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Assessing Natural Disaster Risks for Bus Operation Bases: Focus on Vulnerability and Importance

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Abstract: Natural disasters that cause massive damage have become frequent in Japan, and the damage extends to the transportation sector. There have been several cases in which local bus services were seriously affected due to natural disasters. In a disaster, buses can play a crucial role by acting as a substitute for damaged railroads and transporting volunteers and goods. To consider countermeasures for bus services, it is necessary to identify disaster risks quantitatively. In this study, we first surveyed several bus companies nationwide to determine how many of their bus operation bases were prone to risk from natural disasters. Subsequently, we developed a disaster risk assessment method that evaluates the vulnerability to natural disasters and the social importance of bus operation bases to compare the priority of countermeasures among bus operation bases. Additionally, we conducted a case study for bus operation bases in three prefectures.

Key words: bus operation base, climate change, disaster risk evaluation, vulnerability index, importance index

1. Introduction

1.1 Background and Purpose

Natural disasters that cause massive damage have become frequent in Japan, and the damage extends to the transportation sector. There have been cases where railroads and roads have been cut off and forced into long-term outages, and unprofitable railway lines have been abandoned.

Bus, which transports approximately 14% of all people transported by land transportation and is an important means of transportation for going to school, hospital, shopping, and so on. Furthermore, in the event of a disaster, it can serve as a substitute for a damaged railway line to transport volunteers and relief supplies. Therefore, reducing the risk of natural disasters at the bus operation bases is a crucial concern. Since a bus operation base requires a large amount of land, it is advantageous to be located in an area with low land prices, but such areas are frequently prone to disaster. Given the concern that the number of natural disasters associated with climate change will increase in the future, it is critical to quantify disaster risk and advance disaster countermeasures as soon as possible starting from the high-risk bus operation bases.

In this study, we will investigate the current situation of Japan’s bus operation bases against disasters and highlight the importance of disaster countermeasures. Furthermore, the aim is to develop a disaster risk assessment method that can be used to determine the priority of countermeasures for each bus operation base and contribute to the bus operation bases’ disaster countermeasure promotion plan.

1.2 Literature Review

An example of a study on the risk assessment of natural catastrophes is Kikumoto et al. (2017) [1]. In this study, multiple data representing the number of disasters and the status of disaster countermeasures

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were used as evaluation indices and natural disaster risk was calculated for 47 prefectures across Japan. Seto et al. (2008) [3] and Osawa (2020) [4] conducted research on disaster impact assessment in the field of transportation. These previous studies focused on road networks and evaluated the reliability of connectivity in the event of a disaster. Fukumoto et al. (2012) [2] and Sato et al. (2016) [5] are two studies that summarize transit bus operators' post-disaster reactions. These previous studies have not addressed natural disaster risk assessment for specific facilities or proactive disaster preparedness for bus services. Therefore, the significance of this study is that it develops a method to evaluate disaster risk by considering vulnerability to disasters and social importance as a clue in considering natural disaster countermeasures for bus operation bases.

2. Research Objects

2.1 Disaster Risk Assessment for Bus Operation Bases Nationwide

According to a list of bus operation bases compiled by each Transport Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism. The survey covered 2,375 offices that were confirmed to be operating buses on a regular schedule and on a fixed route from the business website and the local government website as of December 2020.

This study focuses on three types of disasters: floods, tsunamis, and landslides, all of which are expected to become more severe due to future climate change. We used data on "anticipated flood inundation areas (planned scale)", "anticipated tsunami inundation areas" and "predicted landslide disaster areas", obtained from the National Land Information Division [6] and the websites of each municipality. The bus operation bases in these areas were assessed as "damaged", regardless of the magnitude of the assumed disaster. The results are shown in Fig. 1. It turns out that many bus operation bases in Japan are presumed to be damaged, including major cities like Tokyo, Osaka, and Nagoya.

Fig. 2a shows the number of bus operation bases that are expected to be damaged by the number of vehicles belonging to them. Regardless of scale, the number of

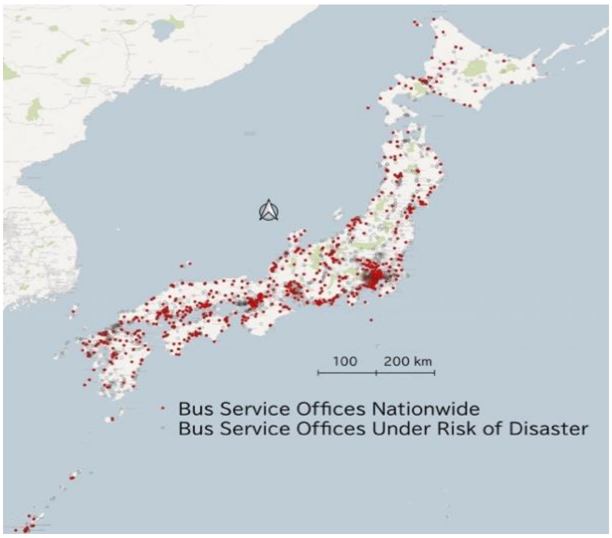
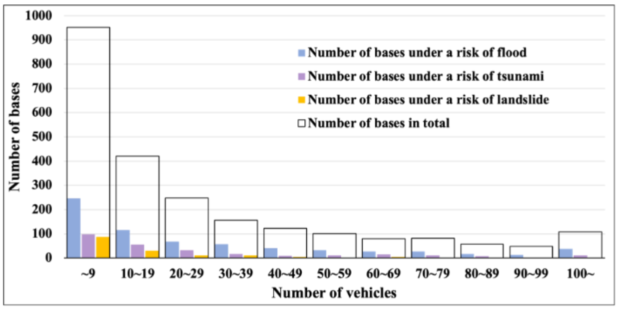
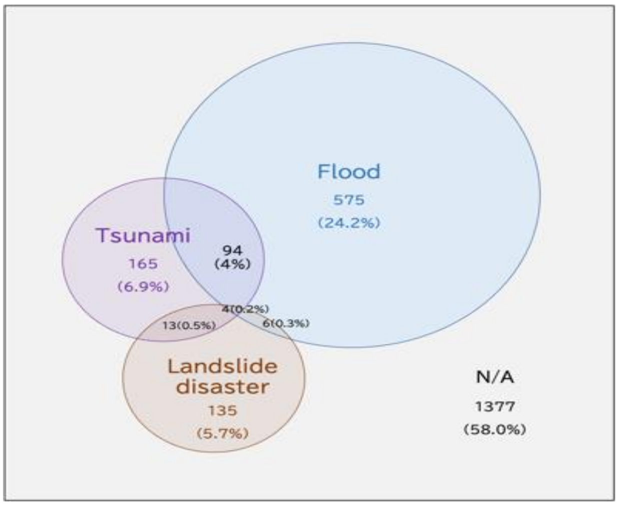


Fig. 1 Distribution of bus operation bases expected to be affected by the disaster.



a. by the number of vehicles



b. by the disaster type

Fig. 2 The number of bus operation bases expected to be affected by the disaster.

bus operation bases expected to be flooded was around 30% of the total. Furthermore, as illustrated in Fig.2b, 998 bus operation bases, approximately 42% of the total, were expected to be damaged by some type of disaster[1].

2.2 Questionnaire Survey on Bus Operation Bases

The above discussion shows that bases throughout Japan that are at risk of disasters. To investigate how operators perceive disaster risk, a questionnaire survey was conducted among all 14 bus operation bases in Aichi, Mie, and Gifu prefectures. A summary of the survey is shown in Table 1.

More than half of the bus operation bases that were likely to be affected by a disaster had taken precautions such as developing a BCP and establishing a vehicle evacuation location, although others had not. This again highlights the need for bus operators to understand disaster risks and to consider pre- and post-disaster countermeasures.

Table 1 Questionnaire survey summary.

Respondents	All 14 operators of scheduled and fixed-route transit buses in Aichi, Mie, and Gifu prefectures
Method	Sending a questionnaire by e-mail
Time	December 2020~January 2021
Response rate	100%
Contents	・Disaster preparedness status of each bases ・bases considered important and the reasons ・Number of enrolled buses ・Number of employees ・Presence or absence of highway buses ・Presence or absence of maintenance factories ・Number of passengers per day ・Population of bus stop sphere and so on

[1] Disaster risk assessment is only applied to specific operation base facilities in this study. Even if the base and the vehicle are safe, when the surrounding roads are damaged, it will be impossible to go in and out. But this point has not been taken into account in this study.

3. Method

3.1 Concept of Risk Assessment and Definition of Terms and Phrases in This Study

Indicators like "risk source", "vulnerability" and "exposure" are generally used for risk assessment, but since the definition of terms and phrases varies depending on the field and researcher, the definition of appropriate words and phrases is important in this study. The two evaluation indices of the "vulnerability index" and "importance index", which are defined and used in this study, are detailed below.

1) Vulnerability index

It is an indicator of how disaster-prone the bus operation bases are. It is determined by using the annual estimated value of the influence on bus operation bases.

2) Importance index

It is a measure of the social significance of bus operation bases. It is calculated by taking the relative value of the evaluation index.

3.2 Indicators of Evaluation

The indicators used for disaster risk assessment are shown in Table 2.

1) Vulnerability index

As the information on the magnitude and likelihood of each disaster that is expected to affect, flood and tsunami damages are measured in terms of Inundation depth (m) and probability of occurrence in 1 year (%), while landslide disasters are measured in terms of area classification (landslide disaster warning area, landslide disaster special warning area) and probability of occurrence in 1 year (%).

2) Importance index

The evaluation is based on four indicators representing the scale of the bus operation base (number of enrolled buses, number of employees, presence or absence of highway buses, presence or absence of maintenance factories) and two indicators representing the degree of impact on the surrounding area (number of passengers per day, population of bus stop sphere).

Table 2 Evaluation index used in this study.

Vulnerability index

Index	Degree of impact on bus operation base	Disaster scale			Probability of disaster occurrence
Factor (Data)	Non-step bus ratio	Flood	Tsunami	Landslide	Probability of annual occurrence
		Inundation depth	Inundation depth	Area classification	
Unite	%	m	m	2 levels	%

Importance index

Index	Scale of the bus operation base				Degree of impact on the surrounding area	
Factor (Data)	number of enrolled buses	number of employees	highway buses	maintenance factories	number of passengers per day	population of bus stop sphere (300 m)
Unite	-	person	presence or absence	presence or absence	person/day	person

3.3 Evaluation Method

1) Vulnerability index

As functional components of the bus operation base, there are offices, maintenance factories, refuelling facilities, etc., all of which are affected by even slight floods and landslide disasters. On the other hand, bus vehicles have different degrees of damage depending on the type of vehicle and the scale of the disaster.

Table 3 shows the setting of the degree of impact on bus operation bases according to the scale of the disaster. The threshold for the damage level in floods and tsunamis was set based on the vehicle height, based on the information obtained from the field survey that "it is difficult to operate when the floor is flooded, and it is impossible to operate when the engine is flooded". As for landslide disasters, the same consideration is taken into account. The expected value of the degree of impact on bus operation bases per year is defined as the product of the calculated degree of impact on bus operation bases and the probability of disaster occurrence. Next, the probability of a disaster with an impact level of 1 is integrated and compared across bus operation bases. Finally, the vulnerability index is defined in the 0-1 range by setting the least probability to 0 and the greatest probability to 1.

Table 3 Setting the degree of impact on bus operation bases according to the scale of the disaster.

Damage level	Flood・Tsunami	Landslide	Degree of impact on bus operation bases
Non-step bus cannot be used	under 0.5 m		(Non-step bus ratio)
All non-step buses and half of the other vehicles are unusable	0.5~1.0 m	landslide disaster warning area	(Non-step bus ratio) ＋ (Percentage of other vehicles) /2
All buses are not available	above 1.0 m	landslide disaster special warning area	1

2) Importance index

The four indicators, which include the number of employees, the number of passengers per day, and the population of the bus stop sphere, are compared among the bus operation bases, with each item being normalized to a scale of 0 to 1. The presence of a maintenance factory and the presence of highway buses are digitized as 0 if there is no, and 1 if there is. An importance index is defined by taking the weighted average of the above six indicators and normalizing it to a scale of 0 to 1, where 0 is the smallest base and 1 is the largest base, as with the vulnerability index.

To sum up, the evaluation flow is shown in Fig. 3. The degree of impact of the disaster on bus operation bases is determined by using the ratio of non-step buses, and the vulnerability index is calculated index by comparing the expected value of the impact on bus operation bases per year. The importance index, on the other hand, is calculated by converting the weighted average of the numerical value obtained from the evaluation index to the same scale as the vulnerability numerical value. Therefore, a disaster risk index is defined by taking the product of the importance index and the vulnerability index.

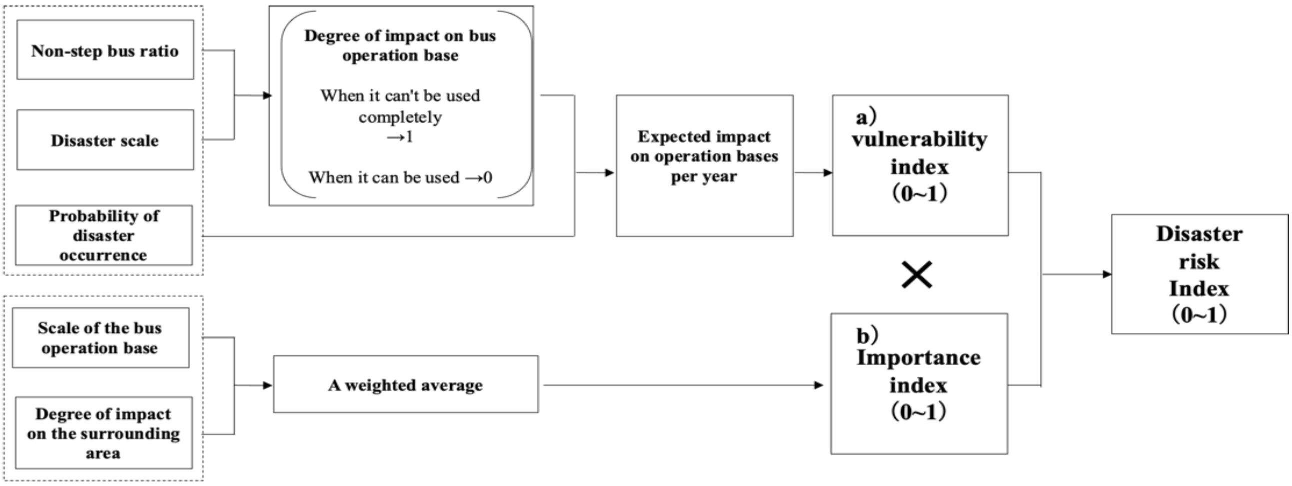


Fig. 3 Evaluation flow.

4. Case Studies and Findings

4.1 Data Setting

A case study was conducted for 58 bus operation bases of 14 business operators using the developed method.

1) Vulnerability index

As mentioned in Chapter 3, we used data from the digital national land information's estimated flood and tsunami inundation areas and landslides disaster warning areas. We determined the probability of occurrence of each disaster as follows:

・Flood

Since the digital national land information provides the notation of the established plan scale (probability of occurrence once every 30 to 200 years), the numerical value was applied.

・Tsunami

With reference to the "J-THIS Tsunami Hazard Station" [8] by the National Research Institute for Earth Science and Disaster Prevention, we set the probability of occurrence once in 100 years in southern Mie Prefecture and once in 500 years in northern Mie Prefecture and western Aichi Prefecture.

・Landslide disaster

According to the National Institute for Land and Infrastructure Management (2020), "the probability of occurring more than once within 100 years on average in landslide disaster special warning areas across the country is about 30%". Therefore, the probability of occurring once every 250 years is set. Also, it was assumed that the landslide disaster warning area had a similar probability of occurrence.

In addition, as mentioned above, the probability of a disaster occurring for each data set utilized in this research is expressed differently in terms of time, thus the comparative analysis was conducted after aligning the probability of a disaster occurring in one year (for instance, 1/250 for a landslide disaster).

2) Importance index

Various data obtained from the questionnaire survey in Chapter 2 were used. To calculate the population of the bus stop area, we used information on the routes served by each office obtained from the questionnaire survey, data on bus routes and bus stops obtained from the National Land Information System, and data on the estimated 2020 population by 500-m mesh.

4.2 Weighting of Each Evaluation Index of the Importance Index

Since it was not possible to determine a way to define a unified weight for each indicator, the following six weight patterns were set up and the results were compared and discussed in this study. The weight-adjusting factors for each of the patterns are in Table 4.

・pattern 1

All weights are equal.

・pattern 2

The scale of bus operation bases is emphasized.

・pattern 3

The importance of highway buses in wide-area transportation is emphasized.

・pattern 4

The scale of the area under the bus office's jurisdiction, such as the number of registered vehicles, passengers, and population of the bus stop sphere, is emphasized.

・pattern 5

The emphasis is on the impact on the surroundings.

・pattern 6

Things that are difficult to transfer or move are emphasized. For instance, vehicles and employees are relatively easy to relocate, but maintenance factories while the populations of bus stop sphere are more difficult.

Table 4 List of weighting patterns of the evaluation index of the importance index.

	pattern1	pattern2	pattern3	pattern4	pattern5	pattern6
Number of enrolled buses	1	3	2	3	1	1
Number of employees	1	3	2	1	1	1
Presence or absence of highway buses	1	2	3	1	2	1
Presence or absence of maintenance factories	1	3	2	1	1	3
Number of passengers per day	1	1	1	2	3	2
Population of bus stop sphere	1	1	1	2	3	3

4.3 Analysis Results

Based on the above settings, the vulnerability index, importance index, and disaster risk index were calculated. The scatter diagram of the vulnerability index and the importance index in each weighting pattern is shown in Fig. 4.

Of the 58 bus operation bases targeted, there were 28 bus operation bases with 0 vulnerabilities (not included in either the flood flooding expected area, tsunami flooding expected area or landslide disaster warning area). A comparison of the figures for each weighting pattern demonstrates that, while the figures are generally similar, the importance indices differ, indicating that the important bus operation bases differ depending on the important factors[2].

Table 5 shows the top 5 bus operation bases in vulnerabilities and importance (6 patterns). All the highly vulnerable bus operation bases were expected to be affected by floods with a relatively high probability of occurrence. For example, the A sales office, which was the most vulnerable, was expected to be heavily flooded once every 30 years with a probability of 1 to 2 meters.

Large-scale bus operation bases in the suburbs, as exemplified by the B office, rose to the top in patterns 2 and 3 which stress the scale of the bus operation base

[2] Because the analysis used data that included the confidential information of the business operator, the name of the business office cannot be specified in this paper. Therefore, for the sake of explanation, they are called by one alphabetic character.

with regard to the bus operation bases of great importance. On the other hand, in patterns 4, 5, and 6, which emphasize the degree of impact on the surrounding area, bus operation bases in Nagoya such as the J bus operation base and the O bus operation base became higher.

Table 6 shows the top 5 bus operation bases with the highest disaster risk in accordance with the importance weighting pattern. Although the ranking varies slightly depending on the weighting pattern, it has been determined that the A office to the G base shown in Table 6 has a high disaster risk in the target area. We won't highlight the advantages and disadvantages of the six patterns in this study. Nevertheless, it was found that, like the A base in this case study, it can be identified regardless of the difference in the weighting pattern, especially in the high-risk bus bases. Furthermore, compared to Table 5, it can be seen that the high disaster risk is brought on by the high vulnerability in bases A, C, and D, as well as the high importance in bases B, E, and G. Relocating is thought to be effective in highly vulnerable bases, whereas decentralization of functions and BCP creation are effective in important bases.

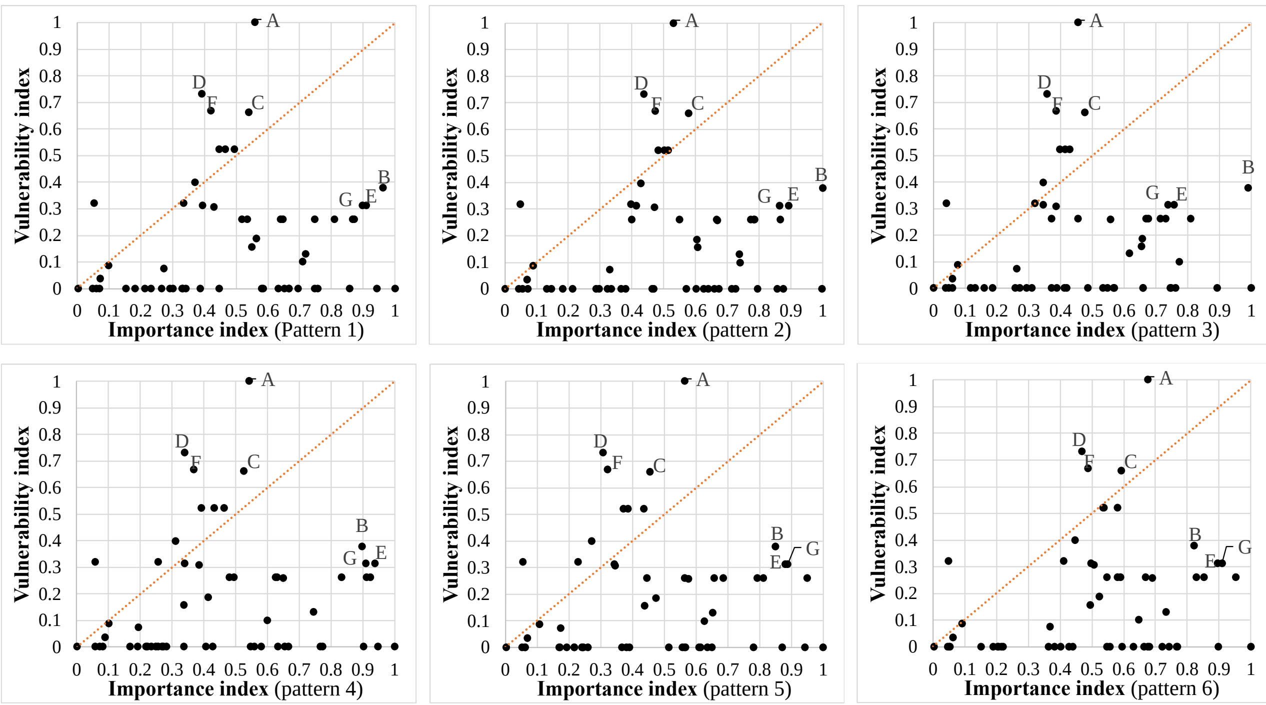


Fig. 4 Scatter diagram of vulnerability index and importance index in each weighting pattern.

Table 5 Top 5 out of 58 bus operation bases with high vulnerability index and importance index.

Rank	Vulnerability index	
1	A	1.000
2	D	0.732
3	F	0.668
4	C	0.661
5	H	0.522

Rank	Importance index											
	Pattern 1		Patten 2		Patten 3		Patten 4		Patten 5		Patten 6	
1	I	1.000	B	1.000	I	1.000	J	1.000	J	1.000	J	1.000
2	B	0.960	I	0.999	B	0.991	I	0.949	O	0.950	O	0.951
3	J	0.941	E	0.892	K	0.892	E	0.938	I	0.944	G	0.908
4	E	0.910	K	0.876	M	0.808	L	0.924	G	0.889	I	0.897
5	G	0.897	L	0.866	N	0.773	O	0.914	E	0.881	E	0.895

Table 6 Top 5 out of all 58 bus operation bases with high disaster risk.

Rank	Disaster risk index											
	pattern 1		pattern 2		pattern 3		pattern 4		pattern 5		pattern 6	
1	A	0.558	A	0.530	A	0.454	A	0.544	A	0.564	A	0.675
2	B	0.363	C	0.381	B	0.375	C	0.348	B	0.322	C	0.391
3	C	0.356	B	0.378	C	0.315	B	0.340	C	0.301	D	0.342
4	D	0.287	D	0.320	D	0.261	E	0.294	G	0.278	F	0.325
5	E	0.285	F	0.315	F	0.257	G	0.285	E	0.276	B	0.310

Considering the preceding findings, the method was demonstrated to be effective for grasping the priority of disaster countermeasures that are difficult to evaluate intuitively through case studies.

5. Conclusions and Discussion

The results obtained from this research are as follows:

We investigated the natural disaster risk (flood, tsunami, landslide disaster) for bus operation bases nationwide, and discovered that about 40% of bus operation bases may not be able to operate normally due to disasters.

A disaster risk assessment method that considers “vulnerability” and social “importance” to disasters is developed to examine the priority of disaster countermeasures for bus operation bases.

The developed method was applied to bus operation bases in three prefectures, Aichi, Gifu, and Mie, and the offices in the target area with high disaster risk were clarified.

The disaster risk assessment method presented in this study is applicable not only to bus operation bases but also to other modes of transportation operation bases.

Applying the disaster risk assessment method in this research at the national level is considered to be very effective in developing a strategic disaster countermeasure promotion plan and raising business operators’ disaster awareness, which will be a future issue of this research. On the other hand, the amount of data necessary for evaluation indicators is enormous, and there are many occasions when data is impossible to collect owing to underdeveloped data or confidential information, which is a practical challenge. For example, the data of bus routes and stops of national land numerical information, which is the basis of the two indicators that represent the degree of impact on the surrounding area, has changed considerably since the development period, and many areas are different from the current status because it has been quite a few years since the maintenance period.

We attempted to analyze six types of weighting patterns between indicators of importance in this research’s case study, but when applied at the national level, it is desirable to apply weighting patterns according to the characteristics of regions and businesses. In future work, we intend to investigate the weighting pattern by conducting interviews survey with business operators.

Furthermore, we have not been able to assess the extent to which advance disaster countermeasures contribute to disaster risk reduction, or the extent to which damage to a maintenance shop affects bus operations based on its facilities, which we intend to incorporate into our method.

Acknowledgments

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