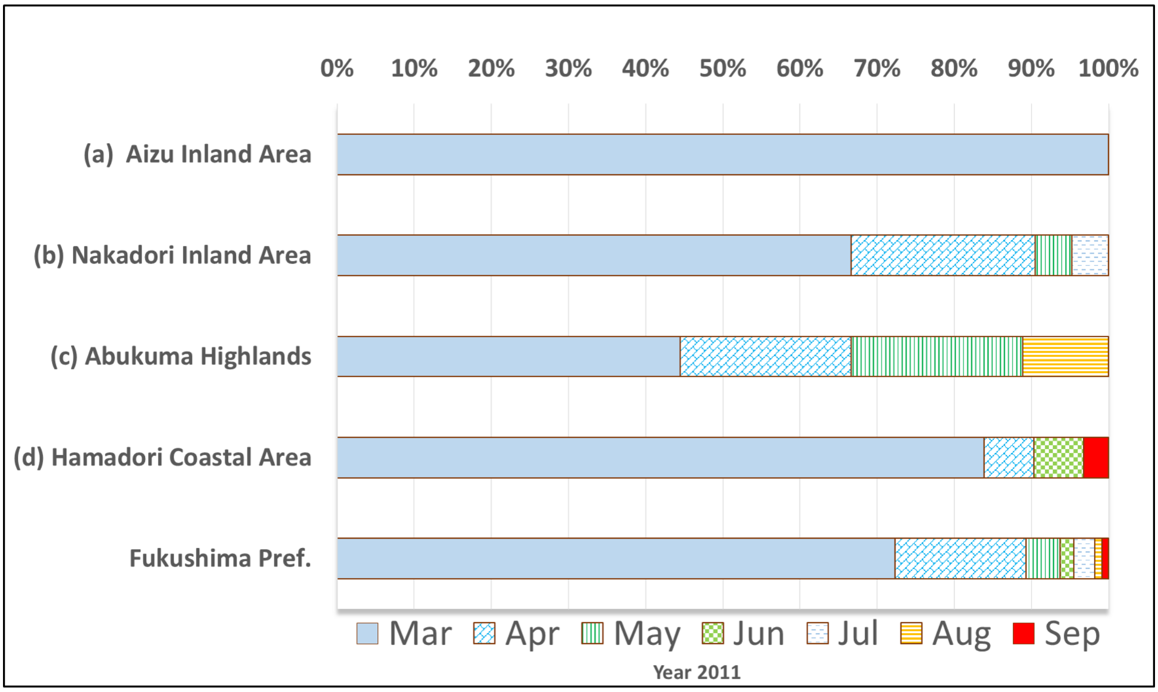

Fig. 6. Traffic Closure Release Location Ratio (2011.3.11-2011.9.30). It is calculated by the "Road closure information due to the 2011 Tohoku Earthquake" which is managed by the Road Management Division, Civil Engineering Department, Fukushima Prefecture.

[12] Itagaki Osamu, Maruyama Kikyu, "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)*, Vol.72, No.4, 2016, pp. I_82-I_89 (In Japanese): https://www.jstage.jst.go.jp/article/jscejseee/68/4/68_I_1186/_article/-char/ja/

[13] Official website of QGIS, A Free and Open Source GeographicInformation System http://www.qgis.org/en/site/

[14] Official website of IBM SPSS Statistics: https://www.ibm.com/products/spss-statistics

[15] Official website of GDAL: ogr2ogr https://gdal.org/programs/ogr2ogr.html

[16] Official website of Vine Linux (In Japanese) https://www.vinelinux.org/

[17] Road Management Division, Civil Engineering Department, Fukushima Prefecture: https://www.pref.fukushima.lg.jp/sec/41035c/

[18] Conservation GIS-consortium Japan road center line (2006): http://cgisj.jp/download_type_list.php

[19] Jieling Wu, Noriaki Endo, and Mitsugu Saito, "Cluster Analysis for Studying Road Recovery of Fukushima Prefecture Following the 2011 Tohoku Earthquake," *Lecture Notes in Engineering and Computer Science: Proceedings of the World Congress on Engineering 2021*, July 7-9, 2021, London, U.K., pp107-112.

[20] MLIT: Information on winter closure routes in the Tohoku region https://www.thr.mlit.go.jp/road/koutsu/heisa/index.html