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Correlation between existing area based on ambulance transport and fractal dimension of road network form

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Abstract— In this study, fractal dimension analysis of the road network is carried out. The evaluation criteria and the start of treatment time are used as a measure to help protect life. The effect of the operation when the fractal number has any relationship with the ambulance, to set the level of road maintenance. The objective of the present study is to develop an evaluation method based on visualization of the effective sphere and setting of the road network form.

Index Terms— Emergency Medical, Fractal dimension analysis, GIS, Ambulance, Road network.

I. INTRODUCTION

As a science dealing with the characteristics of a pattern of the relationship between an individual and the whole, and without a physical scale, fractal theory has been applied in various fields. An analytical method using fractal dimension ^{*1} can quantitatively show the complexity of a shape and seemingly irregular event. This method is also used for studies in the architecture and urban and regional planning field. The emergency medical service in Japan has been regarded as a fire-fighting mission in the Fire Service Act. It is widely recognized as an essential service for protecting public lives and ensuring physical safety. Currently, social unrest, declining birth rates, and an aging society are concerning factors in Japan. These factors, coupled with changes in the disease structure, have led to an increase in emergency dispatches.

In this study, by setting a quantification method based on fractal analysis ^{*2} of a road network model, we present the validity of the method in evaluating the road network in terms of fractal dimension. The study area was Chiba and Funabashi, Chiba Prefecture (Figs. 1–3); information on the road network of the effective area level during emergency transport of medicine was obtained. The following are discussed in terms of the relationship between the total road length and area fractal dimension of the road network of the effective area level: the number of intersections, sphere of existing area, average speed, and total road distance. The fractal dimension analysis is employed for building an effective sphere, that it has efficacy as an analytical technique whereby.

II. EXPLANATION OF THE PREVIOUS STUDIES

Ohuchi et al. (1994) clarified the current status of the pair dispatch system of an ambulance with an attendant doctor system (*doctor car system*) in Funabashi, located in the Chiba Prefecture, as an advanced version of the *doctor car system*; they presented guidelines for the proper placement of emergency medical facilities by the combination of emergencies and medical care in community facilities. ^[1]

Kuroiwa, Sakaguchi, Ohuchi, and Matsubara (2004) applied a typification technique to the urban area using fractal dimension analysis. ^[2]

Tajima, Kikuchi, and Ohuchi (2008) visualized the existing facilities of emergency medical services in Chiba city by performing an analysis from the viewpoint of the number of elderly people in the area and the number of dispatchable emergency services according to the time zone based on an analytical method that considers regional spatial information. ^[3]

Yamada, Shintani, and Ohuchi (2009) generated a model for landscape recognition by focusing on the cognition of “a landscape, which has the identity of Kamakura,” and “a place that has been transformed (recognition),” from the spatial component of the area. ^[4]

Ohuchi et al. (2011) analyzed the “complexity” of space in Agoras by analyzing their architecture using image-processing technology. Image-processing technology was used to perform the initial restoration of the architecture and city form. By constructing a 3D model of each building that is formed centering the plaza in Agora, a fractal analysis was performed of the changes in the arrangement of the facilities from generation to collapse.^[5] Based on the results of these previous studies, the impact of the differences in the scale and shape of existing areas in Chiba City on the corresponding fractal dimensions was understood. In addition, it was confirmed that the correlation between the fractal dimension and the emergency transport of the road network form according to relationship between the fractal dimension and existing areas.^{[6][7]}

III. RESEARCH AREA (FIG. 1)

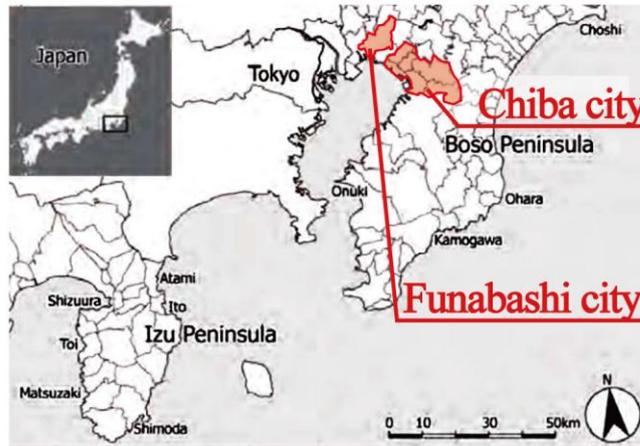


Fig 1: Research area

A. Emergency Medical System in Chiba, Chiba Prefecture

Chiba city in Chiba prefecture runs the emergency medical system using GIS and GPS. There are 24 emergency services in the city (Fig. 2). An ambulance with an attendant doctor system is not employed. Usually, a conventional ambulance is used for conveyance.

A “record of emergency mobilization”, obtained with the cooperation of the Chiba City Fire Department, is used. 5649 records of service are used as valid information; the records were of the period April 1999–2000.

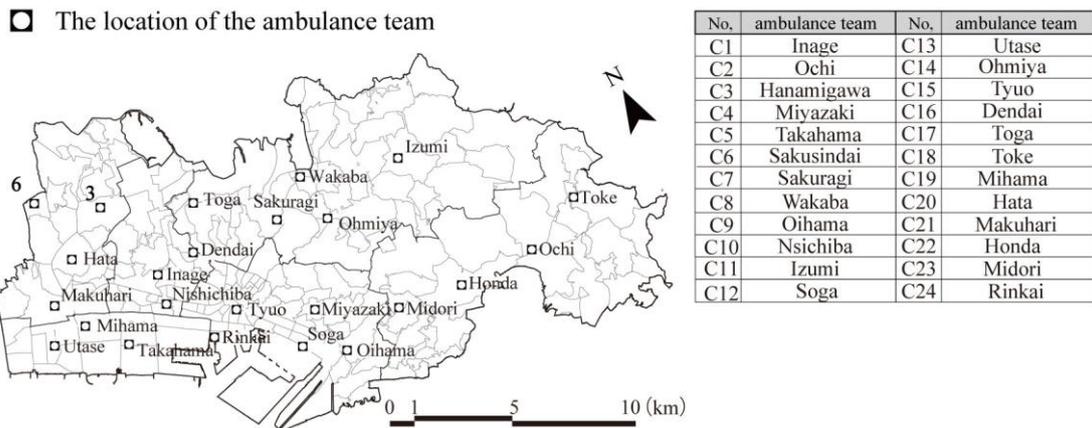


Fig 2: Description of emergency medical service in Chiba

B. Emergency Medical System in Funabashi, Chiba Prefecture

Funabashi city, Chiba Prefecture has been operating the emergency medical system using WebGIS and GPS. There are 12 emergency services in the city (Fig. 3). In addition to just an ambulance, Funabashi city has adopted an ambulance with an attendant doctor system. An ambulance with an attendant doctor system reduces the time

between the accident and the start of medical action. The method combines a pair dispatch*³ method of an ambulance with an attendant doctor and a conventional ambulance; it operates in a manner that allows the initial treatment to start quickly.

Through the cooperation of Funabashi City Fire Department, a total of 27087 cases of “record of the emergency mobilization” were obtained as valid information.

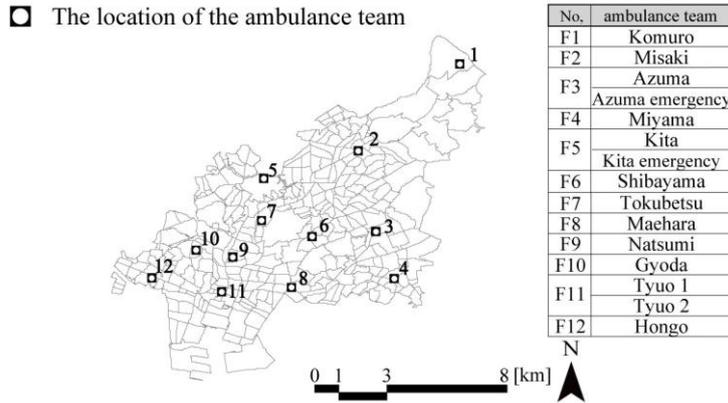


Fig 3: Description of emergency medical service in Funabashi

IV. ANALYTICAL METHOD AND PROCESS

A. Fractal analysis - box-counting method - (Fig. 4)

In this study, fractal dimension analysis is performed using box counting *⁴, and the number of pixels is 4096. When a binary image is covered by squares, with each side measuring (r) pixels, if the number of squares in the target number of pixels is (N)r for each pixel interval (r), the following equation is obtained:

$$N(r) \cdot r^D = C \quad (1)$$

Where C is a constant and D is the fractal dimension. If equation (1) is transformed, the following is obtained:

$$\log N(r) = \log C - D \log r \quad (2)$$

Here, the fractal dimension D indicates the slope of the log r and logN (r) line; the fractal dimension can be estimated using the least-squares method. When the regression line obtained shows good linearity (in other words, when the value of the decision coefficient R² is high), the image being analyzed can be confirmed be fractal in nature.

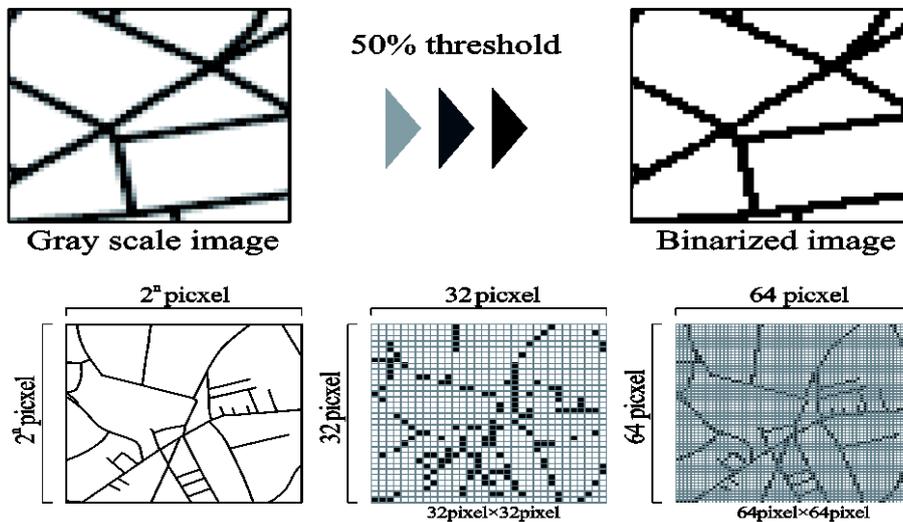


Fig 4: Road network image by box-counting method (Ex)

B. Analytical Method and Process of the Fractal Dimension Analysis

The road network is captured as regional space information; ArcGIS *⁵ is used in this study to analyze the impact of the road form in an emergency medical service. The Geographical Survey Institute publication Digital Map 2500 is used as a spatial database, from which the road network data is created. Based on this data, the fractal dimension analysis of valid existing areas of ambulance conveyance is performed as follows. (Fig. 5)

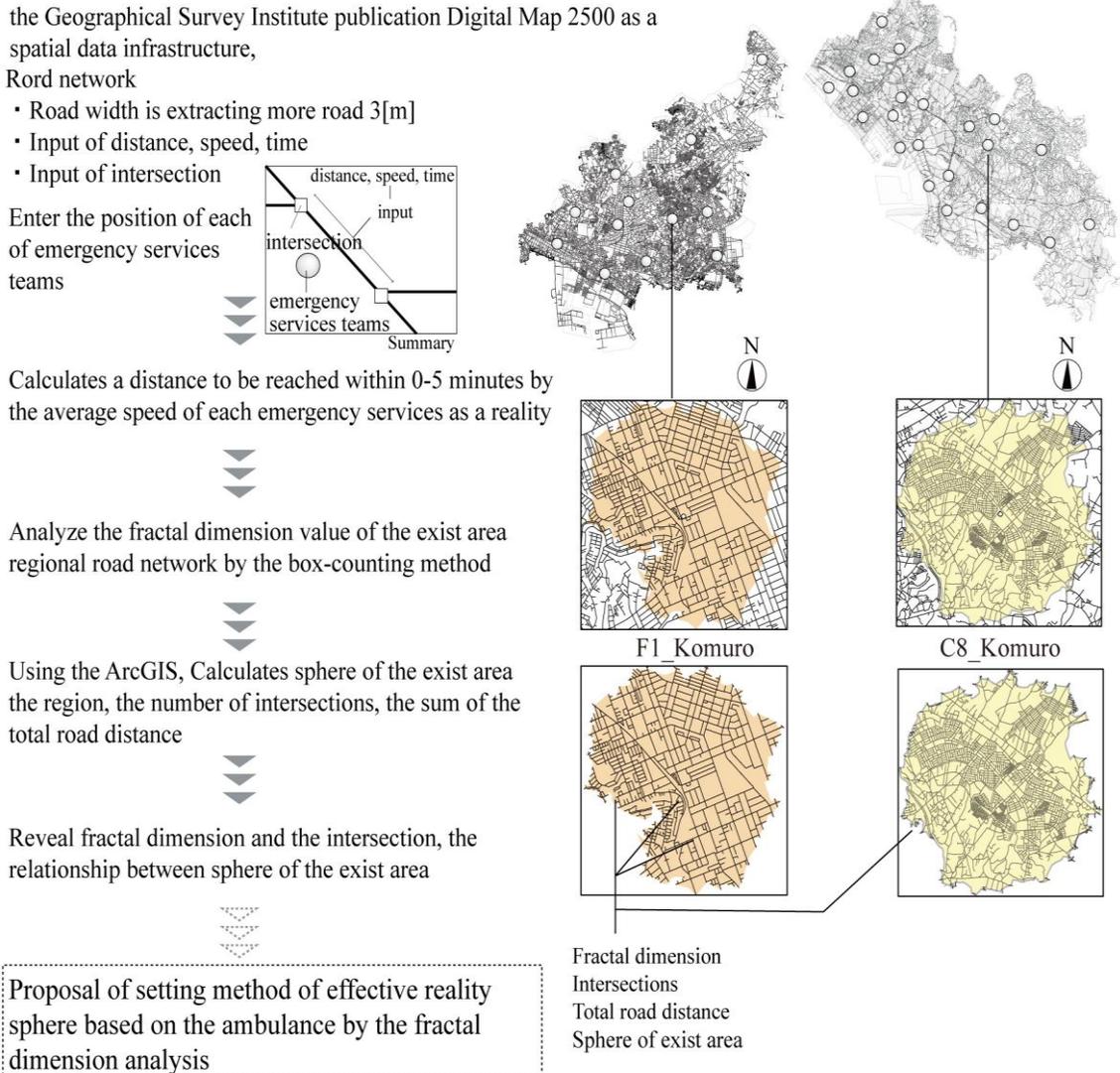


Fig 5: Based on the emergency transport by the fractal dimension analysis Procedure of setting method of exist area

1. The fire departments in the city are plotted on a digital map. The true width of the road width of 3 [m] or more in scale 1/2500 is extracted, and the length is entered as road information into a digital map. Moreover, the average speed of the ambulance and time spent *⁶ by the ambulance obtained via emergency mobilization records are entered.
2. The range that the ambulance can reach within five minutes from the emergency services is calculated as the existing area and visualized (Fig. 6).

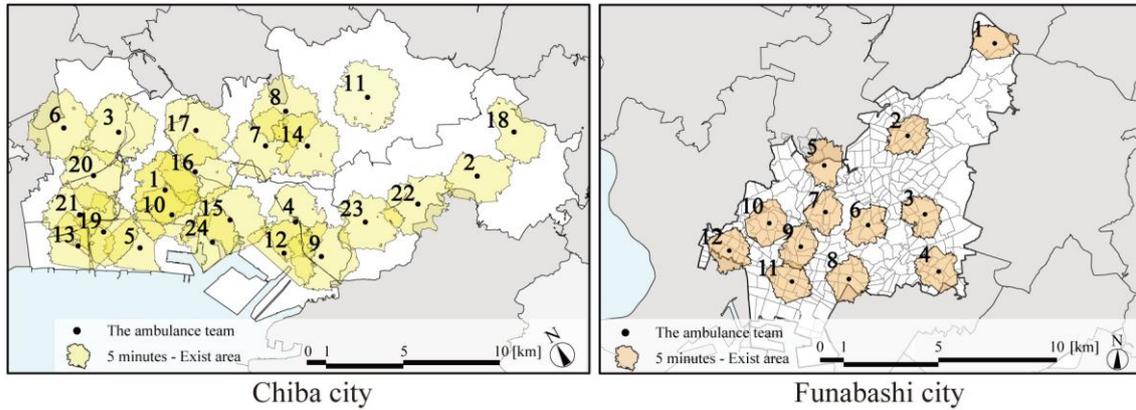


Fig 6: Exist area of the ambulance teams

3. The fractal dimension of the road network in an existing area is analyzed using a box-counting method. Here, in the analysis range, we conduct fractal dimension analysis of four different analysis objects of map scale (uniform or different) and shape (concentric or square) to confirm the presence or absence of a multi-layer structure of the road network form. Further, we verified the analysis range on the map and the validity of its shape and scale.

(I) Analysis range of uniform region and scale of each emergency service (Fig. 7)

In the transport area of a real space (concentric circular), including the entire existing area in each emergency service, the widest area will be the analysis range. We analyzed the area of the road network in the analysis range and uniformly square area and existing area (concentric circular).

C14_ Omiya emergency services 4.112×4.112 [km] (Chiba)

F5_ Kita emergency services 2.184×2.184 [km] (Funabashi)

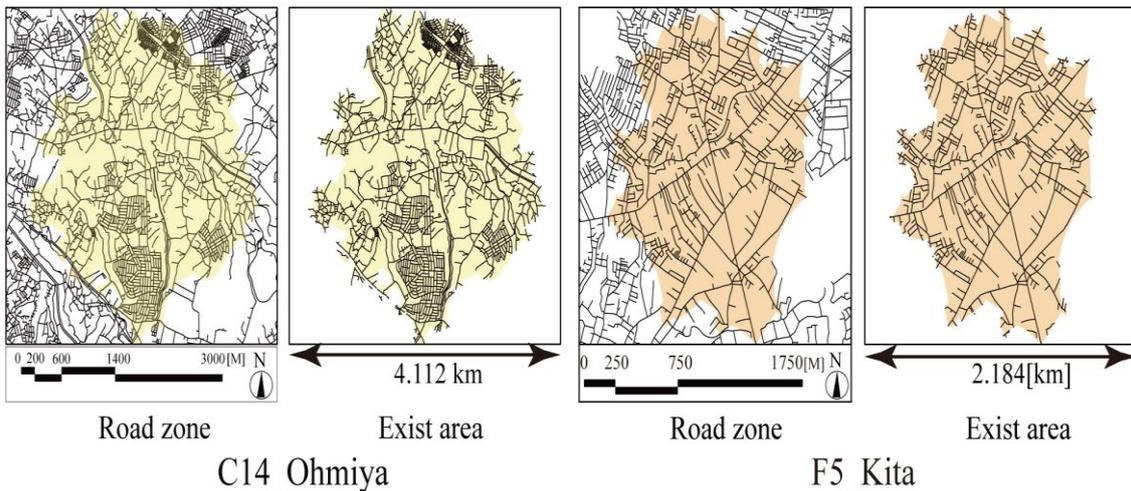


Fig 7: Extraction of the road of exist area of the same analysis range of emergency services

(II) Analysis range of area and scale, which differs for each emergency service (Fig. 8)

The existing area of the transport area (concentric circular) of real space for each emergency service and the minimum area scope of the square including them are analyzed.

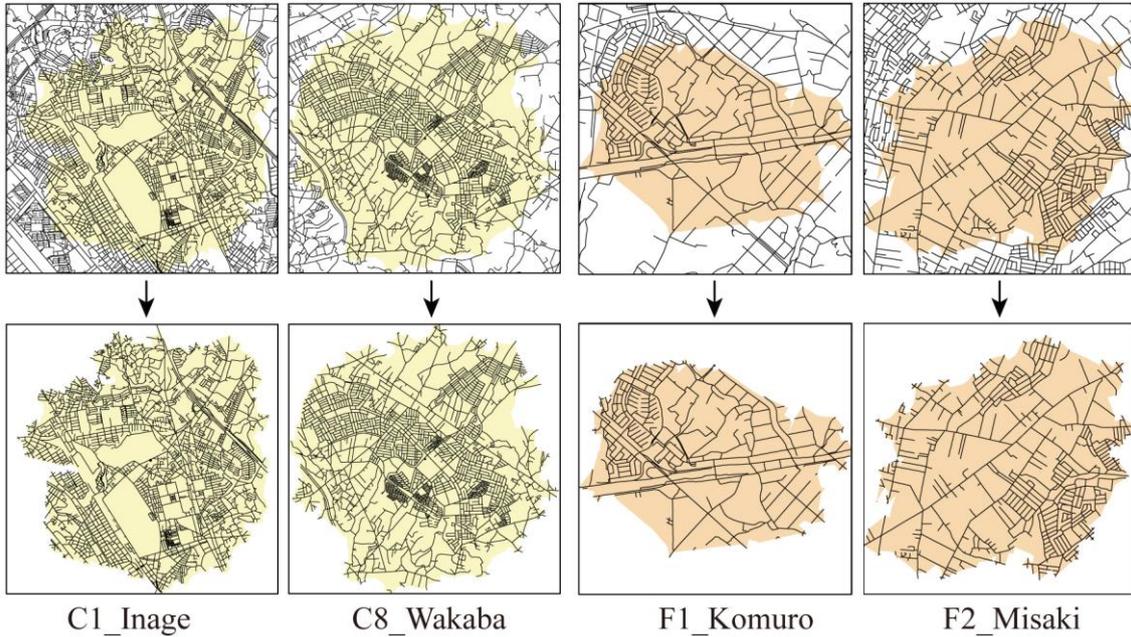


Fig 8: Extraction of the road of exist area in different analysis range of emergency services

4. The relationship between the elements, such as the fractal dimension and number of intersections, and areas in existing areas is analyzed.

V. CONSIDERATION OF FRACTAL DIMENSION

Table 1: Calculation, such as average speed and fractal dimension of each ambulance team in Chiba

No.	the ambulance team	Fractal dimension(D)				Affect the emergency medical elements			
		(I)		(II)		Average speed (km/min)	sphere(km ²)	Intersections (point)	Total road distance (km)
		Road zone	Exist area	Road zone	Exist area				
C1	Inage	1.5427	1.4722	1.5405	1.4874	0.39	8.787	3512	227.115
C2	Ochi	1.3997	1.3267	1.3902	1.3427	0.58	6.557	763	81.979
C3	Hanamigawa	1.4953	1.4252	1.5228	1.4265	0.47	9.485	1918	187.282
C4	Miyazaki	1.5008	1.4434	1.4928	1.4622	0.44	8.579	2828	193.823
C6	Sakusindai	1.4843	1.4411	1.4868	1.4580	0.39	8.901	2585	189.893
C7	Sakuragi	1.5132	1.4428	1.4991	1.4450	0.42	8.557	2629	192.141
C8	Wakaba	1.4829	1.4508	1.4863	1.4698	0.41	9.006	2699	206.559
C9	Oihama	1.4813	1.4226	1.4781	1.4346	0.42	8.968	2332	172.999.
C10	Nisichiba	1.5309	1.4738	1.5225	1.4833	0.39	8.443	2952	208.436
C11	Izumi	1.4495	1.3983	1.4351	1.4005	0.47	8.789	1433	153.676
C14	Ohmiya	1.4843	1.4226	1.4808	1.4171	0.40	8.503	2145	171.031
C15	Tyuo	1.5147	1.4650	1.5423	1.4703	0.36	9.176	2880	215.954
C16	Dendai	1.5363	1.4707	1.5349	1.4862	0.38	9.207	3145	229.718
C17	Toga	1.5089	1.4436	1.5007	1.4514	0.38	8.823	2448	188.659
C18	Toke	1.3881	1.3344	1.3882	1.3489	0.51	5.959	975	76.727
C19	Mihama	1.5163	1.4565	1.5518	1.4666	0.42	8.240	2616	201.200
C20	Hata	1.5163	1.4317	1.5045	1.4386	0.39	7.638	2237	166.759
C22	Honda	1.4182	1.3766	1.4052	1.3800	0.55	7.670	1404	119.924
C23	Midori	1.4459	1.4171	1.4345	1.4317	0.51	7.317	1369	136.039

※Exclude the ambulance teams: C5_Takahama , C12_Soga , C13_Utase , C21_Makuhari , C24_Rinkai



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Table 2: Calculation, such as average speed and fractal dimension of each ambulance team in Funabashi

No.	the ambulance team	Fractal dimension(D)				Affect the emergency medical elements			
		(I)		(II)		Average speed (km/min)	sphere(km ²)	Intersections (point)	Total road distance (km)
		Road zone	Exist area	Road zone	Exist area				
F1	Komuro	1.4295	1.3825	1.4324	1.3945	0.23	2.031	381	40.600
F2	Misaki	1.4743	1.3823	1.4685	1.4019	0.25	2.247	570	47.035
F3	Azuma	1.5090	1.4261	1.5051	1.4550	0.21	2.206	737	59.402
F4	Miyama	1.4871	1.4330	1.4848	1.4431	0.22	2.423	986	62.561
F5	Kita	1.4613	1.3979	1.4613	1.3979	0.25	2.309	719	49.498
F6	Shibayama	1.4673	1.3870	1.4560	1.4059	0.22	2.188	541	47.393
F7	Tokubetsu	1.4503	1.3771	1.4435	1.3765	0.31	2.038	421	40.700
F8	Maehara	1.4812	1.4158	1.4847	1.4302	0.21	2.435	813	60.783
F9	Natsumi	1.4716	1.4137	1.4752	1.4160	0.19	2.132	814	58.378
F11	Tyuo	1.4919	1.4367	1.5004	1.4595	0.19	2.337	787	62.915
F12	Hongou	1.4889	1.4256	1.4881	1.4322	0.18	2.395	769	60.854

※Exclude the ambulance teams: F10_Gyoda

A. Comparative analysis of the analysis range (I) (II) in the fractal dimension (Table.1-2)

1) From the results of the analysis range (I), according to a comparison of the fractal dimension of the square area, which is uniformly scaled with a road network and existing area (concentric), the relationship of the magnitude of dimension values between each emergency crew is homologous; no large difference in the fractal dimension value is observed.

2) From the results of the analysis range (II), according to a comparison of the fractal dimension of the existing area (concentric) of each emergency crew transport area and the minimum range of the square area that subsumes the existing area, it is seen that although there are differences in the scale and the area of the road network of each emergency crew, the relationship of the magnitude of the dimension values between each emergency crew is homologous; no large difference in the fractal dimension value is observed.

3) From the results of the fractal dimension analysis of the road network of the emergency services in Funabashi City and Chiba City, the magnitude relation of the fractal dimension of the existing area (concentric) of each emergency crew transport area is same, although there are differences in the scale, area, and region of the mutual road network of each emergency service.

From the above, through a fractal dimension analysis of the intended analysis, it was confirmed that a fractal that has a multi-layered structure of a road network form also in the case that is the scale (uniform-difference) and the shape (concentric-square) of the map as analysis range are different.

B. Existing area of Chiba City and fractal dimension [analysis range I]

As the fractal dimension of the road network within the existing area is high, the number of intersections, the total road distance, and area was high. It can be said that each element and fractal dimension has a high correlation. It is understood that as fractal dimension is high, the number of intersections increases, and the average speed of the ambulance decreases. It can be considered that when the number of the intersection increases, the average speed of the ambulance decreases because the number of times turns are made increases (Fig. 9).

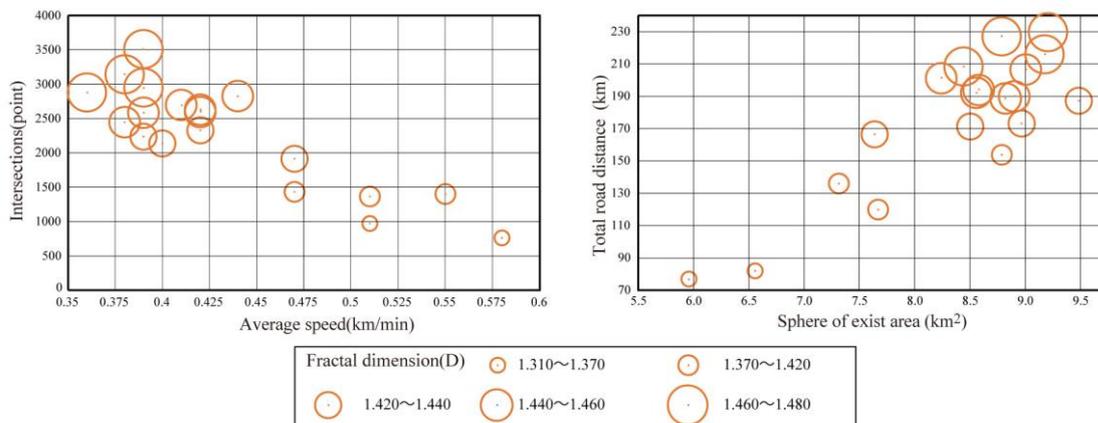


Fig 9: Correlation between the fractal dimension and elements of emergency services in Chiba

C. Existing area of Funabashi City and fractal dimension [analysis range II]

As the fractal dimension is high, the total road distance increases and the number of intersections increases. Further, it is understood that the average speed of the ambulance decreases. It can be said that as the road network becomes dense, the number of intersections increases; decreasing the average speed of the ambulance as number of times turns are made increases. As a result, it is thought that as the fractal dimension is high, the road network form spreads complexly (Fig. 10).

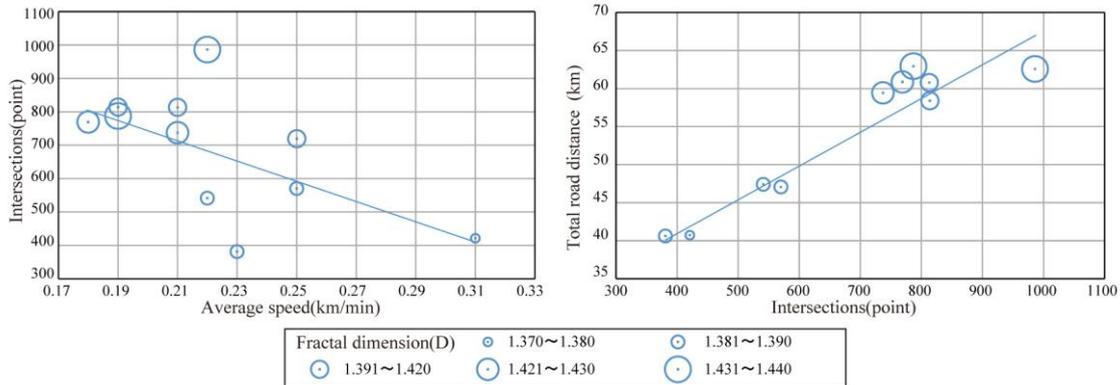


Fig 10: Correlation between the fractal dimension and elements of emergency services in Funabashi

D. Comparison of the existing area in Chiba and Funabashi [analysis range I]

A comparison of the fractal dimension of the road network, the sphere of the existing area, and the average speed is performed (Fig. 11).

Compared to Funabashi City, Chiba City has a faster average rate, and the response area is also wider. Since Funabashi City has an ambulance as well as emergency transport such as ambulance with an attendant doctor, compared to Chiba City, there is no difference in the start time of the initial treatment. It tends to slow the speed of transport when the fractal dimension is high in both regions. However, the actual sphere in emergency medicine spreads out. If the fractal dimension is high, there exists a tendency of the area region of the road network to spread to the surface basis.

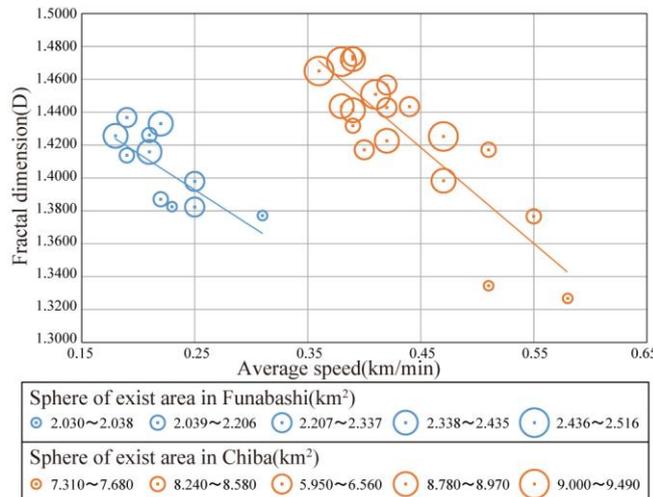


Fig 11: Fractal dimension and elements of emergency services in Funabashi and Chiba

VI. CONCLUSION

The basic index for the study for proper placement of the emergency medical facilities in real space was presented via the correlation between the fractal dimension and the emergency transport of the road network form. The

correlation between the effective existing area based on the emergency transport and road network form was analyzed through fractal dimension analysis in Chiba and Funabashi (Fig. 12).

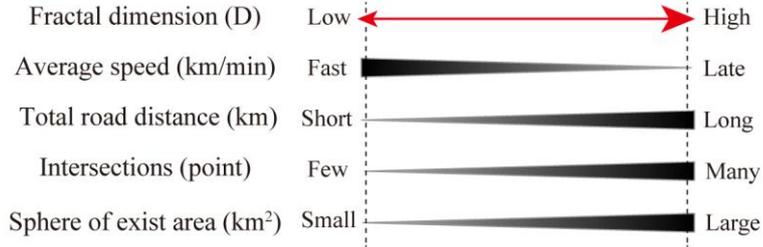


Fig 12: Correlation between the fractal dimension and elements

VII. STUDY FUTURE PLANS

Further fractal analysis of the road network is required. Is scheduled at that time, add information to the road network, such as data about the elements that are expected to affect the ambulance, go with repeated studies and analysis (Fig. 13).

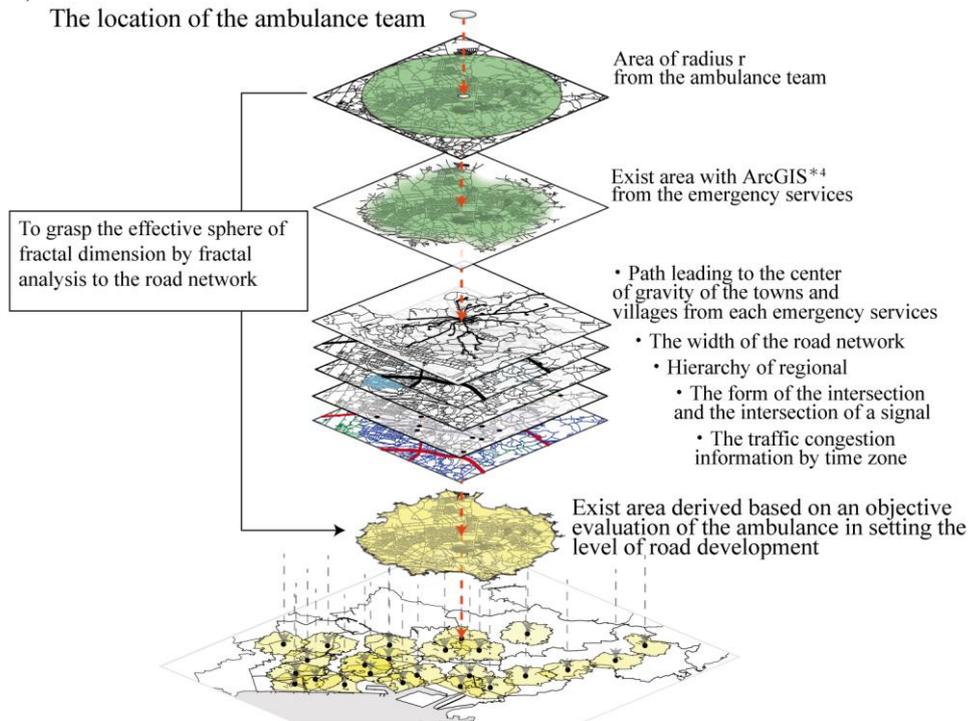


Fig 13: Flow of evaluation method based on fractal analysis of the road network form

VIII. NOTES

*1 Fractal dimension

The fractal dimension is a numerical value obtained by quantifying self-similarity. It is at a rate that is based on similarity, unlike phase dimension; it characterizes a non-integer value.

*2 Fractal analysis

An analysis software (National Institute) from the Agriculture and Food Research Organization National Institute of Livestock and Grassland Science was developed. The fractal analysis system is one in which the box-counting method is used for calculating the fractal dimension. <http://cse.naro.affrc.go.jp/sasaki/>

*3 Pair dispatch

It is a method wherein an ambulance with an attendant doctor (*Doctor car*) in a doctor car station dispatches at the same time as the emergency services, which is closest to the field. It facilitates quick initial treatment.

*4 Box-counting method



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The box-counting method is a method for calculating the fractal dimension as the capacity dimension. Similar dimensions, measurement dimension, and coating dimensions in addition to the volume dimensions can be calculated.

*5 ArcGIS

ArcGIS is geographic information system software in California, USA, Inc. Esri

*6 Time spent

Obtained from recording the emergency dispatch; it is the time required to the current time of wearing awareness time

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