The Accessibility of public facilities for Low-carbon Urban Form in Compact city - A case study in Kumamoto city

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Keywords: Low-carbon society, urban structure, Network analysis, GIS, Kumamoto City

Abstract: With the large commercial facilities moving to the outskirts and the decreasing of the public transportation user, the vehicle usage and the environmental load increasing in recent years in Kumamoto city. This study aimed to propose a procedure for assessing the accessibility and sustainable development of Low-carbon urban structure in Kumamoto city and conduct in-depth discussions on how to improve the accessibility of urban form. Three steps have been set for this research. First, GIS tools (SANET) are applied to take the spatial analysis of public service facilities (bus stop, convenience store, hospital, supermarkets, post offices and banks) in Kumamoto city. Second, implement a method to measure and calculate the accessibility of public service facilities in this study to evaluate the sustainable development of Low-carbon urban structure. Third, a public service facility layout planning is proposed on areas where public services are inadequate and the accessibility is evaluated. The result showed that the proposal of fixed facility and mobile facility of public services in regular time along a certain route, the effect of accessibility improving will be more significant in Kumamoto city.

1. Introduction

A large amount of green house gases (GHGs) have been exhausting with the rapid development of urbanization and human activity, and the reduction of environmental load on energy consumption of daily transportation has been caused extensive concern. A Low-Carbon Society (LCS) [1] is a society which has a minimal output of GHGs emissions into the biosphere, but specifically refers to the CO_2. The international community has come to the conclusion that there is such an accumulation of GHGs (especially CO_2) in the atmosphere due to anthropogenic causes that the climate is changing, with negative impacts on humanity in the foreseeable future.

Man-made CO_2, as a major component of greenhouse gas (GHG) emissions, contributes significantly to the imminent environmental challenges. Although cities are being recognized as the major contributors to the global GHG emissions, they also form an integral part of the sources of solutions. Previous researches[2] indicated that it is necessary to formulate and investigate a mid/long-term action projects on municipal level, such as the urban morphology, traffic system, land use change, etc. to achieve a low-carbon society. Some of the frequently proposed strategies such as more efficient use of fuel, improvement of public transportation, education of citizens, and implementation of ‘car free day’ were put forward in European and American areas. In Japan, four types of representative strategies were approached [3] for realization a low-carbon society: the construction of institutional social system, maintenance of social capital on software and hardware, natural environment management. Implement the low-carbon lifestyle, developing efficient market systems for the carbon-emission tax, emissions trading and sharing the successful experiences to the world, these were the main representative measures of construction of institutional social system. On the aspect of natural environment management, citizen’s participation and a connected ecological network with excellent natural environment were constructed. Moreover, the genetic strategy concerning biomass resources was promoted on the agriculture and forestry ground. The study on urban spatial structure of low carbon city becomes a hotspot in recent years.

With the large commercial facilities moving to the outskirts and the decreasing of the public transportation user, the vehicle usage and the environmental load increasing in recent years. Aiming at building a low-carbon city in Kumamoto City, there are three key strategic guidelines of urban development and construction on aspect of urban structure, the formation of the interrelated urban structure between downtown and sub-center residential area, the establishment of new vitasphere where daily life can be managed with on foot and the bicycle, and the inhibition of transport energy consumption.

In 2011, Ye J. & IKI K. indicated that strong correlation between the regional geographical features and lifestyle of daily activity was evaluated [4]. Previous researches provided

methods to analyze the internal relationship between the regional feature and CO_2 emissions per person or total. The traffic energy consumption on the CO_2 emissions of per trip and the total CO_2 emissions of each region from individual activities were calculated by using Person-Trip (PT) survey data in Kumamoto city. The study concluded that under a precondition of taking full account of regional characteristics, it is a high feasibility to achieve LCS with less CO_2 emissions by adjusting the city's social structure and urban structure in the future transportation planning. The consequence of PT-CO_2 emissions in the ordinary situation, the total amount of PT-CO_2 emissions exhausted from urban activities were 3517.7 tons a day and 1,266,400 tons for one year in Kumamoto city. Moreover, the situations of PT-CO_2 emissions per person were 5.3kg a day and 1.9 tons per year. In previous study, 4 types of regional characteristics were sorted out, DID district residential type, sub-center residential type, surrounding residential type and suburban residential type. From the viewpoint of PT-CO_2 emissions per person and total of PT-CO_2, the effects of the traffic energy consumption reduction of the proposal III (Sub-center residential type) (5.5%, 18.95%) was larger than proposal II (DID district residential type) (2.75%,13.96%) from the 2000 level by 2030. Sub-center of City residential type was considered as a most suitable urban morphology towards LCS in Kumamoto city.

Based on the previous studies, the general objective of this study is to propose a procedure for assessing the accessibility to public service facilities as one aspect of sustainable development of Low-carbon urban structure in Kumamoto city and conduct in-depth discussions on how to improve the accessibility of urban form. Three steps have been set for this research. First, GIS tools (SANET) are applied to take the spatial analysis of public service facilities (bus stop, convenience store, hospital, supermarkets, post offices and banks) in Kumamoto city. Second, implement a method to measure and calculate the accessibility of public service facilities in this study to evaluate the sustainable development of Low-carbon urban structure. Third, a public service facility layout planning is proposed on areas where public services are inadequate and the accessibility is evaluated.

2. Study area

Kumamoto city is a capital city of Kumamoto Prefecture on the center of Kyushu Island in southwestern Japan. It is the 15th largest Japanese city and is well known for being the site of Kumamoto Castle, one of the finest castles in all of Japan. Greater Kumamoto metropolitan area has a population

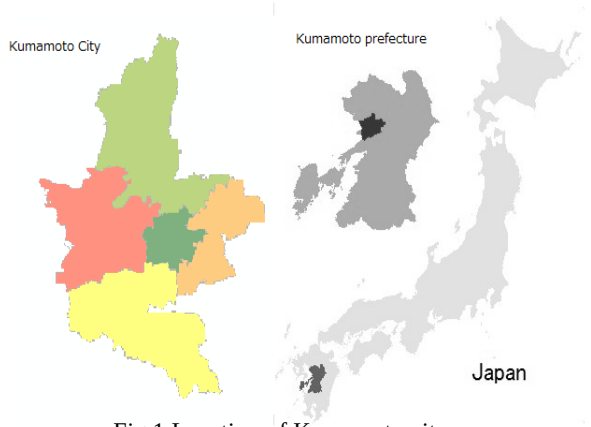


Fig.1 Location of Kumamoto city

of 1,460,000, as of the 2000 census. It has now developed into a modern metropolis with broad streets lined with high-rise buildings. Well-developed local public transport system is provided by the local government. Trams run to a few suburbs near the downtown area. A large bus terminus provides access to both local and intercity destinations. JR Kumamoto station also provides rail links to Japan's extensive rail network. Kumamoto City covers 389.53 km^2 total area, has about 730000 populations (March 1, 2010) with the 1,880/km^2 density.

3. Data sources and methodology

The data sets used in this study comprise road network, Population and Housing Census data (2005), the location of the existing public service facilities data in the study area, have been digitized. The road network data which contains accurate data on the location of all roads and streets was supplied by Infrastructure Planning and Management Laboratory in Kumamoto University. The Population and Housing Census data was obtained from the statistics bureau, the ministry of internal affair and communications. The existing public service facilities include bus stop, convenience store, hospital, supermarkets, post offices and banks etc. The location data of those facilities were got from KUMAMOTO GPMap in 2010.

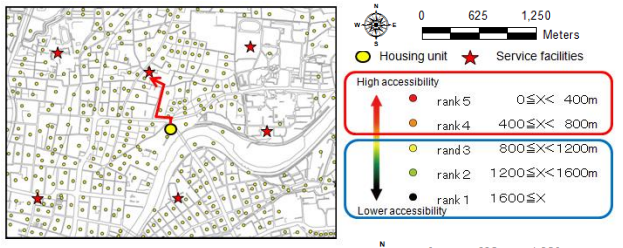
3.1 Spatial analysis

In this study, SANET method is used to conduct the spatial analysis in Kumamoto city. SANET is the Plug-in Program which statistically analyzes spatial patterns of events that occur on/alongside networks. SANET provides a collection of ArcGIS-based tools for analyzing events that occur on or alongside a network. Three tools are used in this study: Kernel density estimation, Global auto nearest neighbor distance method and Global cross nearest neighbor distance method. For a given set of points on a network, Kernel density estimation estimates the density function of the points over a network and it can be showed on 3D by ArcScene.

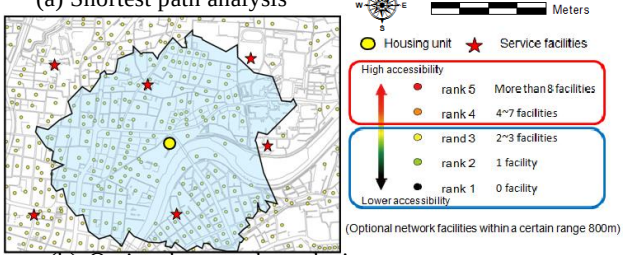
Global auto nearest neighbor distance method and Global cross nearest neighbor distance method this two tools test the complete spatial randomness (CSR) hypothesis in terms of the shortest-path distance from every point in a given set of points placed on a given bounded network to its next nearest point in the set. Note that in the literature, the global auto nearest neighbor distance method is simply referred to as the nearest neighborhood distance method. The global cross nearest neighbor distance method is sometimes referred to as the conditional nearest neighborhood distance method. In general, it is assumed that type B points are temporal, while type A points are stable over time; The CSR hypothesis means that points are independently and identically distributed according to the uniform distribution over the network, or points follow the homogeneous binomial point process on the bounded network.

3.2 Accessibility to public service facilities

Accessibility refers to how easy it is to go to a site. In Network Analysis, accessibility can be measured in terms of travel time, distance, or any other impedance on the network. ArcGIS Network Analysis allows us to solve common network problems, such as finding the best route across a city, finding the closest facility, identifying a service area around a location, etc. The closest facility solver measures the cost of traveling between incidents and facilities and determines which are nearest to one other, report the shortest distance. In this study, we chose the shortest path analysis method to analyze the arrangement model. The shortest path (Fig.2 a) used for analysis is the shortest distance from the housing unit to the service facilities. It is an important index for the accessibility evaluation. Accessibility analysis of locate service facilities include two parts, the distance to the nearest facility and how many optional network facilities within a certain range (Fig.2 b). In this study, we indicated less than 800m is the vitasphere where daily life can be managed with on foot and the bicycle.



(a) Shortest path analysis



(b) Optional network analysis

Fig.2 Accessibility to public service facilities

3.3 Proposal for the Location Plan

The proposal for the location plan is considered on the basis of the shortest path analysis derived from the network analysis. The following points have been applied to the new facility location plan.

1) Based on the accessibility of different facilities in each wards in Kumamoto city, “fixed facility” (like store, long-term service at an immovable space) and “mobile facility” (mobile vendition car, short-term service at a movable space) are considered on proposal for the location plan to improve the accessibility in those area.

2) New service facilities will be considered and located in housing lots or vacant lots to reduce cost and CO_2. Based on these points, the new location plan is shown by the GIS.

4 Results and Discussions

4.1 Spatial analysis of facilities

In this study, two types Kernel density estimation were conducted by using ArcGIS Network Analysis, the normal one on 2D and spatial one on 3D along the Network (bus route) (Fig.3, Fig4). As convenience store for example, Kernel density in central city is higher than others wards, on the East ward and North ward, the density of convenience store follow a gourd-shaped distribution along the bus line route Network Kernel Density of Supermarket, monetary

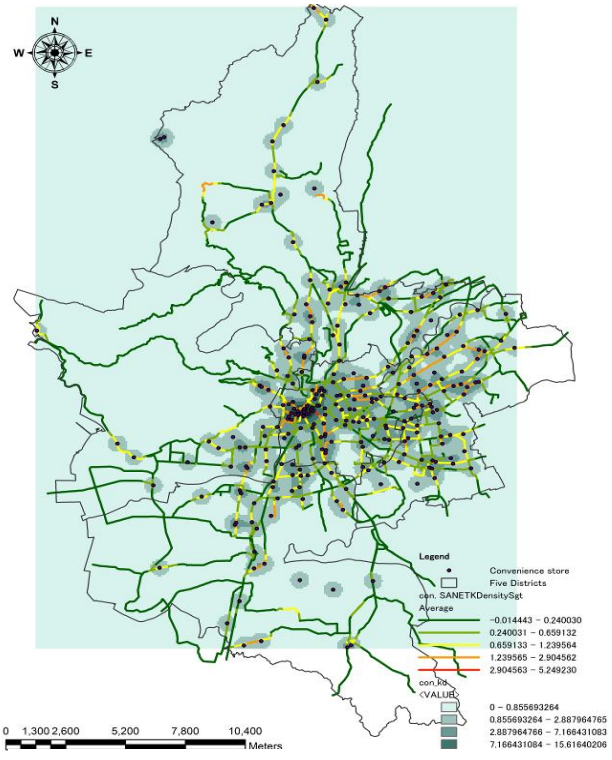


Fig.3 Kernel density estimation convenience stores 2D

facilities, Medical facilities in Kumamoto City also follow a gourd-shaped distribution along the bus line route.

The CSR hypothesis means that points are independently and identically distributed according to the uniform distribution over the network, or points follow the homogeneous binomial point process on the bounded network. The result of Global auto nearest neighbor distance method and Global cross nearest neighbor distance method is showed on Fig.4. The blue curve indicates the observed curve; the red curve indicates the mean value under the CRS hypothesis; the green and pink curves are, respectively, the upper and lower envelop curves under the CSR hypothesis. If the observed curve is in between the upper and lower envelop curves, we cannot reject the CSR hypothesis with 0.95 confidence level. In the above example, the observed curve is above the upper envelop curve for distances more than 800 m, and hence we reject the CSR hypothesis with 0.95 confidence level in that distance range. That is to say, less than 800 m the distribution of convenience stores is randomness but in the range 800m -1600m is tend to be clustered in that distance range (Fig5. a).

Global cross nearest neighbor distance method, tests the complete spatial randomness (CSR) hypothesis in terms of the shortest-path distance from each point in a given set of type B points to its nearest point in a given set of type A points. In general, it is assumed that type B points are temporal, while type A points are stable over time. In this study, the former points are convenience stores and the latter points are Bus stations. In the above example, the observed curve is above the upper envelop curve for distances less than 700 m, and hence we reject the CSR hypothesis with 0.95 confidence level. The convenience stores tend to cluster around Bus stations in this region (Fig5. b).

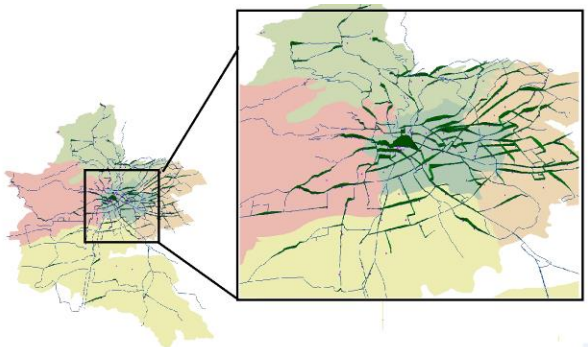


Fig.4 Kernel density estimation convenience stores 3D

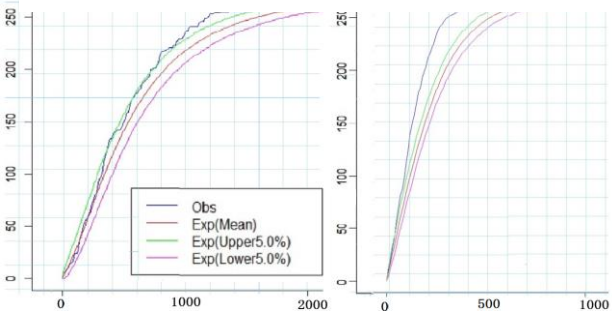
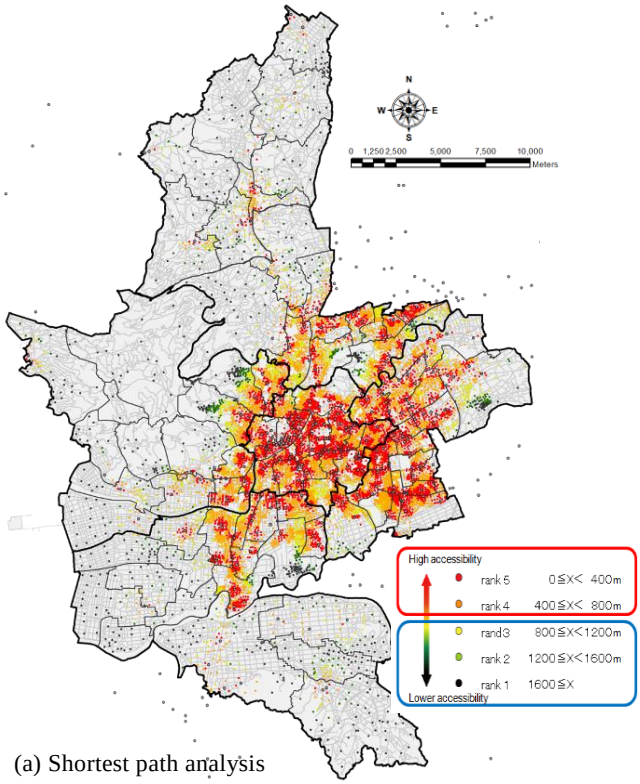


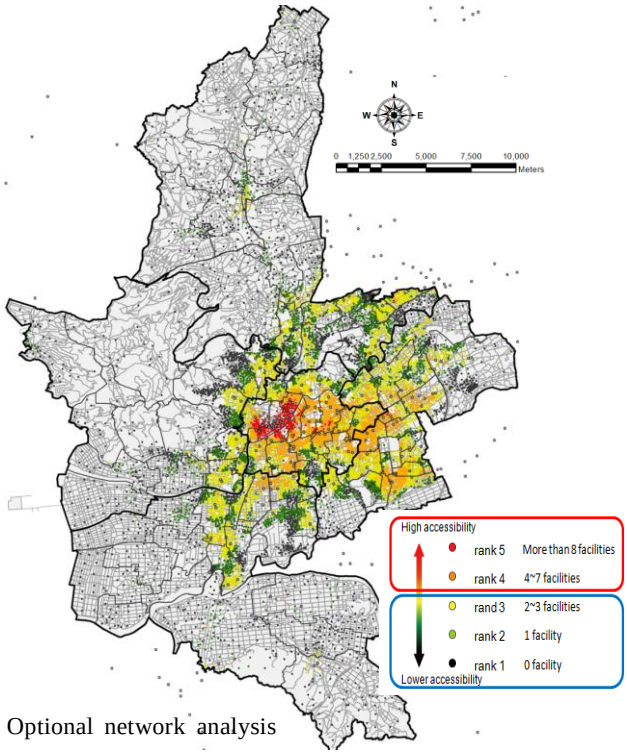
Fig.5 The result of CSR hypothesis

4.2 Accessibility to locate facilities

As the result of accessibility of Kumamoto city, about 83% (rand 4and 5, 141000) people in central ward have high accessibility to access the different facilities without Kurokami and Izumiminami school district. In North ward, about 35% (52000) people live in the area with very lower



(a) Shortest path analysis



(b) Optional network analysis

Fig.6 The accessibility of convenience stores

Tab.1 Result of the accessibility of public facilities (Shortest path analysis)

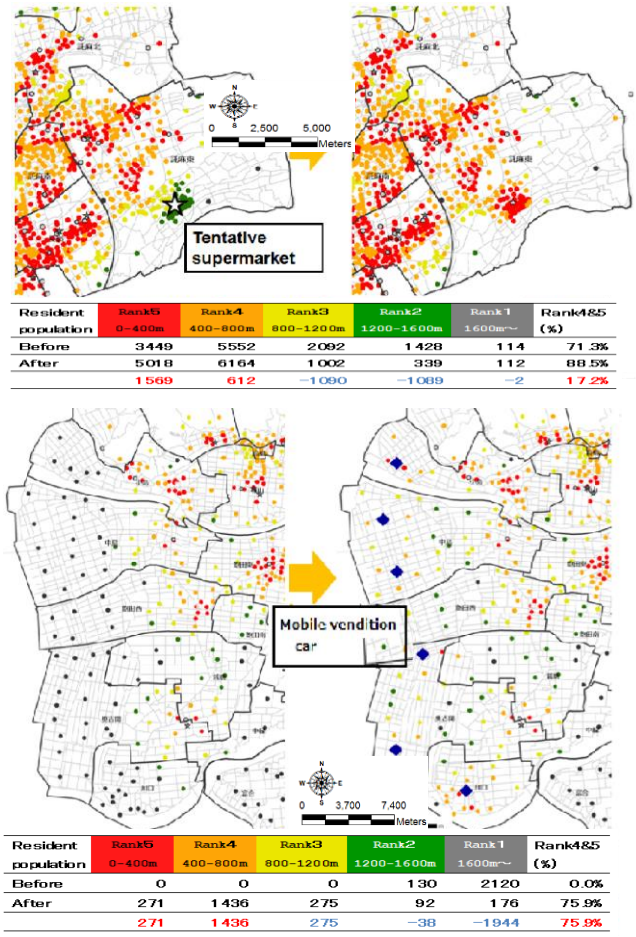
	Convenience store	Bus stop	Hospital	Supermarkets	Post offices and banks
Rank4 &5	about 78%	about 95%	about 41%	about 60%	about 76%
Convenience area	Central, East ward	Central, East area	Central, East area	Central, East area	Central, East area
Inconvenience area	North ward, South and west area	South ward	North ward, South and west area	North ward, South and west area	North ward, South and west area

accessibility except the Ueki and Musasikaouka school district, where is located around the regional administrative center. Refers to different service facilities, about 78% people live in area with less than 800m the distance to convenience stores, and about 22% people live in area with more than 4 optional network facilities in the range 800m.(Tab.1)

4.3 Simulation of location plan

Two type facilities (fixed facility and mobile facility) are considered on proposal for the location plan to improve the accessibility in low level area. As fixed facility (supermarket) in housing lots for example, the accessibility of supermarket is improved from 71.2% to 88.5% who live in the area with less than 800m the distance to supermarket.

In case of mobile vendition car in Kawaguchi school district in West ward, before mobile vendition car was adopted in this area, all most people was difficult to access the supermarket otherwise unless he or she walking more than1200m. It is very inconvenience, especially for older persons. After mobile vendition car was adopted, more than 1700 people can access the vendition car easily than before (Fig.7). In addition, we assume that the car move in regular time along a certain route, then the effect of accessibility improving will be more significant.



Resident population	Rank5 0-400m	Rank4 400-800m	Rank3 800-1200m	Rank2 1200-1600m	Rank1 1600m~	Rank4&5 (%)
Before	3449	5552	2092	1428	114	71.3%
After	5018	6164	1002	339	112	88.5%
	1569	612	-1090	-1089	-2	17.2%

Resident population	Rank5 0-400m	Rank4 400-800m	Rank3 800-1200m	Rank2 1200-1600m	Rank1 1600m~	Rank4&5 (%)
Before	0	0	0	130	2120	0.0%
After	271	1436	275	92	176	75.9%
	271	1436	275	-38	-1944	75.9%

Fig. 7 Accessibility improvements (shortest path analysis) of scenario

5 Conclusions

This study proposed a procedure for assessing the accessibility and sustainable development of Low-carbon urban structure in Kumamoto city and a proposal on how to improve the accessibility of urban form was conducted. GIS tools were applied to develop a method to measure and improve the accessibility of public service facilities for Low-carbon urban form with less distance of each trip. The proposal for the Location Plan was adopted in this study to evaluate the accessibility of facilities in Low-carbon urban structure in Kumamoto city base on the vision using the vacant house. The feasibility of this using vacant house proposal will be discussed more and more in Japan in future. In the future study, slope and width of Net roadwork will be considered to assess the accessibility in Kumamoto city.

[Reference]

1) Maatta-Juntunen, H., et al. Using GIS tools to estimate CO2 emissions related to the accessibility of large retail stores in the Oulu region, Finland. J. Transp. Geogr. (2010), doi:10.1016/j.jtrangeo.2010.03.001

2) TAKAHASHI M., DEGUCHI A., NISHIKAWA H.. Relationship between land use and CO2 emitted by person trip–Case study of Fukuoka cit. J. Archit. Plan. No.588. 2005:103-109

3) The guideline of Low–carbon society planning. Tokyo: Ministry of Land, Infrastructure, Transport and Tourism, 2005.8

4) YE J., IKI K., HOMMA R.. Research on urban structure towards a Low-carbon society from the viewpoint of Person-Trip in Kumamoto city. The 34th AIJ Information Systems Technology symposium. 2011:121-126.

5) Lin S., Lu I., Charles L. Grey relation performance correlations among economics, energy use and carbon dioxide emission in Taiwan, Energy Policy 35 (2007): 1948-1955

6) Chen C., HOMMA R., IKI K., An Analysis of and Proposal for a Location Plan for the Local Community Centers and the Private Community Clubs for the Elderly in Omuta City, Master thesis

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集約型都市構造のための都市サービスのアクセシビリティ評価
－熊本市を事例として－

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キーワード：低炭素社会、都市構造、ネットワーク解析、地理情報システム、熊本市

現在、日本においては、少子・高齢化の進展とともに本格的な人口減少社会を迎え、これまでの「人口増加を前提とした社会経済のあり方」の見直しが迫られている。また、モータリゼーションの進展に伴う市街地の拡大や中心市街地の空洞化、温室効果ガス排出に対する取り組みも求められている。このように、都市づくりの分野でも、これまでの急速に成長・拡大してきた都市化の社会から、安定・成熟した都市型の社会への変化が求められている。

熊本市を集約型都市として再構築するためには、中心市街地だけではなく、それぞれの地域を中心として、生活に必要となる都市サービスが受けやすくなければならない。また、高齢化、車社会の影響も考慮し、交通弱者にも住みやすい都市を形成する必要がある。そのためには、周辺人口や詳細な施設分布といった地理情報を踏まえ、「どこの地域が不便で、何が不足しているのか」といった具体的な問題点や課題などを含めた熊本市の現状について把握する必要がある。

そこで、熊本市におけるサービス施設の分布、人口の分布から、生活上で必要な都市サービス施設の利用しやすさ（アクセシビリティ）を移動の便利さの視点で明らかにすることにより、地域の生活水準を高める手掛かりとし、一部サービスについては水準向上のためのシミュレーションすることを本研究の目的とする。

本研究では、具体的な目的として以下の 3 点を設定し、GIS をもとに分析を進める。

1. 生活サービスの基本となる商業、医療、公共、銀行・郵便、交通サービスを提供する各施設分布の現状分析
2. 生活サービスを受ける市民の分布から、熊本市における都市サービス施設別アクセシビリティ評価
3. 商業サービス・公共サービスにおける施設立地シミュレーションによる整備方策の検討

本研究では、ネットワーク解析を用いて、空間分析、最短路分析・選択性分析という 3 つの観点から各都市サービスへのアクセシビリティを評価した。それによって施設の立地タイプやアクセセシビリティの地域差を把握することができた。さらに、不便な地域として挙げられた地域の中から商業サービスのシミュレーション（施設新設・移動販売）をした。居住人口の多い住宅街では、施設新設の大きな効果を確認することができた。金峰山内、海沿いの移動販売シミュレーションでは、それぞれの移動販売設定点では効果は小さいが、1 つのルートとしてみると、効果的であることが示された。

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