研究成果の刊行に関する一覧表

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
Doi S, Inoue T, Ide H, Nakamura T, Fujita S, Takabayashi K	Using GIS to Simulate Inpatient's Behavior and Visualize Healthcare Demand	Procedia Computer Science	22	1361 –1368	2013

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 22 (2013) 1361 – 1368

Procedia Computer Science

17th International Conference in Knowledge Based and Intelligent Information and Engineering Systems - KES2013

Using GIS to Simulate Inpatient's Behavior and Visualize Healthcare Demand

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Abstract

In this study, we developed the Patient Access Area Model by using a Geographic information system (GIS), and, in order to evaluate the balance of medical supply and demand in the future in small areas, simulated patients' access to hospitals. We set the accessible area by patients' transit time for each hospital. The patients living in each 500 meters mesh were allowed to enter hospitals only within the access area. The hospitals have its limit to admit patients based on their actual numbers of beds. We distributed inpatients from each mesh across hospitals. For the evaluation of demand, if patients could not be distributed to the hospitals within the accessible area, we defined the situation as "over-demand." As a result, although it was expected that over 9000 inpatients will not receive inpatient care in a southwest area region in the studied prefecture, most of the over-demand is in the densely regions along large traffic lines in 2030. Using this model, we can know demand for local health resources more clearly. This method is very useful to plan geographical resource allocation in medical services.

Selection and peer-review under responsibility of KES International

Keywords: GIS; Patient Access Area Model; Estimation; Aging Society; Healthcare Policy

1. Introduction

In recent years, the geographical information system (GIS) has generated interest as a means to express local characteristics. The GIS is a technique that enables a high-throughput analysis and a quick judgment by

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1877-0509
Selection and peer-review under responsibility of KES International
doi:10.1016/j.procs.2013.09.225

managing and processing the data, including geographic position, and comprehensively expressing the data visually [1]. It is widely used by not only governments but also enterprises, both of whom have become able to use the large amount of data due to technological advances in computer communication and the maintenance of statistical data. Moreover, the GIS is applied to many fields of study. For example, Aramaki extracted and analyzed illness information, including the current situation of influenza, from Internet resources such as Twitter, an online social networking service, and developed a system that expressed the results on a map [2]. In the field of medical informatics, the GIS has been applied to condition analysis or the simulation of community and emergency medicine because the GIS made it possible to analyze patients' accessibility to the hospitals. For example, Akiyama and others extracted and analyzed disease data from the Diagnostic Procedure Combination (DPC) to examine the hospital's primary medical area and secondary medical area (SMA) [3]. Hamano and colleagues analyzed data regarding the access to medical facilities of chronic disease patients in a mountainous region [4]. Tajima and colleagues examined the appropriate placement of emergency medicine by analyzing the distance and time to the facilities [5]. All of these studies highlighted the importance of patients' access to medical facilities.

Japan is rapidly becoming a super-aged society. In the Tokyo Metropolitan Area, medical demand is expected to dramatically increase. Therefore, it is essential to systematically maintain the current number of hospital beds. However, estimates have been made of the number of patients in cities and large areas [6,7] but not in rural or small areas. In order to effectively develop community medicine policies, policy makers require estimates of medical services for each community. If we are able to predict health care demand in local areas, then we can effectively maintain health care resources, facilities, and services, such as home medical or visiting nurse care.

In this study, we developed the Patient Access Area Model by using a GIS and simulated patients' access to hospitals in order to evaluate the balance of medical supply and demand in the future.

2. Materials and Methods

As a precondition of the simulation, the target field was set to a 500-m2 area (called a mesh) in Chiba Prefecture. The frequency and duration of research was determined to be every five years from 2010 to 2035. The number of meshes in Chiba Prefecture is 20238. The target of the estimation of the medical demand is the number of in-patients.

This simulation comprised the following three steps:

- Estimation of the future population and the number of future patients;
- Simulation of patients' access to hospitals by using the Patient Access Area Model; and
- Evaluation of medical supply and demand.

2.1. Estimation of the future population

We projected the future population of Chiba Prefecture. A future population projection was published by the National Institute of Population and Social Security Research (IPSS) [8]. Since it was calculated by each local government but not by mesh, we used the government's statistical data for our estimates.

We obtained population information for each gender and five-year age group from the 2010 national census data. The map we used in this study was provided by ZENRIN Co. Ltd. Note that when a mesh had an extremely low population, the population for that mesh was added to the population of an adjacent mesh. The population of age-unknown people was distributed on this map for each gender and five-year age group. Parameters such as live birth rate, live birth sex ratio, and mortality rate were provided by the Ministry of Health, Labour and Welfare of Japan (MHLW). Using these parameters, we calculated the future population

every five years from 2015 to 2035 in each mesh according to the cohort component method [9]. In this simulation, we ignored social and international movements.

2.2. Estimation of the number of future inpatients

Using the estimated population (as described in Section 2.1), we calculated the number of future in-patients. The consultation rate, which was provided by the Ministry of Health, Labour and Welfare of Japan, was multiplied by the population figures for each gender and five-year age group in order to estimate the number of future in-patients. We made the following assumptions: (1) mental diseases would not be targeted and, therefore, were excluded from the estimations; and (2) the consultation rate would not change in the future.

2.3. Setting of 'Patient Access Area' on the mesh map

We positioned the access areas according to patients' transit times from each hospital in order to create a model of patients' hospitalization. Patients' accessibility to the hospitals is very important when we consider their and their families' burdens. In this model, we assumed that each hospital could admit patients only from within its access areas. On the other hand, from the patients' point of view, they were allowed to enter hospitals when the meshes they were living in were within access areas. We used this model to simulate the hospitalization of patients. We named our model the Patient Access Area Model. Fig. 1 shows an overview of our Patient Access Area Model.

We classified all of the hospitals in Chiba Prefecture according to the number of beds. Hospitals with less than 100 beds were classified as "small hospitals," those with less than 400 beds yet greater than 100 beds were classified as "medium hospitals," and those with greater than 400 beds were classified as "big hospitals." Next, we set the transit time according to the classification of the hospitals. The transit time was set to 15, 30, and 60 minutes for big, medium, and small hospitals, respectively. An access area was assumed to be the accessible field by car within the transit time from each of the hospitals. We investigated the access areas by using the GIS and the "ACT Distance Calculation Service" provided by Advanced Core Technology Co. Ltd. [10].

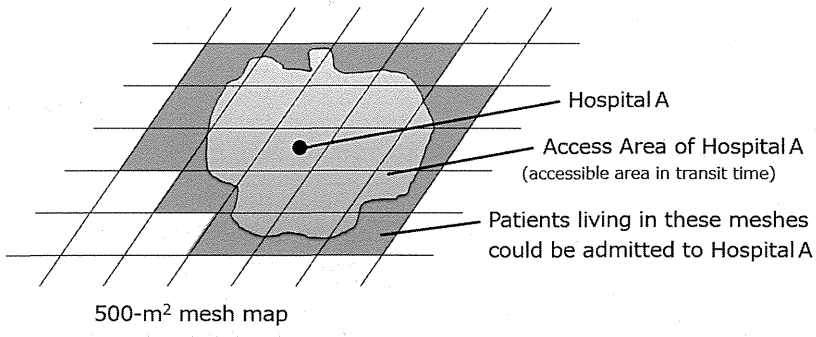

Fig. 1. Overview of 'Patient Access Area Model'

2.4. Simulation of access of patients' hospitalization

As described in Section 2.2, we estimated the number of patients in each of the meshes. In this model, we distributed the in-patients from each of the meshes across the hospitals. Fig. 2 shows an overview of the distribution of in-patients.

Sometimes a mesh belongs to the access area of several hospitals. As shown Fig. 2, because Mesh 1 belongs to the access areas of Hospitals A, B, and C, the in-patients living in Mesh 1 could be distributed to any of the three hospitals. However, for each hospital, there is a limit to how many patients they could admit based on the

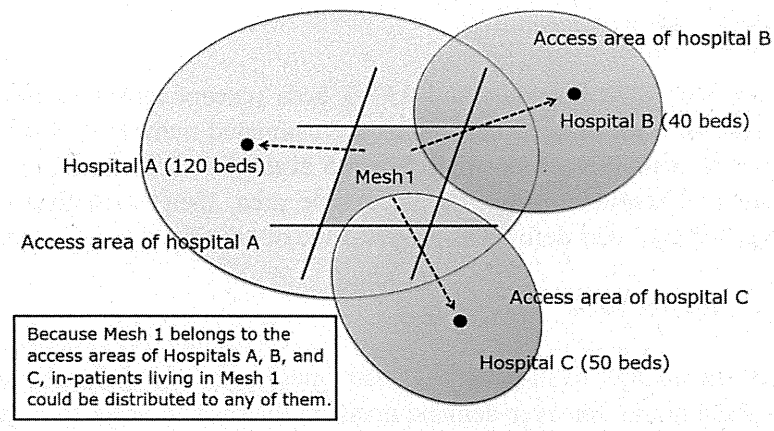

Fig. 2. Overview of 'Patient Access Area Model'

number of beds they have. When the access areas of hospitals overlapped on a mesh, we allocated the in-patients to one of the hospitals. The number of patients whom we were able to distribute was dependent on the algorithm of the distribution of in-patients. In this study, after we had examined several algorithms, we selected the one that allowed for the distribution of the maximum number of in-patients.

Fig. 3 illustrates the flow of the distribution of in-patients for the selected algorithm. This flow consisted of roughly the following three steps: (1) we chose a hospital that would be given in-patients; (2) we chose a mesh in which in-patients had been living; and (3) we distributed the in-patients to the hospital. The selection of a hospital depended on the number of patients whom we were able to distribute to the hospital. Similarly, the selection of a mesh depended on the number of beds available to distribute the in-patients living in the mesh.

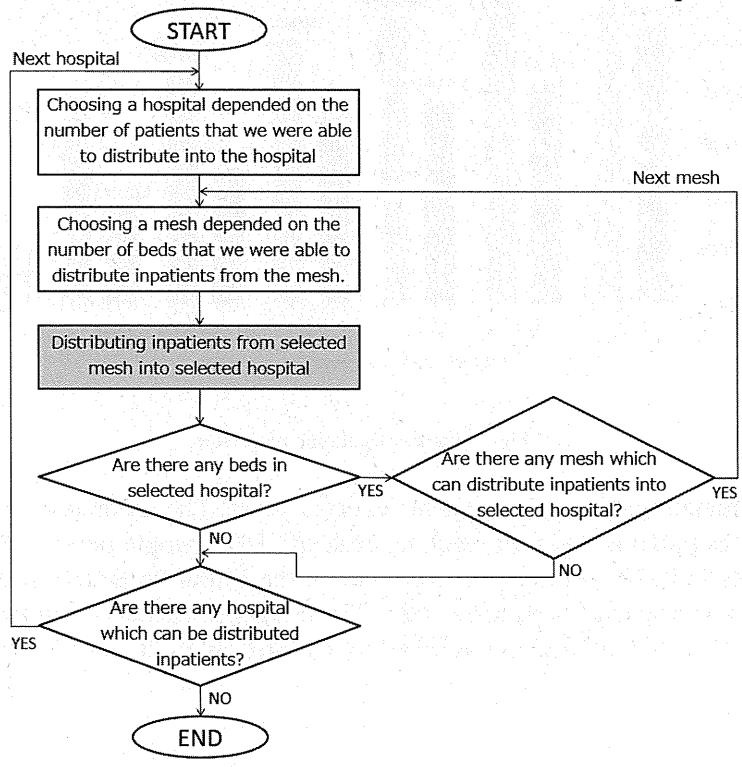

Fig. 3. Flow of inpatients distribution

2.5. Evaluation of medical supply and demand

In April 1, 2012, there were 278 hospitals and 43363 beds (except those for mental diseases) in Chiba Prefecture [11]. In this research, we defined demand as the estimated number of in-patients in this prefecture and supply as the number of beds in each hospital. For the evaluation of supply and demand, if the patients could not be admitted to the hospitals within the accessible area, then we defined the situation as "over-demand." Similarly, "over-supply" was defined as the presence of unutilized beds in the hospitals.

2.6. Projection of the over-demand area

Because we calculated the number of in-patients in each mesh, we were able to investigate over-demand in each mesh. We tried to place marks for over-demand areas on the map in order to visualize the areas of over-demand in Chiba Prefecture. In addition, we updated the maps every five years to predict changes in demand.

3. Result

3.1. Future population and the number of in-patients

Fig. 4 shows the results of our future population projection. We compared this result with the projection that was published by the IPSS in 2005. In this study, because we calculated the population in each mesh, the result expressed in Fig. 4 is the sum of them.

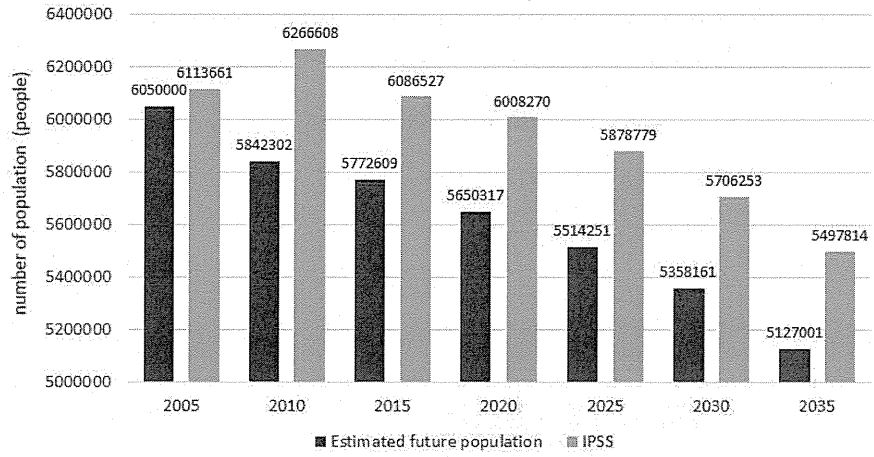

Fig. 4. Future population projection

Fig. 5 shows the estimated number of in-patients every 5 years. The number of in-patients will continue to increase due to an aging population and will reach its peak of 51824 people per day in 2030. This is 1.38 times the number of in-patients in 2010. If the number of beds in the Chiba Prefecture is maintained at only 43363 beds, then there will be a shortage of beds after 2020. The estimated number of in-patients in 2010 (37485 in-patients) was 6.5% more than the projection published by the MHLW in 2008 (35200 inpatients).

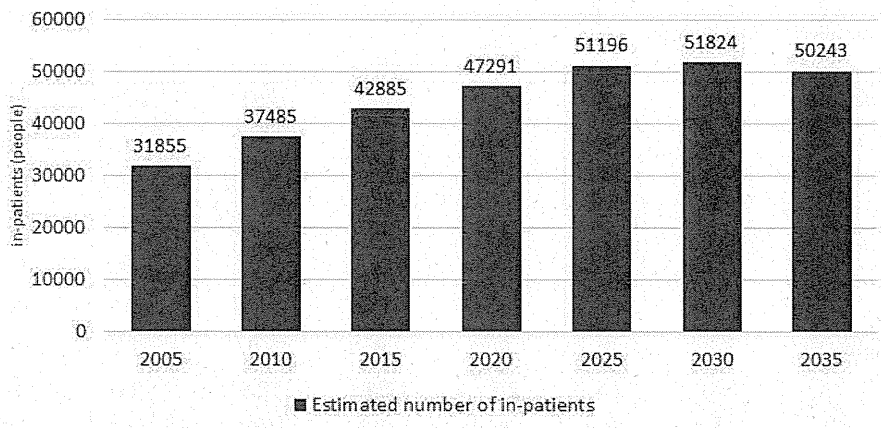

Fig. 5. Estimated number of inpatients

3.2. Evaluation of medical supply and demand

We used the Patient Access Area Model to evaluate medical supply and demand by comparing the number of in-patients (demand) to the number of beds (supply).

Table 1 shows the number of beds to which in-patients had not been distributed. Note that this is an over-supply scenario and it was summed for each secondary healthcare area (SHA), which usually consists of several cities and towns. In 2015, there were about 6000 beds throughout the northwest part of Chiba Prefecture such as the Chiba and South Tokatsu SHA, but the number of beds will continue to decrease. After 2025, almost no SHA will have spare beds except for the Awa SHA.

Table 1. The estimated number of over-supply

Secondly Healthcare Area	2010	2015	2020	2025	2030	2035
Chiba	1770	0	0	0	0	0
Tokatsu-Nanbu	2956	95	0	0	0	0
Tokatsu-Hokubu	0	0	0	0	0	0
Inba	666	0	0	0	0	0
Katori-Kaisou	0	0	0	0	0	0
Sanbu-Chosei-Isumi	0	0	0	0	5	59
Awa	570	526	579	608	719	848
Kimitsu	0	0	0	0	0	0
Ichihara	0	0	0	0	0	0
Sum	5962	621	579	608	724	907

Table 2 shows the number of in-patients who had not been admitted into hospitals. Note that this is an over-demand scenario and it is summed for each SHA. This result suggests that hospitals will be able to accommodate all in-patients until 2015. However, over-demand will continue to increase after 2025 because of increases of the population of people aged 65 years or older. In 2030, over-demand will peak and reach over 9000 in-patients per day. Specifically, over-demand will increase dramatically in the northwest part of Chiba Prefecture. In contrast, over-demand will hardly appear in the east and south part of Chiba Prefecture, such as the Sanbu-Chousei-Isumi, Awa, and the Kimitsu SHA.

Table 2. The estimated number of over-demand

Secondly Healthcare Area	2010	2015	2020	2025	2030	2035
Chiba	0	0	1966.1	2952.4	3258.1	2777.8
Tokatsu-Nanbu	0	0	2192.4	4501.8	4957.0	4426.9
Tokatsu-Hokubu	0	0	190.5	614.4	628.2	426.2
Inba	0	0	0	174.2	179.6	63.7
Katori-Kaisou	0	53.2	53.6	90.3	50.2	11.0
Sanbu-Chosei-Isumi	0	0	0	2.3	11.4	0
Awa	2.2	2.4	2.9	3.0	3.3	3.4
Kimitsu	0	0	14.7	14.3	13.4	0
Ichihara	0	0	0	0	0	0
Sum	2.2	55.7	4420.0	8352.8	9101.2	7709.0

3.3. Projection of the over-demand area

Fig. 6 shows the meshes where over-demand will appear in 2030. Although both the Chiba and Tokatsu-Nanbu SMAs will have a lot of over-demand (Table 2), Fig. 6 shows that it would not be distributed uniformly across these regions; most of the over-demand will be concentrated in densely populated regions along large traffic lines.

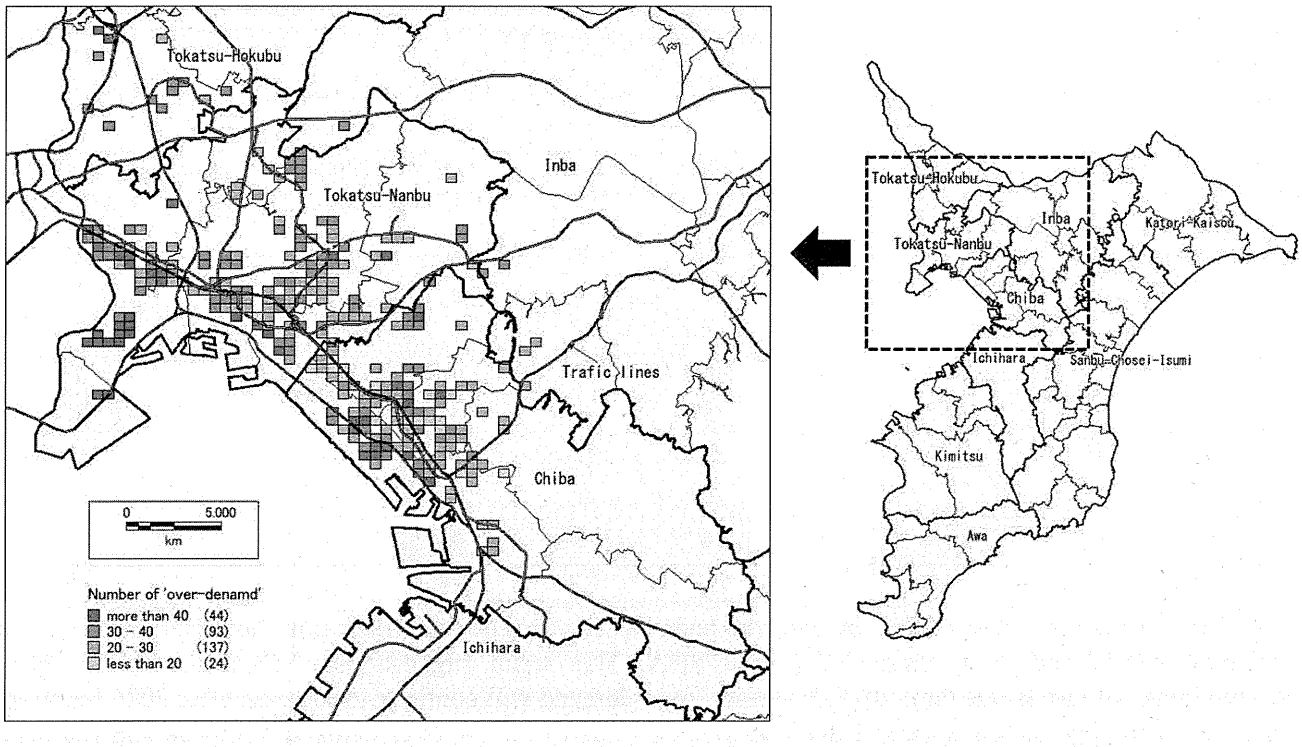

Fig. 6. Map of 'over-demand'

4. Discussion

This study developed an innovative method, the Patient Access Area Model, to estimate the demand for health care by integrating geographic information. Using this method, we were able to geographically visualize the demand for health care. In this research, we chose Chiba Prefecture as an example; however, this method could be applied to estimate supply and demand in other urban areas as well. Because geographic information systems are becoming increasingly more affordable, policy makers and subsequent researchers will be able to verify and expand on our analysis. In future, we must also consider other aspects of medical care, including emergency medicine and acute and recovery phase medicine, to evaluate situations realistically and with more precision.

5. Conclusion

We developed the Patient Access Area Model to evaluate the balance of supply and demand for future medical care in small areas. Using this model, we can get a clearer understanding of the demand for local health resources. This method will likely be very useful for planning resource allocation for medical services.

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