HOW A SHRINKING SOCIETY CAN PREPARE FOR THE FUTURE: ANALYSIS AND IMPLICATIONS OF DEPOPULATION FOR INFRASTRUCTURE PLANNING IN JAPAN

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ABSTRACT

Since the opening of the country in the Meiji era, modern infrastructure development in Japan has progressed in keeping with the industrialisation of society. As Japan moves through the demographic transition, along with the decrease in birth rate and the increase in the elderly population, Japan's population size has begun to decrease year by year since 2008. These changes in population structure and size will inevitably lead to changes in citizens' demands for infrastructure facilities and public services. Infrastructure is a part of society and a set of basic physical systems that should change its quantity and quality of provided services according to the changes in social environment.

This thesis examines research questions from the socio-demographic perspective: How do demographic factors affect infrastructure planning at regional and national levels in Japan? The purpose is to analyse to what extent the changes in population size and structure that substantially affect infrastructure planning at regional and national levels. The analysis applied improved gravity model (Chapter 6), The two step floating catchment area method (Chapter 7), fixed effects model, random effects model and mixed effects model (Chapter 8), combined with the ArcGIS visualisation function, quantitatively analysed the impact of population changes on the planning of elderly care facilities in Sendai City, primary schools in Nagano City and housing throughout Japan. The three types of infrastructure facilities were selected for this study due to their close relationship with three significant aspects of population change in Japan, namely aging, declining birth rate, and population decline. In order to conduct a multi-dimensional and systematic investigation of the impact of population change on infrastructure planning, the quantitative analysis has been performed at different geographic scales.

The main findings are summarized as follows: (1) there are disparities in elderly care facilities' distribution in Sendai City; (2) the allocation of primary educational resources in Nagano City is unbalanced; (3) changes in the population structure affect housing demand in complicated ways. In general, the advent of population decline provides an opportunity to review the systems and mechanisms of infrastructure planning based on population growth during the high growth period, it also gives a push to realize the effective utilization of social resources and obtaining the benefits of depopulation, thereby making it possible to obtain a depopulation dividend. The experiences of Japan are also likely to potentially apply to other countries encountering similar demographics.

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CHAPTER 1

INTRODUCTION

1.1 - The Purpose of the Study

Japan is the first East Asian country to cross the threshold into population decline at a national scale (Matanle, 2017). Japan experienced a short-lived baby boom from 1947 to 1949, which was then followed by a second baby boom from 1971 to 1974. However, since 1974, Japan has failed to raise its total fertility rate to the population replacement level (MIC, 2015). Government statistics indicate that Japan's population peaked in 2008 after a sharp increase in the modern era but has since begun to experience a rapid decline at a rate never seen in recorded human history. The Japanese government has launched several major initiatives to tackle its demographic challenges. The media and the public have also expressed their concern about these population issues. However, discussions on how to manage, operate and maintain infrastructure that fulfils postwar reconstruction, supports high economic growth, and responds to the rapid increase in urban population in a society with a declining population have been inadequate.

This study is aimed at undertaking a quantitative analysis to assess how population change affects infrastructure planning within the country as a post-developmental society. This study asks the following research question: How do demographic factors affect infrastructure planning at regional and national levels in Japan? To answer this main question comprehensively, the following sub questions are designed: (1) How can infrastructure planners in Japan respond to regional and national demographic changes? (2) What can other countries with similar demographic situations learn from Japan's experience? The infrastructure planners defined in this study include not only decision-makers of infrastructure facility construction and relevant governments and power departments but also include institutions and scholars on population projections and social welfare who advise on the implementation of infrastructure planning.

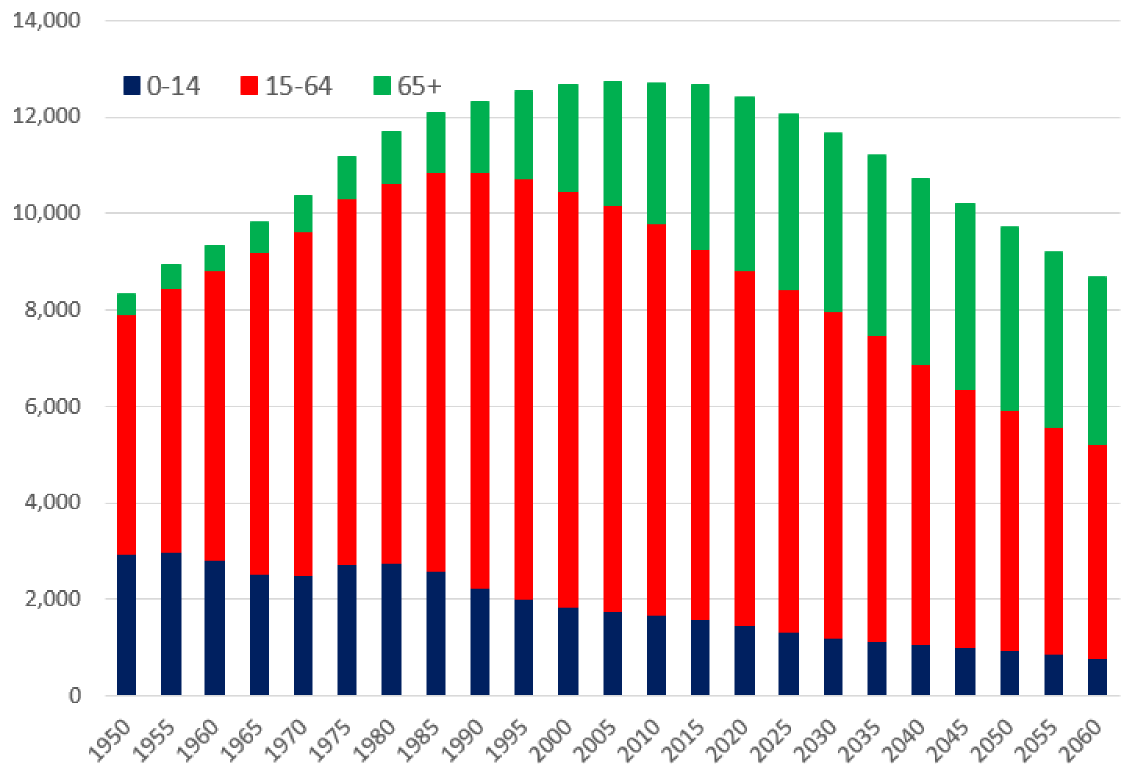
Changes in population size and structure inevitably result in varying objective demands on the sustainable development of the society and its economy. Infrastructure on the other hand have been recognized as critical to ensure the quality of living and sustainable regional development in contemporary times (Allen, 2013). Infrastructure is a part of society and a set of basic physical systems that should change its quantity and quality of provided services according to the changes in social environment. Infrastructure planning should be provided to maximise and satisfy the needs of regional population settings, consequently achieving effective and rational use of social resources. Besides allowing us to expound on and facilitate the development of suitable policies to help decision-makers address the effects of Japan's reducing population on its infrastructure, the study's findings are also likely to potentially apply to other nations with similar demographic settings.

1.2 - Demographic Change in Japan and Its Regional Disparities

1.2.1 - Depopulation

The population of Japan has been increasing continuously since Meiji Restoration (Meiji Ishin). Population increased 3.6 times from 35 million to 128 million between 1875 and 2008 (MIC, 2015). The history of modernisation in Japan is also the history of population growth. The 20th century was also the 'century of population growth' for Japan. However, the population of Japan entered a long-term decline in the 21st century after peaking at 128.08 million people in 2008 due to the increase in the number of deaths and the decrease in the number of births (MIC, 2015). According to the median birth and death estimates published in 2015 by the National Institute of Population and Social Security Research (IPSS) in Japan, the population of Japan will reach 99.1 million in 2048 and 86.74 million in 2060. This change is a decrease of 41.34 million people from 2008, which suggests that Japan will lose about one-third of its population in half a century (Figure 1.1).

Figure 1.1 – Trends in Population of Japan (1950 – 2060) (Unit: 10,000)



Sources: Population Projection for Japan: 2016-2065 (2015), IPSS.

Population decline has practically normalised in most prefectures in Japan. Although the population of the so-called three metropolitan areas[1], particularly the four prefectures of Tokyo area, continue

[1] Three metropolitan areas: Tokyo Area (Tokyo, Chiba, Kanagawa and Saitama), Osaka Area (Osaka, Kyoto, Nara and Hyogo) and Nagoya Area (Mie, Aichi and Gifu). Non-metropolitan area: Other than the 3 major city areas.

to increase, the population in numerous prefectures in non-metropolitan areas continued to decline since around the mid-1980s. Many of these prefectures also experienced a declining population from 1955 to 1970 when high economic growth continued, but the population decline factor at that time was mainly population outflow (Ogawa and Kondo et al., 2005). The natural decline, in which the number of births falls below the number of deaths, gradually increases its weight in population change. Population decline then became an inevitable phenomenon in these prefectures since 1990.

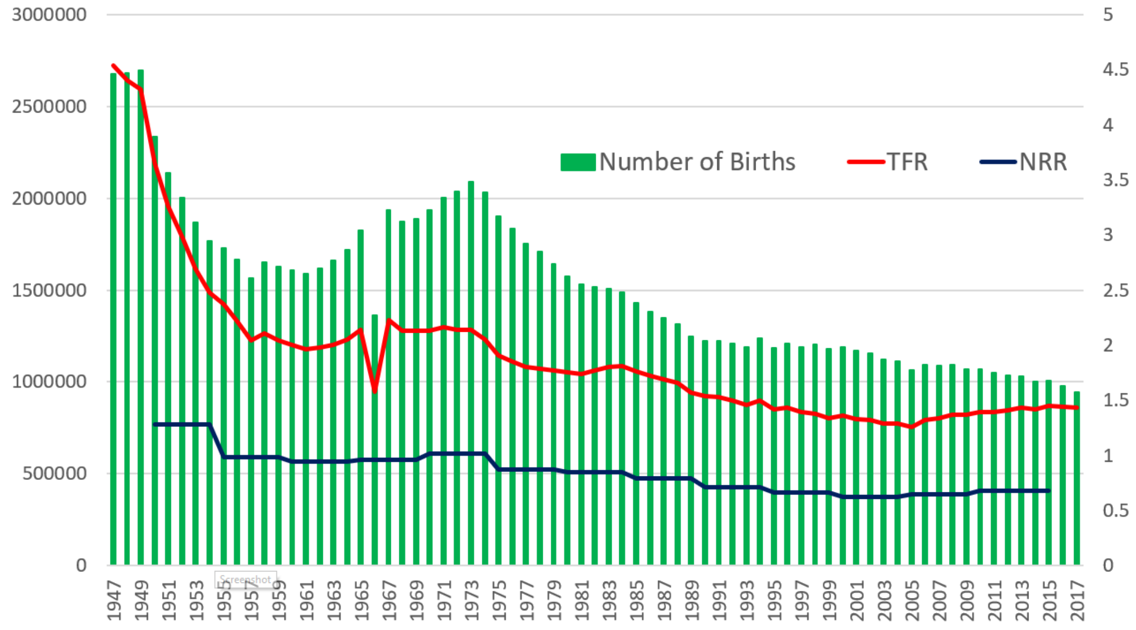
According to 'Japan's regional population forecast (estimated in March 2013)' published by the IPSS on future trends in demographic size by prefectures, the number of prefectures that experience population decline will continue to increase in the future. The number of prefectures that will experience population decline between 2015 and 2020, excluding Okinawa Prefecture, will reach 46, and the population in Okinawa Prefecture between 2020 and 2025 will also decrease. Put the matter another way, the total population is expected to decrease in all Japanese prefectures after 2025. The total population in 2040 is also estimated to be lower than that in 2010 in all prefectures. The degree of population decline also largely varies from region to region. The total population in Japan is expected to decrease by 13.4% from 2005 to 2035. In terms of region, the number of prefectures that will decrease by 20% or more, 10% to 20% and 0% to 10% of its population is predicted to be 18, 23 and 4 prefectures, respectively.

1.2.2 - Fertility decline

The main cause of Japan becoming a depopulation society in the early 21st century is its declining fertility level (Ishii, 2013). The annual number of births in Japan was approximately 2.7 million in the first baby boom period (1947-1949) and about 2.1 million in the second baby boom period (1971-1974), but it fell below 2 million in 1975 and continued to decrease. This number then fell below 1.5 million in 1984, and it has gradually declined since 1991 with a repeatedly increasing and decreasing trend. The number of births in 2015 was 1,005,677, which is an increase of 2,138 from 1,003,539 in the previous year.

Total fertility rate (TFR) was over 4.3 during the first baby boom period, but it fell sharply after 1950. Afterwards, it remained on the 2.1 level including the second baby boom period, but it decreased again after falling below 2.0 in 1975. This rate fell to 1.57 in 1989, and in 2005, it fell to 1.26, the lowest record ever. In recent years, the TFR trend has continued to increase slightly. In 2015, it was 1.45, 0.03 points higher than that of the previous year (Figure 1.2). The TFR nationwide in 2015 was 1.45, but among the 47 prefectures, 35 prefectures exceeded this level, and 12 prefectures fell below this level. Moreover, no prefecture in the Kanto region has exceeded this level. The rates of most prefectures in the Kansai region are also below the national level. In addition, the TFRs of the prefectures in the Chubu, Chugoku/Shikoku and Kyushu regions are higher than the national average level. Among them, the highest TFR was in Okinawa Prefecture (1.96), followed by Shimane Prefecture (1.78) and the lowest TFR was in Tokyo (1.24), followed by Hokkaido (1.31) (MIC, 2015).

Figure 1.2 – Number of Births, TFR and NRR in Japan: 1947-2015[2]



Sources: Declining Birthrate White Paper (2017), Cabinet Office, Government of Japan, UN data.

A significant indicator of demographic evaluation is net reproduction rate (NRR). In this context, quantity refers to as the anticipated number of female newborns delivered by a woman during the course of her life. Notably, NRR is considered to be a more desirable indicator when compared with TFR. This is attributed to the fact that the TFR is fraught with parity composition effect and tempo distortion (Kohler, Billari & Ortega, 2002). If the NRR value stands at 1, this implies that a newborn female child is likely to produce one daughter by the time her reproductive period ends in case she was subject to a given period's fertility rates and mortality rates throughout her life. Thus, in the long run, the population will not increase nor decrease but will reach the population replacement level. The value of '1' is an important reference value for NRR. A value higher than 1 indicates an increasing population, and that less than 1 indicates otherwise. The statistics in Figure 1.2 shows the NRR in Japan from 1950 to 2015. The figure shows that after a substantial decline at the end of 20th century, the NRR in Japan remained stable between 1995 and 2015, but it was insufficient to replace the previous generation of mothers. The low NRR value also confirms the low fertility level in Japan from another perspective.

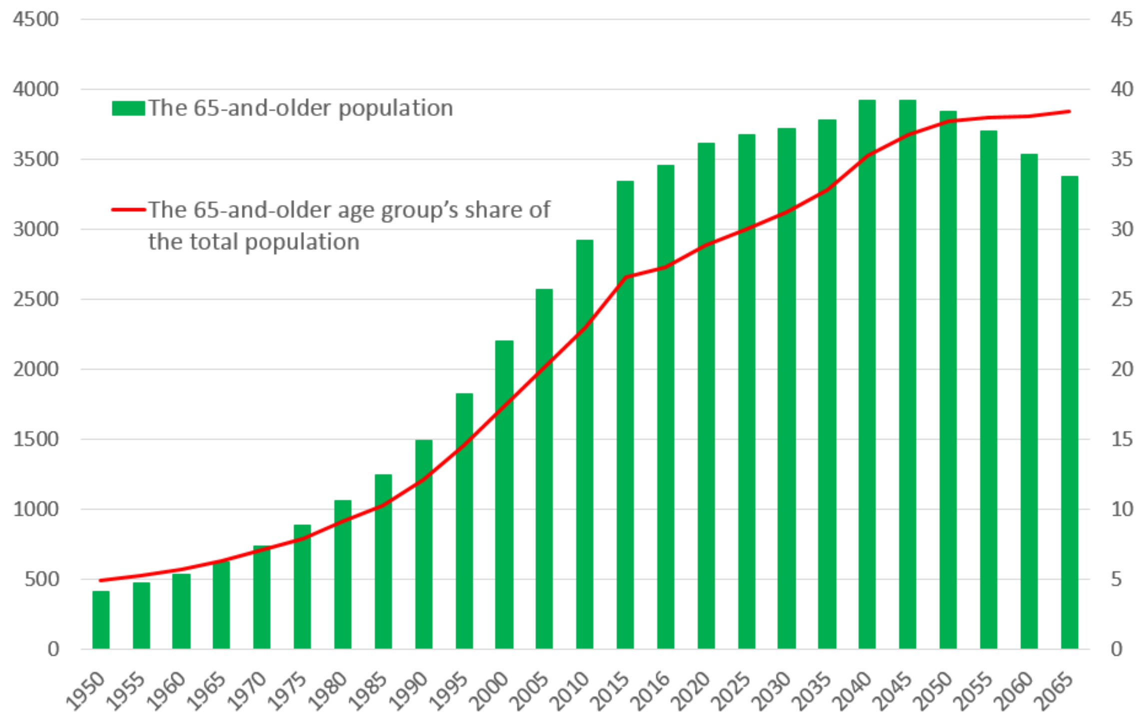
[2] In 1966, the TFR was showing a sharp drop. In Japan, there is a superstition of "Hinoe-Uma (Fire-Horse)". The superstition is that "girls born in the fire horse have a strong temperament and will kill their husband in the future." Thus, it seems that many couples avoided pregnancy and childbirth in 1966, the year of the fire horse.

1.2.3 - Ageing

In addition to declining fertility, ageing is another indicator that causes population decline. Population decline occurs due to the number of deaths exceeding that of births. Although the decrease in the number of births can be explained by a declining birth rate, it only explains one of the factors of depopulation. Another factor that may cause Japan to experience rapid population decline in the future is the significant increase in the number of deaths due to the increase in the number of the elderly people. The population of Japan began to age due to the decrease in the number of births and the increase in the life expectancy since the 1950s (Matsuno and Yoshida, 2008a). The percentage of population aged 65 years or over in the total population, which is one indicator of ageing, was only 4.9% in 1950, but exceeded 10% in 1985 and reached 27.3% in 2015.

Ageing in several developed Western countries has been in progress since the end of the 19th century, but Japan is the world's leading ageing country today as population ageing in Japan has advanced rapidly after WW2. According to the Population Projection for Japan: 2016-2065 conducted by the IPSS, the percentage of population aged 65 years or over in the total population will continue to rise in the future and will reach 33.3% in 2036. Even as the aged population declines from 2042 onwards, this percentage is on the rise, whereas the total population is decreasing. The percentage will reach 38.4% in 2065, which means Japan will be an ageing society, wherein 1 in about 2.6 Japanese nationals is an elderly person over 65 years old (Figure 1.3).

Figure 1.3 – Japan's Ageing Population (Unit: 10,000)



Sources: Annual Report on the Ageing Society (2017), Cabinet Office, Government of Japan.

In terms of region, most prefectures in non-metropolitan areas that experience continuous population decline already had an ageing rate of more than 25% in 2015. The ageing rate in 2015 is highest in Akita Prefecture (33.8%) and lowest in Okinawa Prefecture (19.6%). Ageing rate will rise in all prefectures in the future. The ageing rate in 2040 is expected to reach the highest in Akita Prefecture (43.8%) and the lowest in Okinawa Prefecture (30.3%). Considering the situation in three major metropolitan areas, the ageing rate in Chiba Prefecture increased by 10.6 points from 25.9% in 2015 to 36.5% in 2040 and rose 11.1 points in Kanagawa Prefecture from 23.9% to 35.0% during the same period (IPSS, 2015). Thus, Japan’s ageing population will exhibit nationwide increase, including metropolitan areas in the near future.

1.3 - How Changing Demographics Can Influence Social Development: A Concise Overview

Rapid depopulation, declining birth rate and ageing population cause problems in several aspects, such as the economy, local societal development, fiscal and social security system. As the results of depopulation, ageing and declining birth rate, the labour input of society can be directly reduced due the reduction of the working age population. Moreover, as the number of retired people increases due to population ageing, the savings of a country are reduced due to a larger age group withdrawing savings compared with the age group that saves. Thus, the supply side of the economy can be negatively affected by the reduction of labour input and the inhibition of capital stock accumulation. In addition, due to the increased proportion of the elderly population in the total population, there is a concern that the social security burden in pension, medical care and long term care would increase.

On the other hand, the changes in population size and structure have a direct impact on supply and demand of public infrastructure services in society. One example in Japan is: Although population ageing has been achieved mainly in non-metropolitan areas so far, it is forecast that ageing would progress rapidly in metropolitan areas in the near future. Thus, it is easy to expect that there would be changes in the demand for a function of cities in both metropolitan areas and non-metropolitan areas, as an increased number of elderly people would retire in metropolitan areas and some of them might return to non-metropolitan areas. Such demographic changes pose a challenge to the regional infrastructure planning and also put forward new requirements for the improvement of the regional pension systems.

In addition, in the towns and cities of non-metropolitan areas, the number of people responsible for community activities would continue to decline due to the falling birth rate and ageing of working population in coming years. Such changes in the population structure would lead to difficulties in securing personnel for medical care and long term care and it would also be difficult to provide the necessary services, which would be a serious obstacle to the preservation of the quality of the residents’ lives in these local communities. The situation in metropolitan areas is also not optimistic. For example, in Tokyo, where the remarkable in-migration has continued to exist, there are challenges, such as dealing with the relationship between the rapid increase of elderly people and lack of elderly care services. Moreover, the population concentration in Tokyo might lead to further declining birth rate in Japan due to the severe child care environment in Tokyo.

Scholars have conducted considerable research on the relationship of population change with the social security system, financial situation, industrial structure and the changes in consumption patterns in the context of Japanese society (Matsuno and Yoshida, 2008a; Ogawa and Kondo, 2005). However, the empirical studies that have analysed the interrelationships between demographic change and the development of public facilities are extremely scarce in the case of Japan. Therefore, this thesis attempts to address this academic gap.

1.4 - Why Infrastructure Matters?

The word "infrastructure" is a compound word consisting of "infra" meaning the lower part or the foundation and "structura" meaning structure and construction in Latin (Nakamura et al., 2017). In order to explain what infrastructure is, an approach is often used that divides what is supposed to be infrastructure into several subsets and defines these contents. To illustrate, it is known that definitions are divided into the following: personal infrastructure, material infrastructure, and institutional infrastructure. Material infrastructure refers to the so-called tangible things such as roads, water supply and sewerage; attributes, numbers and structures of the working population including education, qualifications, etc. that are included in human infrastructure; and codified rules and informal constraints, guarantee procedures, etc. that are classified as institutional infrastructure (Buhr, 2007). Material infrastructure is sometimes called technical infrastructure or physical infrastructure, to clarify contrast with personal infrastructure. In addition, technical infrastructure can be classified as point infrastructure / point - network infrastructure / network infrastructure (Buhr, 2007). In this study, discussions are made focusing on material infrastructure.

The research subjects of this study are selected according to the classification used by the Economic Council in 1967 for regional infrastructure stock estimates (Table 1.1). The idea that regards this as the scope of infrastructure is mainly focused on the functional aspect and on the public nature and the social nature of the service provided away from the business entity (Cabinet Office, 2007). Due to statistical constraints and data availability, in the following analysis chapters, this study selects three types of infrastructure within this scope for quantitative analysis. The types of infrastructure analysed in this study are elderly care facilities, primary schools and housing. These three types are selected because the pros and cons of these facilities in providing public services are directly related to the triple demographic challenge that Japan is facing: ageing, fertility decline, depopulation. The further details of these infrastructure are provided in the chapters on empirical analysis as different analysis methods are applied specifically to certain types of infrastructure.

Table 1.1 - Scope of Infrastructure Systems

Category	Examples
Education	Schools
Housing	Public housing, Dwellings
Life Support	Solid waste management, Urban parks, Hospitals, Social care facilities, Natural parks, Educational facilities
Public Utilities	Drinking water supply, Industrial water supply, Waste water management, Electricity supply, Gas supply, Heat supply
Transport	Railways, Underground systems, Light-rail transit, Ports, Airports, Buses
Road	Roads, streets
Disaster Management	Anti-flood afforestation, Coastal management, Flood control, Landslide prevention
Administrative Public Office Buildings	Administrative public office buildings

Sources: Cabinet Office (2007), Buhr (2007), Uemura (2014).

Before discussing infrastructure development in an era of depopulation, ageing and falling birth rate, this section outlines the present circumstances that surround the development of infrastructure in Japan. Japan's public infrastructure has been intensively developed with the aim of being at the same level as those of developed countries in Europe and the United States. Unlike in developed countries in Europe and the United States where development occurred over a long period, public infrastructure in Japan has progressed within a relatively short period of only 50 to 60 years since 1955. Public infrastructure was first intensively developed around 1955, which began during the recovery era after the end of WW2, until the 1970s, including the time when the Tokyo Olympic Games was held in 1964. During this period, residential and industrial roads, water and sewer pipes, water purification and sewage treatment plants, public rental houses, public schools, and other structures were developed in three major metropolitan areas, namely, Tokyo, Osaka and Nagoya, in response to rapid urbanisation. Plans to link the entire nation through highways were then established, even after the period of high economic growth. A nationwide comprehensive development plan was also implemented from 1980 to 1990, and public investment was increased as an economic measure in the 1990s. The Japanese government steadily increased the amount of investment until the 2000s and has expanded domestic network infrastructures, such as road networks. During this period, especially in the 1980s, public investment increased in local cities (The 21st Century Public Policy Institute, 2015).

The expansion of these public infrastructures aimed to cope with the increase in population and socio-economic development. After WW2, the total population of Japan continued to increase and exceeded 100 million for the first time in 1967. From 1945 to 1965, the total population increased from approximately 72 to 99 million or by approximately 38% (roughly 27 million people). In addition, total population increased by 22% (22 million people) from 1965 to 1985. Therefore, during this period, public infrastructure was positively upgraded and increased in terms of the total amount and scale, and the demand for public services also increased which absorbed the heightened public infrastructure supply. In addition, an infrastructure that has been rapidly improved can adapt to the demand of rapid increments in population and promises a comfortable city life commensurate with economic growth.

Since 2008, Japan has been facing a decline in population across the country, which is occurring alongside a deceleration in economic growth. The demand for receiving services from infrastructures that the government initially anticipated can no longer be anticipated (decrease in demand). In addition, on the one hand, as a result of such large amount of public investment, public infrastructure that was intensively developed during the 1980s and 1990s is presently obsolete and this trend is expected to continue in the future. The number of public infrastructure that needs to be updated is expected to reach a peak between the 2030s and 2040s (Table 1.2). Moreover, infrastructure development was carried out later in non-metropolitan areas than in three metropolitan areas. Thus, most infrastructures have yet to reach the end of their useful life. However, since the 1990s, a large number of public infrastructure projects were implemented as economic stimulus measures. Hence, even when the peak of the renewal period (around 2030) is exceeded, the renewal demand is expected to continue to occur in non-metropolitan areas.

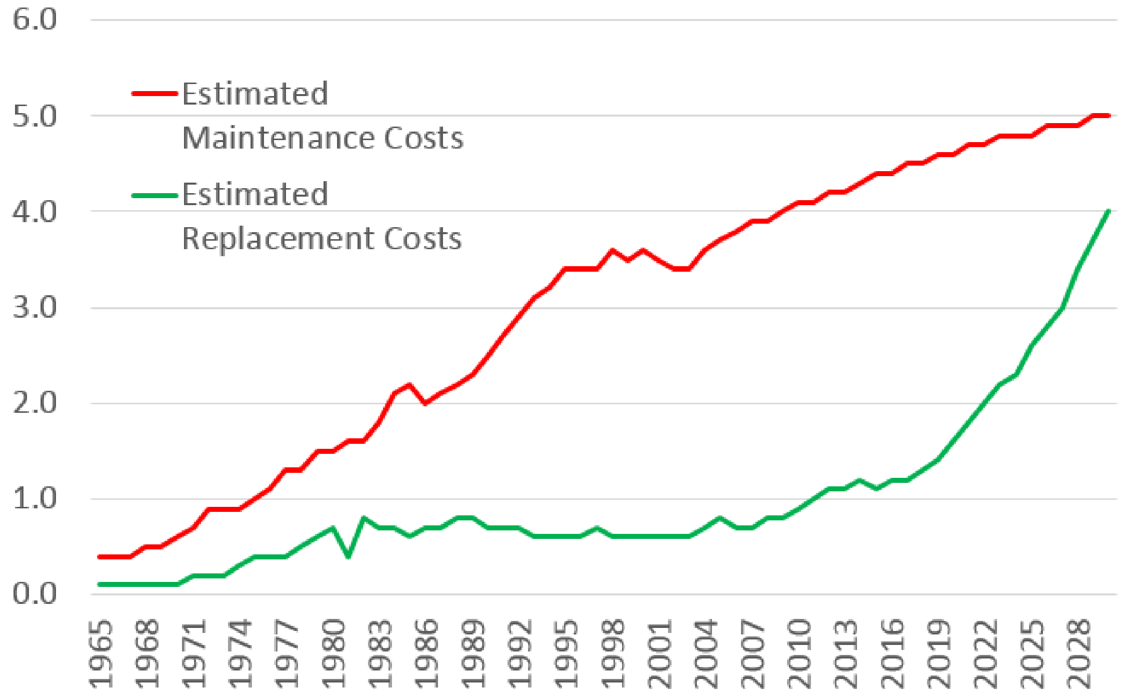
On the other hand, since the total population of Japan will decrease by approximately 20% over the next 30 years (IPSS 2015), if population density is diluted and the decreased population spreads in sprawled urban areas, then concentrating and renewing public infrastructure in line with population decline will be difficult. This situation will lead to inefficient regional management and investment on public infrastructure renewal will be dispersed and under-scaled financial difficulties. Hence, living convenience for citizens will suffer. Moreover, in an ageing society, mismatches between expected services and actual provided services may occur and increase. Furthermore, financial circumstances become weaker due to shrinking economy, and a decrease in the working age population can be expected due to the decline in fertility.

Table 1.2 - The Percentage of the Public Infrastructure That are 50 Years Old from Date of Construction in Japan

Type	Percentage		
	2009	2019	2029
Roads	8%	25%	51%
River Management Facility	11%	25%	51%
Wastewater Management Facility	3%	7%	22%
Quay Wall	5%	19%	48%

Sources: Ushijima, 2013, P41.

Figure 1.4 – The Estimated Maintenance and Replacement Costs of Public Infrastructure in Japan (Trillion JPY)



Sources: White Paper on Land, Infrastructure, Transport and Tourism in Japan (2006), Ministry of Land, Infrastructure, Transport and Tourism.

To address this concern, a number of local governments in Japan are working on revitalizing central urban areas, enhancing public transportation and restraining the expansion of urban areas. They are aiming to achieve the so-called compact city in the near future. The Japanese government also implemented policies in line with these directions, such as requesting all municipalities to prepare a comprehensive public infrastructure management plan, revising the Urban Revitalization Special Measures Law and establishing a site planning system (The 21st Century Public Policy Institute, 2015). Although local governments are committed to the realization of the compact city and the nation-wide renewal and update of infrastructure, most of them are still hovering on the crossroads of such reform since the specific means needed to achieve these goals are bound to differ between different areas due to differences in socio-economic and demographic conditions.

Infrastructure planning is influenced by various external factors, such as financial demand, investors' change of strategy for fund provision and changes in technology. The existence of these external factors complicates the discussion on the relationship between demographic change and infrastructure improvement. Therefore, besides the impact of population on infrastructure planning, the interrelationship between infrastructure development and other fields also warrants further discussion.

1.5 - Population Dynamics in Planning for Infrastructure

Infrastructure is a component of society, and an artificial system in which the quantity and quality of its services should be changed in line with the changes in the environment. Therefore, public infrastructure requires artificial management and resource input to sustain its improvement. Failure to take appropriate measures will usher a crisis similar to the infrastructure collapse that occurred in the United States during the 1960s (Choate and Walter, 1981)[3]. Also, if an infrastructure that is no longer used is neglected may adversely affect society in terms of landscape and security.

On the surface, the declining population seems to facilitate the reduction of ageing infrastructure and easing the burden of infrastructure management. However, the reality is not necessarily the case. The removal of infrastructure is impracticable. Once infrastructure is destroyed, it has to be artificially reconstructed if the possibility exists that a regional population will increase in the future, then infrastructure cannot be removed easily despite the current decline in the population. Therefore, even in an era of population decline, infrastructure planning needs to continue to respond to the local/regional population change.

1.6 - Contributions and Thesis Structure

Aware of the above-mentioned problem, this study focuses on the substantive impact of demographic change on infrastructure planning, and it proposes ideas and presents discussions on how to maintain infrastructure (including adjustments in number and scale) to adapt to regional sustainable development in the context of a shrinking population. One possible reason behind making appropriate infrastructure planning according to the regional population settings is to promote the regional development via obtaining positive gains brought on by population decline,

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[3] During the 1960s-1970s, the public facilities in the US are wearing out faster than they are being replaced due to the imbalanced capital investment (Choate and Walter, 1981).

thus receiving the 'depopulation dividend'; this refers to achieving harmonious and sustainable development of the population and society (Matanle, Sáez-Pérez, Li and Buehler, 2022).

While there is plenty of information about the linkage between infrastructure planning and population growth, there is a dearth of information on how depopulation affects infrastructure planning within a post-industrial society. In addition, the previous studies in this area has been limited in method and scope. This study is one of the empirical researches that investigates the impact of changes in demographic size and structure on infrastructure planning at regional level. Particularly, the analysis focuses on examining the impact of different aspects of population change on the planning of different types of infrastructure. Such research design makes the analysis process targeted, and based on the analysis results, it is helpful to make constructive suggestions for the planning of certain infrastructure in depopulated areas. This analysis could be timely given the large number of ageing infrastructure in Japan that need to be renovated in the near future. Therefore, this study is an objective, comprehensive, and time-sensitive scientific analysis of the population problems unique to Japanese society. Overall, this project not only contributes in the academic field to fill relevant gaps but also presents a positive social and practical significance.

A quantitative analysis of the impact of population decline on planning three diverse types of infrastructure facilities at different geographic scales has been performed in this study. Specifically, the impact of population changes on the accessibility of elderly care facilities in Sendai City, the accessibility of primary schools in Nagano City and the national housing demand in Japan has been analysed. This study selected three types of infrastructure facilities because they are closely related to three important aspects of Japan's population changes – ageing, declining birth rate and population decline. By conducting targeted analysis, this study strives to obtain more intuitive analysis results and discuss the impact of population decline on infrastructure planning.

The reason why this study chooses Sendai City and Nagano City as the research objects is that the population composition and socioeconomic background of the two cities are representative for certain facilities, and the analysis results can provide reference for other regions. The reason for limiting the analysis dimension at the city (regional) level is that elderly care services and primary education resources are geographically intensive public services, and a smaller analysis unit is conducive to obtaining more accurate results. The purpose of expanding the analysis dimension of housing demand to the whole country (national level) is to examine the macroscopic impact of population changes, and to conduct regional comparisons, thereby drawing richer conclusions.

To be more specific, the analysis in Chapter 6 and Chapter 7 of the study focuses on junior high school districts as the primary unit to analyse and assess the impact of population change on the accessibility of elderly care services and primary schools. These districts are not only used for commuting to junior high schools but are also considered a type of daily living area created by the government's urban policy (Nishino and Omori, 2014). Moreover, in Chapter 8, this study uses nationwide data and makes sub-regional comparisons to ascertain the impact of population change on housing demand. To summarise, by performing a quantitative analysis of different types of infrastructure facilities in different geographical areas, this study conducts a multi-dimensional and systematic investigation of the impact of population decline on infrastructure planning in Japan.

The thesis is structured as follows.

Chapter 1 introduces the aim, background and structure of this study.

Chapter 2 is a literature review summarising the main contents and findings of previous studies. This chapter identifies the gaps in the literature, considers how to address them and sketches out the logical progression of this study. The theoretical foundations of this study are also discussed. Chapter 3 describes the principles of the gravity model, two-step floating catchment area (2SFCA) method, mixed effects model, fixed effects model and random effects model. These are the main models applied in the quantitative analysis chapters in order to achieve accurate outcomes by obtaining the advantages of each data set.

Chapter 4 describes the data sets used for the empirical analysis and discusses their advantages and limitations. Then, the operationalisation of the main variables for the statistical analyses are provided.

Chapter 5 delineates the overall perspective and history of population change and infrastructure development in Japan. This chapter is designed to provide demographic evidence and basic policy knowledge for the empirical analysis in the subsequent chapters.

Chapter 6, 7 and 8 are the main chapters. Each chapter analyses the impact of population changes on the planning of different types of infrastructure from different perspectives by applying various models.

Chapter 6 explores the spatial fairness of the delivery of elderly care services through an accessibility analysis of Sendai City. The improved gravity model is applied to measure accessibility from demographic and spatial perspectives. Through visualizing the analysis results using ArcGIS, the model identifies areas with shortages of elderly care services.

Chapter 7 examines the spatial distribution characteristics and layout efficiency of primary education resources in Nagano City. The analysis adopts the 2SFCA method and the visualisation function of ArcGIS. By examining the accessibility value, the spatial distribution fairness and service area coverage efficiency of primary education resources at the sub-regional level are analysed quantitatively.

Chapter 8 analyses the impact of population change on housing demand across Japan. The differences in this impact are analysed with reference to the Kanto, Kinki and Chubu areas. The mixed model, fixed effects model and random effects model are applied in the analysis, and the impacts of various demographic variables on housing demand are determined.

Chapter 9 discusses the main findings of this study against the outcomes of previous studies to clarify the contributions to the knowledge. Suggestions for policies regarding infrastructure planning in the depopulated areas of Japan are subsequently discussed. Then, the chapter concludes by considering the extent to which the findings of this study are potentially applicable to other East Asian countries, such as China and South Korea, which are experiencing or are expected to experience similar demographic changes in the near future. Finally, the directions and areas for further research are identified.

CHAPTER 2

LITERATURE REVIEW

2.1 - Introduction

As discussed in Chapter 1, discussions on how to manage, operate and maintain infrastructure in a society with demographic shrinkage have been inadequate. The following review of the existing literature brings together some of the most relevant researches on infrastructure planning in the field of demographic change. The review also confirms the reason for conducting this research and shows its logical progression from an academic perspective. The demographic development in Japan is expected to include a decline in domestic population, disproportionate regional development of population densities and a change in the age pyramid. These demographic changes will be accompanied by a change in demand for public services. However, our knowledge of the theoretical links between population change and infrastructure planning in the case of Japan is still sketchy, partly because most academic studies in this field have been conducted in Western countries (for instance, the US and Germany). The relationship between demographic change and the improvement of public infrastructure has also undergone change within the context of demographic transition, which implies that some findings of previous studies are out of date. Therefore, further empirical evidence on these changing relationships is needed. Within this perspective, I conduct a literature review in this chapter to derive predictions for the empirical analysis in following chapters.

Section 2.2 broadly introduces the impact of population decline on the economy and society before discussing its impact on infrastructure planning. Sections 2.3 - 2.5 discuss research about the implications of population change on the improvement of public infrastructure from social, environmental and economic perspectives. Most related studies in the context of the Japanese society have focused on the relation between population decline and the social security system, the financial situation, the industrial structure, and changes in consumption patterns. Empirical studies that have analysed the interrelationship between demographic change and the development of social public infrastructure are extremely scarce in the case of Japan, the majority of previous studies mentioned in these sections are based on Western countries. After reviewing the impact of population change on facility planning, section 2.6 presents the theoretical rationale for constructing the models used in the analysis chapters. In addition to discussing why this study chose facility location theory and accessibility theory as its theoretical foundations, this section also illustrates how this study develops these theories in the analysis. Section 2.7 provides sound information about Japan's experience in infrastructure spending by discussing its rationality, mainly from a political perspective. Finally, Section 2.8 summarises the main arguments of previous studies and defines the academic gap in this topic. A discussion is also provided to put forward the related knowledge and literature (academic contribution).

2.2 - Depopulation Impacts

The impact of population decline on the economy and society is diverse. According to previous studies, the impact of depopulation can be found in areas such as macroeconomy, labour supply, fiscal deficit, regional development, savings rate, capital formation, consumption, investment, social security and infrastructure planning.

As known from demographic dividend theory, changes in the population structure are known to greatly impact the macroeconomy (Bloom et al. 2003). The macroeconomic impact is examined in terms of both supply and demand. On the demand side, population decline means a decline in consumers, negatively impacting the macroeconomy. However, the change in the population structure due to the declining birth rate and an ageing population has a mixed impact on the macroeconomy: a positive impact due to an increase in the demand for medical and welfare services for the elderly and a negative impact due to the overall decrease in demand due to ageing. On the supply side, however, optimism and pessimism are mixed regarding the impact of factors other than population, such as technological progress, capital accumulation and labour productivity improvement (Kyogoku and Takahashi, 2008). However, when focusing on the relationship between population size, growth rate and per capita economic growth, population growth has little effect on economic growth, and even if demographic structure, pension system reforms and technological progress rates are changed to some extent, it has been pointed out that the per capita economic growth rate and savings rate do not change as much as expected (Kaizuka et al. 2008).

Besides, a decrease in the working-age population directly impacts the labour supply (Kyogoku and Takahashi, 2008). In Japan, the working-age population is declining continuously as the population declines. Even if the retirement target of the working-age population is extended to 65, the working-age population in 2030 will be smaller than that in 2005. Moreover, since immigrants and foreign labour force cannot be expected excessively in Japan, measures in fields other than population are necessary, such as overseas transfer of production and improvement of labour productivity through technological innovation (Uto, Kitazume and Asami et al. 2013).

Moreover, the impact on public finances and social security has been pointed out as external factors related to macroeconomics. With regard to financial impact, a decrease in the population is expected to lead to a decrease in local tax revenues. Specifically, Kaneko (2006) confirmed the correlation between population changes and changes in prefectural tax, corporate enterprise tax, municipal tax and property tax from 2000 to 2003, and a strong correlation between tax revenue changes and population changes has been confirmed. Additionally, according to the Ministry of Internal Affairs and Communications' 2012 report, in the 2007 financial statements, considering that one-third of the local tax is the inhabitant tax, the local public finance is expected to be greatly affected by future population decline.

Regarding the impact on social security, population decline raises medical and long-term welfare care costs. Since 1970, medical expenses have increased as the population has aged. The long-term care insurance system that started in 2000 slowed the growth of medical insurance benefits, but the growth of welfare-related benefits is increasing (Kyogoku and Takahashi, 2008). Although these problems are mostly caused by ageing and not directly linked to depopulation, an impact on social security is inevitable when the population declines, since the associated costs have to be supported by a smaller working-age population.

About the impact on consumption, basic expenditure (food, utilities, water, rent, daily necessities, etc.) and selective expenditure (car, travel, eating out and education) are discussed separately. Basic expenditure is largely impacted due to changes in consumer size, which is directly linked to population decline, but the different outlooks on the impact on selective expenditure have been discussed (Kyogoku and Takahashi, 2008). As the population ages, which is the pre-stage of population decline, the elderly are generally expected to increase their consumption demand as they consume actively. However, at the same time, as the elderly mainly purchase services, it has been pointed out that such an increase in consumption may not lead to increased investment. Kyogoku and Takahashi (2008) argued that in general, as elderly people have less income, even with a high propensity to consume, the actual increase in their consumption is limited. Consequently, both consumption and investment are expected to stagnate under a declining population.

On the other hand, the impact of population decline on infrastructure planning is more complex. Previous research in this area has demonstrated that the impact may vary due to changes in the population size, the rate at which these changes are occurring, spatial distribution, composition, etc. Additionally, research has been done from the perspectives of the social, environmental, and economic impacts on regional development. These findings are discussed in detail in the following three sections.

2.3 - Social Perspectives

Previous studies have suggested that depopulation influences network infrastructure, such as roads, agricultural irrigation in Japan (Furuyama, 2007) and telecommunications in the United States (McKenzie, 1999). Matsuno and Yoshida (2008b), and Glock and Häussermann (2004), also argued that population decline affects the number of operational public housing, schools and healthcare facilities. Moreover, previous studies have focused on the decline in infrastructure usability (Uchida and Deguchi, 2006), the deterioration of safety (Tanbo, 2002), the increase in financial burden, the reduction in maintenance level (Schiller and Siedentop, 2006) and the rise in environmental burdens (Uemura, 2014), which result from population decline at the global or national level. Section 2.3 to section 2.5 systematically examine the various impacts of depopulation on infrastructure planning from social, environmental and economic perspectives. Sahely et al. (2005) proposed these three perspectives, which set a framework for the assessment of infrastructure systems under the sustainable development concept. This framework focuses on the key interaction between infrastructure and the surrounding social, environmental and economic systems over dynamic time and spatial horizons.

The social impact of population decline on infrastructure planning is reflected in reduced convenience and security. Various services and infrastructure people needed in their daily lives are built based on certain population size. The required population size varies, depending on the type of service and infrastructure. When a population decline occurs and the number of people needed to maintain services and infrastructure decreases, local governments may consider withdrawing these facilities. There is a risk of inconvenience in daily life, such as difficulty in obtaining public services required by local residents.

Regarding the decline in convenience, Chatterjee and Mahmood (2022) have conducted a study based on the rapidly growing demographic changes in Bangladesh's elderly population over the past decade and the social situation with suboptimal levels of public services due to resource constraints and poor management of public initiatives. The study explores the importance of ‘hard’ social infrastructure and ‘soft’ social infrastructure in improving the social well-being of older people. Using the WHO framework of an age-friendly built environment, the areas of current and future community public service needs and gaps in the supply of social infrastructure are identified, providing a basis for future equitable social services for older populations. Just (2004) and Buhr (2007) found that habitability disperses due to declining population, which in turn leads to decrease in traffic demand, profitability of transportation services, and the operation frequency. In addition, aggregation of shops and administrative facilities may lead to an increase in the trip length of movement than that before the population decline (Hummel and Lux, 2007). Puthukkulam, Gaur, and Vinod et al. (2022) use the Okamura–Hata model to calculate the coverage of mobile towers in the Jodhpur District by adding parameters such as population density, railway lines, road infrastructure, etc. The results show that the sharp increase in population density between 2010 and 2019 is the main cause of spectrum congestion. The analytical process of the study also confirmed the usability and reliability of the WebApp Builder module of ArcGIS in designing and developing future installations of mobile towers.

Buhr (2007) and Taira (2005) indicated that changes in population density requires modification of the street network – reduction in road capacity and addition of parking sites are cited as examples. Also, in order to save costs, roadside ban on dangerous zones and downgrading of road bridges to pedestrian overpass have already happened in rural areas in Japan (Matsuno and Yoshida, 2008a). Similarly, Uto, Kitazume and Asami et al. (2013) concluded that decommissioning of roads can reduce the total cost of maintenance by reducing the costs of resurfacing, replacement, and ploughing of the road surface. Demolition of roads may also lead to a reduction in related public service delivery, such as garbage collection and street cleaning. However, determining the roads to be decommissioned is difficult, since the reduced access for the remaining residents and business establishments may negatively impact property values. And the connections among a city's adjacent areas should also be retained. Clearly, identifying the locations and extent of the removal of roads is a challenging project (Hoornbeek and Schwarz, 2009).

Jibrin Isah (2021) uses population size and travel distance as the criteria for allocating social infrastructure and examines the efficiency of social infrastructure allocation in the Zuru region of Nigeria. The analysis focuses on public primary schools and primary health care facilities, using Euclidean and road network methods in ArcGIS to establish service areas for each facility to examine whether these facilities provide adequate services. The results show that the current distribution of facilities in the study area is unreasonable, which results in unequal access to public services in each region. The study also identified the areas with the poorest access to basic social services. Additionally, based on the results of the analysis, the study made recommendations for future public facility planning in the Zuru region.

On the other hand, Just (2004) found that due to the decrease in the number of students, traffic congestion on school roads has decreased. Moreover, the declining population of young people causes the abolition of school facilities (Roy and Matthew, 1995). It is also known that a decreasing population simultaneously causes ageing, but ageing will lead to an increase in medical needs and welfare agencies, resulting in a shortage of medical staff and health services (Buhr, 2007; Taira, 2005). Also, the need to expand public facility services – such as education, welfare facilities and nursery schools – will also increase to cope with the declining population (Mckenzie, 1999).

Faure (2020) discusses the impact of demographic change on the supply of housing and water sector infrastructure in urban environments in European and American countries. The research first examines the institutional responses of the housing and water sectors to the influx of displaced persons during the European refugee crisis in 2015 and 2016. The study then examines the impact of socioeconomic changes and population density changes on water supply. The results show that quantifying population movements and assessing population characteristics are critical for planning. In the context of the refugee crisis, making uninformed assumptions about the habits and needs of displaced people can lead to poor decision-making. And in cities like Washington, D.C., ignoring sociodemographic characteristics can hinder a utility's ability to provide adequate water service. The study confirms the impact of demographic factors on public facility planning and sheds light on the complexity of that impact.

Marumo (2020) uses a fixed-effects model to analyse the impact of population growth on infrastructure impact operations in the Bojanala Platinum District in South Africa. The study concludes that the population growth has negatively impacted the provision of infrastructure services. Additionally, population growth and other economic factors have had complex impacts on water services. Moreover, the rise in poverty has led to an increase in demand for electricity connection infrastructure. This shows that demographic changes will have different effects on the operation of different types of facilities.

Ouma, Macharia, and Okiro et al. (2021) use cost distance as an example to analyse regional differences in distance to the nearest primary health care facility, using Uganda as an example. In a sparsely distributed region with regard to population such as sub-Saharan Africa, where the paucity of resources is evident, the key to providing healthcare access is to decrease time or distance to facilities. The results showed that the proportion of the population within an hour of reaching medical facilities in 13 regions of the country ranged from 64.6% to 96.7% in the dry season and from 61.1% to 96.3% in the rainy season. Therefore, this analysis highlights the need for care in building models to accurately collect data and interpret results in the context of constraints.

Jiao and Azimian (2021) use a multinomial logit model to estimate the proportion of walking, driving, and bus trips to analyse the spatial accessibility of grocery stores in Travis County, Texas, to identify food desert areas. The results show that most areas have suboptimal accessibility, but some areas have improved their accessibility due to the presence of cars. The results of this study confirm the importance of using different analysis scales in the analysis, and the selection of indicators will have an impact on the analysis results. The indicators should be carefully selected according to the actual situation of the analysis area.

Suzanne, Mridula, and Ahmed et al. (2021) analyse regional differences in access to post-abortion care across Nigeria and Côte d'Ivoire. The analysis used data on women of reproductive age and geographic data on health facilities serving the areas in which they lived. The results show that poor, rural, and less educated women are at a disadvantage in receiving post-abortion care services, and there are significant inequalities in service delivery. The study concludes by suggesting that primary facilities should be increased to reduce avoidable abortion-related maternal morbidity and mortality. This study demonstrates that the relevance of the distribution of special populations to facility planning should be emphasized in future research.

The study by Khazi-Syed, Pecherskiy, and Krambeck (2022), conducted in the context of the Covid-19 pandemic, discusses methods for identifying areas in developing countries with difficult access to public healthcare through open-source data. The study created a computational framework by pooling population data from Facebook, temporal data from Mapbox, and road data from OpenStreetMap, in conjunction with the World Bank's open-source GOSTNets network routing tools. The computational framework was created to estimate the feasibility of medical facility access in two pilot regions in Indonesia and the Philippines. The results were confirmed to be consistent with the observed health trends in these countries, and the study proposes that this estimation method should be incorporated into future pandemic prevention and health visit planning.

Niedzielski (2021) explores how three typical accessibility metrics, closest facility, cumulative opportunity and space-time constrained, affect modal differences in the accessibility of grocery stores in Warsaw, Poland. The study found that each indicator has advantages and disadvantages for measuring accessibility when analysing the rates during off-peak hours and peak hours. In general, spatiotemporal metrics indicate that traffic accessibility is better than the nearest facility metric, which, in turn, indicates that traffic accessibility is better than cumulative opportunity. This study broadens the horizon of accessibility research and provides a reference for the selection of indicators.

In addition, the issue of vacant houses has been studied by numerous authors while discussing the impact of population decline on regional security. While the population is declining, the total number of homes is increasing, resulting in a consistent increase in the number of vacant homes in Japan. In particular, the number of vacant homes, including homes for which there are no plans to rent or sell and have no resident households for a long time, is increasing. Some of these vacant houses have undecided management and disposal policies and tend to be poorly managed, compared to vacant houses in other categories.

Besides, the number of vacant stores, factory sites, and abandoned cultivated land is increasing due to the shrinkage of local economic and industrial activities and the shortage of successors. As the number of vacant houses increases, disaster prevention issues such as deterioration of the local landscape and public security, collapse, and fire are potential hazards, leading to an erosion in the attractiveness of the area.

Regarding this security concerns, Matsuno and Yoshida (2008b) focused on the increase in vacant houses due to the declining population. They argued that in order to prevent illegal invasion and increase in maintenance costs, it is necessary to reduce the number of oversupplied houses and remove the attached underground infrastructure, the obsolete public facilities, such as primary schools and gymnasiums. Then, it may happen that the diversion of the school site or post-abolishment facility is not permitted, or the budget for building dismantling cannot be secured. Moreover, it may cause new problems, such as the delay in disposal of the site, and the management of diverted museums in deficit (Matsuno and Yoshida, 2008a, Taira, 2005).

Schiller and Siedentop (2006) has specified a definite correlation between decisions related to land use and infrastructure costs in cities with diminishing land areas. The study emphasised that urban density mainly defines the requirements for and costs of urban infrastructure and its operation. Generally, cost calculations for infrastructure assume that it will be maximised. However, such assumption is absent in cities with decreasing populations, where the minimal use of infrastructure and utilities leads to high per capita costs. The model of Schiller compares two scenarios. The first scenario comprises an enhanced sub-urbanisation and green field development. In particular, this case predominantly involves single-detached family houses and a dispersed pattern of demolition for vacant buildings in the urban core. The second scenario pertains to Schiller’s views as a sustainable use of building stock. That is, development is substantially balanced between a central city and its suburbs, high-density residential and infill developments are extensively emphasised and the demolition of vacant buildings is pursued in specific areas combined with the decommissioning of infrastructure. Schiller's results indicate the need for an active interdependence between regional and infrastructure planning for the development of efficient infrastructure networks, specifically in the population decline context (Hoornbeek and Schwarz, 2009).

Building-based and transportation facilities are generally abolished due to the declining population. For water supply and sewage systems, the abolishment of the branch may be considered, but the core part of the water supply and sewer network cannot be abolished easily (Hummel and Lux, 2007). In fact, although water demand has decreased due to the declining population, there have been cases where the length of water and sewage pipes has increased by 50% or more due to the sprawl that occurred simultaneously (Matsuno and Yoshida, 2008b). In addition, even if the population decreases, it is difficult to abolish the network because there is no reduction in peak water use volume, demand for drainage of rainwater, and water supply for the fire hydrants (Moss, 2008). However, significant population decline leads to the abolition of water purification plants. In Berlin, six plants in the water supply system and two in the sewage system were shut down after the integration (Moss 2003). Besides, the shrinkage of the service area is reported (Koziol, 2004). Furuyama (2007) argued that it is difficult to maintain drainage canals and reservoirs with a declining population.

From the above, we can see that it is generally difficult to adapt the network infrastructure (mainly energy supply facilities) to the declining population, compared to the building-based infrastructure (Schiller and Siedentop, 2006). Specifically, given the redundancy of infrastructure networks and the risks and costs of removing the existing facilities, abolishment works cannot necessarily be conducted even in the context of population decline (Hoornbeek and Schwarz, 2009). Moreover, the adjustment of the existing infrastructure in a rational manner necessitates changing the original values of revitalisation for matching economic growth.

2.4 - Environmental Perspective

Previous studies have also come to a complex conclusion regarding the environmental impact of population decline on infrastructure development. As population decline continues in Japan, environmental burdens such as greenhouse gas emissions and waste emissions associated with energy consumption are expected to decrease. However, it is also envisaged that the per capita environmental load in the household sector may increase due to lifestyle changes, an ageing population, and an increase in the number of households.

Previous studies examining the environmental impact of a declining population on infrastructure focus mainly on landscape, pollution, resource, and energy use. Jia, Tang, and Zhang et al. (2022)

examine the impact of urban population changes on the urban infrastructure planning. The study analyses the impact of five types of infrastructure, including roads, water supply pipes, drainage pipes, buses and schools, on landscape indicators in 78 large cities in China. The study found a super-linear quantitative relationship between infrastructure and urban landscape indicators. The study also pointed out that cities with more complex urban forms require more infrastructure investment in space. The study reiterates the need to incorporate ecological landscape indicators into urban planning.

Based on Urban Resilience Theory (URT) and Human-Nature Connection Theory (HNCT), Parker, Jackie and Simpson (2020) examine the mechanisms for harnessing urban green infrastructure to mitigate climate change and improve human health. The findings confirm that UGI and HNCT can be the basis for action to reduce the impact of these crises and that green infrastructure can be integrated with the theoretical foundation by promoting policy and planning frameworks and developing alternatives to fossil fuel energy sources. The study concludes by proposing the use of this concept in long-term planning for the period of global urban population growth expected by the end of the 21st century.

Taira (2005) indicated the complex impact of depopulation on the landscape. On the one hand, problems of hygiene occur with the reduction in land-use efficiency, because the removal of facilities leaves the idle and unattended land overrun by weeds. On the other hand, maintenance of the landscape can be achieved as the establishment of new facilities is reduced and renewal and redevelopment work are centralized. Thus, the alteration of the natural environment is reduced, and the greenness of the landscape is preserved.

Xinhai, Wang, and Tang (2021) examine the impact of transportation facilities on the utilization efficiency of urban land systems. The analysis explores the spatial spillover effects and threshold effects of transportation infrastructure on land use by constructing a spatial Durbin model using panel data from 30 regions in China from 2003 to 2018. The study found that transportation infrastructure has a significant positive spatial spillover effect on land use efficiency. However, the threshold effect shows a marginal effect on land use efficiency showing a downward trend with the improvement of transportation infrastructure. Those results provide theoretical support and inspiration for sustainable development of land use and transportation infrastructure construction.

Fisch (2022) examines the rationality of the Japanese government's ‘fortification’ of the northeast coast with a huge concrete seawall after the Great East Japan Earthquake in 2011. The final conclusion questioned the validity of such infrastructure planning by discussing the feasibility of integrating concrete seawalls and nature. The study argues that the plan encloses the population in a limited area and limits access to a better ecological environment there.

Wen, Albert, and Von Haaren (2020) use the 2SFCA method to estimate the area of urban green and blue infrastructure (UGBI) per capita in Hannover, Germany, and further analyse the accessibility of these facilities for the elderly. The study found that although levels of accessibility varied between communities, older adults were generally not disadvantaged in accessing UGBI resources. The findings provide policy recommendations to improve linkages between residential areas and UGBI.

Wang, Wang, and Liu (2021) examine the spatial accessibility of urban parks in Ipswich City (Australia) and Enschede City (Netherlands). The results show that the distance threshold and choice of transportation mode have a greater impact on accessibility than destination location. Moreover, road network-based analysis methods provide a more realistic measure of accessibility than other methods when distance thresholds and traffic patterns are held constant. The analysis also discusses the selection of the most appropriate accessibility metrics and the judgment methods used in different contexts. The results provide a reference for improving urban planning indicators. The selection of indicators in the analysis also has reference significance.

The study by Hereher (2020) is another study that confirms the effectiveness of geographic information system (GIS) for public facility planning. The study constructed the database by collecting the infrastructure variables, such as schools, hospitals, banks, mosques, gas stations, police centres, shopping malls, archaeological sites, vegetation, etc., from Oman's National Spatial Data Service. Then risk projections in the event of a disaster were made for the tropical cyclone-prone areas off the coast of Oman. The study found that the Al-Batinah coastal plain in northern Oman is the most tsunami-prone area due to its low elevation and high concentration of population, infrastructure, and services.

With respect to pollution, reduction of the pollutant load due to the reduction of air pollutant emissions, domestic wastewater, environmental burdens, such as extension of life at the final disposal site due to decreased amount of waste, has been found (Taira, 2005). Meanwhile, the same research observed that to ensure the efficiency of waste disposal, the consolidation and elimination of cleaning plants occur; the waste transport distance increases, and the problem of garbage export arises. In the case of water supply, if the number of households increases and the population density decreases, the total water demand increases. As the water retention time increases, in order to prevent contamination of water supply caused by water temperature rise and microbial increase, it is necessary to clean the pipe more than ever (Moss, 2008; Hummel and Lux 2007). In addition, since drawal from underground water decreases, the groundwater level rises, causing inundation in the underground part of the building (Moss, 2008). As for the sewage system, a decrease in water demand leads to sediments being generated in the pipe due to a decrease in the amount of water, which requires extra flushing for removal (Hummel and Lux 2007). Moss (2008) also pointed out that problems such as early deterioration of the pipeline, generation of offensive odor, and contamination of the groundwater and soil around the pipeline arise.

Regarding resource and energy use, depopulation brings a decrease in water, heat and electricity consumption (Moss, 2008; Hummel and Lux 2007). Yang and Faust (2022) analyse the impact of population changes on the water supply system. By observing the robustness of the water network structure, the study makes a comparative analysis of population decrease cities and population increase cities. The results confirm that population dynamics are closely related to node location changes in water network connectivity. Therefore, the study argues for the inclusion of population distribution, movement, and other factors in water infrastructure planning. Koziol (2004) found that since 1990, in cities of East Germany after the integration, water, sewerage, and heat use decreased by 25% to 30% due to population decrease, and a decline of 30% in the population reduced water consumption by 50%. Ewert and Prskawetz (2002) indicated that as the population spreading does not necessarily reduce traffic trips, it is premature to think that population decline will result in a reduction in resource use and solve ecological problems instantaneously. Also, from the relationship between land development and energy use, Ujihara, Taniguchi and Matsunaka (2007) conducted a comparative analysis of sprawling urban area and planned urban area, they found the former is more inefficient in the infrastructure network use; the environmental load for normal maintenance is also higher in the former area. However, the results showed that infrastructure removing activity in the sprawling urban area can obtain greater environmental load reduction effect in the process of urban withdrawal (Ujihara, Taniguchi and Matsunaka, 2007).

Some previous studies have pursued the effect of population size on energy use and CO_2 emissions. Dietz and Rosa (1997) conducted a multiple regression analysis on the 1989 data of 111 countries and determined that the impact of population increase on CO_2 emissions was nearly linear (the impacts of population are roughly proportional to its size) and substantially excessive for countries with large populations. Nordhaus and Yohe (1983) and Edmonds et al. (1986) indicated that population is a moderately insignificant basis of uncertainty in projecting CO_2 emissions. However, scrutinising the alternate expectations indicated that the low rank of population as an uncertainty factor is not the result of the insensitivity to population of the models. Instead, demographic momentum turns population into a substantially definite variable compared with other variables included in such models. Gaffin and O'Neill (1997) used the DICE model to analyse the ideal CO_2 emission levels. They assumed that the population adheres to the high, medium and low paths prescribed by the United Nations. Moreover, these researchers learned that the optimal emissions in 2150 will differ by a factor of over six across the aforementioned three scenarios. This projection will result in a scaling up and down with population change. Additionally, the changes in age structure (e.g. ageing) have direct consequences because the consumption of energy has a tendency to adjust over a lifespan (Yamasaki and Tominaga 1997). An ageing population also has an indirect effect on energy consumption because of the accompanying decrease in household size, which leads to a loss of economies of scale, particularly in terms of energy use at household level. (O'Neill and Chen 2002).

Interestingly, the environmental impact that depopulation has on infrastructure is that both improvement and exteriority are found in all three categories: landscape, pollution, resource and energy use. Simply, not only the fact that the population declines, but also the degree of population decline, the situation of dispersion of population and the history of development of infrastructure have a great influence on the occurrence of these environmental implications. Thus, in order to discuss the impact of a declining population on infrastructure in the environmental aspect, it is necessary to pay attention to population distribution (changes in population density) – in addition to population size – and to the location and scale of facilities.

2.5 - Economic Perspective

The economic influence that declining population has on infrastructure planning is as follows: (1) Various costs are incurred to maintain infrastructure, which causes increase or decrease in the overall cost; (2) Increase in per capita infrastructure-related burden as the total costs is borne by a small number of people; and (3) Assuming that the cost of operating public facilities remains constant, a decrease in population may lead to a reduction in the quality of public services, unless the per capita burden increases.

According to prior studies, local public finance is also affected by population decline. Local governments' tax revenues decline owing to not just the reducing population but also the ensuing slowdown in economic and industrial activities. Meanwhile, the challenges caused by rising social security costs caused by the aging population and local public finance management is likely to exacerbate. In the event this situation continues unabated, the possibility of administrative services being abolished or free services entailing a charge cannot be ruled out, thereby causing a decline in the convenience of living.

Lakhotia, Lam, and Chang et al. (2021) examine the relationship between road funding allocation and population distribution around major road facilities using publicly available data from the U.S. Census Bureau and the Florida Department of Transportation. The study found that areas with smaller population distributions were less likely to receive adequate funding allocations, and most highways were near residential areas with high incomes. The analysis provides a demographic reference for future highway budgeting and mapping and confirms the essential role of population factors in public facility planning.

Regarding the change in expenses, the decrease in traffic volume due to the declining population may reduce the road maintenance cost (Koziol, 2004). Lan, Gong, and Da et al. (2020) established a fixed-effects model by using data from 35 large and medium-sized cities in China to study the impact of population inflow and social infrastructure planning on urban vitality. The findings suggest that population inflows can affect urban vitality through interactions with social infrastructure. Specifically, the increase in inflows will have a positive effect on urban vitality through the increase in education fiscal expenditure and, at the same time, will lead to an increase in medical and health fiscal expenditure, thereby inhibiting the positive effect on urban vitality. The research has reference significance for investigating the influence mechanism of the population on urban development.

In addition, Roy and Matthew (1995) suggested that the maintenance costs can be reduced by consolidating the facilities due to population decline. On the other hand, some studies make the opposite claim. Regarding removal of building-based facilities after consolidation, maintenance costs increase from the viewpoint of maintaining security and accident prevention under severe financial circumstances (Matsuno and Yoshida, 2008a). The maintenance cost of infrastructure, assuming a large population, does not necessarily decrease even if the use decreases (Feser and Sweeney, 1999). The fiscal deficit expands due to the community bus operation as a substitute for the abolition of bus services by private businesses (Taira, 2005). Expansion of traffic service area brings increase in maintenance cost and time cost (Buhr, 2007; Hummel and Lux, 2007). The maintenance and management expenses of aged building-based infrastructure increases (Hoornbeek and Schwarz 2009; Taira 2005); not only the renewal costs but also the direct/indirect retirement costs rise when considering renewal (Just 2004).

With regard to the increase in per capita cost burden (fee), several studies have been conducted in the fields of transportation, water usage and education (Koziol, 2004; Just, 2004; Taira, 2005; Moss, 2008). In particular, Buhr (2007) indicated that part of the cost of network infrastructure will be passed on to the local governments and users within the reduction in building-based infrastructure. In addition, this per capita cost increase causes further reduction in the convenience of infrastructure, which may also lead to further population outflow (Taira, 2005). Besides, Mckenzie (1999) argued that in a declining rural community located in the Western Australia's central wheatbelt, after the railway was abolished due to the decrease in traffic volume, because of the declining population, the road traffic volume increased; as a result, the railway maintenance and management expenses, which the government had incurred in the railway era, have been turned to be paid by the municipalities and users.

In terms of the economic impact of demographic change on infrastructure, both positive and negative sides are present, as well as other aspects in total. When looking at the changes in per capita burden, before the population declined, most public infrastructure related costs were wide and thinly borne by the whole country. However, changes in the way of service supply may increase the burden on the local residents. Moreover, there is a high possibility that the burden per capita will inevitably increase, unless it is supposed to significantly reduce in the infrastructure services (Uemura, 2014).

2.6 - Theoretical Framework

The urban public facility location theory and accessibility theory provide effective research methods for studying spatial layout of public infrastructure facilities. These two theories construct the theoretical framework of quantitative analysis. This section will show how and why these theories are applicable for the analysis of the implications of depopulation on infrastructure planning.

2.6.1 - Urban Public Facility Location Theory

In 1968, Teitz proposed urban public facility location theory, outlining how to optimally lay out urban public facilities under the premise of efficiency and fairness. The study created a new field, location research, in geography. Teitz (1968) noticed the fundamental difference between the decision-making of public and private facilities, and incorporated the assumption of the balance model of public facilities location distribution in neoclassical welfare economics into a simple theoretical framework of standardization and quantification. The study reveals the potential value of incorporating political and economic variables into location theory. The goal of urban public facility location theory is to improve the rationality and scientificity of the allocation and layout of urban public infrastructure facilities, to maximise efficiency and fairness and to ensure the healthy development of society. Construction of public facilities is mainly oriented to the public service needs of residents. However, given the characteristics of being government-led and non-profitable, the layout and location of public facilities disagree with the application of traditional location selection theory. The concern and research on public facilities can be traced back to the 19th century. Public facility research mainly experienced the stages of classical location theory, modern location theory and contemporary location theory. Classical location theory advocates that the main objective of the public facilities site selection is to save freight and minimise costs. Thunen’s agricultural location theory and Weber’s industrial location theory are the most representative ones (Zhong, 2011). The modern location theory pays attention to the commerce and processing industry, aiming at maximizing profits. The field of contemporary location theory has been continuously expanding, from the traditional industrial layout to the location layout of public facilities and residential area, and pays attention to social benefits rather than simply focusing on saving costs and increasing profits.

Geography scholars use GIS to evaluate the balance of facility distribution from the perspective of spatial accessibility and adjust facility layout on this basis, with relatively satisfactory results. Spatial accessibility is one of the most effective tools to measure the rationality of the spatial allocation of public service resources. It is widely used to evaluate the layout of public facilities like emergency services, transportation, education, and medical care (Morrissey, Ballas, Clarke and Hynes, 2013; Murray and Wu, 2003; Talen, 2001; Guagliardo, 2009). Spatial accessibility methods mainly include least-cost distance model method, cumulative chance method, gravity model method, topology method, two-step floating catchment area method, and kernel density method (Radke and Mu, 2000; Müller, Tscharaktschiew and Haase K, 2008; Gibin, Longley and Atkinson, 2007). Among them, the gravity model method is one of the most widely used measurement methods. Its characteristic is to incorporate the service capacity of facilities, the population size of the demand side, and the spatial interaction between the supply and demand sides into a unified analysis framework based on the consideration of the transportation network and travel mode. As a method for evaluating the rationality of public facilities layout, Spatial accessibility analysis has the characteristics of simplicity and efficiency. In recent years, scholars have gradually incorporated non-spatial factors into the research of spatial accessibility, based on the characteristics of the demander (such as behavioural psychology) to evaluate the accessibility of facilities (Wang and Luo, 2005; Naess, 2006).

After 2010, the research and development of public facilities planning decision support system became an important direction for the comprehensive use of GIS and quantitative geographic methods to optimize public facility layout. Numerous studies have established an integrated planning decision support system in solving the optimal location problem by combining the data processing and map display functions of GIS with the spatial analysis capabilities of the location model so that the model calculation results can be expressed intuitively and clearly (Ortega, López and Monzón, 2012; Gharani, Stewart and Ryan, 2015). Simultaneously, depending on the needs, the system's visibility interactive module is used to control and adjust the model's objectives, constraints and parameters, allowing decision-makers to compare and select various schemes. Although public facility location research topics are diverse and have covered a wide range of facilities in recent years, they are inseparable from the mainstream of balanced spatial distribution. Scholars are trying to accurately evaluate facility distribution status from multiple angles and construct various location models to optimize facility layout to bridge the gap between research and practice. It should be noted that the rapid development of public facilities location research in recent years is closely related to the application of GIS, which enables the realization of various models and optimization methods.

This research discusses the development of appropriate infrastructure planning considering the declining population. Specifically, it analyses “what will change in infrastructure planning due to depopulation” and “how to deal with that change”. Under the premise of demographic shrinkage, the public facility location theory is indispensable for discussing what points need to be kept in mind when considering the service level of infrastructure. Because the traditional gravity model ignores the role of key factors such as population size and different facility scale levels (Song et al. 2010; Xiong et al. 2012; Yang et al, 2016), this research has improved the traditional gravity model by accounting for the influence of population size and level of elderly care facilities on the selection behaviour of the elderly. Moreover, most of the existing studies use counties (districts) as the research units and rarely select smaller areas as the research unit (Cheng et al, 2016; Pan et al, 2016; Ding and Chen, 2017; Tong and Chen, 2017). Selecting a smaller research unit can more effectively reflect the differences in the spatial accessibility of facilities in the area and accurately determine the basic unit that lacks services the most. Based on this consideration, this study chose residential areas as the research unit in Chapter 6 and 7, which increased the accuracy of the research results.

2.6.2 - Accessibility Theory

Research on the location of public facilities focuses on the rationality of spatial layout, whereas spatial accessibility is considered an effective means of planning the spatial layout of public facilities. In 1959, Hansen introduced accessibility for the first time, defining it as the opportunity for interaction between different nodes in a transportation network and applying it to evaluate the use of urban land resources. Since then, various disciplines, such as urban geography, urban planning, geographic information systems (GIS) and transportation geography, have paid attention to accessibility studies, and they have been widely used in fields, such as land use, transportation planning and site selection analysis of facilities.

Factors, such as time, distance, travel costs, etc. can hinder travel and reduce accessibility. Originally modelled on Newton's law of gravitation, the travel cost between the origin and destination was treated as a function of distance, later travel time was considered, and in some analyses, the effect of the monetary cost was directly taken into account (Cui and Levinson 2019; El-Geneidy et al. 2016). Subsequent research has often defined travel as a "derivative need," a process that people endure to achieve their desired goals. As a result, the perception and measurement of travel costs have also become systematic and diverse (Carrion and Levinson 2019; Lagune-Reutler et al. 2016). Different travel modes result in different costs, such as time and money. Several studies (Abou-Zeid et al. 2012; Chen et al. 2019; van Lierop and El-Geneidy 2018) found that people find it more pleasant to walk or cycle than to take crowded public transportation, saving money costs and increasing time costs.

In contrast to this, Hensher (2019) found that higher income groups tend to spend higher monetary costs in exchange for shorter travel times. Besides, the choice of each travel cost will also be restricted by objective conditions. Moya Gómez and García-Palomares (2015) argued that fluctuations in traffic conditions can cause differences in the shortest paths at different times of the day. Similarly, Farber et al. (2014) and Lei and Church (2010) indicated that transfer times are affected by the timetable of public transport. After continuous improvement of existing research, when applying accessibility theory for analysis, under the premise of specific assumptions, the construction of the model can be carried out in conjunction with the utility-based method and the location-based method to provide a combined specific model, which includes different travel costs to measure accessibility (Wu and Levinson 2020).

From above, we can see the role of accessibility in the field of spatial layout of public facilities becomes increasingly evident. For example, using GIS through spatial accessibility analysis to comprehensively consider factors, such as demand, supply and distance of public facilities resources, can improve the accuracy and effectiveness of spatial arrangement of public facility resources at a small scale. Therefore, when studying the rationality of space allocation and scale of public infrastructure, considering spatial accessibility has become one of the most effective methods.

Accessibility theory provides an effective way to assess the rationality of infrastructure facilities' location and size in each region. Moreover, within the context of accessibility theory, we can observe the rationality of infrastructure facilities' location and size change accompanied by the demographic change in each region.

The models building in Chapters 6 and 7 of this study referred to this idea. The specific application process is discussed in Chapter 3. The selection of variables in the model and the construction of the models are presented in detail in the analysis chapters.

2.7 - Criticism on Japan's Experience of Urban Planning and Infrastructure Investment

As discussed in sections 2.3-2.5, empirical studies regarding the interrelationship between demographic change and public infrastructure planning are extremely scarce concerning Japan. Therefore, this section provides a brief review of literature about Japan's experience of urban planning and infrastructure spending to provide background knowledge for the analysis in the following chapters.

2.7.1 - The Compact City Concept

Japan has been grappling with a declining birth rate, ageing and population. In 2016, the Act on Special Measures Concerning Urban Renaissance was partially revised, and a new urban planning framework named a site optimisation plan was introduced as an approach to sustainable urban planning. To reorganise the city into a compact form, specific areas, such as urban function induction areas and residential induction areas, were defined, and various functions, such as residence, medical welfare, commerce and public transportation, were guided there. Therefore, notification was required when conducting development activities beyond these two areas. Instead, locations in the two zones are eligible for various forms of tax and fiscal and financial support. Thus, the current urban policy largely involves transitioning to a policy known as a compact city. The background to this is the recognition that today's cities are "expanding too much" after the high-growth and bubble periods and that they are unsuitable for the declining population and birth rate and ageing population.

Different researchers have different definitions of compact cities. This research defines the following spatial elements, which Kaido (2007) described in reference to promoting a compact city:

1. High density;
2. Positioning bases in stages from the centre of the city (central city area) to the centre of the neighbourhood city where daily life amenities are provided;
3. Do not allow urban areas to expand in a disorderly manner;
4. Availability of familiar green space where a citizen can fulfil daily life needs without using a

car;
5. Ability to use open spaces and so on; and
6. Connecting cities with public transportation networks.

In 2015, the Ministry of Land, Infrastructure, Transport and Tourism announced its “Compact City Policy”, which positioned the accumulation of residential and urban functions as an effective policy that can improve convenience, revitalise central urban areas and reduce administrative costs. In addition, in the “National Grand Design 2050” announced in 2014, the Ministry of Land, Infrastructure, Transport and Tourism also proposed the “Compact Plus Network” as a forward-thinking approach for nation-building in 2050.

With reference to the impact of compact cities on residents’ lives, Kutsuzawa et al. (2022) examined the effects of the formation of a compact city on travel distance and duration for each mode of transportation within the city. The travel time for each means of transportation was used as the dependent variable, and the Normalized Standard Distance (NSD), an index of compact cities, was used as the explanatory variable. Consequently, it was shown that the more compact the city, the shorter the distance travelled by the city’s residents, the more opportunities for walking to match the travelled distance and the longer the walking duration. In addition, Taniguchi et al. (2006) highlighted that much time had to be dedicated to walking when travelling in low-rise residential areas with high population density. The researcher also indicated that the walking duration is low in residential areas with low population density. In other countries, Stevenson et al. (2016), considering six major cities (Melbourne, Boston, London, Copenhagen, Delhi and Sao Paulo) as examples, found that compact city forms promote public transport, walking and cycling, which, in turn, improves the health of residents. Baskan et al. (2017) performed a regression analysis of population density and living conditions from four perspectives (physical, psychological, social and environmental). The results from this research show that the three cities with significantly higher population densities have higher levels of life satisfaction.

These studies were analysed using the population density of whole cities or sub-regions as indicators. However, the movement of residents in the city often extends over the entire urban area for commuting, shopping and social activities, and the data on the population density of the city or small area fails to capture the movement distance. For example, even if the population density of the city appears high, if the distribution of population and commercial and other activity bases in the suburbs is sparse, then the distance from the suburbs to the destination is long, and the means of transportation are restricted. Therefore, it is necessary to use an index that combines “proximity” and “population density” based on the state of movement in the region. This study combines these indicators in the analysis. The specific research design is explained in detail in Chapter 3 and each quantitative analysis chapter.

2.7.2 - The Politics of Infrastructure Investment Allocation

Infrastructure is the underlying foundation that propels the growth of national and local economies and enhances citizens' quality of life. Moreover, inadequate infrastructure development hinders access to social services, widens regional disparities and obstructs social stability. Japan has continued to exist with its investment-type economy, particularly with the high weight of public fixed capital formation. In the process of post-war reconstruction, industries centred on the heavy chemical industry developed rapidly and basic infrastructure, like roads and harbours also developed as a basis for promoting economic activities of private enterprises[4]. Consequently, Japan achieved the second largest GDP in the world after a period of high economic growth. Compared to other developed countries, the proportion of Japan's public investment in GDP has been consistently high since the end of the WW2. For example, in the 1960s, the ratio of public capital formation to GDP was 6.6%, and this ratio experienced a sustained increase since then (Saito, 2006). In particular, public investment was invoked as a number of economic stimulus measures, between 1991 and 1995, public investment was increased at an annual rate of 7.6% following the bubble economy's collapse. Moreover, short-term public investment in 2009 increased by 15.6% compared to the previous year, as stimulus measures after the Lehman shock (Kamio, Inagaki and Kitazaki, 2011).

When comparing internationally, it can be pointed out that Japan's investment-type economy continues to be at a high level, with high investment-to-GDP ratio including private investment and rates almost the same as that in increasingly developing countries. Additionally, housing investment and private enterprise facilities are also nearly at the same level as the US at absolute levels, but public capital formation is more than double than that in the US at absolute level; its height is outstanding. Until the oil shock, Western European countries also had a relatively high ratio of public capital formation to GDP, higher than that in the United States, but then Western European countries declined thereafter; only Japan maintains high level among advanced countries (Saito, 2006). However, from a long-term perspective, unlike fiscal policy measures like social security and taxation, public investment is accumulated as stocks and it is thought that it contributes to production activity and economic welfare as social infrastructure.

In East Asia, infrastructure planning has promoted and sustained economic growth and rendered growth more inclusive. In this regard, infrastructure development has been safeguarded to support the construction of production networks and boost domestic demand. Infrastructure planning, such as roads and electricity, has also played an important role in poverty reduction (Shimizu 2016). Infrastructure development in East Asia has progressed steadily. Infrastructure levels differ from country to country, and even though some countries have reached world standards, there is still a

[4] In Japan, after the WW2, from the recognition that social infrastructure is deficient compared to other developed countries, starting with the new long-term economic plan in 1957 and the income doubling plan in 1960, the government started promoting expansion of public investment.

great need for improvement. Considering the relationship with GDP per capita, countries with lower incomes generally lag in infrastructure development. In particular, there is a significant difference between high-income and low-income countries in terms of transportation, such as electricity and roads. In terms of the overall infrastructure quality ranking, Japan ranks 7th with 6.2, South Korea ranks 20th with 5.6 and China ranks 51st with 4.5 in 2015, thereby suggesting considerable scope and opportunities for infrastructure development (UNESCAP, 2015).

In recent years, criticism of social infrastructure development in Japan has become stronger due to serious environmental problems, deteriorating financial conditions and bid rigging related to orders for public projects. Along with other such criticisms, it is argued that the effectiveness and rationality of infrastructure planning should be reconsidered. Iwamoto et al. (1996), Ibori and Doi (1998) and others analysed the optimal scale of Japanese social infrastructure stock from the social discount rate. Yoshino and Nakahigashi (2001) showed that in Japan, the marginal productivity of social infrastructure is larger in metropolitan areas than in rural areas, indicating that the social infrastructure of rural areas is excessive from the viewpoint of efficiency. Additionally, Yoshino and Nakahigashi (2000) analysed the marginal productivity by industry, arguing that the overall social infrastructure stock in Japan is excessive because the productivity is low in the primary industry. Also, as a time-series analysis, although it is impossible to compare simply because the estimation method and period differ, Iwamoto et al. (1996) and Mitsui et al. (1995) roughly estimated that the accumulation of social infrastructure stock in Japan was too small in the 1980s. On the other hand, Yoshino et al. (1999) evaluate the simultaneous period as excessive. Moreover, Asako et al. (1994) analysed the structure of social infrastructure, arguing that due to the distortion of inter-regional allocation, the current social infrastructure stock has a productivity loss of 3% against GDP in Japan. Further, according to Itaba and Saito (1999)—a previous study on the economic effect of social infrastructure stock—despite widely distributed production base and roads' investment in rural areas, the effect of investment cannot be seen as the growth rate in certain area is low. In particular, since the 1990s, public investment implemented in the context of economic measures focused mainly on road investment. As the demand for roads slowed down, such economic measures could not boost productivity in rural areas. Moreover, in addition to the ageing and declining population, there is concern that infrastructure developed during the period of rapid and stable growth will deteriorate and become excessive.

Regarding this, several criticisms are directed towards the effectiveness of infrastructure facilities in Japan from a political perspective. Since the late 20th century, many individuals in Japan have viewed certain public infrastructure projects as unnecessary. Recently, the connection between infrastructure construction and political activities has become noticeable among scholars (Woodhall, 1996; Tamada, 2006). Saito (2008) conducted an analysis of the relationship between infrastructure investment and regional political economy. According to Saito (2008), most public works in Japan are implemented in specific areas. On the one hand, locally elected parliamentarians or government officials (chiefs, legislator and bureaucrats) conduct different events or activities in their respective localities to attract public works. On the other hand, political chiefs and legislators are delegated to oversee the election in their respective districts. The policy on 'do not do wasteful public works and carry out projects as little as possible' may entice the 'support' of the public, but this approach will not gain enough 'votes' for the election. Regional promotion, mainly through public projects, may be the best measure to secure and obtain votes in Japan (Saito, 2008).

Strong demands for regional promotion are often initiated by operators (including concerned individuals) with businesses based in a certain region. Given their flexible time, these operators are more likely to engage in political activities than the regular workers. The votes of business operators and their stakeholders become 'fixed votes' and support the winning of a specific political party or legislator. However, some voters (mostly employers) do not commit to local political campaigns and instead support the overarching policy to improve the efficiency of public work projects. The votes of such individuals are called 'floating votes'. Floating votes are likely to change the sway of elections. From the standpoint of political parties and candidate members, relying on floating votes is risky, and thus, they may attempt to increase the probability of winning by relying on fixed votes. To ensure the delivery of fixed votes, electoral candidates tend to present measures for regional promotion to their constituencies. With the aim of capturing fixed votes, political parties prioritise enticing businesses, but without seeking ways to improve business efficiency in these regions. In this context, not only the political parties and legislators should be included in project planning, but also their constituencies (Saito, 2008).

Bureaucrats directly participate in the decision-making and implementation of public projects alongside political officers and legislators. Bureaucrats or local officers assisting in the public work projects may be assigned to monitor the work sites or oversee the project budgeting. Bureaucrats can also take charge in the practical affairs of implementing politically decided public projects. In these contexts, project implementation may be achieved with the least cost possible. However, bureaucrats tend to lack the incentive to pursue the abovementioned tasks. At the stage of project budgeting, a desirable scenario for bureaucrats in Japan is to allocate the largest amount possible to ministries and agencies. Consequently, the degree of social importance of self-administering ministries and agencies can be increased, the degree of contribution to the society can be strengthened and public–private convenience can be enhanced. Nonetheless, the setup of the government as the implementing body of public projects is an interesting case. That is, the efficient implementation of projects is highly unlikely among by government officials because their efforts, such as spending less than the allocated budget, are hardly compensated or incentivised. By contrast, in private enterprises, efforts to reduce costs equate to increase in profits, which then are rewarded in the form of salary increase and promotion. However, bureaucratic organisations do not have the incentive and reward system of private enterprises (Saito, 2008).

In summary, the political parties, parliamentarians and bureaucrats, who are the main parties of public works and lead the decision making and implementation of such projects, cannot be easily enticed with incentives (i.e. a consequence of optimal spending). Moreover, even if the parties themselves have aimed to become efficient implementers of public works by reforming their own awareness, winning in the elections is still not guaranteed. Moreover, the parties are unlikely to be promoted as executives, which means that they will still not be in the position to affect the final decisions and the implementation of public works. In such circumstances, it is futile to recommend that the above parties change their views about improving the efficiency of public projects in Japan. A fundamental strategy is to change the system, such that the parties are given incentives, thereby streamlining the project process. These reforms are fundamental, which implies that they cannot be realised in a short period. However, if the creation of such systems to bring forth efficiency ‘from the inside’ cannot be expected soon, then it is sensible that the reform on promoting efficiency will be derived ‘from the outside’. This scheme may not be the perfect choice for either side, but it seems realistic and fairly effective in building a system that can complement the agenda of both sides in terms of ensuring efficiency of public projects (Saito, 2008).

With regards to the abovementioned key points, several studies have been conducted on how legislators aiming for re-election and the administration party aiming to maintain political leadership can promote public policies and implement public projects. In the following discussion, with reference to the work of Persson and Tabelini (2000), I divide the existing research into two process-related topics, namely, pre-election politics (including the influence of election system and election competition) and post-election politics (including the influence of budget formation and agenda operation). Based on this division, I examine the type of divergence that exists between policy benefits (as discussed in political science or political economics papers) and realistic benefits generated by infrastructure completion. In cases wherein infrastructure investment becomes a topic of empirical research in political science, the allocation factors of investment as a consequence of ‘profit induction politics’ are often analysed.

A prevailing viewpoint is that ‘benefits concentrate locally and the cost burden is collected widely and thinly by all voters’; this argument, which is traditionally supported by public choice theory, suggests that incentives for elected legislators are generated by constituents who benefit from the public projects. Cox and McCabbins (1986) consider political party organisations as essentially ‘a cartel for the distribution of profits’, claiming that policy resources should be allocated with a strong basis. With regards to US politics, it has been reported that ‘the parliamentary ruling party is fighting the election favourably by profit induction and thus extending their votes’. According to Levitt and Snyder Jr. (1995), ‘more government spending, especially infrastructure investment, was heading towards areas with higher Democratic votes’. Both analyses on the US political affairs have considered government expenditure as a dependent variable; however, these studies did not assess the real effects of completed infrastructure projects.

In addition, some empirical analyses have focused on the political process after the election. In particular, ‘voting transactions in the legislature within the US Congress were known as log rolling’, in which ‘unanimity [is] customary in the passage of public work budget proposals’ (Stratmann, 1997). Weingast (1981) analysed the incentive problem from the perspective of expenses used by the government at different levels and internalised as benefits by specific constituencies. The findings suggest that if expenditures ultimately manifest as election results, then the cost–benefit calculation will be distorted, thus hindering the efficient supply of public goods.

Thus, “political benefits” in profit-inducing politics and economic benefits from actual infrastructure investment significantly differ. Firstly, most political science analyses are short-term settings in which one profit distribution corresponds to one election. However, such settings cannot capture the characteristics of social infrastructure improvement because of the long wait for plan announcements, construction and service. Secondly, benefits are implicitly assumed to be consumed immediately after allocation in almost all profit-inducing political analyses. However, economic benefits due to the existence of infrastructure are sustainable over long periods. For example, through the construction of productive infrastructure in an area, market access is expected to be easy, and the trade area is projected to expand. In addition, local residents benefit from expanding employment opportunities and wage increases. Therefore, a considerable productivity effect or asset effect in infrastructure investment equates to a great gap between policy benefits that are grasped as flows and policy benefits that are actually recognised by voters.

Thirdly, infrastructure investment is irreversible. The level of benefits of infrastructure investment is fixed midway, and the nature differs from subsidies and fiscal reinforcement measures that can adjust budget amounts for each fiscal year. Almost no action, such as intentionally destroying infrastructure once constructed, is involved. Investment in infrastructure means permanently supplying benefits as regional public goods to a given region. Fourthly, in the profit induction analysis, infrastructure investment tends to be defined as the allocation of private materials or the allocation of local public goods with extremely small externalities. In reality, however, physical infrastructure considerably influences the real economy, and the effect is nonexclusive within a given region. Although political incentives and governance issues about efficiently investing in infrastructure have been discussed, the emphasis of such discussions mainly lies on the aspects of private materials that accompany infrastructure construction. Specifically, the productivity effect and asset effect that are permanently generated as public goods due to social infrastructure formation have generally been ignored. The problems inherent in infrastructure investment are far more complicated than those discussed thus far. At any rate, the infrastructure construction in Japan can be considered as political public projects to a certain extent, as its planning is largely impacted by political activities. Therefore, the political perspective will be a big consideration in the analysis and conclusion of this study.

Scholars have also argued that Japan’s infrastructure investments are politically biased instead of being guided by an efficiency perspective. The relationship between public investment and politics has been widely researched from various perspectives across all geographies. Levitt and Snyder

(1995) and Ansolabehere and Snyder (2006) conducted representative studies that leveraged empirical analysis to clarify the effects of partisanship and the impact of the voting system on federal spending for local governments in the United States. Levitt and Snyder (1995) indicated the positive impact of democratic vote share on local federal spending (per capita), suggesting the importance of local partisanship. On the other hand, Ansolabehere and Snyder (2006) performed an empirical analysis of subsidies from state and local governments and found that local governments with a high voter turnout for the ruling party were given preferential treatment in subsidy distribution.

In Japan, Nagamine (2001), Tanabe and Goto (2005) and Saito (2010) analysed the distribution of public investment among regions and political factors. Nagamine (2001) used administrative investment data from 1993 to 1995, divided road investment directly under the control of the national government and road investment by prefectures and conducted a cross-sectional regression analysis that considered political factors. However, political factors such as the Liberal Democratic Party (LDP) vote share, the number of elections and the number of ministerial positions are insignificant. On the other hand, Tanabe and Goto (2005) conducted a regression analysis on the amount of investment in prefectural roads from 1998 to 2002 and found that the LDP vote share was significantly positive. The impact of political power on investment was also suggested. However, although this study applied a panel analysis, there is room for improvement as the sample period is extremely limited, and only the LDP vote share is used to indicate political power.

In addition, Saito (2010) suggested the possibility that subsidies have been used to induce profits, as transportation infrastructure investment devastates voters and is ineffective in channelling profits to support the needs of local communities. Doi and Ashiya (1997) showed that the share of national treasury disbursements by prefecture from the 1950s to the 1990s is positive for the share of ruling party members and negative for the ruling party vote share. These empirical results led to the conclusion that the prefectures with more ruling party members received more subsidies, whereas the prefectures in which competition with opposition parties was fiercer received more subsidies. Most studies on this subject suggest the influences of the ruling party and electoral system factors on the inter-regional allocation of public investment and subsidies. However, some studies, such as the one conducted by Hirano (2011), argued that the influence of individual politicians on the regional allocation of public investment is limited. Therefore, studies on the inter-regional allocation of public investment and political factors have not yielded consistent results in Japan.

The above criticisms on the effectiveness of public facilities in Japan can be understood as a mismatch between the supply and demand of public facilities. In other words, it can be understood that the scale and spatial allocation of public facilities are not reasonable enough; their allocation needs to consider the interaction of multiple factors simultaneously, including facility service scope, location conditions, transportation costs, service population size/structure, facility investment and facility accessibility. Numerous scholars have tried to find a theoretical optimal location by balancing a series of goals and determining the optimal layout of basic public service facilities in light of the actual situation. Using a two-step mobile search analysis method, Mitchel Langford (2014) studied a measure model of the impact of alternative population distribution on the accessibility of public services based on GIS accessibility analysis and an empirical study was conducted in the Cardiff area in southern Wales. Zografos et al. (2017) proposed a layered configuration model for basic public services based on a road traffic network system, satisfying multiple objectives and defined it as goal planning method. Bilal (2008) proposed a multi-objective spatial optimisation configuration model and conducted an empirical study with the location planning of the parking transfer facility in Columbus, Ohio as an example. The study found that three major issues must be addressed in the planning of parking and transfer facilities: coverage of as many potential users as possible, parking and transfer facilities should be built as close as possible to major roads and deployment of facilities in existing systems as much as possible. The above studies on the spatial allocation of public facilities will be an inspiration to the planning of future public facilities in Japan. For Japan, which has entered an era of population decline, reexamination of social resource allocation is required. It is strongly required to respond accurately to trends of economic and society change and create social infrastructure as a stock, which can support the whole country.

2.8 - Summary

As mentioned in chapter one, the main research question of this study is to critically analyse the outcome of the work of infrastructure planners in Japan, this section will shows the logical process of the formation of this research question by summarizing the limitations of previous studies discussed above. From sections 2.2-2.5, we can see that the demographic changes have complex impacts on infrastructure planning. However, in previous studies, treatment of population-related variables in infrastructure planning has been limited essentially to considerations of changes in demographic size only, despite the anticipated significant changes in other demographic factors in all regions in Japan, especially population density, having potentially important direct and indirect effects on infrastructure planning. The treatment of demographic size does not extend as well far beyond its use as a scale factor. Moreover, few existing researches have taken into account geographical factors in their discussion of the impact of demographic change on infrastructure improvement. In addition, in previous studies, the influence of demographic change on the improvement of several types of evident infrastructure in Japan have been addressed. However, most of these studies are discussed from a qualitative point of view, and there are very few studies using data for quantitative analysis. Furthermore, from section 2.5, we can see that several criticisms are directed towards the effectiveness of infrastructure in Japan, making it necessary to argue whether the infrastructure planner’s rationale for the infrastructure project is sufficient.

In the light of these findings, it is fair to say that research on the impact of demographic change on infrastructure is still in its early stage. Although there has been a burgeoning literature analysing the relationship between population change and infrastructure planning from various aspects, comparably less attention has been given to empirically uncovering the causal mechanisms that yield these relationships. Wider and more detailed research is necessary to discuss this topic comprehensively and draw more definitive conclusions. Therefore, future research should consider using more targeted analytical methods and obtaining more detailed data. Particularly, future studies have considerable room for improvement that could contribute to more flexible and credible scenarios of future infrastructure demand projection and planning, and a more complete understanding of historical patterns of infrastructure demand.

In this sense, this study focuses on the influence of changes in demographic size and structure on infrastructure demand and planning as well as on the importance of region-specific research. The current analysis will be performed using a substantially holistic and inter-temporal data set. Particularly, the objective is to investigate the magnitude of changes in demographic size and structure that substantially affect public infrastructures, as well as the types of infrastructure considerably affected by these demographic changes. Moreover, given the analyses by Matanle (2013) and Matanle (2011), there are only a limited number of studies investigating the impact of population decline on public infrastructure planning. These two studies demonstrate that public anti-disaster facilities are crucial in a country such as Japan, where natural disasters occur frequently. Since many anti-disaster facilities in Japan are located in shrinking regions, future research should focus on and discuss the impact of population changes on the planning of such infrastructure. Additionally, as discussed in section 2.5, future infrastructure planning in Japan must also pay attention to meeting the country's (1) topographical conditions, like high slope, long and complicated coastlines, (2) natural conditions including the presence of the four seasons, typhoon, with the possibility of earthquake, (3) demographic conditions including the population size and age structure, (4) historical and geographical conditions as a late developed country, surrounded by developing countries.

Furthermore, Matanle's (2013) conclusion also questions the rationality and guiding ideology of the sea wall planning conducted by the local government in response to the tsunami. As simply building a high sea wall cannot effectively prevent all natural disasters, other additional methods should be considered for longer-term planning of public infrastructure in depopulated areas. Building on the ideas introduced in these studies, this paper examines and discusses the rationality of planning for different types of facilities based on the analysis results. Future infrastructure planning must take into account Japan's various resources (human resources, technology, private capital, and national land resources) to proceed smoothly. Additionally, the planners must also recognise Japan's socio-economic and demographic conditions objectively and incorporate them more effectively. Hence, improvements to the development of credible projections of infrastructure demand and planning can be achieved through a better understanding of demographic determinants.

Matanle (2017) performed a qualitative analysis of the Sado Island in the Niigata Prefecture to illustrate the residents' responses to the shrinkage of the regional economy and decrease of population size. The findings indicate that the local residents and government are reassessing the priority of economic growth. They accept the inevitability of continued shrinkage and assess its relevance for their living conditions; instead of looking for re-establishment of economic growth, these societies seek opportunities to achieve regional stability and sustainable development under the conditions of population decline. This is an attempt to obtain the positive gains of depopulation, as the region places improving the quality of life ahead of its pursuit of economic re-growth. Relatedly, Matanle and Sáez Pérez (2019) noted that population decline may bring opportunities to obtain a depopulation dividend, that is, positive outcomes from peaceful and non-coercive depopulation that contribute to socio-cultural, political-economic and environmental sustainability. These findings offer new ways of thinking for how to manage the impact of population decline on society, while also providing a reference for the analysis of this study. In the subsequent analysis, this study demonstrates the reliability of this claim and discusses the possibility of obtaining depopulation dividends through infrastructure planning by using Japan as an example.

This study conducts a comprehensive analysis of impacts of depopulation on different types of infrastructure. Such analysis provides a conceptualization of causal mechanism dimensions between population change and infrastructure planning. The outcomes provide updated empirical studies related to such causal mechanisms, assess the state of the relationship between population change and infrastructure planning and offer several provisional conclusions about operating mechanisms. The findings draw empirical evidence and provide references for future public policy response to infrastructure planning.

The current research also has advantages in improvement of research methods. This research is among the few existing empirical studies that investigate the impact of population change on infrastructure planning and improvement. Prior studies in this area are limited in method (e.g. most research have been qualitative) and scope (e.g. case studies conducted in a single area focusing on a single type of infrastructure). By contrast, the current research uses an empirical approach and performs a comprehensive analysis of the subject while considering most types of infrastructure in Japan at the regional level.. This study would be valuable for several reasons. First, it would clarify the outlook for the potential range of projected social, environmental and economic consequences of changes in infrastructure scale and number. Second, it would provide a reference for better reasonable estimates of future maintenance and operating costs of infrastructure. Third, understanding infrastructure demand across different demographic groups can help in the assessment of potential distributional effects of service improvement efforts. Finally, I am optimistic that the outcomes of this Japan-based study will be particularly informative when analysing similar situations in other countries, such as China and South Korea, as they follow their respective paths through similar patterns of demographic changes.

CHAPTER 3

METHODOLOGY

3.1 - Introduction

Chapters 1 and 2 clarified the background and purpose of this study. This chapter is designed to present the methodologies applied in the analysis chapters and show how these methods are used to assess the appropriateness of infrastructure planning. This study uses an improved gravity model, two-step floating catchment area method, and fixed effects / random effects to examine the appropriateness of planning for elderly care facilities, primary schools and housing supply.

This chapter consists of the following sections: Section 3.2 shows how urban public facility location theory and accessibility theory discussed in Chapter 2 fit into the current research design. Sections 3.3–3.5 introduce different methods to study the spatial accessibility of various types of infrastructure facilities and discuss how this study develops these models. Section 3.3 highlights that the strength of the gravity model used in this study lies in its use of geographical methods for data observation and model comparison for accessibility analysis and logical reasoning. Section 3.4 discusses the strengths and weaknesses of the two-step floating catchment area method. Finally, Section 3.5 evaluates the usefulness of the mixed models, fixed effects, and random effects models to analyse the impact of population change on housing demand across Japan.

3.2 - Application of Theoretical Foundations

3.2.1 - Classification of Accessibility in spatial analysis

Accessibility varies according to different classification criteria. Broad accessibility includes five aspects, namely admissibility, availability, acceptability, accommodability and affordability (Roy and William, 1981). Admissibility and availability primarily reflect spatial information, referred to as spatial accessibility. Acceptability, accommodability and affordability are referred to as non-spatial accessibility. On different spatial scales, the specific objects measured by accessibility are different. In the regional context, accessibility reflects the difficulty of spatial interaction between regions, mainly measuring the spatial difference of regional economic development (Mackiewicz and Ratajczak, 1996). Within a city, accessibility is mainly used to measure the depth and breadth of geographic relationships between urban residents and social economic activities. The accessibility within the city is divided into individual accessibility and location accessibility. The former refers to the difficulty of reaching the destination under the constraints of time and space, reflecting the quality of life of the residents. The latter refers to the approachable ability of a location (Kwan, Murray, and O'kelly, 2003). This study explores spatial accessibility of public infrastructure. Therefore, the analysis of accessibility in this study mainly focuses on the spatial accessibility within a city. The specific classification is shown in Table 3.1.

Table 3.1 – Classification of Accessibility

Accessibility							
Regional Context	Within City		Spatial Accessibility		Non-spatial Accessibility		
Regional Accessibility	Individual Accessibility	Location Accessibility	Admissibility	Availability	Acceptability	Accommodability	Affordability

Sources: Kwan, Murray, and O'kelly (2003), Mackiewicz and Ratajczak (1996), Roy and William (1981)

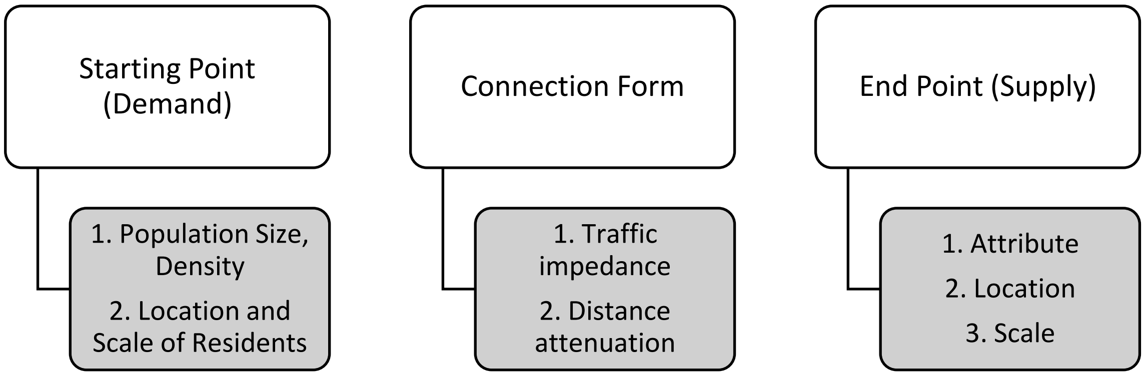
The spatial accessibility of public infrastructure refers to the ease with, which urban residents access facilities and services through vehicles and roads, and the interrelationship between residents and public infrastructure facilities. It reflects whether the accessibility of groups in different regions to certain public services in a particular area is fair, thereby, identifying areas that should be of concern if they lack accessibility to such facilities.

In other words, the concept of spatial accessibility of public infrastructure facilities can be understood from three perspectives: (1) From the perspective of space barrier: the accessibility of public service facilities refers to the cost incurred by the residents when they arrive at the facility to obtain services; (2) From the perspective of opportunity: the spatial accessibility of public service facilities refers to the number of opportunities for residents to get medical treatment, shopping, schooling, recreation and so on within a certain range of travel. The greater the number of opportunities available, the higher the spatial accessibility of urban public infrastructure facilities in the area; (3) From the perspective of spatial interaction: the spatial accessibility of public infrastructure facilities refers to the mutual influence or potential of residents and public infrastructure facilities. The greater the interaction, the better the spatial accessibility of urban infrastructure facilities.

3.2.2 - Spatial Accessibility Analysis of Public Infrastructure Facilities

Studying the spatial accessibility of public infrastructure facilities is inseparable from the starting point and the end point, and the form of connection that maintains the starting point and the ending point. Together, they constitute the three most important elements that affect spatial accessibility (Joseph and Phillips, 1984; Tong and Chen, 2017), as shown in Figure 3.1.

Figure 3.1 – Key Elements



Sources: Joseph and Phillips, 1984; Tong and Chen, 2017.

When studying the spatial accessibility of public infrastructure facilities, the starting point refers to the demander of public service – residents, and the end point refers to various types of public infrastructure facilities that meet the needs of residents. The connection form is the transportation system between the residents and facilities. When studying the implication of demographic change on spatial accessibility of public infrastructure facilities, this study provides the analysis of the three elements of spatial accessibility.

When urban residents choose public infrastructure facilities to obtain public services, they are mainly affected by the location, scale and population size of the residential areas. For example, the impact of location of residents and population size on spatial accessibility are obvious. When the residential area is located in a place with complete transportation and various other facilities, the number of places the residents can reach in a certain period of time is large, greater opportunities to obtain services are insured, which indicates that the space accessibility is good. When the population size of a certain area is relatively large, it leads to insufficient supply of public service facilities near the residential area, which makes the residents opt for services in farther areas, which increases their travel costs.

The spatial distribution and attributes of various public infrastructure facilities (such as office, school, business, entertainment, etc.), their attractiveness and scale, all affect the level of accessibility of such facilities. For example, in a particular area, if the educational facilities are evenly distributed, each student's educational accessibility level is equal. Conversely, if all educational facilities are concentrated in a small area, the closer the residents are to the area, the higher the level of spatial accessibility. Moreover, when there are two hospitals that have similar distance to settlements, residents will often choose large-scale hospitals with high service levels. That is to say, the larger the scale of the facilities, the greater the attraction of public infrastructure facilities to residents.

The transportation system reflects the convenience from the starting point to the end point, affecting the travel time and cost incurred by the residents. The construction of transportation infrastructure has created conditions for residents’ travel. With the improvement of the construction level of transportation facilities, the travel time for residents to obtain public services has been greatly reduced, and such spatial accessibility has been continuously improved. Traffic impedance and distance attenuation are two key factors, which lead to impact of traffic systems on spatial accessibility.

The traffic impedance is reflected in the difficulty level from the start point to the end point. According to different research situations, it is mainly represented by the following variables: time (time spent on travel), distance (travel distance), cost (travel cost), comfort, etc. The choice of urban road grade, road speed limitation and the method of travel of residents will affect the traffic impedance. Therefore, it is necessary to comprehensively consider these three factors when calculating traffic impedance of residents. The effect of distance attenuation on spatial accessibility is manifested with the increase in the distance travelled by urban residents, the interaction between the starting point and the target point is weakened. The distance attenuation function is another key factor in spatial accessibility assessment.

The measure of spatial accessibility is the most commonly used method for geographic analysis to study whether the spatial distribution of public service facilities is reasonable. Accessibility represents the ease with which one point reaches another point, and spatial accessibility focuses on the spatial attributes of accessibility. Spatial access to public infrastructure can be understood as the ease with which people can access public facilities and gain public services by means of vehicles and roads. Public infrastructure accessibility considerations are relatively comprehensive and can more accurately reflect the actual situation of residents' access to social service resources. Western scholars often regard equal spatial accessibility as the primary goal of public facilities' spatial layout (Zhong, 2011).

At present, various methods are still used to understand spatial accessibility, one of which is the number of services, activities or resources that can be obtained from a location. These numbers reflect the closeness of groups in different regions to a particular social service facility and reflect the fairness of spatial layout of social services. Through spatial accessibility analysis, spatial layout of social service facilities is inspected, and areas that lack corresponding social service facilities are identified to improve overall societal fairness. Scholars have applied spatial accessibility assessment methods to study the spatial distribution of various types of public service facilities. As different public facilities feature their own characteristics and attributes, accessibility assessment methods are used to analyse different types of public facilities by applying different measurement methods. According to the characteristics of public facilities, this study selects the gravity model based on the spatial interaction method, two-step floating catchment area method and the proportional method to analyse different types of facilities. These methods will be introduced as follows.

3.3 - Gravity Model

The measurement method based on the gravity model is widely used in the measurement of the accessibility of public facilities. The existing researches that apply gravity model analysis have comprehensively considered factors such as residents' demand, space barriers (time and distance), and infrastructure service capability (Porta, Latora, Wang, et al, 2012). However, the consideration of the impact of different levels (scales) of public infrastructure on the usage choice behaviour of residents is relatively lacking. After summarizing the concept of the gravity model and its application in infrastructure spatial accessibility measurement, this study introduces the 'public facility level scale influence coefficient' to modify and improve the gravity model formula and uses Japan as an example to explore how it will be improved and applied to analyse the spatial accessibility of public infrastructure and the judgment of underserved areas in the Japanese context.

The gravity model is examined in regional economics and geography to learn the principle of universal gravitation and study the interaction between social and economic space; it is one of the classic models of spatial interaction. French scholar, Joseph-Louis Lagrange first proposed the concept of universal gravitational potential based on Newton's mechanics and energy. Later, some scholars (Weibull, 1976; Gharani et al, 2015; Wu et al, 2017) introduced this concept into geography and gradually developed the gravity model.

The potential indicates the energy produced from one object to another. For example, the energy 'A_{ij}' produced by 'j' for 'i'' is 'M_j / D_{ij}', where 'M_j' represents the scale of activity of point 'j' and 'D_{ij}' represents the travel impedance factor between points 'i' and 'j' (distance or time). When 'A_i' is used to represent the sum of potentials generated by 'n', discretely distributed objects in the system for point i, and 'β' is the coefficient of travel friction, the general formula of the gravity model can be expressed as:

$$\boldsymbol{A_i = \sum_{j=1}^{n} A_{ij} = \sum_{j=1}^{n} \frac{M_j}{D_{ij}^{\beta}}} \tag{3.1}$$

The gravity model is widely used to compare the size of regional attractiveness or land use and traffic conditions within the city, and to analyse the advantages and disadvantages of comparative economic development. In 1959, Hansen proposed the gravity model as a measure of accessibility, and since then scholars have gradually applied it to measure the spatial accessibility of various public infrastructure facilities. When using the gravity model to measure the spatial accessibility 'A_i' of a residential area 'i', to all relevant facilities in the study area, 'M_j' represents the service capacity of the public facility 'j', and 'A_i' is actually the cumulative value of attraction of various public facilities in the study area to the residential area 'i'. As the travel impedance 'D_{ij}' increases, 'A_i' will decrease accordingly. The larger the 'A_i' value, the better the spatial accessibility.

The general formula of the gravity model considers the utility service capacity and the distance factor but does not consider the competition for limited resources formed by different residents sharing the same public facilities. Therefore, the following biased results are obtained by applying the general gravity model: If the service capacity of two facilities are equal, even if the size of the service population of these two facilities differs greatly, the spatial accessibility of the two facilities is the same under the same travel impedance, but it is obvious that these two facilities do not actually have the same spatial accessibility. In order to solve this problem, Joseph and Bantock (1982), added a population size impact factor 'V_j' to the general formula of the gravity model. When using 'P_k' to represent the population of settlement 'k', the improved formula is expressed as follows:

$$\boldsymbol{A_i = \sum_{j=1}^{n} A_{ij} = \sum_{j=1}^{n} \frac{M_j}{D_{ij}^{\beta} V_j}, \text{ and } V_j = \sum_{k=1}^{m} \frac{P_k}{D_{kj}^{\beta}}} \tag{3.2}$$

Although formula (3.2) considers the competition of residents for limited public service resources, it ignores the influence of different scales of public infrastructure facilities on residents' usage choice behaviour. Different levels/scales of public infrastructure in real life have different levels of attraction for residents. For example, high-level medical facilities are large in scale and strong in technical strength, which can often attract residents who are far away, especially when they face intractable diseases; while low-level medical facilities are small in scale and relatively weak in technical strength, and usually only provide emergency services to nearby residents or address minor illnesses and are thus unable to attract residents who are far away.

The impact of scale of public facilities on usage choice behaviour of residents is reflected in the travel time limit (distance) in this study, for example, the location of public facilities from settlement points exceeding X km in distance and X minutes in travel time, is considered as no longer used by residents. Accordingly, we can use 'D_j' to represent the travel time limit (distance) of public facilities, 'j'. Public facilities of different levels have different values of 'D_j', and the higher the level of public facilities, the larger the value of 'D_j'.

For the same public facility 'j', it is obvious that the smaller the distance 'D_{ij}' between the residential area 'i' and the facility 'j', the smaller the influence of distance on residents' usage choice behaviour. The closer the values of 'D_{ij}' and 'D_j', the greater this influence. When the value of 'D_{ij}' goes beyond 'D_j', it is concluded that residents no longer choose to use such facilities. In this study, the influence factor 'S_{ij}' is used to express the influence of public facilities 'j' on the utilization behaviour of residential area 'i'. The improved formula is expressed as follows:

$$A_i = \sum_{j=1}^{n} A_{ij} = \sum_{j=1}^{n} \frac{S_{ij}M_j}{D_{ij}^{\beta}V_j}, \text{ and } V_j = \sum_{k=1}^{m} \frac{S_{kj}P_k}{D_{kj}^{\beta}}, \; S_{ij} = 1 - (\frac{D_{ij}}{D_j})^{\beta}$$

(3.3)

In formula (3.3), 'A_i' represents the spatial accessibility of the residential area 'i' to all accessible public facilities; 'M_j' represents the service capacity of the public facility; 'j' can be the number of beds, the number of health technicians (teachers), etc.; 'P_k' represents the population of the settlement 'k'; 'V_j' represents the population size impact factor; 'D_{ij}' represents the travel impedance factor (time or distance) between the residential area 'i' and the public facility 'j'; 'S_{ij}' is a level/scale influence coefficient that represents the influence of the public facility 'j' of different levels/scales on the utilization behaviour of residential area 'i'; 'D_j' represents the travel time limit (distance), as discussed above, public facilities of different levels/scales can set a different value of 'D_j'; 'β' represents the travel friction coefficient; and 'n' and 'm' represent the number of public facilities and settlements, respectively.

For formula (3), if 'D_{ij}' ≥ 'D_j', then there the corresponding $S_{ij} \leq 0$, which means that the travel time limit (distance) is exceeded. In that case, the specific public facility is not attractive to residents. In the calculation, all negative values of 'S_{ij}' will be set to 0. It is not difficult to find that formula (3) is actually a model of the total amount of public facilities' resources available to residents at all levels/scales. It takes into account the service capacity of public facilities, the population size of settlements, the relationship between public facilities and settlements, the travel impedance and the impact of different scales of public facilities on residents' utilization behaviour. Compared with the traditional gravity model, this improved model can better reflect the actual situation. It should measure the ability of each person to have access to public facilities, which includes the number of beds per person and/or the number of medical technicians (teachers) per person.

Along this line, the improved gravity model can be also applied for analysis of accessibility of schools by further adjustment of the formula. The traditional gravity model ignores the problem of school district governance by urban residents. In evaluating the spatial accessibility of basic education facilities, the analysis need to consider the actual situation of how urban residents select schools. Under normal circumstances, most students will go to designated schools according to district, and few students will choose to attend prestigious schools in Japan. This study will improve gravity models by considering the district space governance. The improved formula is as follows:

$$A_i = \sum_{a}^{1} \frac{M_j}{D_{ij}^{\beta}V_j}, \text{ and } V_j = \sum_{b}^{1} \frac{P_k}{D_{kj}^{\beta}},$$

$$1 \leq a \leq n, \; 1 \leq b \leq m$$

(3.4)

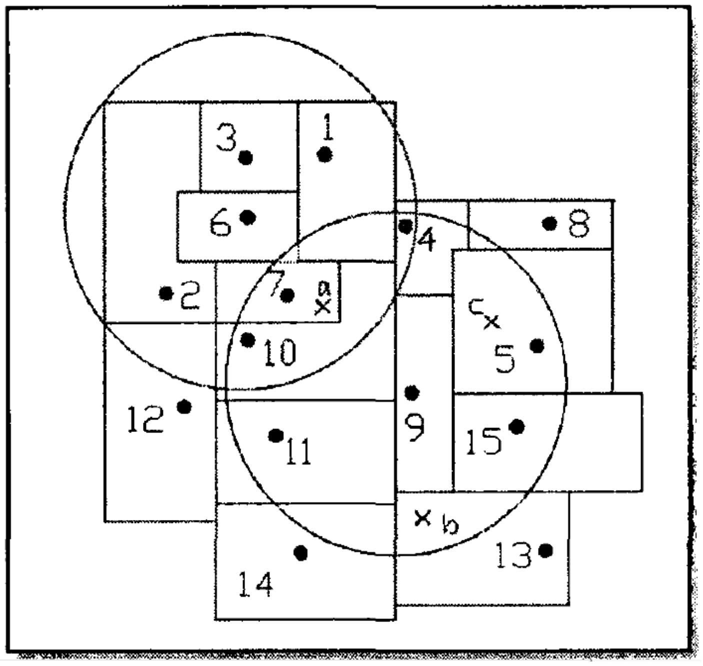
In formula (3.4), 'M_j' represents the service capacity of the school; 'j' can be the number of teachers, etc.; 'P_k' represents the population of the settlement 'k'; 'V_j' represents the population size impact factor; 'D_{ij}' represents the travel impedance factor (time or distance) between the residential area 'i' and the school 'j'; 'β' represents the travel friction coefficient; and 'a' and 'b' represent the number of schools and settlements, respectively.

When a=1, the space management of the school district is considered, and students have no inter-regional school selection behaviour. When a=n, b=m, the school district lacks space management, and students are not restricted in their school selection. When 1<a<n, 1<b<m, both the space governance of the school district and cross-regional school selection are considered. In summary, the gravity model comprehensively considers the characteristics of demand factors (population), supply factors (institutional scale), and distance impedance (distance between residences and facilities) between the supply and demand points, which can better reflect the difficulty of the population's access to public facilities and resources in different regions. Therefore, this study will apply the gravity model to analyse the accessibility of hospitals, schools, and elderly care facilities.

3.4 - Two-step Floating Catchment Area Method

The early floating catchment area method represented the spatial accessibility of demand points by calculating the supply-demand ratio. Figure 3.2 is a special case of the early floating catchment area model. Note that the radius of the circle remains the same from one place to another. For the search area of demand point 6 (the upper left circle, generally expressed as a given time threshold or distance threshold length), there is only 1 supply point, which is 'a', with the demand value of 7 (including demand points 1, 2, 3, 4, 6, 7 and 10 which the supply point has equal treatment for). Therefore, the spatial accessibility of demand point 6 is 1/7. The supply points of the demand point 9 is 3, that is, 'a', 'b', and 'c', with the demand value of 7 (including demand points 4, 5, 7, 9, 10, 11, 15) and therefore, the spatial accessibility of demand point 9 is 3/7.

Figure 3.2 – Early Floating Catchment Area Model



The early floating catchment area method has some shortcomings. It potentially assumes that all residents in the search area can obtain the services provided by the supply point. However, the distance between demand points and supply point in the search area may exceed the distance limit of the residents' travel. Moreover, the service object of the supply point is not limited to residents in the search area; it may also provide services to residents nearby or even outside the search area.

In order to overcome the above shortcomings, Radke (2000) proposed a two-step floating catchment area method, which is based on both demand points and supply points and moves the search area twice which is why it is called the two-step floating catchment area method (referred to as 2SFCA model). The model is described as follows:

$$R_j = \frac{S_j}{\sum_{k\in(d_{kj}\le d_0)} P_k} \quad \textbf{(3.5)}$$

The first step is to search for all the demand points 'k' in the range of the traffic time threshold or the travel distance threshold 'd' and calculate the supply-demand ratio 'R_j'. If the demand point is represented by population size, then 'R_j' is the per capita supply, which can be expressed as the supply capacity of point 'j'; where 'S_j' is the supply volume of point 'j'; 'd_{kj}' is the traffic impedance between 'k' and 'j'; and 'P_k' is the demand value of the demand point in the search area, generally expressed as population size.

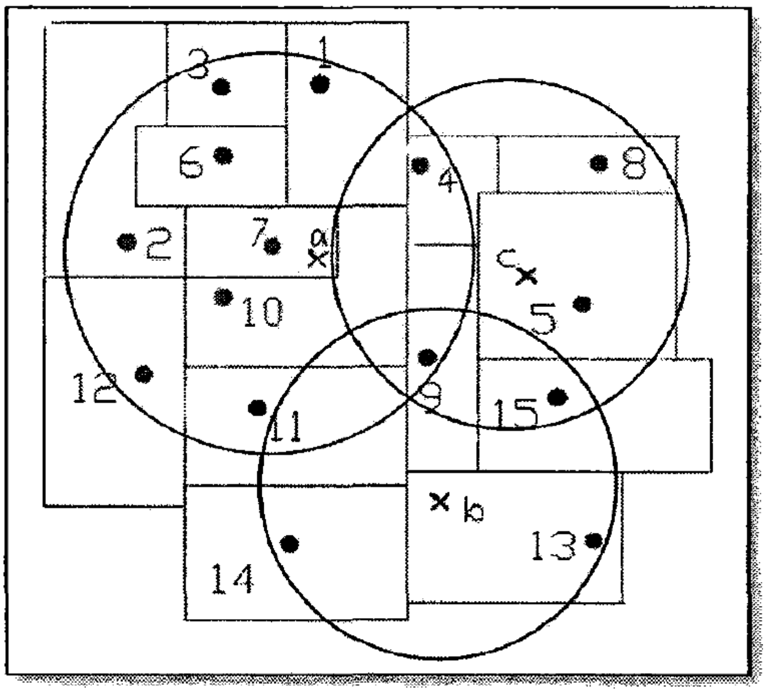
$$A_i^F = \sum_{j\in(d_{kj}\le d_0)} R_j = \sum_{j\in(d_{ij}\le d_0)} \frac{S_j}{\sum_{k\in(d_{kj}\le d_0)} P_k}$$

(3.6)

The second step is to search for all the supply points ‘j’ within the range of the traffic time threshold or the travel distance threshold ‘d_0’, then the spatial accessibility ‘A_i^F’ of point ‘i’ can be obtained by summarising the supply-demand ratio ‘R_j’ of all supply points within the range of the threshold; where ‘d_{ij}’ is the traffic impedance between ‘i' and ‘j’; ‘R_j’ is the supply-demand ratio of the supply point ‘j’ in the ‘i’ search area. The larger the ‘A_i^F’ value, the higher the spatial accessibility of point ‘i'.

This method takes into account the interaction between demand points and supply points in the study area, and the spatial accessibility calculated by each demand point is different. Figure 3.3 is an illustration of a 2SFCA model. Search area ‘a’ has 1 supply point; since the supply amount is 1 unit and there are 10 demand points, the supply-demand ratio of supply point ‘a’ is 1/10. Using the same principle, the supply-demand ratio of the supply point ‘b’ of the search area ‘b’ is 1/4 and the supply-demand ratio of the supply point ‘c’ of the search area ‘c’ is 1/5. According to the above analysis, the residents of demand point 6 can only use the service of supply point ‘a’ within a given traffic time threshold or travel distance threshold, and thus its spatial accessibility is ‘R_a’=0.1. On the other hand, residents of demand point 9 can use the services of ‘a’, ‘b’, and ‘c’ (as it is covered by the search areas of ‘a’, ‘b’, and ‘c’), and can also reach the supply points ‘a’, ‘b’, and ‘c’ within the same threshold range, so, its spatial accessibility is ‘R_a’+‘R_b’+‘R_c’=1/10+1/4+1/5=0.55.

Figure 3.3 – The 2SFCA Model



The 2SFCA model does not consider the influence of distance attenuation. The model assumes that the spatial accessibility of each demand point is equivalent within the travel distance limit, ignoring the difference between the spatial accessibility of different demand points. In order to overcome this shortcoming, this study considers the influence of the traffic distance between the demand point and the supply point within the travel distance limit on the basis of the 2SFCA model, so as to accurately distinguish the difference between the spatial accessibility of different supply points. The improved 2SFCA is actually a combination of the 2SFCA model and the gravity model. The improved 2SFCA model has the following expressions:

$$A_i^F = \sum_{j\in(d_{kj}\leq d_0)} R_j = \sum_{j\in(d_{ij}\leq d_0)} \frac{\alpha_j S_j}{d_{ij}^{\beta} \sum_{k\in(d_{kj}\leq d_0)} P_k}$$

(3.7)

In this study, ‘a_j’ is the scale factor of the public facilities; the supply volume ‘S_j’ of the public facilities is represented by the facility area or the daily average passenger flow; ‘β’ is the travel friction coefficient, and the traffic impedance ‘d_{ij}’ is expressed by the travel time; ‘P_k’ is the population of residents in the search area (i.e. ‘d_{kj}’</=d_0); and the distance threshold ‘d_0’ obtains spatial reachability by selecting different threshold intervals and setting weighted summation. This study will utilise the 2SFCA model to analyse the accessibility of anti-disaster facilities. Anti-disaster facilities refer to infrastructure planning of a certain scale and function to cope with sudden natural disasters and accidents (Liu, 2012). These are places or buildings that can provide refuge, basic living security, rescue and command for residents. This study will analyse the accessibility of parks, green spaces, airports, and ports. According to Hakimi (1964), the key to the planning of anti-disaster facilities is to minimize the average weight distance from all demand points to certain facilities (distance can also be expressed as traffic time). The 2SFCA model analyses the minimum and maximum distance from any demand point to its nearest facility. In addition, the 2SFCA model not only considers the capacity of anti-disaster facilities but also considers the factors of traffic conditions and population distribution. Therefore, it is reasonable to apply the 2SFCA model to analyse and evaluate the accessibility of anti-disaster facilities.

3.5 - Fixed Effects, and Random Effects Models

The identification of causal relationships can be estimated using panel data. This section focuses on the fixed effects and random effects models that were commonly used when analyzing panel data.

$$Y_{it} = \mathrm{b}X_{it} + F_i + v_{it}$$

(3.8)

Panel data is the data set observed over multiple periods for multiple individuals. When analyzing panel data, as in Eq. (3.8), it is common to include the explained variable; the explanatory variable;

the error term with two subscripts; the individual i and the time point t; and the element Fi unique to the individual that does not change with time in the equation . However, estimating Eq. (3.8) using the least squares method may cause a bias in the estimated value. When this equation is estimated by including Fi in the error term through the least squares method, the error term may be autocorrelated and may correlate with the explanatory variables. As a result, in most cases, the error term assumptions for obtaining the Best Linear Unbiased Estimator (BLUE) will fail.

Therefore, it is necessary to treat Eq. (3.8) as a random effects or fixed effects model when using panel data, depending on the characteristics of F_i. The random effects model assumes that F_i is independent of the explanatory variable X_{it}, while the fixed effects model assumes that F_i is not independent of this variable. The form of the estimation formula is the same as that of Eq. (3.8), but it should be noted that the estimation model differs depending on the intrinsic effect and the independence of the explanatory variables. The following sections introduce these two types of models.

$$\boldsymbol{Y_{it}} = \mathbf{b}\boldsymbol{X_{it}} + (\boldsymbol{F_i} + \boldsymbol{v_{it}}) = \mathbf{b}\boldsymbol{X_{it}} + \boldsymbol{u_{it}} \tag{3.9}$$

In the random effects model, F_i in Eq. (3.8) is included in the error term; thus, in Eq. (3.9), $F_i + v_{it}$ is treated as the error term. At this time, due to the presence of F_i, autocorrelation may occur between the error terms at different time points t of the same individual i. In that case, the assumption that the covariance of the error term = 0 is not satisfied. Even if Eq. (3.8) is estimated by the least squares method, efficiency cannot be obtained, and the parameter does not become BLUE. Therefore, the random effects model is estimated using the generalized least squares method that considers the autocorrelation of the error term.

Here, it is worth noting that the random effects model assumes that Fi exists but is independent of the explanatory variable X_{it}, because if the F_i contained in the error term correlates with the explanatory variables, the assumption that the error term and the explanatory variables are independent cannot be satisfied. Therefore, even if Eq. (3.8) is estimated by the generalized least squares method, the parameters are inconsistent, and BLUE cannot be achieved.

Unlike the random effects model, the fixed effects model assumes that F_i and the explanatory variable X_{it} are correlated; therefore, if F_i is included in the error term, a correlation is created between the explanatory variable X_{it} and the error term ($F_i + v_{it}$), and consistency cannot be obtained. Thus, it becomes necessary to make an estimation that explicitly considers F_i in the fixed effects model. While there are several methods for estimation that explicitly consider F_i, the simplest is to create a dummy variable for each individual and include it in the estimation formula as an explanatory variable. However, since this method requires a large number of dummy variables to be included in the explanatory variables, it is quite time-consuming and therefore not often used in practice.

In the fixed effects model, instead of using a dummy variable for every individual, F_i that does not change over time is removed by assuming an estimation formula that takes the deviation from the period mean value for each individual. More specifically, both sides of Eq. (3.10) are first averaged over the entire period t for each individual i and expressed as Eq. (3.11); here, $\overline{Y_{it}}$ and $\overline{X_{it}}$ refer to the period mean of Y_{it} and X_{it} for the individual i. However, since Fi does not change over time, the period average value $\overline{F_i}$ is the same as F_i.

$$\boldsymbol{Y_{it}} = \mathbf{b}\boldsymbol{X_{it}} + \boldsymbol{F_i} + \boldsymbol{v_{it}} \tag{3.10}$$

$$\overline{\boldsymbol{Y_i}} = \mathbf{b}\overline{\boldsymbol{X_i}} + \boldsymbol{F_i} + \overline{\boldsymbol{v_i}} \tag{3.11}$$

$$(\boldsymbol{Y_{it}} - \overline{\boldsymbol{Y_i}}) = \mathbf{b}(\boldsymbol{X_{it}} - \overline{\boldsymbol{X_i}}) + (\boldsymbol{F_i} - \boldsymbol{F_i}) + (\boldsymbol{v_{it}} - \overline{\boldsymbol{v_i}}) \tag{3.12}$$

$$\widetilde{\boldsymbol{Y_{it}}} = \mathbf{b}\widetilde{\boldsymbol{X_{it}}} + \widetilde{\boldsymbol{v_{it}}} \tag{3.13}$$

Next, Eq. (3.11) is subtracted from Eq. (3.10) to obtain Eq. (3.12). As Eq. (3.12) is shown as a deviation from the period mean on both sides, it should be noted that the deviation from the period average of F_i is zero, thus F_i is removed in this equation. Therefore, as shown in Eq. (3.13), the fixed effects model is estimated by the least squares method, using $\widetilde{Y_{it}}$ and $\widetilde{X_{it}}$, which are obtained by converting the explained and explanatory variables by taking the deviation from the period mean value. Since F_i is removed in Eq. (3.13), the error term becomes independent from the explanatory variables, and a consistent estimate can be obtained.

Due to the names of the random and fixed effects models, it is easy to misunderstand that the difference between them is simply that if the Fi fluctuates with probability, it comprises a random effects model, while if it is fixed without fluctuating, it is a fixed effects model. Since both are expressed by Eq. (3.8), they are classified according to the characteristics of F_i. However, the names are not of concern in this study; as discussed above, the difference between the random and fixed effects models is whether or not there is a correlation between F_i and the explanatory variable X_{it}.

Since the panel data has a large sample size and includes variations in both the cross section and the time series, a lot of information can fortunately be used for estimation; these benefits apply to both the random and the fixed effects models. However, estimation using the fixed effects model has the unique merit that it allows for the easy obtainment of consistent parameter estimators, as discussed in the previous section. Nevertheless, one restricting factor is that the fixed effects model, which removes F_i by taking the period average or the deviation from the previous period, can be applied only to the linear model.

As described above, the fixed effects model has both advantages and disadvantages, thus it is generally applied according to the specific purpose of analysis. Statistically, the Hausman test is commonly used as a method to determine whether to select the fixed or the random effects model.

In the Hausman test, the null hypothesis is that F_i and the explanatory variable X_{it} are independent. If the null hypothesis cannot be rejected, the random effects model is selected; if it can be rejected, the fixed effects model is selected. Normally, the result of the Hausman test shows the significance level at which the null hypothesis can be rejected and uses the p-value as a certain probability (the probability that the random effects model is correct). Therefore, the fixed effects model is supported when the p-value of the Hausman test is sufficiently small, such as 0.01, 0.05, or 0.10, while the random effects model is supported when the p-value is large.

The F-test can also be applied to select the right estimation model when analyzing panel data. This test examines the null hypothesis that all intrinsic effects are zero; if the null hypothesis is not rejected due to the F-test, there is no intrinsic effect, and the least squares method is used. However, in most cases, intrinsic effects are present when using panel data, and thus it is common to omit the F-test and decide between the random and fixed effects models by using the Hausman test.

3.6 - Summary

This chapter presents an overview of the main types of statistical models applied in the analysis chapters. The construction of these models is based on urban public facility location theory and accessibility theory discussed in Chapter 2 and developed and improved according to the characteristics of the research objects. Particularly, this study applies an improved gravity model to analysis accessibility from residential areas to elderly care facilities in Sendai City (Chapter 6); a two-step floating catchment area method to examine the accessibility from residential areas to primary schools in Nagano City (Chapter 7); and fixed effects/random effects to consider the impact of change in population size and structure on housing demand throughout Japan (Chapter 8). Detailed explanations of the further improvement of these models and how to apply them to the data set are provided in the succeeding chapters.

CHAPTER 4

DEMOGRAPHIC AND SPATIAL DATA ACQUISITION

As has been discussed previously, the application of the statistical models in this study requires corresponding datasets to answer the study's research question: Are Japan's infrastructure planners responding appropriately to Japan's demographic change? The following sections introduce different kinds of datasets employed in the empirical chapters and illustrate the role of each dataset.

4.1 - An Introduction to Data and Information

This study is designed to conduct empirical analysis using several data sets to clearly the research questions mentioned in the previous section: A public opinion survey on the future image of Japan with regard to its population and social economy (SJPS), Vital Statistics (VS), National Accounts Statistics (NAS), and National Land Numerical Information (NLNI) data.

SJPS was conducted in August 2014 by the Cabinet Office of the Japanese government. This survey aimed to understand public awareness of the future image of Japan and use its findings as references for formulating future social policies and measures. The VS survey is designed to collect vital events in Japan and obtain a basic data source for population and policy making on health, labour and welfare. This survey is conducted from 1st January to 31st December of the survey year. The NAS, using data from Report on Prefectural Accounts produced by the Cabinet Office, can be applied to study the regional variations in each demand item, such as per capital GDP, Gross National Income (GNI) and National Income.

Among these datasets, the VS survey is the primary source to obtain demographic data. The robustness of Japan's vital statistics system is ascribed to its linkage with the family registration or koseki (戸籍) system. The declarations of births, demises, as well as weddings conform to the family registration law by updating the family composition. Moreover, the koseki system's value has gained ubiquitous recognition and is widely known to authenticate the relationships between the different members of a registered family. Therefore, the VS survey can provide timely and accurate demographic data.

Moreover, this study uses the NLNI dataset obtained from the Ministry of Land, Infrastructure, Transport and Tourism of Japan for the geographic information of the different types of public infrastructure. In Japan, the Basic Law on Promotion of Geospatial Information Utilization was enacted in 2007. Consequently, the use of geospatial information is considered essential for the future economic society, and the government has been taking the lead and promoting the process. Additionally, the "Basic Plan for Promotion of Geospatial Information Utilization" states that based on the progress of information technology and the requirements of the society, the government aims to realise a society with efficiently and extensively utilised geospatial information such that everyone can use this information anytime and anywhere and obtain accurate information for sophisticated analysis. Based on this idea, the Ministry of Land, Infrastructure, Transport and Tourism became a government consolidator, and the "National Land Numerical Information download service" was developed as one of the sites publishing diverse geospatial information. There are 61 kinds of eight data classified on the site. Many of these are data collected and categorised by law. It is spatial information that informs about "where and what". In other words, the "Digital National Land Information" is a fundamental database providing information about lands such as terrain, land use, public facilities, etc., in order to contribute to the promotion of national land policies such as national land planning, block plan and national land formation plan. This information is maintained as GIS data. The National Land Numerical Information is divided into the following categories.

Table 4.1 - National Land Numerical Information, Categories

Designated Regional Area	The Three Major Metropolitan Planning Areas, City Area, Agricultural Areas, Forest Areas, etc.
Coastal Zones	Fishery Ports, Tidal and Marine Facilities, Coastal Zone mesh, etc.
Nature	Altitude and Gradient Tertiary Mesh, Land Classification Mesh, Climatic Data Mesh, etc.
Land Related	Publication of Land Prices, Prefectural Land Price Surveys, Land Use Tertiary Mesh, etc.
National Land Skeleton data	Administrative Divisions, Coastal Lines, Lakes, Rivers, Railways, Airports, Ports, etc.
Facilities	Public Facilities, Power Stations, Cultural Assets, etc.
Census of Commerce	Census of Commerce Mesh, Census of Manufacture Mesh, Census of Agriculture Mesh, etc.
Hydrology	Basin and Non-Water Catchment Area Mesh, etc.

Sources: http://nlftp.mlit.go.jp/ksj-e/index.html

The data required to apply the analytical model discussed in Chapter 3 includes the following: the demand point location dataset within the study area, the infrastructure location dataset, the line dataset connecting the demand points and infrastructure facilities and other relevant informational data. The acquisition process of these data is introduced in the following sections.

4.2 - Demand Point Location Data Acquisition

As described in Chapter 3, when studying spatial accessibility, the research area is generally divided into several traffic analysis areas as basic units for analysis (the traffic analysis area always uses the basic unit of the national census for division); the densely inhabited district (DID) of the traffic analysis area is then used as the demand point for further analysis. This study attempts to use

Google Maps' point of interest (POI) data, OpenStreetMap and NLNI data to investigate the level of accessibility of certain infrastructure facilities by using the residential area's DID as the demand point. Demand point information about various public facilities is difficult to obtain from open data sources. To acquire the demand point dataset of the research area, the grid is created using a software platform, and the centre point of the grid is extracted as the candidate demand point of the area. Then, the obtained candidate demand point layer is superimposed with the realistic DID map (obtained from Google POIs and NLNI as discussed previously) layer to obtain a spatial dataset of the final demand point for the relevant public facility. For the study area, the smaller the grid size, the higher the calculation accuracy. However, the index of the operation time also increases. Because the main purpose of the spatial accessibility evaluation of public infrastructure facilities is to quantitatively describe their spatial distribution and the social space fairness they reflect, this study selects several representative residential areas based on the Google POI data and NLNI data to participate in the model operation to reduce the amount of model calculation and improve calculation accuracy. Then the spatial accessibility values of these selected demand points are measured by conducting inverse distance weighted calculation and, finally, the level of accessibility of different types of infrastructure facilities can be obtained for further analysis and evaluation.

The selection of the representative residential areas (demand points) mainly follows the following principles:

(1) The sample residential area should be representative within a certain area. The building structure and layout of the selected area should be the same or similar to that of most surrounding residential areas, and the road network structure should reflect the main road network features in the area.
(2) The spatial distribution of the selected residential areas should be uniform and the minimum spatial separation between them should be no less than 1 kilometre.
(3) In order to facilitate the acquisition of the population data, the spatial extent of the selected residential areas should be basically consistent with that of the residential communities corresponding to the urban planning area. Therefore, it is ensured that the demographic data of the selected residential areas can be obtained from the residential community information corresponding to the national potential survey and the resident basic account.

4.3 - Infrastructure Location Data Acquisition

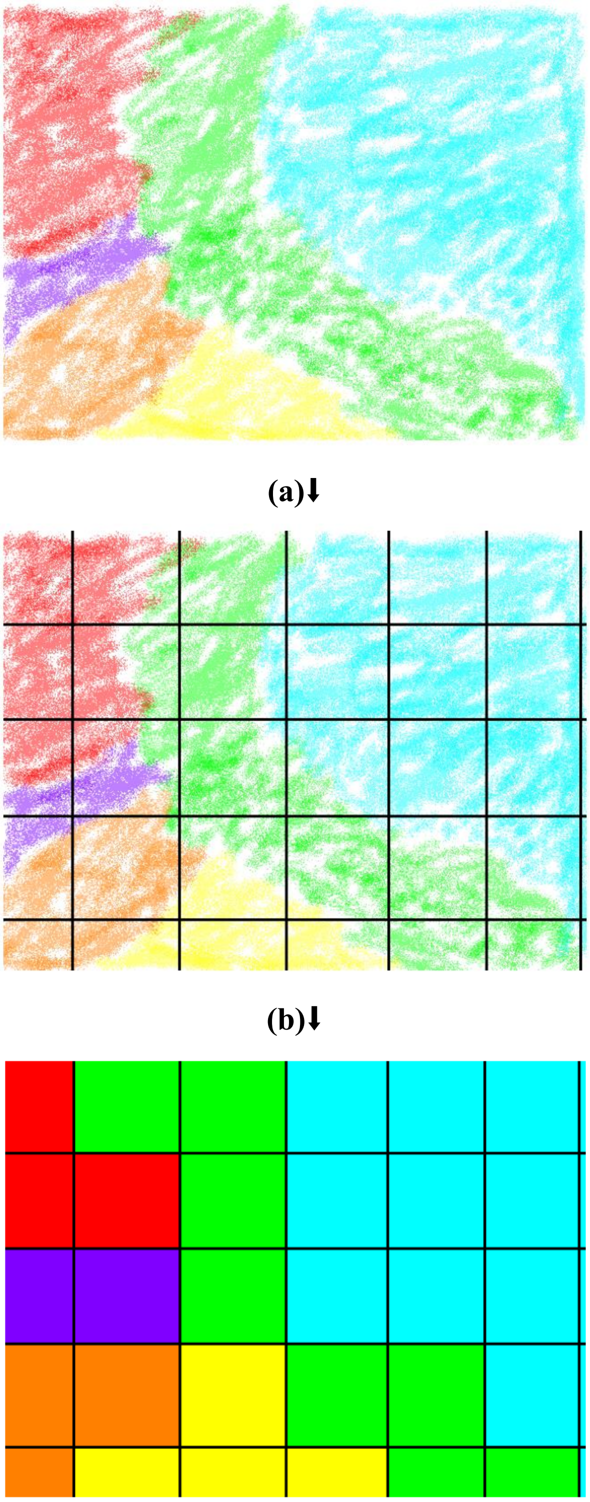
This section describes the NLNI data utilised in the analysis chapters. The NLNI data, which were originally created by various agencies, including the former National Land Agency and the Maritime Safety Agency, are various digital data groups concerning Japan's entire national land. The NLNI provides necessary data to each ministry and agency for formulating their respective land plan. Data development was started sequentially from 1974 for data creation. Since 1991, data have been created at each ministry and agency, and new data are being created and updated at present.

Initially, the NLNI was created for the formulation and implementation of national land development plans, such as the National Comprehensive Development Plan and National Land Use Plan. However, data were provided to public agencies for free to encourage their use in various fields. Currently, the use targets are expanded, and data are provided to the general public for free through the Internet. However, as data format is created for its easy usage among ministries and agencies, numerous data formats do not correspond to the so-called general GIS software. Therefore, immediately representing the downloaded NLNI data on the map is impossible. However, representation becomes possible by using a software (National Land Numerical Information Data Converter Tool) that converts the NLNI data into an ArcInfo shapefile.

As discussed, the NLNI was developed by the National Land Agency and Geographical Survey Institute as the basic numerical geographic data for objective regional plan formulation. The NLNI can be categorised and quantified to the extent that covers the entire country of Japan. The contents of the NLNI are as follows: (1) Designated regional area, (2) Coastal zones, (3) Nature, (4) Land related, (5) National land skeleton, (6) Facilities, (7) Census of commerce and (8) Hydrology. Specific data include geographical factors, such as natural parks, harbours, fishing ports, roads, railroads, lakes, routes, land subsidence areas, climate values and land prices. The NLNI data can be roughly divided into two types: (1) raster and (2) vector. Mesh data are based on raster type data, and dot, line and polygon data are based on vector type data.

Mesh data divide a region with an orthogonal lattice surrounded by equidistant longitude and latitude lines and encode the statistical data of target attributes (land use situation and natural terrain mesh) for each lattice. Mesh division of the NLNI follows the standard region mesh system. Primary mesh corresponds to the topographical map size of 1/200,000. Secondary mesh corresponding to a topographic map of 1/25,000 is obtained by dividing the primary mesh into eight vertical and horizontal sections. Furthermore, a tertiary mesh (reference region mesh) can be obtained by dividing the secondary mesh into 10 vertical and horizontal sections. The size of the tertiary mesh is 30 s in the latitude direction and 45 s in the longitude direction (approximately 1 km^2), and the entire land of Japan is divided into approximately 390,000 meshes. Figure 4.1 presents representation process of mesh data. Suppose that a map is classified into four types of land use (a). This map is divided by several orthogonal lattices created with a certain size (b). Then, the large land area contained in each lattice is used to expresses the mesh data (c).

Figure 4.1 – Representation Process of Mesh Data



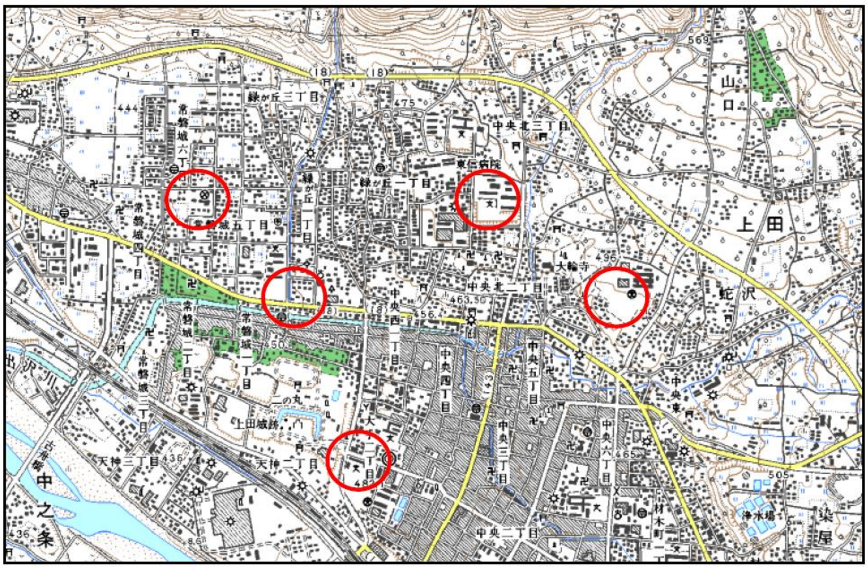
(a)⬇

(b)⬇

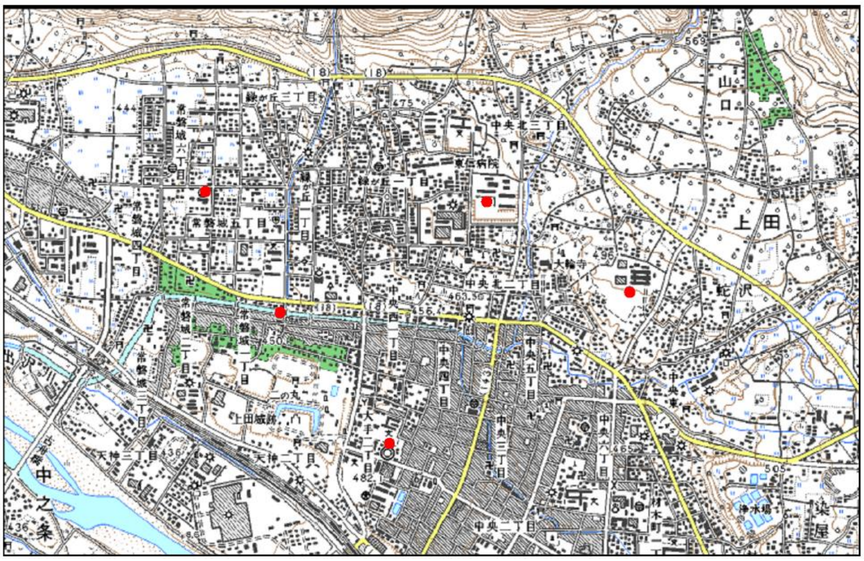
(c)

Point data belong to vector type and provide map information by point format. Point data are used to represent the location of public facilities. Figure 4.2 shows the process of representing point data. School, as an example of a public facility, is expressed as point data. The school is shown in the map with a red circle (a). Point data can be expressed by placing a point at the indicated location (b).

Figure 4.2 – Representation Process of Point Data



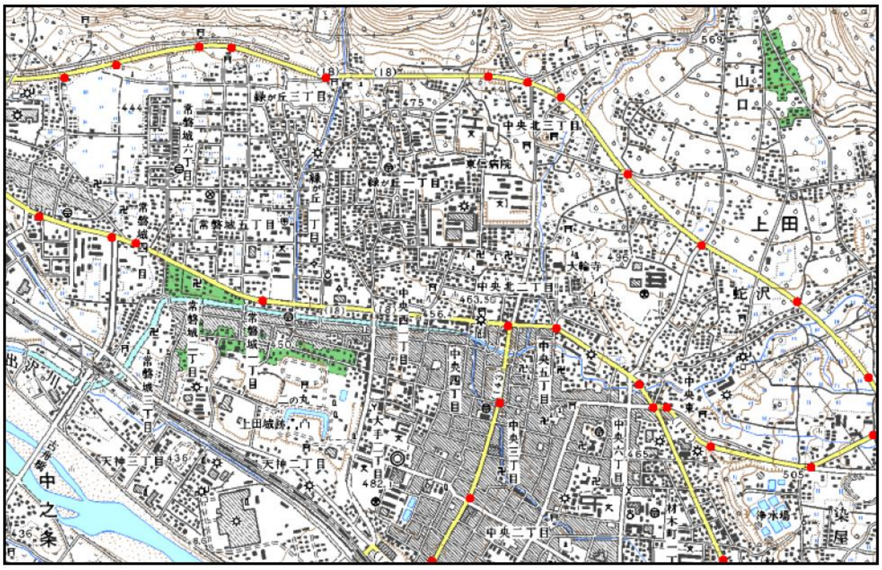
(a)⬇



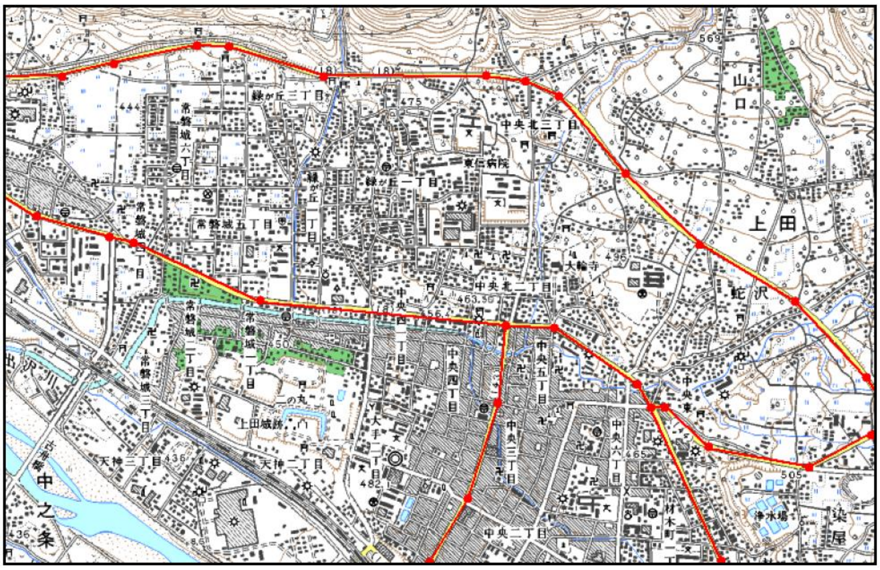
(b)

Line data refer to a data format provided as line information by a set of vector type point data. Line data express map information that can be represented by line segments, such as railroads and roads, through a collection of point information (railway, road, river and active fault). Figure 4.3 exhibits the representation process of line data. Point data, which are components of line data, are also shown (a). This point exists at the branch point and the inflection point of the road. Then, line data are expressed by connecting these points to create a line segment (b).

Figure 4.3 – Representation Process of Line Data



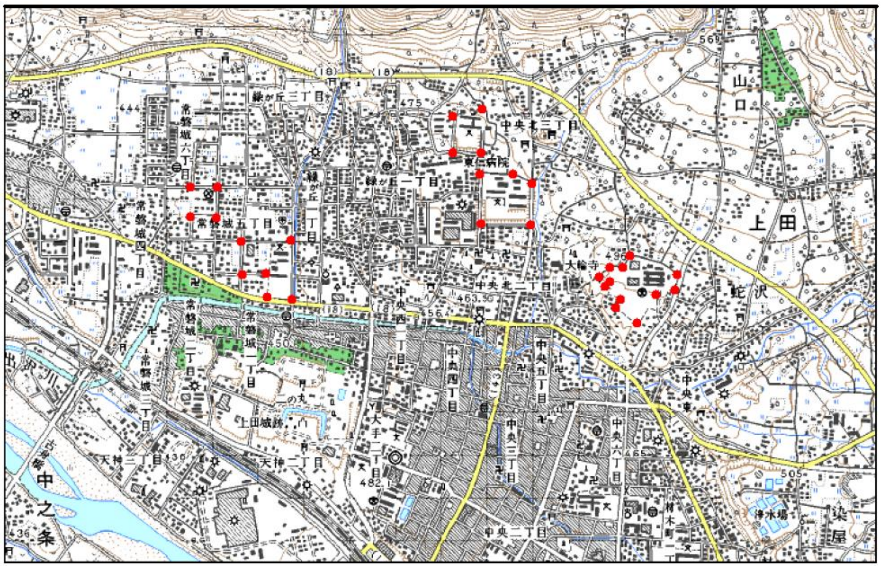
(a)⬇



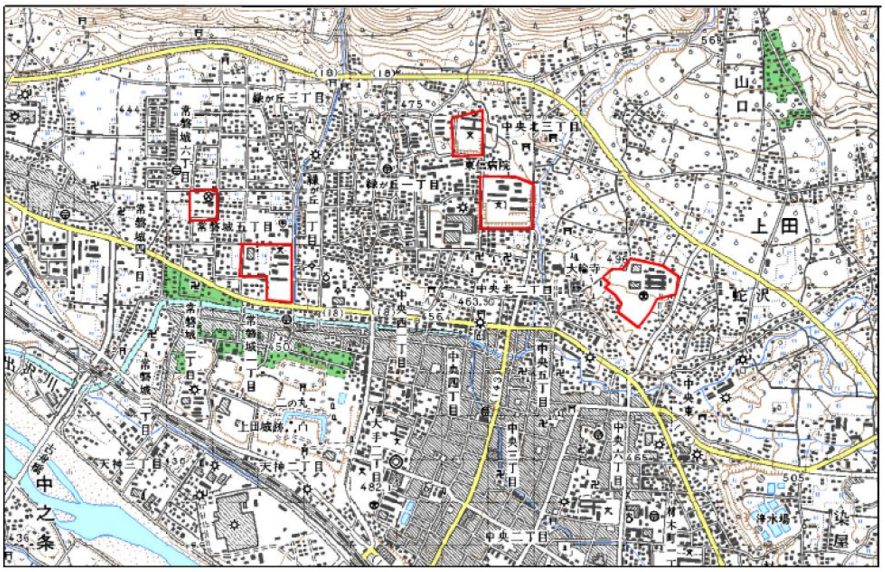
(b)

Polygon data represent an area of surface information with vector data. This data format is provided as surface information by utilising vector type point data. Polygon data express closed areas generated by connecting line segments that compose a surface as one polygon information (three metropolitan planning areas, forests and lakes). Figure 4.4 shows the representation process of polygon data. Figure 4.4 presents the school. The school's section is expressed as point data (a). Then, polygon data are expressed by concatenating the points to create one closed area (b).

Figure 4.4 – Representation Process of Polygon Data



(a)⬇



(b)

In addition to these four data formats, 'table (ledger) data' are also available in the NLNI. 'Table (ledger) data' are obtained by extracting only the attributes of each geographic information (point, line, polygon and mesh) and inputting it in a table. For example, in the 'storm surge/tsunami' data, records of storm surge and tsunami disasters over the past 50 to 100 years are summarised as a table. As these data do not include position information and coordinate values, the information must be correlated with the certain point on the map to be displayed.

4.4 - Selection of Infrastructure Facility's Scale Indicators

This study entails the use of OpenStreetMap and NLNI data to obtain spatial distribution maps of infrastructure facilities and residential areas. As introduced in the previous chapters, Chapters 6, 7, and 8 analyse the impact of demographic changes on elderly care facilities, primary schools, and housing demand, respectively. In particular, Chapters 6 and 7 will assess the rationality of facilities' locational distribution by analysing geographic accessibility. When analysing accessibility, data about the service capacity and scale of each facility are also required in addition to data containing spatial information. Although different analytical angles are used, Chapter 8 also defines indicators to measure the size of housing demand. In the selection of scale indicators, this study made the design as shown in Table 4.2.

Table 4.2 - Scale Indicators

Types	Indicators
Elderly care facilities	Maximum acceptable number of users
Primary schools	Number of teachers, number of students, building area.
Housing	Contracted area, unit sales price

With respect to elderly care facilities, Chapter 6 uses the maximum capacity of each facility as a measure of service capacity. Regarding schools, the analysis chooses the number of students, the number of teachers, as well as the building area of the school to measure the educational level (service capacity) of the school. Chapter 7 expounds on the specific weight of each indicator. Moreover, the data of these indicators are not only obtained from the NDNL database but also refer to relevant data published by government departments.

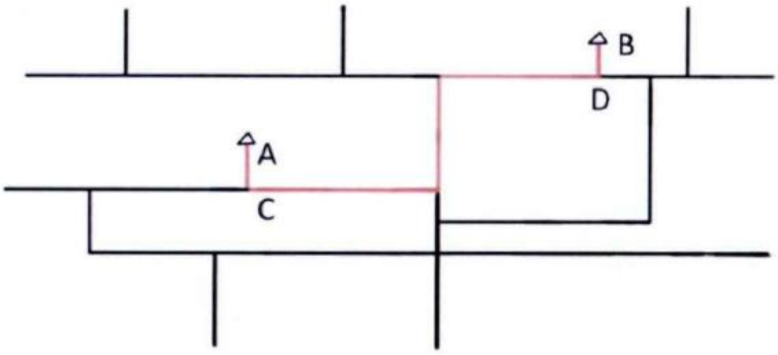
4.5 - Connection Form Data Acquisition

4.5.1 - Road Network Modelling and Traffic Impedance Calculation

With the deep understanding of spatial accessibility and the development of the spatial accessibility measurement model, road network modelling has become an important basis for spatial accessibility analysis. Traffic impedance is generally obtained through analysis of the road network, which is a typical topology network. The three basic components are nodes, edges and weights. The Geodatabase provides a network model for simulating real roads — network datasets, which contain network elements, connectivity, attributes, directions, constraints, etc. that can well simulate road networks.

Multiple network paths can be taken between the starting and target point. Depending on the characteristics of the person, the impedance (distance, time, cost, etc.) is often selected to be the smallest. Thus, in the spatial accessibility metric, the traffic impedance is mainly obtained according to the shortest path between the starting and target point. The distance between both points is mainly composed of three parts (as shown in Figure 4.5).

Figure 4.5 – The Distance Between the Starting and Target Point



In the figure, A-C represents the linear distance from the starting point to the nearest road node on the road network; C-D represents the network distance between the road node connected to the starting point and the one connected to the target point; D-B represents the linear distance from the nearest road node to the target point on the road network. The network distance between C-D refers to the shortest path among all possible traffic paths. The shortest path distance can be obtained by the shortest path analysis method. The shortest path analysis algorithms mainly include the Dijkstra algorithm and the heuristic search algorithm. As the shortest path algorithm is applied to the network analysis of GIS, the traffic distance between the starting and target points can be obtained by using a network analysis module (networkanalyst), proximity analysis (near) and spatial join (join) operation. The calculation process of road network traffic distance can be shown as follows:

Search for the nearest point C on the road network from each starting point A to get set 1; Calculate the linear distance between each starting point and its corresponding point C to get Table 1; Search for the point D on the road network closest to each target point B to get set 2; Calculate the linear distance between each target point and its corresponding point D to get Table 2; Calculate the shortest network distance between Sets 1 and 2 to get Table 3; Combine the results of Tables 1, 2 and 3 to get the shortest distance between the starting and target points.

This study uses the traffic data in the NLNI data and real-time information from the road traffic information centre to obtain road network and historical road condition table data of each prefecture in Japan. The attribute fields of the tabular data are as follows: time_id and r_id. Time_id indicates time period encoding; the data collection interval is 5 minutes and there are 288 acquisition time periods in 24 hours, coded from time 0–time 287. R_id is the road code, and the different coded roads indicates the corresponding road conditions. The road conditions are divided into four types: A (unblocked), B (slow), C (congested) and D (severe congested), as shown in Table 4.3:

Table 4.3 – The Historical Traffic Data

	t0	……	t287
r1	A	……	B
……	……	……	……
rn	C	……	D

According to the analysis report of the Road Traffic Information Centre in Japan and other relevant data, the driving speed range and speed starting values of vehicles under different road conditions and grades (this study combines secondary and branch roads in the NLNI data into secondary roads) are shown in Tables 4.4 and 4.5:

Table 4.4 – Driving Speed Range

Conditions/Grades	Severe Congested	Congested	Slow	Unblocked
Highways	V<10	10≤V≤20	20<V≤40	V>40
Primary Roads	V<5	5≤V≤12	12<V≤25	V>25
Secondary Roads	V<5	5≤V≤10	10<V≤20	V>20

Table 4.5 – Driving Speed Starting Values

Conditions/Grades	Severe Congested	Congested	Slow	Unblocked
Highway	15	18	30	56
Primary Roads	12	14	20	40
Secondary Roads	8	10	18	30

The actual travel speed of the vehicle should refer to the number of lanes. According to the relationship between the vehicle's speed and the number of lanes proposed in the previous study, the travel speed of roads with different lanes of different grades under different road conditions can be obtained:

$$\boldsymbol{Vt_i = Vt_0} * [\left(\frac{L}{2} - L_0\right) * \mathbf{0.05 + 1}]$$

(Equation 4.1)

Where Vt_i is the actual driving speed under different road conditions of different road grades; i corresponds to four different road conditions of A, B, C and D; Vt_0 is the starting value of different road grade speeds of different road conditions; L is the number of lanes of actual roads (the number of lanes for data collection is the number of two-way lanes, but the actual speed refers to one-way lanes. Therefore, the value of the number of lanes is divided by 2); L_0 is the number of reference lanes. The reference lane values are shown in Table 4.6.

Table 4.6 – Reference Lane Values

Grades	Number of Reference Lanes
Highways	3
Primary Roads	2
Secondary Roads	1.5

4.5.2 - Driving Speed Calculation Model

In the spatial accessibility evaluation of infrastructure facilities, residents' travel time is generally selected as the traffic impedance indicator. For urban residents, the traffic congestion level of their road network will have an important impact on their travel choices. Based on the characteristics of the road system, this study uses historical road condition data to model the driving speed of different road grades to reflect the actual traffic capacity and time impedance of residents' travel in each selected residential area.

People's travel has certain regularity and stability, for example, as in the congestion of a certain section of road without considering traffic accidents. Through the daily road congestion situation — A (unblocked), B (slow), C (congested) and D (severe congested), and then through weighted average calculation, The following formula can be used to calculate speed from Monday to Sunday:

$$\boldsymbol{Va_i = \frac{1}{288} * (\sum A * Vt_a + \sum B * Vt_b + \sum C * Vt_c + \sum D * Vt_d)}$$

(Equation 4.2)

Here, Va_t represents the average speed of the road all day (total 288 periods) from Monday to Sunday; Vt_d represents the speed of the road under different road grades with different congestion conditions. The calculation of this speed is based on equation 4.1; $\sum A$,$\sum B$,$\sum C$ and $\sum D$ respectively indicate the number of statistical periods when the road is unblocked, slow, congested and severely congested.

In order to make the calculated speed better reflect the average level of road network traffic, the annual speed is averaged in a one-week cycle, using the following formula:

$$\boldsymbol{Va_l = \frac{\sum_{j=1}^{12} Va_{ij}}{12}}$$

(Equation 4.3)

Here, Va_l represents the average speed value per week, and Va_{ij} represents the average weekly speed corresponding to different months. Finally, in order to facilitate the subsequent analysis, the values calculated based on Equation 4.1 are averaged again and, finally, the average daily travel speed V_a is obtained.

$$\boldsymbol{V_a = \frac{\sum_{j=1}^{7} Va_l}{7}}$$

(Equation 4.4)

According to the driving speed calculation model (Equation 4.4), the calculation results can be added to the road attribute, and time impedance (in minutes) of residents' travel can be calculated by the following method.

$$\textbf{TravelTime} = \frac{\boldsymbol{ShapeLength * 0.001}}{\boldsymbol{v}} * \textbf{60}$$

(Equation 4.5)

Here, ShapeLength is the length of the road. The unit of length in projection coordinates is 'm', and the speed unit is 'km/h'. The final time impedance is more intuitive in minutes, thus the value is multiplied by 60.

4.6 - Summary

This chapter provides an introduction to the data used in the analysis chapters. It also elucidates how to obtain data related to each analysis element and summarises the speed as well as the calculation ideas involved in the road network. Specific data analysis methods and the ways of combining spatial data, attribute data, and models are discussed in detail in the analysis subsections of each chapter.

CHAPTER 5

POPULATION TRENDS AND INFRASTRUCTURE POLICIES

5.1 - Introduction

The first four chapters clarify the research questions, research perspectives, and research methods of this study using mathematical models, combined with GIS software, to analyse the impact of population decline on infrastructure planning in Japan. This chapter further discusses the process of Japan's population changes and the contents of Japan’s infrastructure planning-related policies based on government statistics and documents, providing background knowledge and a foundation for the analysis of the subsequent three chapters. The structure of this chapter is as follows. Section 5.2 provides a detailed introduction to the changes in the size and structure of Japan’s population. Section 5.3 reviews the content and impact of Japan's six national land plans. Section 5.4 discusses the prospects for future infrastructure planning in conjunction with demographic changes and Japan's socioeconomic conditions. Section 5.5 summarizes this chapter.

5.2 - Population Change in Japan

Japan has already entered a period of depopulation. It is predicted that it will decrease at an average annual rate of 0.8% in the future, and the number will drop below 100 million by 2050 (a medium estimate of about 92 million). The changes in the working-age population (between the ages of 15 and 64) are more characteristic. The working-age population in 2050 (about 47.2 million people) is expected to be almost the same as the working-age population in 1945 (about 47.9 million people). In addition, with the rapid ageing in Japan, the elderly population (aged 65 and over) in 2050 will reach about 36.5 million, which is very close to the size of the working-age population (MIC, 2015). Additionally, the household structure is changing drastically, and the number of single and nuclear households is expected to increase dramatically in the near future.

The Meiji era saw a significant expansion in the national population distribution with economic development and population growth. There was a rapid increase in the number and scale of cities. It was during this period of high economic growth that regional differences in population and economic development became a problem. People and investment were concentrated in the southern Kanto (Tokyo), Keihanshin (Osaka), and Tokai (Nagoya) areas, creating a severe regional disparity. The main reason for this disparity was the difference in infrastructure development, such as railways, highways, industry attractions, and sewerage.

As a countermeasure, the government implemented the 1962 Comprehensive National Development Plan (CNDP), followed by the 2nd CNDP (1969), 3rd CNDP (1977), 4th CNDP (1987), and 5th CNDP (1998). These plans aim for balanced national land development to eliminate regional disparities. Despite this, metropolitan areas remain overcrowded, while rural agricultural, mountain, and fishing villages and remote islands are notably depopulated. Reflecting this trend, indicators of population concentration have been on the rise for a long time, except immediately after the Pacific War (Kitou, 2012).

After the Pacific War, the population was concentrated in the Tokyo, Osaka, and Nagoya areas. These Pacific coastal areas are equipped with airports and port facilities and are home to several well-established companies and businesses. The main stage of heavy chemical industrialization saw an influx of young people—the labour force—to these areas. After the first oil crisis, the population influx into the three major metropolitan areas temporarily stagnated. Although it began to rebound during the bubble period and the latter half of the 1990s, the Osaka area has generally been in net outflow since the 1990s. In turn, the population of the Nagoya area is currently maintained at the very limit (Kitou, 2012).

During the past three periods of population growth[5], the population was concentrated in a specific area; when civilization matured and the population stagnated or decreased, the concentration tended to decrease. When a new civilization matures to some extent, the technologies and systems that support society and the people's lifestyles will spread throughout the country (Kitou, 2012). The decentralization of the population to rural areas is thought to have progressed with such widespread use. Alternatively, it can be seen as a sign of the relative decline in political and economic power in the central region.

However, this time, the scenario is different. Even though population growth has already halted, the degree of population concentration in specific areas, which has risen since around 1930, when the four major industrial zones were formed, is still increasing. Specifically, even after 2008, when population growth peaked, the population continued to increase in Tokyo, Kanagawa, Saitama, Chiba, Aichi, Shiga, and Okinawa.

Future estimates of this regional disparity are difficult because changes in population by prefecture are greatly affected by the movement of people. There is no guarantee that the historical migratory pattern will continue. It is also unclear what the form of migration will be, especially at the present rate at which the population is declining. That is why the prefectural population estimates that reflect the results of the census are different from the total population and are only calculated up to 30 years in the future.

Therefore, we can look at the data up to 2050, as estimated by the Land Council established by the Ministry of Land, Infrastructure, Transport and Tourism in 2011. In this regional population estimation, the natural increase or decrease due to birth and death uses the data from the National

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[5] Late Jomon period, Heian-Kamakura period, and late Edo period.

Institute of Population and Social Security Research, and the social increase or decrease due to movement between regions uses the relationship between the population of the young labour force generation (15–39 years old) and the prefectural income per capita. They divide Japan's map into sections of about 1 km square each, and the results show that only 2% of the lots will increase in population size between 2005 and 2050, and the population will decrease in the remaining lots. Although some increase lots can be found in the Osaka area and Okinawa, most of them are concentrated in the Tokyo area (Saitama, Chiba, Tokyo, Kanagawa) and the Nagoya area (Gifu, Aichi, Mie) (MLIT, 2011).

If the whole country is divided into wide area blocks, population size will decrease everywhere except for a slight increase in the Okinawa area. However, the rate of decrease is small in the metropolitan areas (Kanto region and Yamanashi) and the Chubu area (Nagano, Gifu, Shizuoka, Aichi, Mie), and even smaller in the Tokyo and Nagoya areas. The scale of population decline can be realized by looking at the specific numbers. By 2050, 66% of the lots will have a population of less than half of the population in 2005; 42% of the lots will have a population of less than one quarter during the same period. Even more shocking is that, by 2050, 22% of lots will become 'non-residential areas' where no one lives. In Japan, more than one-fifth of the land where people currently live will disappear (MLIT, 2011).

If the above predictions are correct, the degree of population concentration in a specific area will increase further. Japan will enter an era in which 'population decline' and 'population concentration' develop simultaneously, which it has never experienced in the past.

On the other hand, Matsutani (2015) shows a different angle to the estimation of the population concentration in specific areas. The rate of population change for each regional block is viewed by dividing age composition into three categories: 'young population', 'working-age population', and 'elderly population'. In all region blocks, the elderly population will increase in the future. By 2035, the elderly population will increase by 45% nationwide, and its share of the total population will increase from the current 20% to 34%. However, there is a huge regional difference in the elderly population. The area where the number of elderly people changes most drastically is the Tokyo area. The Ministry of Land, Infrastructure, Transport and Tourism estimates that it will increase 1.9 times between 2005 and 2050. The regions with the next highest growth rates are the Chubu, Kinki, and Northern Kanto regions (MLIT, 2011).

At present, these four regions have one thing in common: the proportion of young people in these areas is relatively large because they have attracted many young people so far. In metropolitan areas, where the proportion of the working-age population is large, financial resources were secured, so there was a financial margin. However, the current working-age population is equal to the future elderly population (dependent population). Since the influx of population from other prefectures is expected to decrease in the future, the proportion of the elderly population in those metropolitan areas is expected to increase sharply by 2050 (Matsutani, 2015; MLIT, 2011).

In other words, the ratio of the dependent population, which is the sum of the elderly and young population, is expected to be higher in metropolitan areas in the future. As the dependent population increases, the social security costs for them will increase, and the financial burden for the working-age population will also increase. Conversely, in areas that have previously sent young people to cities, such as Shikoku, Chugoku and the Northeast areas, the rate of increase in the elderly population will be relatively low, and changes in the dependent population may also remain stable. Therefore, the financial burden on working-age population will be lightened, and the inhabitants' standard of living may rise.

In this scenario, it is unclear how far the current population concentration could be dispersed by migration from metropolises to rural areas. However, the concentration in the Tokyo area may ease to some extent (Matsutani, 2015). When the Great East Japan Earthquake struck on March 11, 2011, it temporarily halted the supply of industrial components from Japan to other areas worldwide. This led to people arguing that the spatial risk of the industry should be dispersed. Improving the concentration in the Tokyo area and achieving balanced development in various parts of the country has been a slogan for national comprehensive development since the period of high economic growth. It may not be long before the Japanese government's long-cherished wishes come true due to socio-changes in the era of depopulation.

After WWII, the total number of households in Japan continued to increase at a rate that exceeded the rate of increase in the total population until 2015. The total population increased 1.4 times between 1960 and 2000, but the total number of households increased 2.1 times, from 22.54 million to 46.78 million. As mentioned above, although the total population began to decline in 2008, the total number of households continued to increase, peaking at 50.48 million households in 2015, and is expected to finally begin to decline thereafter (Ato and Tsuya, 2007).

The total number of households has continued to increase, exceeding the population growth, and is expected to continue to increase in the future. This is because households continue to shrink (the average number of household members decreases), and this tendency is not expected to change in the future. The average household size dropped from 4.14 to 2.67 between 1960 and 2000. Although it is not significantly different from the average level in Western developed countries where nuclear families have become commonplace, the rate in Japan is expected to drop to 2.37 by 2025 (Ato and Tsuya, 2007).

The reasons for this drop are: 1. A decrease in the number of children born to couples due to the spread of family planning until around 1960; 2. A decrease in the proportion of direct family households and an increase in the proportion of single households due to the nuclear family, that has continued after WWII; 3. An increase in the number of unmarried people and a declining birthrate since the mid-1970s. In recent years, 'household independence' has been particularly remarkable in Japan. The proportion of single-person households was only 16.1% in 1960 but increased to 27.6% in 2000. The proportion of single-family residents in Japan's total population increased from 3.8% to 10.2% within the same period. The National Institute of Population and Social Security Research estimates that the proportion of single-person households will continue to rise, reaching 34.6% by 2025. In other words, the proportion of single-family residents in the total population is expected to reach 14.2% (Ato and Tsuya, 2007).

With the progress of the ageing population, the 'ageing of households' is also remarkable. The number of households with relatives aged 65 and over increased 3.4 times from 4.47 million to 15.05 million between 1960 and 2000 (Ato and Tsuya, 2007). Moreover, with the rapid increase in the number of nuclear families, the number of elderly couple households and elderly single-person households increased 15.3 times from 260,000 to 3.98 million and 13.2 times from 230,000 to 3.03 million, respectively. The ratio of households with relatives aged 65 and over (elderly couple households and elderly single households) to the total number of households increased from 20.1% (1.2% and 1.0%) to 32.2% (8.5% and 6.5%) during the same period (Ato and Tsuya, 2007).

As the population ages, the absolute number of elderly households and their share of the total number of households will continue to increase. According to estimates by the National Institute of Population and Social Security Research, the number of elderly single households is expected to increase 2.3 times from 2000 to 2025, reaching 6.9 million households, and the percentage of total households will increase to 13.7% (Ato and Tsuya, 2007).

Such changes in the population size and structure will have great impacts on infrastructure planning. The challenge is maintaining a large amount of infrastructure in a period when finance, population and bearers cannot be secured. In addition to these population and financial constraints, the demand (expected value) for infrastructure is increasing, contributing to a society with reduced environmental impact and strengthening earthquake resistance. As a result, the infrastructure has been improved about 40 times since the 1950s (CAO, 2007). However, in the future, the working-age population, which will decrease to near the postwar level, will have to proceed with renewal and improvement of infrastructure maintenance while considering the issues of ageing and environmental improvement. The following sections discuss the difficulty of future infrastructure planning in Japan from the aspects of demand, funding and bearers.

Demand decreases

As the population declines, the number of infrastructure users may decrease unless the number of foreign visitors increases significantly. Normally, infrastructure is designed by judging the demand forecast that occurs during the service period of the infrastructure (assuming 30 to 50 years, etc.) and the result of cost-benefit based on it. It is effective in an era of stable economy and rising population. However, it is difficult to forecast medium-to-long-term demand as the population declines and the economy shrinks. In that sense, it was difficult to predict the subsequent population decline and economic stagnation of roads, airports, ports, etc. that were improved in the latter half of the 1990s. In this way, infrastructure developed on the premise of growth may become over-supplied at the stage of population decline, and it may cost a lot of funds and labour for maintenance.

In Japan, infrastructure has been developed to close the population and economic disparities between urban and rural areas. Therefore, the more difficult the economic situation is, the more infrastructure is accumulated. However, in the future, there is a dilemma that the population will decrease more in rural areas where such infrastructure is intensively developed than in urban areas. Therefore, in those rural areas, the economy and society will be forced to operate in a more difficult financial situation while having an excess infrastructure compared to its shrinking population.

Reduced financial support

Until now, funds for infrastructure improvement have been mainly implemented through public investment. The resources are covered not only by tax revenues but also by borrowings from future generations, such as government bonds and local bonds. First of all, government agencies have to pay back these huge debts. Given that the population will continue to decline in the future, Japan cannot expect a significant increase in tax revenues. The five national taxes, which are the source of local taxes and local allocation taxes, have fallen due to a sharp decline in personal income and a sharp deterioration in corporate profits. The public debt costs have remained high due to past debt repayment.

In addition, the impact of institutional reforms that have supported policy finance is also significant. For example, due to the FILP reform, which started in 2001, the obligation to deposit postal savings and pension reserves was abolished. Moreover, by making the principle of voluntary procurement of FILP agencies that carry out financial investment and development of infrastructure, the proportion of funds supplied with public credit is declining. Due to such a decrease in monetary funds, the government may be unable to cover future infrastructure renewal and maintenance costs. When renewal investment falls below financial resources, the challenge is how the government will cover and deal with this excess.

Shortage of technical human resources

Experienced engineers are required because infrastructure planning and management still depend on the human experience. However, the number of technical personnel in the public affairs sector is decreasing year by year, according to the plan to reduce the number of local public servants. According to the “Results of Survey on Capacity Management of Local Public Employees” published by the Ministry of Internal Affairs and Communications, the number of civil engineers, which was 88,831 in 2004, decreased to 81,414 in 2009 (8.4% decrease). The number of construction engineers also decreased from 21,632 to 20,243 during the same period (6.4% decrease) (Kamio, Inagaki and Kitazaki, 2011).

Many engineers involved in such infrastructure often belong to local governments or public interest companies. There are many high school and technical college graduates in the public sector, and the weight of the elderly is high. In addition, future estimates of the number of production processes and labour workers in the public affairs sector and the electricity, gas, heat supply and water services sectors show that the number of workers will gradually decrease and the ratio of older people will increase (Kamio, Inagaki and Kitazaki, 2011). Therefore, it is necessary to carry out long-term and time-consuming efforts, such as recruitment, training and succession and medium-to-long-term measures, to retain technical and skill-related human resources from this stage.

5.3 - Comprehensive National Development Plans

Since the World War II, Japan's infrastructure development has been carried out in connection with economic planning. The Comprehensive National Development Plan (CNDP), which is a national land plan, was a spatial expression of a development plan for economic purposes. It was formulated from the 1st to the 5th Plans from 1962 to 1998 and stipulates the ideal state of comprehensive national land development. It is based on the National Land Comprehensive Development Law, enacted in 1950 by the Economic Council. In addition, under the National Land Comprehensive Development Law, which is a higher-level plan, long-term plans for public works were carried out, such as for roads, parks, and housing. There were also regional plans, such as the metropolitan area development plan, Kinki area development plan, and prefectural development plan.

This section considers how infrastructure development plans have changed during the age of population growth, by looking at how infrastructure development has been dealt with in these plans. It mainly targets the CNDP, which has defined the direction of infrastructure development in Japan, and focuses on the relationship between the infrastructure development plan of each era and its timeliness, spatiality, efficiency, fairness, and sustainability. This is to consider how to plan for population decline, by giving an overview of social issues and the modification of infrastructure development plans.

The Comprehensive National Development Plan, specifically, directs infrastructure development across the entire country; and, based on this, the metropolitan area development plan and the regional development promotion plan, including the regional infrastructure development, are formulated. The planning system has an upper plan, influenced by the Comprehensive National Development Plan, and lower-level local development plans. Plans for each infrastructure field are being drafted.

The following sections summarise each Comprehensive National Development Plan, while giving historical context and details of infrastructure planning at the time.

5.3.1 - The First Comprehensive National Development Plan (1CNDP)

In 1960, the National Income Doubling Plan was implemented under Prime Minister Ikeda's Cabinet. The plan proposed the Pacific Belt Zone concept as an advanced industrial location. In order to improve investment efficiency, investment needed to focus on a specific region, that is, the industrially advanced Pacific Belt region, which was formulated with the idea that it will contribute to the national economic growth of Japan. In addition, in order to utilize direct investment in production, priority was given to the enhancement of industrial infrastructure, such as roads and port facilities. The term "social infrastructure" was used for the first time in Japan's economic plan in the 1CNDP.

However, from the time of the formulation of the National Income Doubling Plan, there was concern that investment in areas other than the Pacific Belt would be postponed, leading to widening disparities. This generated fierce opposition to the plan. Therefore, in 1961, the Economic Planning Agency established the Regional Economic Issues Investigation Committee as an affiliated organization. In its report, "Regional Economic Issues and Countermeasures", it stated that it is essential to harmonize the principles of efficiency and necessity as the basic policy of national land development. In other words, development is based on investing a little social infrastructure, according to the ratio of marginal capital to income, to obtain large marginal income. This is guided by the need to balance political and social freedoms with safety and stability. It is necessary to consider the balance between these two perspectives.

In response to the above flow, the First Comprehensive National Development Plan was formulated in 1962. This was a plan to promote the underdeveloped region. The base development method was set up, and Japan's territory was divided into overcrowded areas, maintenance areas, and development areas. The government aimed to make industrial production more efficient by setting up large-scale development areas in the Pacific Belt and elsewhere.

In the 1960s, the government drew up a grand design for infrastructure development and contributed financial resources against the background of "big government". During this period, it was clear that investing in the industrial base mainly in the Pacific belt area and ensuring fairness between regions by redistributing the income obtained there would contribute efficiently to the development of the nation, and infrastructure. The targets of investment were basic infrastructure, such as established large agglomeration areas, bases in metropolises and industrial areas, and main roads and railways that connected those bases (Uto, Kitazume and Asami et al. 2013).

5.3.2 - The Second Comprehensive National Development Plan (2CNDP)

The rapid economic growth of the 1960s promoted the further concentration of population and industry in the existing agglomeration areas, and there was concern about the shortage of infrastructure and industrial land. In 1964, the Act on Promotion of Special Area Development for Industrial Development was enacted by a member of the Diet, and only the area within the Pacific Belt Zone was designated for industrial development. Under these circumstances, the new Comprehensive National Development Plan was enacted in 1969. The plan set out the basic skeleton of the infrastructure and included the nationwide Shinkansen network and a large-scale development project, and the grand design that is the basis of the current facility development was drawn.

The large scale of the plan helped bring about rapid economic growth. However, in the latter half of the 1960s, this was accompanied by increasing pollution and associated diseases, such as asthma, Minamata disease and Itai-itai disease. Around 1970, solving environmental problems became major political issues, and there were many criticisms of those policies that prioritized economic development. Then, in 1971, the United States decided to suspend the exchange of dollars and gold and to impose import charges, causing the Nixon shock.

Under these circumstances, the Kakuei Tanaka Cabinet, which advocated "the plan for remodeling the Japanese archipelago," was established in 1972, and promoted development in both large cities and regions, while being based on the 2CNDP. According to the plan, connecting the Japanese archipelago with high-speed transportation networks such as highways and bullet trains was believed to promote the industrialization of rural areas and solve the problems of depopulation, overcrowding and pollution at the same time. However, as a result of the archipelago remodeling boom, land prices nationwide skyrocketed. According to the 1986 White Paper on Land, this was caused by factors including increased demand for land for commercial and residential use, increasing urban populations, and the boom in archipelago remodelling. This was caused by speculative land demand, and the price of land rose significantly, regardless of the area or use. As land prices continued to rise, land became a target for speculation, and the land myth became established. Soaring land prices have increased the value of land assets, but have made it difficult to acquire public land and delayed the development of living-related social infrastructure. In large cities, sprawl to the suburbs progressed, hindering the effective use of land.

The 2CNDP also took over the line of the 1CNDP. Under the idea of big government, the infrastructure development plan as a means to redistribute income from urban areas to the rural areas became strong. One of the goals of the basic plan was to expand and balance the development potential to the whole country for the effective utilization of the national land. The 2CNDP stipulated that excessive biasing of national land use to some regions would lead to a decline in economic efficiency, and that each region should promote its own development planning. Therefore, the plan tried to balance the pursuit of economic efficiency with consideration for fairness between rural areas and large cities. The 2CNDP was focused on maximizing efficiency. It sought to improve the main axis of the country by prioritizing investment in developed regions, and promoting development via a ‘new network’. In addition, the 2CNDP divided the whole of Japan into blocks, and listed the development directions and projects of each area. It was a clear plan that the government should take the initiative in infrastructure development. The targets of specific infrastructure investment were mainly new large-scale industrial bases in rural areas, such as communication facilities, main air routes, bullet trains, and highways for connecting industrial bases (Uto, Kitazume and Asami et al. 2013).

5.3.3 - The Third Comprehensive National Development Plan (3CNDP)

It has become clear that the adverse effects of the rapid economic growth undertaken by 2CNDP include the deterioration of environment and the rise in land prices due to land speculation. The new comprehensive inspection work to review the 2CNDP was started in 1971, and in August 1973, the megacity and its countermeasures were announced. It was pointed out that, if the current population concentration continues in the future, Tokyo will reach its limit as a city in 1985, facing land, water, electricity shortages, traffic congestion, pollution problems, and garbage problems.

Against this background, the 3CNDP began with a review of the 2CNDP, and the main planning issues were focused on fields different from the conventional ones. It was to systematically develop a healthy and culturally comprehensive environment for human settlement, which was rooted in historical and traditional culture, and had a sense of stability and harmony between humans and nature, while making the best use of regional characteristics. In other words, while 2CNDP mentioned the transportation communication system and the construction of industrial bases at the beginning, 3CNDP put environmental issues at the beginning, followed by national land conservation and utilization (for disasters), housing, and food, energy problems, etc..
The planning period was set to show the basic goals for the next 10 years, taking into account the

review of 3CNDP and the ultra-long-term outlook for the year 2000. The actual formulation work was carried out in 1975, and the plan was formulated with the goal of 1985 to 1990. Specifically, 3CNDP set up a settlement area concept and tried to promote settlement in rural areas. Different from 1CNDP and 2CNDP, 3CNDP was not led by the national government, but was characterized by the fact that the municipalities took the initiative in implementing the settlement area concept. Regarding the direction of the development of the settlement area, the local government decided the intention of the residents based on the existing measures of the area, etc., while considering the watershed. In prefectures, it was decided to cooperate with municipalities to develop basic facilities to ensure the use and management of national land resources, the formation of transportation networks, and the stability of residence. On the other hand, in consideration of the implementation of comprehensive measures by local governments in the settlement area, the role of the national government was to promote the enhancement and strengthening of various measures for the development of the settlement area. It was reflected that, with the end of the economic miracle, the national government could no longer afford public investment.

3CNDP pointed out that it was necessary to first improve the local environment in order to establish settlements in rural areas. Specifically, according to the notification model settlement area plan formulation guidelines issued by the National Land Agency in July 1979, 40 areas for environmental improvement nationwide were designated based on requests from each region, and four areas were designated based on the intention of the National Land Agency. A total of 44 areas were targeted. However, although the settlement area concept was an idea that local governments would create a stable and safe comprehensive living environment, while making the best use of the characteristics of the area, the method taken to realize it was not much different from the conventional one conducted by 2CNDP. In other words, the designation of the settlement area by the national government resulted in a national initiative. In addition, as for the maintenance projects targeted for support measures, such as subsidies from the national government, river maintenance and infrastructure development projects for attracting factories were focused on. In response to this, factories were invited in various places for the purpose of creating employment. Along with this, land was turned over to industry, industrial water supplies, roads, harbors, sewerage systems were established, and housing was constructed.

Due to the effects of the secondary oil crisis that occurred in 1979, there was low economic growth during this period. The regional disparity in prefectural income was widening, and both the national and local governments were feeling a sense of crisis. Under such circumstances, a ‘Technopolis’ concept, modelled on Silicon Valley in the United States, was proposed in a report by the Industrial Structure Council in March 1980. In 1983, the High Technology Industrial Accumulation Area Development Promotion Law (Technopolis Law) was enacted, and development was promoted at

26 locations nationwide. The Ministry of International Trade and Industry's original plan envisioned one location nationwide with an investment of one trillion yen, but, as the regional disparities widened, nearly 40 regions applied for regional designation. The system also set subsidies for companies in terms of taxation, finance, etc., and the actual public investment was mainly for companies or industries, such as airports, highways, industrial complex development, and redevelopment in front of stations.

In the latter half of the 1970s, in the midst of the global recession triggered by the 1973 oil crisis and with the shrinking public sector, Japan was fully equipped with basic infrastructure nationwide, and the problem of fiscal consolidation became apparent. It was a time when the government reduced public investment. Against this backdrop, 3CNDP brought a new perspective to dealing with problems that had persisted since the latter half of the 1960s, such as pollution and limited resources. It introduced the idea of sustainable development. In response to the overcrowding of cities and the deterioration of the natural environment, 3CNDP reflected on the conventional idea of emphasizing efficiency, which prioritizes development that leads to the growth of Gross Domestic Product (GDP). However, at its core, 3CNDP inherited 2CNDP's attitude of ensuring fairness between regions by redistributing income, and it had a Technopolis concept with the goal of alleviating overcrowding in large cities and aiming for balanced regional development. Investment in industrial infrastructure, such as land development, based on the Technopolis concept, continued in various parts of the region. However, due to the decentralization movement, local governments were required to bear some investment burden for funding (Uto, Kitazume and Asami et al. 2013).

5.3.4 - The Fourth Comprehensive National Development Plan (4CNDP)

In the 1980s, neo-liberalism emerged internationally, including the United Kingdom and the United States, and various deregulations and the opening of the public sector were carried out toward a "small government", and the utilization of private sector vitality was promoted. In Japan as well, fiscal consolidation has become an issue since 1980. The idea of forming social infrastructure, which is the expansion of the national minimum, was changed. The privatization of public enterprises began, and the private sector business was promoted. Public investment was severely curtailed from 1981 until 1985, while investment in social infrastructure development through fiscal investment and a loan program increased.

Additionally, the Japanese economy improved from the first half of the 1980s, and the population of Tokyo began to increase again against the background of the internationalization of finance and information. The population of Tokyo had been increasing since 1982, and land prices, which had been calming since the mid-1970s, began to rise. With the rise in land demand in Tokyo, attention was focused on the development of the Tokyo Bay Area. The Nakasone Cabinet, which was established in November 1982 with a pledge of administrative and financial reform, aimed at national land development centered on urban redevelopment, while reducing the financial burden by utilizing private capital and selling public land. Under these circumstances, the formulation of the 4CNDP focused on avoiding overconcentration in Tokyo and resolving issues like ageing and internationalisation. In the 1984 interim report, a preparatory work for 4CNDP, the current situation was recognized that the centralized structure of people, goods, money, and information in Tokyo was a problem. There was an urgent need to formulate 4CNDP in order to correct this. Prime Minister Nakasone stated that it was necessary to clarify the status and function of the world city Tokyo in 4CNDP. In December 1986, the National Land Council Planning Subcommittee released an interim report of the 4CNDP. This clarified the direction of positioning Tokyo as an international financial information city and focusing on its development.

On the other hand, the local authorities across Japan raised an objection that it was disrespectful to them. Therefore, 4CNDP was further revised, and the Cabinet decided in June 1987 to form a multipolar decentralized national land that aims for balanced development of the public land, rather than finally confirming the high population concentration in the Tokyo metropolitan area. The target year of 4CNDP was set to 2000, and the basic goal was to build a multipolar decentralized land. Then, the exchange network concept was proposed as a method for constructing a multipolar decentralized land. In other words, in order to alleviate unipolar concentration and aim for multipolar decentralization, it was shown that interregional exchanges should be promoted and infrastructure development for forming networks connecting poles should be prioritized. Specifically, "improvement of transportation and communication systems for settlement and exchange" was mentioned as "formation of national land axis". The proposals also included the development of 15 airports nationwide as an international transportation network; the enlargement of 15 base ports nationwide; the formation of a high-standard main road network of 14,000 km as a domestic main transportation network; the start of Shinkansen development; and the enlargement of some regional airports. As for the development of information and communication systems, the nationwide expansion of the comprehensive digital network and regional information service. The development of communication bases and the promotion of networking of interregional systems were mentioned. As a result, 4CNDP promoted the development of local transportation and information infrastructure (Uto, Kitazume and Asami et al. 2013).

In local areas, conventional infrastructure development was promoted by public investment, while private funds were invested in infrastructure in large cities such as Tokyo. In addition to the background that the utilization of the vitality of the private sector by neoliberalism was the mainstream in Britain and the United States, there was also the background that domestic demand expanded with restrained fiscal stimulus and urban development was focused on as a private investment destination. In 1986, the Nakasone Cabinet enacted the Civil Activity Law (Temporary Law for Promotion of Specified Facility Development by Utilizing the Capabilities of Private Businesses), and private businesses further increased their presence in the public sector.

In the 4CNDP, which came into effect in 1987, in consideration of the fairness of local areas and metropolitan areas, a multipolar decentralized national land concept was proclaimed to correct the excess concentration in Tokyo. On the other hand, with the progress of internationalization, Tokyo increased its presence as an international city, and in response to the private utilization and deregulation route promoted under the leadership of Prime Minister Nakasone, Tokyo's function as one of the world's financial centres has been fulfilled. As a result, the efficiency of intensive development of Tokyo was emphasized, and the development in the Tokyo area was further promoted. In addition, 4CNDP focused on the utilization of the private sector as a new development entity and source of finance, and the way of collaboration between the public sector and the private sector. The relaxation of many urban development regulations facilitated private investment in urban development projects and real estate development. In addition, the second sector method was often adopted as an operating method. It was a time when local governments also invested in infrastructure themselves and cultural facilities, for example, were developed.

5.3.5 - The 21st Century National Land Grand Design

The collapse of the bubble economy became evident in 1991 when the Japanese economy stalled rapidly, and the government was under a huge budget deficit. In the latter half of the 1990s, the rise of East Asian countries became apparent, and there were concerns about a decline in Japan’s competitiveness. Under these circumstances, and with the 21st century on the horizon, the 21st Century National Land Grand Design (Fifth Comprehensive National Development Plan, 5CNDP) was enforced in 1998 as a completely new national land plan. The major differences to past plans were the abolishment of the wording "Comprehensive National Development Plan" from the name, that the quantitative goals for infrastructure development were no longer specified, and that the opinions of Internet users were solicited when formulating the plan.

Although the plan takes over the multi-polar decentralized land of 4CNDP, it was stated that the hierarchical structure between cities would be transformed into a horizontal network structure. In addition, as a regional cooperation axis, the plan was envisioned to organize the regions connected on the axis, and promises were made to strengthen interregional cooperation. Therefore, instead of being bound by the idea of developing a full set of infrastructure facilities in one local public body, more efficient investment in collaboration with other local public bodies in the development of national land infrastructure was promoted based on the idea of regional cooperation. Additionally, joint investment was promoted on the premise of wide-area use. This marked a major shift from the conventional policy of satisfying general infrastructure development within one local government.

Due to the influence of the development and suburbanization during the bubble period, the exhaustion of the central area of the local city was an issue, and it was decided that renovation of the urban metropolitan area had to be carried out. This was the first time that the utilization of existing infrastructure was evident in the plan. In addition, under the Koizumi administration after 2002, various deregulations were enforced in urban development, and large-scale redevelopment in the city center and on office buildings in the center of local cities was promoted.

As for the planning concept, in addition to the conventional inter-regional fairness, the intergenerational fairness of the cost burden for infrastructure development was mentioned for the first time. Furthermore, it was stipulated that the participation of various actors as maintenance actors should be promoted, and the importance of cooperation between them was indicated to improve the efficiency of national infrastructure investment. In addition to the conventional facility development, the provision of resident services was also mentioned regarding the role of the private sector. This was expected to not only contribute funds to private companies but also share the business risks, and the private finance initiative method has become active. In addition to the local public bodies that have been mentioned since 3CNDP, 5CNDP highlights the importance of establishing a system for resident participation and consensus building regarding the planning entity. In addition, the scope of what the "private sector" refers to has expanded: whereas up to 4CNDP it mainly referred to companies, with 5CNDP it has also come to include local sectors such as residents. Furthermore, due to the financial difficulties of the government, efficiency has come to be discussed from the perspective of "how small investment can make a big difference." (Uto, Kitazume and Asami et al. 2013).

5.3.6 - National Spatial Strategies

In the 2000s, due to the rapidly declining birthrate, an ageing population, and the decline in the superiority of Japanese industry in the world as a result of economic globalization, a sense of crisis about the existence of the regional economic base began to emerge. Under these circumstances, the National Spatial Strategies were formulated with the aim of "National Spatial Strategies for Improving the Quality of Land Suitable for a Mature Society with a Declining Population." The main policy of the new national land plan is to carry out the wide-area regional plan with the aim of correcting the unipolar and uniaxial national land structures. To put this policy into practice, local governments are required to have the authority and financial resources to implement measures necessary for regional management under their own choice and responsibility, and they are strongly in favor of decentralization.

Regarding the infrastructure development plan, while exchange and cooperation with East Asia are emphasized, the strengthening of international ports and metropolitan area base airports is mentioned as a way to play a part in the Asian gateway. In addition, since the Koizumi administration was established in 2002, many large-scale redevelopments have been carried out in both the city centers and central areas of local cities under active deregulation. On the other hand, it is also characterized by the fact that the investment target is not limited to the conventional area infrastructure, but also includes the barrier-free undergrounding of utility poles, landscape repair, and greening, to name but a few, that help improve the quality of life.

The biggest difference between the National Spatial Strategies and the previous plans is that the role of citizens as the main body of infrastructure development is increasing. It has been claimed that this is necessary to secure a “new public” carrier and improve the activity environment, and it is expected that every citizen becomes a carrier of public services around them. Regarding infrastructure, it has been suggested that there should be an increase in maintenance and renewal investment to cope with the deterioration of facilities. But while this is technically the responsibility of the national and local governments that own the facilities, it is required of stakeholders, such as local residents, to expand the national infrastructure management in which it voluntarily and actively participates. In addition to the conventional private sector, the National Spatial Strategies suggested new measures to secure funds, such as mini public offering bonds, NPO banks, community funds, and town development funds as "small funds circulation."

Furthermore, it is stipulated that the role of local governments will shift from focusing on self-directed efforts such as attracting factories to emphasizing the initiative and business mindset of the private sector. This implies that the government will be unable to take care of the region as it has in the past. The National Spatial Strategies also touch on the need for technology inheritance across generations, which is an issue that did not exist in the past. In addition, the concept of national infrastructure stock management was introduced as a maintenance method, and the importance of optimizing and prioritizing investment in an ageing infrastructure has been highlighted.

Economic efficiency has been consistently prioritized in terms of its significance in Japan’s infrastructure planning. The difference is that up to the 4CNDP, the idea of prioritizing infrastructure development, which contributes to economic development, and distributing the income as the economy develops was the basis, but since the 5CNDP, the financial resources of the public sector have become tighter, so that the focus of efficiency has shifted to investment efficiency, which is to achieve a large result with as little investment as possible.

At first, the issue of fairness in infrastructure development was between big cities and regions. The policy was to distribute the income of metropolitan areas to rural areas, but there were times when the investment target was oriented towards metropolitan areas. In 5CNDP, intergenerational equity was newly added as an issue for consideration. This is because the problem of the declining birthrate and the ageing population had become apparent under the declining population, making it necessary to consider the appropriate beneficiary burden to equitably share the costs between the current generation and future generations in infrastructure development.

Sustainability in infrastructure development is another issue that has been discussed relatively recently. In the latter half of the 1960s, the limits of urban growth were becoming apparent due to the problems of pollution and overcrowding in urban areas. Then in the 1973 oil crisis and the subsequent recession, 3CNDP emerged with the idea that development sustainability could be said to have sprung up, such as "the finiteness of national land resources" and "the inability to sustain high economic growth."

In 4CNDP, environmental sustainability was mentioned from the point of view that the benefits of the environment should be enjoyed sustainably; thus the expression, "sustainable use of the land," appeared for the first time in 5CNDP. The 5CNDP also emphasized the importance of sustainability in a wide range of fields such as the natural environment, agriculture, energy, and industry. Furthermore, in the 2008 National Spatial Strategies, the sustainability of infrastructure maintenance was mentioned not only from the perspective of the sustainability of national land use but also from that of cross-generational sharing of financial resources and human resource development. In addition, the National Spatial Strategies considered the need to respond to the increase in maintenance and renewal investment to cope with the ageing of infrastructure, and the plan focused not only on new infrastructure but also on the maintenance of existing ones. In the beginning, discussions on environmental aspects such as pollution and resources were the main focus, but recently, technical discussions have also been added.

During the population growth period, improving the infrastructure development rate is the mission of the infrastructure development plan, but the future infrastructure development plan in the depopulating society has been the maintenance of the existing ones, and considering which aspects should be the target of the maintenance becomes more important than constructing new infrastructural facilities. The main focus is on planning to determine the area of selection and concentration.

Also, in the past, it was considered good to build a heavy, long, sturdy and long-lasting infrastructure. However, as population decline is occurring locally, and considering that its rate and the speed of ageing infrastructure do not always match, it is necessary to consider infrastructure development with minimum specifications in near future. The minimum specs mean that infrastructure that can be shared beyond the boundaries of local governments should be shared and managed on the premise of wide-area cooperation proposed in the National Spatial Strategies; it also means that the infrastructure required for each specific area should be of a scale that can be maintained and managed within the area. Infrastructural facilities should be designed for short-term use of about 10 to 20 years so that they can be easily reduced when the local population decreases, but the quality should not be compromised to guarantee minimum safety.

On the contrary, decentralisation has, in recent years, been a topic of active discussion. When authority and financial resources are handed over to local areas, local infrastructure suffers a decrease in users, and it is difficult to bear a considerable amount of infrastructure maintenance costs with a small number of users, whether downsizing or renewing. On the other hand, the number of users of infrastructure in metropolitan areas does not decrease as much, for which it is cost-effective renewing the infrastructure with the same number of users at present. For this reason, decentralisation of infrastructure development in an era of depopulation will eventually increase the burden on local governments. It is important to consider the needs and burdens of each district to minimise unnecessary construction of new and renewal of existing infrastructure. It is also important to develop the necessary infrastructure nationwide with a certain amount of equal burden to make possible the realisation of the freedom of residence guaranteed by the Constitution. For this reason, the challenge is how to balance the partial optimisation centred on the regions with the overall optimisation of the entire country. It will be necessary to float funds in metropolitan areas and then send them to local areas while aiming for overall optimisation. At this time, it is also important not to create regional gaps in service levels, such as clarifying the national minimum and promoting downsizing.

In this way, the infrastructure development plan in the era of population decline is based on optimising the level of infrastructure development, including spec down, shortening the useful life of infrastructure while focusing on maintenance and management, observing population trends when renewing and manageing the gap between infrastructure capacity and infrastructure service demand. This gap management requires the management of spatial planning (Uto, Kitazume and Asami et al. 2013).

5.4 - The Prospects for Future Infrastructure Planning

The above sections summarise the historical transition of infrastructure planning policy in Japan. The following sections discuss changes in the socio-economic environment surrounding infrastructure and the prospects for future infrastructure planning. As Japan's infrastructure enters the consolidation stage from expansion, it is time to consider the next form of infrastructure capable of responding to population decline, ageing and environmental problems. Because Japan is the first country in the world to experience a nationwide population decline, it is an opportunity to change Japan's society and economy by actively changing its infrastructure.

In Japan, infrastructure facilities built during the period of high economic growth are ageing. It goes without saying that tangible things grow old, and in the case of Japan, the ageing of infrastructural facilities occur intensively in a short period. The country first invested intensively in infrastructure from 1955 to 1970. During this period, in mainly metropolitan areas such as Tokyo, Osaka and Nagoya, residential and industrial roads, water and sewer pipes, water purification plants and sewage treatment plants, public rental housing, public schools, etc., grew rapidly. These developments prepared the country for rapid urbanization. Since these facilities' useful life is set at 30 to 50 years, the renewal time expired around 2010 (Kamio, Inagaki and Kitazaki, 2011).

Since then, investment in the road sector has increased due to high economic growth and steady promotion of the Comprehensive National Development Plan in the 1980s and 1990s. Public investment expenditures influenced the efforts due to economic measures since the 1990s, and the investment amount steadily increased until the 2000s, which can be seen by comparing the amount of investment in infrastructure with the number of births. On the one hand, the number of births in Japan peaked at 2.1 million in 1973 and has since declined to just over 1 million in 2000. On the other hand, the amount of infrastructure investment in 1973 was 12.3 trillion yen, but the peak was in 1995 – with about 32 trillion yen – which is 20 years behind the peak of the number of births. This mismatch poses a major challenge to infrastructure planning (Kamio, Inagaki and Kitazaki, 2011).

According to the data of the Cabinet Office, when the investment amount after 30 years is accumulated on a nationwide basis, the ageing infrastructure accounts for more than 30% of the total while the ratio of the infrastructure that has reached 30 years is still increasing. Notably, the percentage of infrastructure that has passed 30 years is higher in metropolitan areas – such as Tokyo, Osaka and Nagoya – than in other prefectures (CAO, 2007).

According to a Tokyo Metropolitan Government survey, the percentage of infrastructure constructed in the 1940s and 1950s, that is, infrastructure over 30 years old, make up about 43% of bridges (road bridges), 46% of public housing and 70% of the port facilities. Tokyo is working in the direction of repair and renewal. However, some infrastructures begin to deteriorate in function and service after 30 years of construction. For example, when the Ministry of Land, Infrastructure, Transport and Tourism investigated the collapse of the sewer pipes in 2009, it was found that the number of collapsed pipe increased rapidly 30 years after the laying. In this way, infrastructure ageing has been steadily worsening, and it is time to consider 30 years as a turning point for ageing infrastructure and start taking immediate steps (Kamio, Inagaki and Kitazaki, 2011).

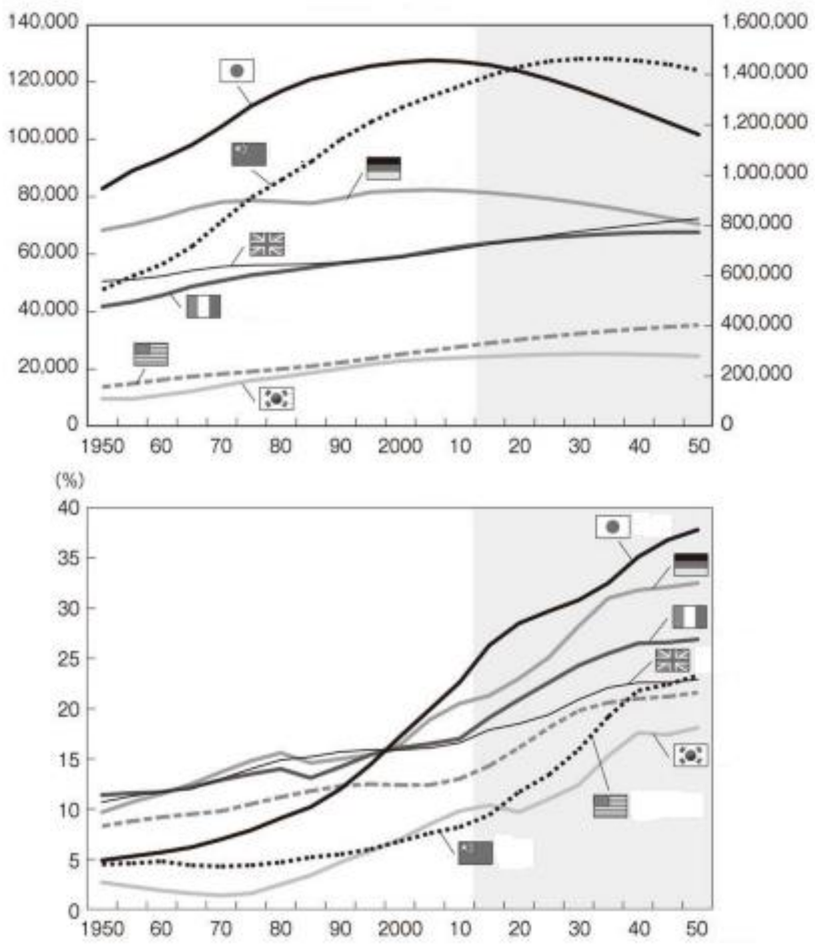
With regard to the cost of renewal for ageing infrastructure investment, it is estimated that the cumulative amount up till 2050 will reach about 500 trillion yen while the maximum annual cost will be 20 trillion yen (CAO, 2007). Since infrastructure has been intensively invested at specific times, the renewal will increase sharply around 2030 and 2040. It is difficult for the current level of public investment to cover this renewal cost with only government spending. This is not the only cost that should be dealt with in the future. Expenses for demolition, relocation, compensation, etc. of the facilities must also be calculated.

The cost of building renewal is about 1.1 times the amount of new investment, and the cost of renewing bridges is about 3 times that of new investment because performance improvements such as widening and earthquake resistance must also be implemented (MLIT, 2005). Therefore, it is difficult to easily demolish and create new facilities one after the other. Looking at the outlook for renewal by infrastructure field, the peak of renewal of living infrastructure such as water and sewage will appear first, followed by the second peak of public facilities and that of national land conservation infrastructure. It is then expected that the peak of domestic network infrastructure centred on roads will be prioritized. This is just a trial estimation, and it is difficult for symptomatic treatment to respond when the need for renewal arises. Government agencies have to deal with it in advance to some extent.

A unique issue for Japan is that infrastructure accumulation and population decline coincide. There isn’t such a problem in western countries, i.e. with long-established infrastructure and many structures with a history of hundreds of years. Japan is the only country that has the worst debt among the G7 countries, with a general government debt-to-GDP ratio of 192.9 (2009). Not many countries will face a rapid population decline and ageing in the future. Japan, which has an infrastructure stock of more than 700 trillion yen, will face severe environmental changes (Kamio, Inagaki and Kitazaki, 2011).

Figure 5.1 shows the population trends and future trends of ageing in the major countries of the world. The speed of ageing is remarkable in Japan, Germany, France, the United Kingdom and the United States. It is expected to almost double the speed in future. On the other hand, only Japan and Germany are expected to have a declining population in the future. In particular, Japan is the only developed country that may experience rapid population decline and ageing by 2050. Germany will experience ageing and population decline just as in Japan. But once it experienced population decline in 1970, the degree of decline after 2010 was highly gradual compared to Japan. In France, the population is expected to continue to increase, although the population is ageing, partly due to the recent increase in the birth rate. In the United States, the population, including immigrants, is still increasing. However, in China and South Korea, it is predicted that population decline and ageing will occur at the same time for about 20 to 30 years behind Japan. In particular, China will experience the same rapid population decline and ageing as Japan. Therefore, Japan will be required to play the role as a developed country that solves infrastructure planning issues in advance under the burden of population decline and ageing for China and other Asian countries.

Figure 5.1 – Population Trends and Future Trends of Ageing



Source: Kamio, Inagaki and Kitazaki (2011)

Considering the future of Japanese society, maintaining or renewing the infrastructure that has supported the country’s growth and has accumulated on the premise that Japan will continue to grow will be difficult. Although it is essential to make the existing capital last as long as possible, it is necessary to make major changes in the form of infrastructure, the method of providing services and the method of management and operation while looking at the future socio-economic environment. From now on, Japan has reached a turning point in nation-building in various ways, such as financial deterioration, changes in regional structure and population decline. It is necessary to redesign to match such a turning point. Through the redesign of social infrastructure, acting as a catalyst, it can be expected that all social systems – such as Japan's economic and business structures, people's working styles, public-private relations, public organizations and financial systems – will change.

Moreover, Japan's capital stock is not fully utilised in economic activities. There is an indicator of a country's GDP divided by that country's capital stock. In other words, it is a measure of the efficiency of 'how much added-value (GDP) can be generated by the input (total amount of capital stock) required for economic activities.' This value is relatively low in Japan, among other developed countries. For example, the ratio of nominal GDP to total capital (stock amount) in 2008 was 1.06 in the United States, 1.19 in the United Kingdom, 1.05 in France, and 0.87 in Germany. While the rate of each country has been moving around 1, Japan has a low value of 0.54 (Kamio, Inagaki and Kitazaki, 2011). This is either because the capital stock is too large compared with the same GDP or because the GDP level is much lower than the level of the capital stock.

On the other hand, Japan has more than doubled the ratio of infrastructure stock to total capital stock compared to Germany and the United Kingdom. According to the national accounts, the value of government assets in Japan in 2008 was 355 trillion yen, which amount to 280,000 yen per capita of the total population. Japan's government asset is smaller than the United States (equivalent to 330,000 yen per capita) but higher than European countries such as the United Kingdom (equivalent to 190,000 yen) and Germany (equivalent to 160,000 yen) (Kamio, Inagaki and Kitazaki, 2011).

Considering the relationship between the rate of population decline and infrastructure planning, it is observed that problems in infrastructure development become apparent when the population decline occurs at an annual rate of around 0.5%. Many Japanese municipalities, where the population decline rate exceeds 1% annually, are local communities with dwindling populations, or small and medium-sized cities in local areas rather than the metropolitan areas in Pacific Belt (Kamio, Inagaki and Kitazaki, 2011). The impact of population decline on infrastructure planning is not a problem for large city municipalities but a problem for small and medium-sized municipalities.

For a region with a declining population and excessive infrastructure to respond to the declining population, the following measures can be taken: Decide which infrastructure to keep (considering the scale and density efficiency); gather people to live around the infrastructure, and remove the infrastructure that is no longer needed.

Infrastructure planning in the era of depopulation needs to be discussed not only for the sake of improving infrastructural facilities but also for population allocation. Just as infrastructure development was centred on industrial infrastructure development in the era of population growth and was linked to industrial policy, even in the era of population decline, its development plans should continue to be integrated with industrial promotion measures, land use plans, and city planning. However, it should be noted that as the overall population is declining, infrastructure development based on excessive expectations will exceed the financial burden capacity of regions.

In a discussion about spatiality, it has been pointed out that it is more efficient to reduce the end of the network infrastructure such as water and sewage than to reduce the middle of the network at the time of reduction (Koziol, 2004). Furthermore, the spatial layout of urban areas should be reorganized to improve the efficiency of infrastructure service supply, such as arranging decentralised urban areas on a linear network and promoting rebuilding in highly convenient areas. The importance of this has also been noted by Uemura (2014). It has been observed that the conventional slogan “More green, less density” is inappropriate in the era of depopulation, for it is necessary to lead to a higher density city from the viewpoint of infrastructure (Schiller and Siedentop, 2006).

These countermeasures should be introduced not only individually but also in combination. For example, it is necessary to downsize network infrastructure and housing in an integrated manner, for, in many cases, large-scale retirement has better results than total removal (Just 2004). In addition, it is important to restore the over-expanded city to a compact form, change the idea of quantitative expansion of social infrastructure, but effectively use the existing ones, and harmonize with the natural environment the production of green areas (Tanbo, 2002). Hoornbeek and Schwarz (2009) argued that there is a possibility of cooperation between types of infrastructural facilities. By removing the road pavement, it is not necessary to collect rainwater, reducing the amount of energy used by relying on public transportation, and minimizing the expansion of the water supply service area will lead to the reduction of energy consumption.

The countermeasures against the impact of population declines are, in the end, efforts to flexibly respond to the continuous changes in demand caused by the population declines, with the infrastructure that is difficult to change temporally and spatially. How to give flexible space planning management to hard infrastructure development will be a necessary viewpoint for infrastructure planning in the era of population decline.

5.5 - Summary

This chapter summarises the changing process of Japan’s population and reviews the infrastructure planning-related policies in the country. On this basis, the social and economic environment of future public facilities planning is discussed, which provides background knowledge and a factual basis for the subsequent analysis chapters. For the first time in human history, Japan faces the challenge of dealing with its massive ageing infrastructure in the era of depopulation. Why is it difficult to properly maintain, repair and renew ageing infrastructure under the context of depopulation? The answer lies in the fact that infrastructure has been increased and expanded on the premise of growth while the population and households are currently declining.

1. Infrastructure combines durable materials such as concrete with machines and information systems in large scale. Therefore, it costs more than a certain amount to repair and demolish while observing the financial situation. Furthermore, there is a view that the life of the concrete structure that supports the infrastructure is semi-permanent in the case of a dam, for example, and it may last for a long time beyond generations. Therefore, it is difficult to demolish once the facility is maintained in terms of cost and environment. In this way, considering such characteristics, it is necessary to consider the shape of infrastructure in preparation for the population decline.

2. Infrastructure is difficult to eliminate if there are people who use it, and even if it is partially destroyed or reduced, it is still necessary to consider the continuity of services. Also, the existence of infrastructure itself has a great impact not only on the people who use it but also on the surrounding environment and the local economy. Hence, it is necessary to hear the opinions of various residents and stakeholders in order to improve or abolish it. Thus, it takes a lot of time to reach a consensus.

However, Japan's infrastructure has not always been developed at a constant speed. Rapid investment has been made since the period of high economic miracle, and maintenance has been carried out fairly rapidly. Therefore, dealing with the ageing of the already accumulated infrastructure is a serious issue. Government agencies need to continue to address this challenge for years to come. In other words, the population will continue to decline for at least the next 50 years and shrink to the same level after WWII (Kamio, Inagaki and Kitazaki, 2011). Therefore, it is necessary to redesign the amount, shape and mechanism of infrastructure suitable for changes in the social environment over the next 50 years.

Owing to economic growth and population expansion from the high-growth period to the beginning of the 20th century, the lives of Japanese people have changed drastically, including improved lifestyle, extended lifespan and the evolution of nuclear families. In the imminent period of population decline, the demographic structure will change notably owing to the increasing elderly population and declining birth rate. This is expected to have a major impact on the lives of Japanese people again. Thirty years in future, when the elderly people will constitute 40% of the total population and one-person elderly households will account for 20% of the total households in Japan, how will the elderly be empowered to lead a healthy life? How will the children, who will bear the future of Japan, receive quality education? How will uninhabited houses be managed to ensure an efficient social environment? Undoubtedly, it is necessary to actively plan the future while considering the social problems caused by changing population dynamics.

In a society with declining population, reports have demonstrated negative effects of the decrease in population size and in the number of households, such as an increase in anxiety levels in the elderly population about living conditions, consolidation of schools owing to a decrease in youth population and an increase in uninhabited houses and lots. However, contrary to economic fluctuations and disasters, changes in population dynamics will continue in the coming decades. The advent of population decline will also provide an opportunity to review the systems and mechanisms based on population growth during the high-growth period that have already resulted in institutional fatigue, and to remodel those suitable for a mature society. By actively preparing for issues expected to become more apparent in the future, government agencies will not only have the choice of inciting positive demographic changes but also of creating new values to achieve sustainable development.

CHAPTER 6

SPATIAL ACCESS TO ELDERLY CARE SERVICES AND ITS EQUITY - A CASE STUDY IN SENDAI CITY

6.1 - Introduction

As discussed in Chapters 1 and 5, Japan is facing rapid population decline and an increase in the ageing population as opposed to births. Government projections indicate that the elderly population and the rate of ageing will continue to increase. Estimates from 2025 onward show that the absolute number of the elderly population itself will not change significantly, but the proportion of the elderly to the total population will increase to reach nearly 40%. While the demand for medical care and elderly care will increase as a result, the working population will decrease, and such a change will have a great impact on the medical and elderly care sector, as it is expected that the supply of services will be insufficient for meeting the demand.

However, by 2035, when the baby boomer generation reaches the age of 85 or grows even older, Japan's elderly care needs, which are likely to keep rising till then, are expected to follow a downward trend (there might be differences in the exact timing due to population changes in each region). Thus, elderly care in Japan is expected to face two major eras: the era of 'increasing needs' and the subsequent era of 'decreasing needs'. In addition to changes in the population structure, advances in medical technology are also changing the face of elderly care services. In this situation, providing efficient and fair elderly care services becomes particularly important.

This chapter explores the spatial fairness of the delivery of elderly care services through an accessibility analysis conducted in Sendai City. The purpose of this analysis is to measure the accessibility and equalisation level of the delivery of elderly care services from demographic and spatial perspectives and then identify areas with a shortage of elderly care services, which suffer from a lack of spatial equalisation in terms of obtaining public services. The findings of the analysis were processed via ArcGIS by applying the improved gravity model. The outcomes of the analysis provide suggestions on improving the planning and layout of regional elderly care facilities from demographic and spatial perspectives. The findings also improve our understanding of spatial layout theories (discussed in Chapter 3) and make the organic integration of geospatial simulation and infrastructure planning easier.

This chapter consists of the following sections: Section 2 discusses the reasons for selecting Sendai as the analysis object by introducing the current status and future trends of ageing in the city. Section 3 shows the current distribution patterns of elderly care facilities in Sendai. Sections 6.2 and 6.3 provide some context for subsequent analysis. Section 6.4 presents the data set and the models applied in the analysis. This section also shows how the traditional gravity model was developed in this study, which was done to obtain results with higher precision. Section 6.5 presents the findings, the outcomes of which are visualised via ArcGIS to identify the areas experiencing service shortages. Section 6.6 interprets the results of the analysis against the background of the socio-economic situation of Sendai. Finally, Section 6.7 provides a summary of the chapter by providing a scientific base and reference points for the planning of future elderly care facilities in the context of depopulation and ageing.

6.2 - Ageing in Sendai

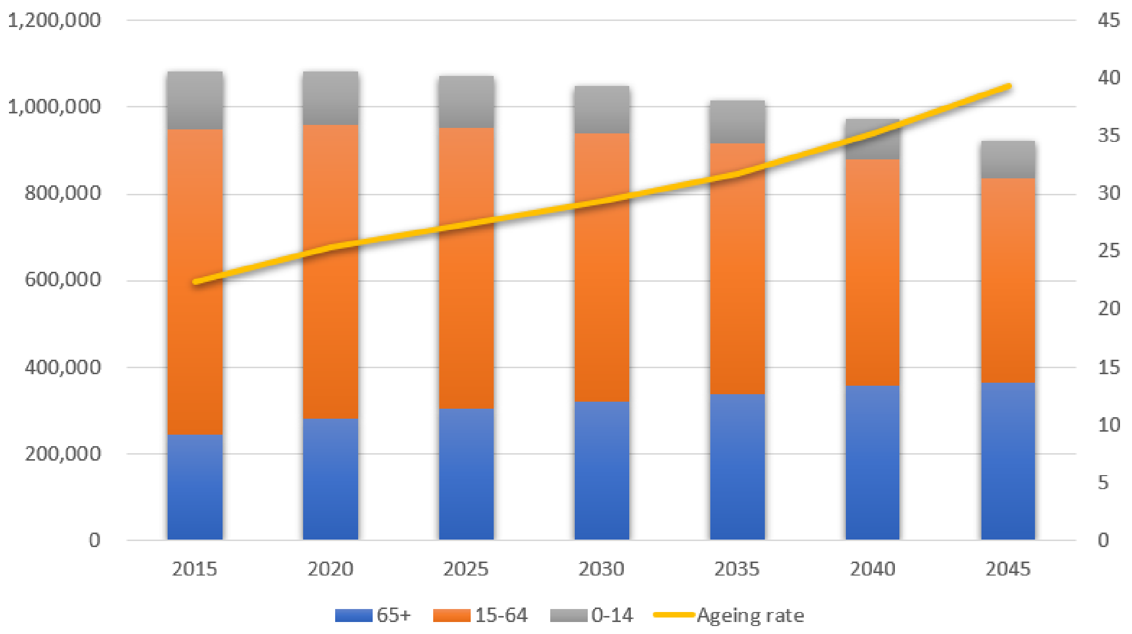
According to the census released by the Ministry of Internal Affairs and Communications (MIC, 2015), the total population of Japan was approximately 127,090,000 on 1 October 2015, which was approximately 962,600 less than the population in 2010. From 2010 to 2015, 40 out of 47 prefectures experienced a decline in total population, and further considerable depopulation is expected in the near future. In particular, a sharp decline is predicted for the population aged 75 and above nationwide, which is expected to peak in 2050. Presently, the quantitative expansion of elderly care facilities has been carried out in accordance with the increase in the elderly population. However, due to the aforementioned changes, it has become necessary to shift to an intensive scale of elderly facilities, that will cater for the provision of care services to the increasing elderly population to be served.

Figure 6.1 – Sendai City

Sources: https://www.tohokuandtokyo.org/route_23/

Sendai City has a total population of 1,082,000 (estimated in 2015), an area of 786 km^2, and a population density of 1387 people/km^2. The total population is expected to decrease to 1,072,000 in 2025 (1% less than in 2015) and to 920,000 in 2045 (14% less than in 2025). Similar to national trends, the rate of ageing is advancing in Sendai. On 1 April 2017, the elderly population aged 65 and above was 239,903 (as compared to 233,525 in the same period of the previous year), accounting for 22.8% of the total population (22.2% in the same period of the previous year). Additionally, the number of people aged 75 and above is predicted to increase from 299,000 in 2015 to 385,000 in 2025 (a 29% increase from 2015) and to 429,000 in 2040 (11% more than in 2025). Owing to the decrease in the young and working-age populations, the proportion of the population aged 65 and above among the total population will continue to increase and will reach 27.4% in 2025 and 35.2% in 2040. However, Sendai is expected to experience a decrease in the prevalence of this age group after 2050 (Department of Statistical Analysis, Sendai, 2017).

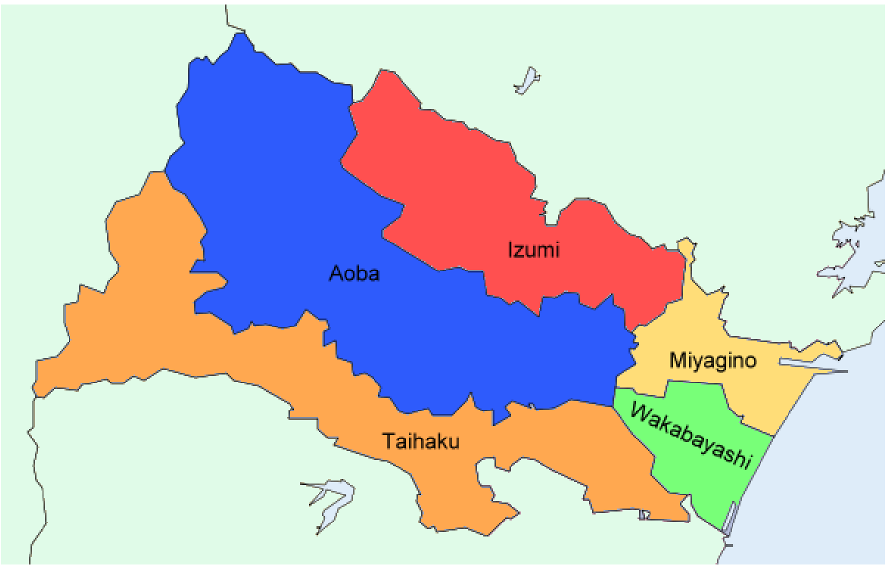
Figure 6.2 – Ageing in Sendai



Sources: National Institute of Population and Social Security Research, 2018.

According to estimates by the National Institute of Population and Social Security Research, the ageing rate of all five wards in Sendai are below the national average (27.3%). In particular, the rate of ageing is advancing in Taihaku (23.8%) and Izumi (23.8%), followed by Wakabayashi (22.3%) and Aoba (21.8%). Miyagino (21.2%) has the lowest ageing rate in the city; it is 2.6% lower than that of Taihaku and Izumi, thereby resulting in a small regional difference in the ageing level.

Figure 6.3 – Sendai Wards

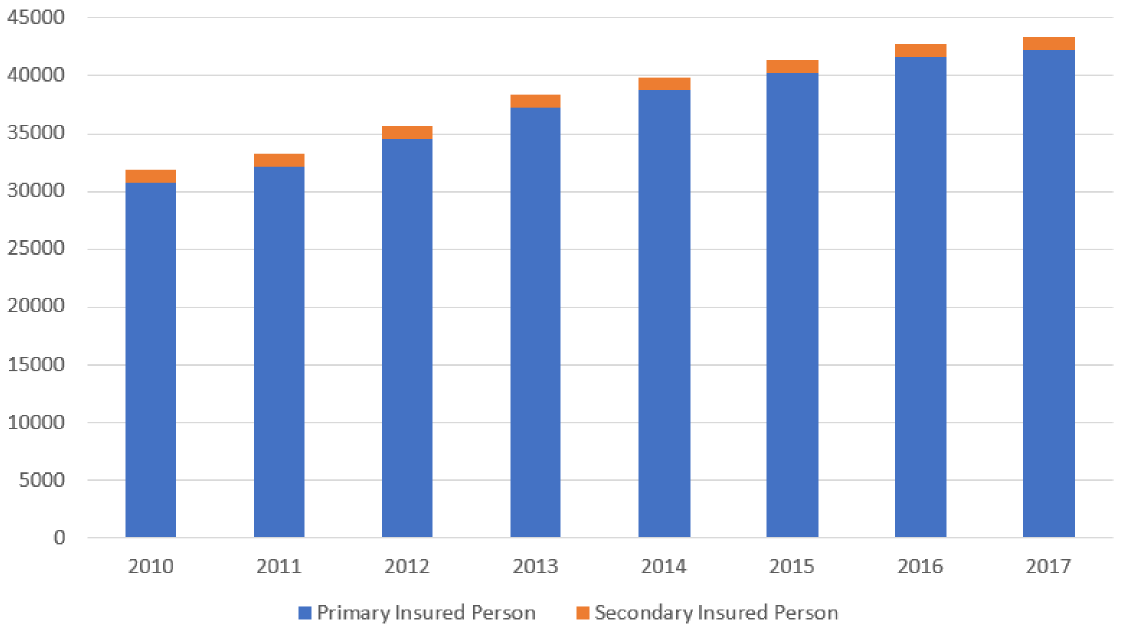


Sources: https://www.armedconflicts.com/Sendai-20185-21488-24066-t123709

In terms of junior high school districts (a standard point of reference for official care services area settings), the rate of ageing is the most advanced in Koryo (39.5%), followed by Hitokita (38.8%) and Choumeigaoka (37.4%). Moreover, in some of the areas devastated by the 2011 Great East Japan earthquake, one in three people was aged 65 and over. Nanakita (13.3%) has the lowest ageing rate, followed by Tomizawa (14.3%). The ageing rate in these areas is found to be 25% lower than that of advanced areas, which shows considerable difference at the junior high school districts level when compared to the ward level. Additionally, in Sendai, the number of citizens aged 75 and above already accounts for more than 50% of the population aged 65 and above, and this has been the case since 2010 (Department of Statistical Analysis, Sendai, 2017). These figures show that there is a severe shortage of elderly care services in Sendai. The following sections detail the current situation of elderly care services in the city.

As of the end of March 2017, Sendai had 43,341 persons certified for long-term care/support needs, of which 42,304 were primary insured persons (aged 65 and above). It is expected that the number of certified persons will continue to increase further until the 2030s as the number of elderly people increases.

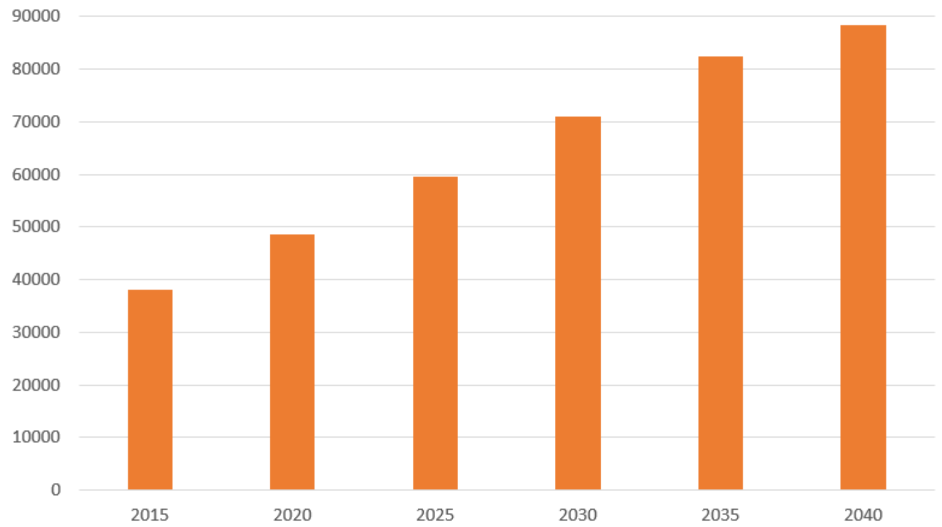
Figure 6.4 – Changes in the Number of People Certified for Long-Term Care Need



Sources: Department of Statistical Analysis, Sendai, 2017.

In terms of future estimates of the number of people aged 65 years and above suffering from dementia, assuming that the prevalence of dementia at each age will increase parallel to the increase in the prevalence of diabetes, the number is expected to be around 60,000 in 2025 and over 80,000 in 2035.

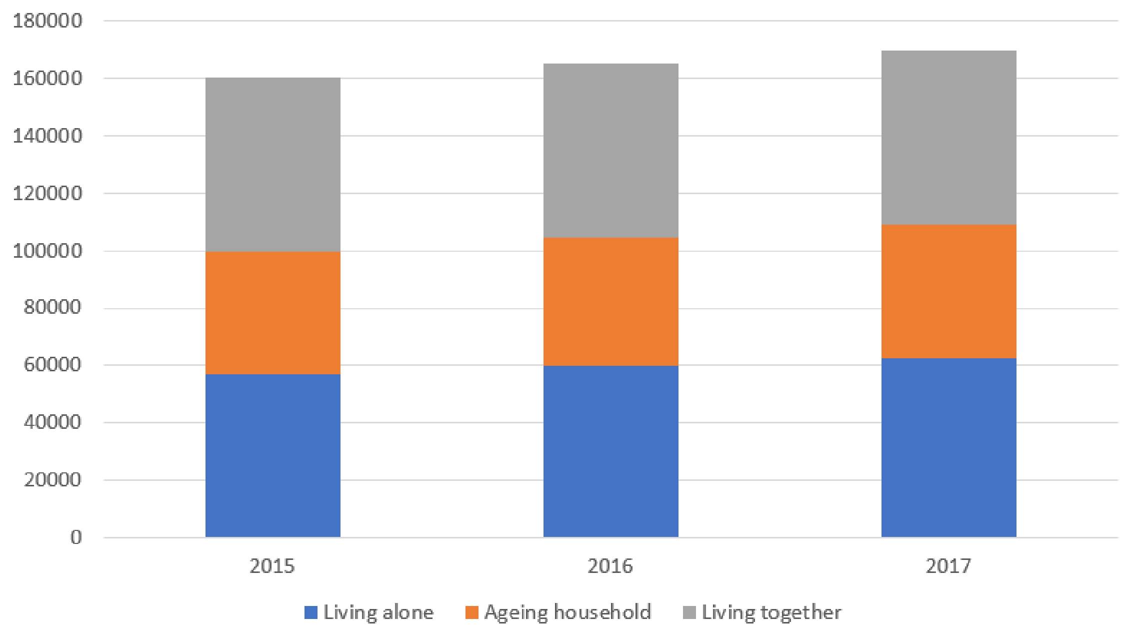
Figure 6.5 – Changes in the Number of People with Dementia Aged 65+



Sources: Department of Statistical Analysis, Sendai, 2017.

It is also noteworthy that the number of older people living alone and the number of households consisting of only people aged 65 and above are gradually increasing. As the baby boomer and baby-boomer junior generations get older, the number of elderly people will increase rapidly in large cities. In contrast, due to the current decline in birth rate, the working-age population will decrease significantly. Therefore, to prepare for an elderly population that will require increased nursing care and to respond to the rapid increase in one-person elderly households, it is important to revitalize the local community accordingly to respond to increased long-term care needs.

Figure 6.6 – Family Structure of Elderly People in Sendai



Sources: Department of Statistical Analysis, Sendai, 2017.

The per capita medical expense (National Health Insurance) in Sendai is JPY 324,000 and the per capita long-term care benefit amount is JPY 246,000 – both rates are at par with the national average. The total capacity of elderly care facilities in Sendai is 14545 people (88 per 1,000 people aged 75 and above), which is below the national average level. Among them, the capacity of long-term care insurance facilities is 9047 people, and the capacity of senior citizens' apartment complexes is 5498 people. Therefore, the capacity of long-term care insurance facilities is almost on par with the national average, but that of senior citizens' apartment complexes is below the national average. In addition, the total number of care staff is 15931 people, which is on par with the national average.

Sendai was chosen for the case analysis because it is the central city of the Tohoku area, situated between the Nakakita River and the Hirose River and close to Sendai Bay. Its geographical and economic landscape and other conditions are homogeneous, which is conducive to model construction and experimental simulation. From general to special, the Sendai case study reveals the current characteristics and development trends of urban elderly care services, thus providing a solid reference for the spatial optimisation of elderly care facilities and offering a realistic basis for further analysis.

6.3 - The State of Elderly Care in Sendai

This section presents an overview of the situation of the elderly care facilities in Sendai. The elderly care facilities in Japan are broadly divided into the outpatient type and the occupancy type. The outpatient type includes: Outpatient day long-term care (通所介護, Tsusho kaigo); Rehabilitation Day Care Service (通所リハビリテーション, Tsusho rihabiriteshon); Daytime nursing care, community-based daytime nursing care, and services corresponding to daytime nursing care (地域密着型通所介護, Chiikimitchakugata tsusho kaigo); Communal daily long-term care for dementia patients (group homes) (認知症対応型通所介護, Ninchisho taiogata tsusho kaigo); Outpatient rehabilitation preventive long-term care (介護予防通所リハビリテーション, Kaigoyobo tsusho rihabiriteshon); Preventive long-term care for dementia patients in communal living (介護予防認知症対応型通所介護, Kaigoyobo ninchisho taiogata tsusho kaigo).

The occupancy type includes: Geriatric health services facilities (介護老人福祉施設, Kaigorojin fukushi shisetsu); Long-term care health facilities (介護老人保健施設, Kaigorojin hoken shisetsu); Sanatorium medical facilities for the elderly requiring long-term care (介護療養型医療施設, Kaigo ryoyogata iryo shisetsu); Living care for persons at government-designated facilities (特定施設入居者生活介護, Tokuteishisetsu nyukyosha seikatsu kaigo); Communal-living care for dementia patients (認知症対応型共同生活介護, Ninchisho taiogata kyodoseikatsu kaigo); Community-based welfare care facilities for the elderly that provide daily care for facility residents (地域密着型介護老人福祉施設入所者生活介護, Chiiki micchakugata kaigorojin fukushi shisetsu nyushosha seikatsu kaigo); Daily life care for persons living at designated community-based facilities (地域密着型特定施設入所者生活介護, Chiiki micchakugata tokuteishisetsu nyushosha seikatsu kaigo).

In the latter half of the 1980s, many elderly care facilities started to get supplies, and this increased significantly even in the mid-1990s. It is thought that the cause of this increase was that many of them were supplied as long-term care medical facilities during that period. After the enforcement of the Long-Term Care Insurance Law in 2000, medical care beds were converted to geriatric health services facilities as a measure. Consequently, the number of geriatric health services facilities was increasing. However, since the latter half of the 2000s, as the support measures for this conversion were completed, the number of geriatric health services facilities has hardly increased. In addition, the number of welfare care facilities for the elderly (so-called ‘special nursing homes for the elderly’) increased significantly in the 1990s. However, since the beginning of the 2000s, the support measures related to the opening of the facilities, which had been generous until then, have been reduced. So there is a tendency for the number to increase slightly at the start, but basically, it does not increase much after that. The number of fee-based nursing care facilities (so-called ‘paid elderly homes’) began to increase in the 2000s, and although it is thought that quantitative restrictions have also been involved in the situation since then, the number has hardly increased recently.

In this way, although the number and scale of the occupancy-type elderly care facilities have increased significantly, the trend of support measures from the government is shifting from large-scale facilities to community-based, small-scale ones. It is thought that the overall scale will not increase as before. From another perspective, since the elderly population is likely to decrease from around 2030 at the national level, it is not a smart idea to increase the facilities' scale as much as before. The increase creates issues, such as how to respond to service needs due to changes in the scale and the distribution of elderly people in the future and how to provide efficient service as community-based facilities. The perspective of how to continue operating existing facilities effectively is also becoming increasingly important.

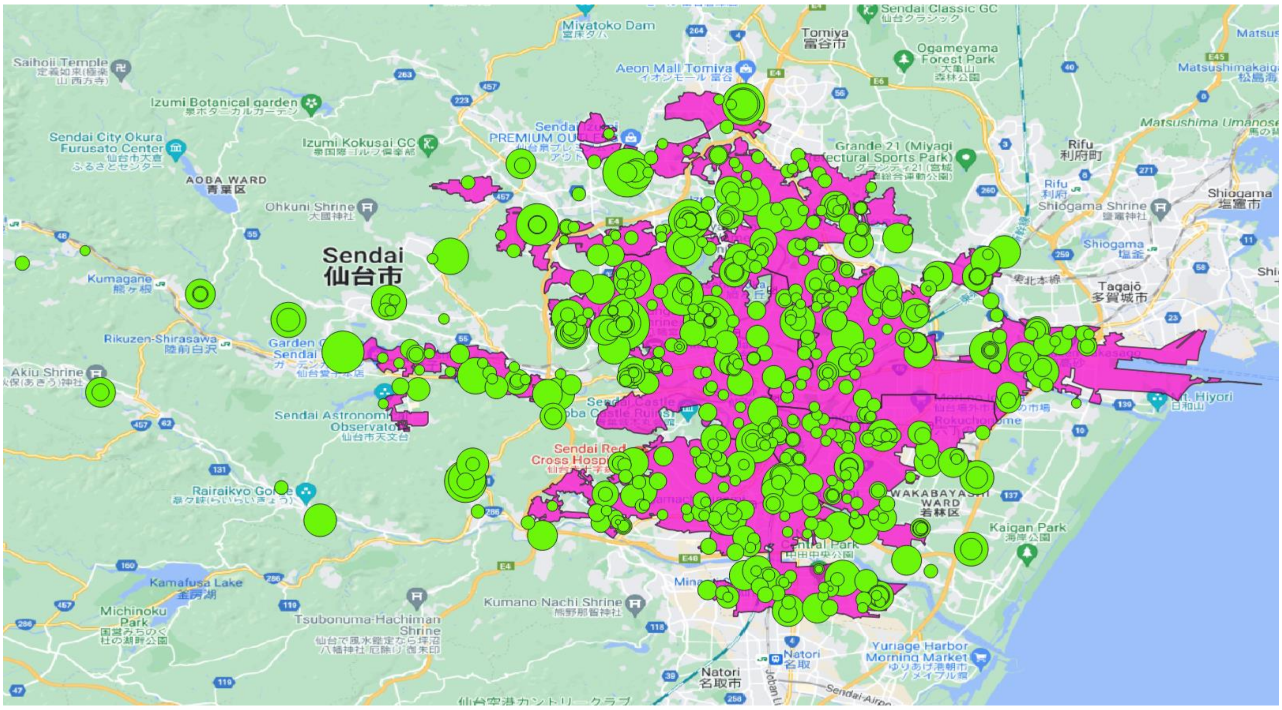
As the population of elderly people with long-term care needs increases, it becomes crucial to develop a comprehensive community-care system that provides seamless long-term medical care and prevention, housing and life-support services by expanding the social business, including improvements in the long-term care system and increased use of non-insurance services. Additionally, supporting people requiring long-term care by effectively operating the comprehensive community-care system and building a strong safety net is indispensable.

According to the 'Nursing Care Service Information Disclosure System' published by the Ministry of Health, Labour and Welfare and the National Land Numerical Information provided by the Ministry of Land, Infrastructure, Transport and Tourism, 605 elderly care facilities are located in Sendai.

After sifting through the data obtained from the NLNI database, the location of each elderly care facility in Sendai can be imported into ArcMap, thereby producing a distribution map of elderly care facilities in the city. The map shows that the distribution of elderly care facilities in Sendai is generally dense in the central area and sparse in peri-urban areas. Additionally, facilities located in the central area are generally limited in size. Most large-sized facilities are located on the outskirts of the city. This distribution is directly proportionate to the availability of land resources. Moreover, the number of facilities in the west and southwest areas is observed to be limited and scattered.

It is desirable to consider the location of the elderly care facilities according to the distribution of the elderly population, who are the target users. Currently, most of the elderly care facilities in Sendai are located in the centre of the city (Densely Inhabited Districts), and the distribution of the elderly population is large in the city centre areas. Hence, it is considered that there is no big difference in the positional relationship between the facilities and the location of the target users at the present. However, it can be seen that there are few facilities for the scale of the elderly in the peri-urban areas and the suburban areas outside the city.

Figure 6.7 – Elderly Care Facilities Spatial Distribution



Sources: National Land Numerical Information database, produced by using QGIS.

In terms of the number of elderly care facilities per 1,000 people aged 75 and above, the highest rate is in Wakabayashi at 11.72, which is slightly higher than the national average (11.31), while the rate in Aoba is the lowest (9.22), followed by Miyagino (10.55), Izumi (10.68) and Taihaku (11.27) (Japan Medical Analysis Platform, 2021). Thus, the rates in four wards of Sendai are found to be below the national average. These rates also indicate the serious spatial differences in the distribution of elderly care facilities in the city.

Due to the high density of buildings and overcrowding of land in the central areas, the service capacity of some facilities located here is limited. In 2021, in terms of the service capacity of elderly care facilities per 1,000 people aged 75 and above, the rate in Wakabayashi was the lowest at 62.77, followed by the rate in Miyagino at 65.95, while the rates in Izumi (82.97) and Taihaku (79.35) were above the national average (68.67). The rates in Aoba (90.57) were also observed to be considerably higher than that of the national average. These rates show regional differences in the elderly care service supply capacity in Sendai. In terms of the number of care staff per 1,000 people aged 75 and over, all wards (Aoba: 72.48, Wakabayashi: 69.43, Izumi: 77.19, Taihaku: 82.83, Miyagino: 75.09) were noted to have higher rates than the national average (68.25) (Japan Medical Analysis Platform, 2021). However, these figures also show the presence of considerable regional differences in the number of care staff in Sendai.

To respond to the ageing society and establish a system for providing sustainable medical care and long-term care, the Japanese government issued a bill on the Development of Related Laws to Promote Comprehensive Security of Medical Care and Long-term Care in the Community. The bill was passed by the ordinary Diet session in 2014. Based on the law, the government is promoting the ‘comprehensive community care system’ (Article 5 of the law) centred on the long-term care insurance system. The aim of the ‘comprehensive community care system’ is that by 2025, when the baby boomer generation will be over 75 years old, even if the elderly are in severe need of long-term care, they will be able to live on their own in their homes or communities during the late stages of their lives. The law aims to build a framework that integrally provides the five services of ‘housing’, ‘medical care’, ‘nursing care’, ‘prevention’, and ‘living support’.

However, three major problems hinder the promotion of the comprehensive community care system. The first is the financial problem. As the population is ageing, social security costs are expanding, and Japan's budget deficit is on the rise. Social security benefits in 2007 cost about 90 trillion yen, but in 2016, the rates went up to about 116 trillion yen, which was almost 20% of the GDP. In other words, the average annual social security benefit costs have expanded at a rate of about 2.6 trillion yen per year over a decade (Japan Medical Analysis Platform, 2021). By 2025, when the baby boomers will be over 75 years old, the pressure on social security costs is likely to increase, especially for medical care and long-term care. In fact, according to the Ministry of Health, Labour and Welfare’s Revision of Future Estimates of Social Security Expenses (March 2012), from FY 2015 to FY 2025, pensions will cost about 56 to 60 trillion yen due to the activation of the macroeconomic slides. However, the costs involved in medical care and long-term care are expected to explode from about 50 trillion yen to about 75 trillion yen.

The second problem is how to respond to the rapid increase in the number of elderly people and the declining population. The demand for medical care and long-term care tends to be higher for the late-stage elderly (75 years old and over) than for the early-stage elderly (65–74 years old). However, according to the National Institute of Population and Social Security Research's future population estimates (medium estimates), the number of late-stage elderly, which was only about 9 million in 2000, will reach about 20 million in 2025. In addition, the number of late-stage elderly in 2020 will be about 1.3 times, in 2030 about 1.6 times, and in 2050 about 1.7 times that of 2010. Therefore, the medical care and the long-term care needs will increase rapidly. Especially in urban areas, waiting lists for special nursing homes for the elderly will soar, and the shortage of elderly care facilities will become even more serious.

The third problem is the response to the disappearance of the local areas. According to the ‘Grand Design 2050 of the Land’ announced by the Ministry of Land, Infrastructure, Transport and Tourism in July 2014, the areas where the population in 2050 will be less than half of its population in 2010 will occupy more than 60% of the current residential areas. It is predicted that about 20% of these areas will be non-residential. Looking at this by population size, the smaller the population size will become, the greater will be the rate of population decline, and the population of cities, wards, towns and villages with a current population of less than 10,000 will decrease by about half. Japan’s population in 2010 will be halved in 2083, within 70 years, but as mentioned above, in those local areas, the population will be less than half in about 40 years (2010–2050), which means that the rate of depopulation in these areas will be about twice or more than the national average population decline rate (speed). As a result, municipalities with smaller populations are more likely to face a crisis in their financial base.

The ways to solve the three aforesaid problems at the same time are limited. One of the effective measures that can be considered is, as pointed out by Oguro (2015), the promotion of the ‘Care Compact City’, which is the fusion of the ‘comprehensive community care system’ and the ‘compact city’ that aims to consolidate the population. ‘Care Compact City’ is an attempt to efficiently and effectively provide services such as medical care and long-term care in the centralised, high-quality housing and community spaces of a ‘compact city’. At the same time, it is extremely important to analyse the appropriate range of the long-term care facilities while determining the distribution and the forecast of the demographics.

Such an analysis is closely related to the problem of the optimal locations of the facilities. Recently, due to the rapid development of GIS, it has become possible to grasp and analyse it in a visualised form. Currently, few analyses use GIS in Japan. Bogami, Yamada, and Ueno (2005) applied simulation analysis to outpatient facilities for the elderly in Kanazawa City. In addition to the distribution of the elderly population, factors such as the number of times the elderly use the facility and the number of people who can enter the facility were also taken into consideration, and the relationship between the facility location and its demand was analysed. The outcomes clarified that (1) the elderly people in the city centres can receive sufficient outpatient services, but the elderly people in the mountainous areas cannot receive appropriate outpatient services due to a lack of nearby facilities and that (2) the percentage of the elderly population that cannot use the facilities even under the restriction of the maximum usage distance of 2.5 km is less than 2%.

In addition, Takahashi, Odagiri, and Uchida (2006) calculated the ‘number of people requiring long-term care’ by dividing the Voronoi diagram into each location of the outpatient long-term care facilities in Kofu City, Yamanashi Prefecture. The analysis presented two results: (1) the number of people requiring long-term care is large in the centre of the city and the north-western part, and one idea is to prioritise facility development in these areas; (2) the areas of the Voronoi partition differ greatly between the two regions, and besides the large demand for long-term care services in the north-western part, the range in which one facility is expected to provide services is also wide. Furukawa and Naito (2015) analysed the placement problem of the salons for the elderly using the Voronoi partition in Komatsushima City, Tokushima Prefecture. The analysis showed that when selecting the location of a facility for the elderly, the distribution of the target users of the facility should be grasped in advance and the importance of the corresponding location policy should be clarified. As described above, it has become clear that the use of GIS is effective when considering the facility location policies. There are no studies that apply the statistical model to analyse the rationality of the facilities’ locations in Japan.

6.4 - Data and Methodologies

6.4.1 - Database

The 2015 national census was selected to provide accurate and comprehensive demographic information for analysis. The geographic data of residential points and elderly care facilities were obtained through the NLNI. The location and scale of the facility were also referred to the 'Sendai kurashi no mappu' (せんだいくらしのまっぷ), the geographic information system provided by the Public Relations Section, General Affairs Bureau of Sendai City. The ageing rates and the number of elderly people in each residential area were obtained from the Sendai City Elderly Health and Welfare Plan/Nursing Care Insurance Business Plan 2021–2023 enacted by the Health and Welfare Bureau, Senior Planning Division of Sendai City. In this analysis, a geographic database was established through ArcMap, linking demand points, road networks, and supply points to calculate the accessibility rates of elderly care services in each residential area. Several variables in the model, introduced in Section 6.4, were integrated and calculated through the network analysis tool present in ArcGIS. Finally, the ArcMap mapping function was used to visualise the results of the analysis.

The establishment of the database commenced by loading OpenStreetMap (OSM) on ArcMap to vectorise the administrative map of Sendai and configure the projection and geographic coordinate system. Thus, three layers – point, line, and polygon – were created, and their corresponding attribute fields and features were established (Figure 6.8). Among them, the point layer mainly comprised buildings, the line layer mainly comprised roads, transportation networks, and boundary lines of surrounding cities and counties, and the polygon layer mainly comprised city and town areas. Then, the spatial data of residential areas (Figure 6.9) and elderly care facilities (Figure 6.10) obtained from the NLNI were imported as new layers. The residential area layer contained the attribute fields dealing with the size of the population aged 65 and above, the elderly care facility layer contained fields dealing with the maximum acceptable numbers, and the generated road network layer from the OSM dealt with the road length and type (Figure 6.11). These data were necessary for conducting an analysis. The processing method is described in detail in the next section.

Figure 6.8 – OSM Layers

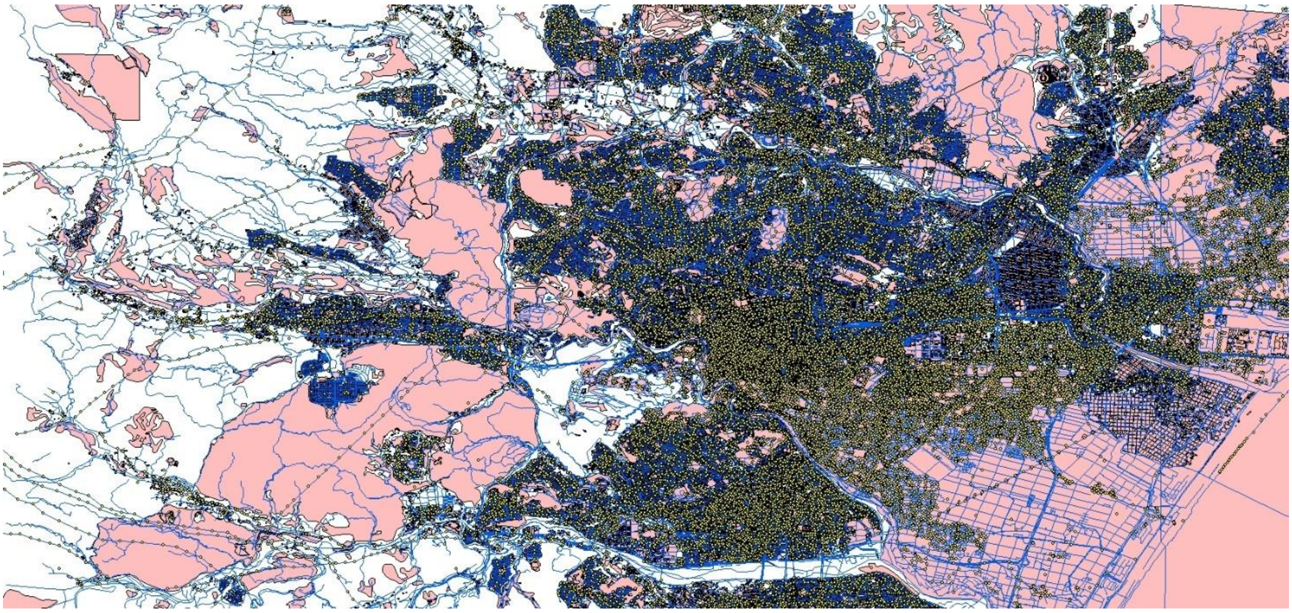


Figure 6.9 – Residential Area Layer

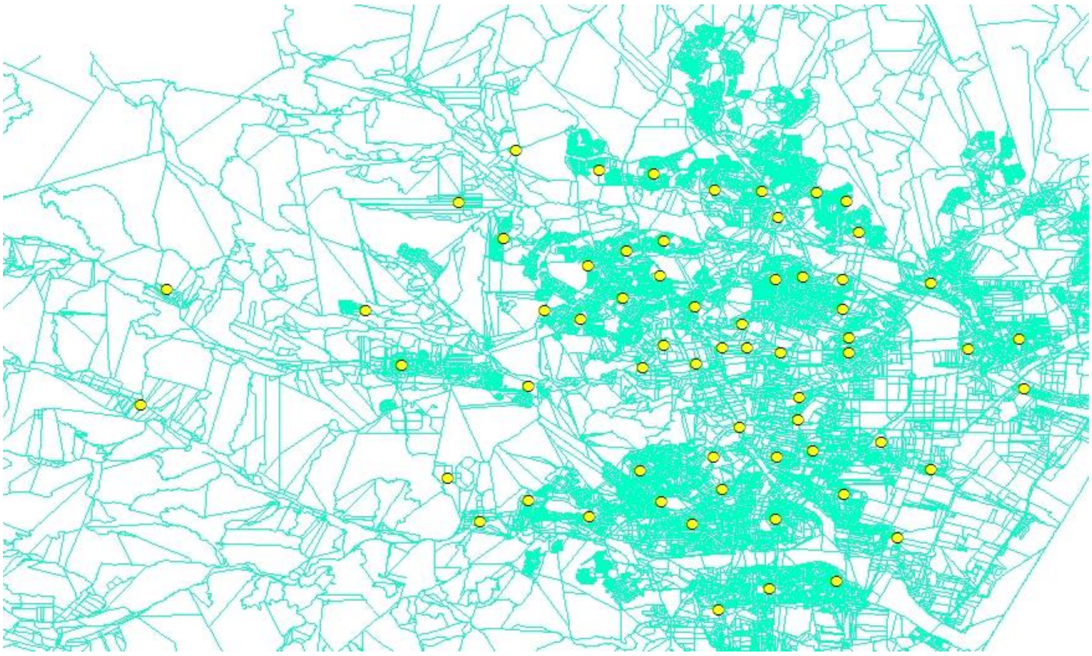


Figure 6.10 – Elderly Care Facility Layer

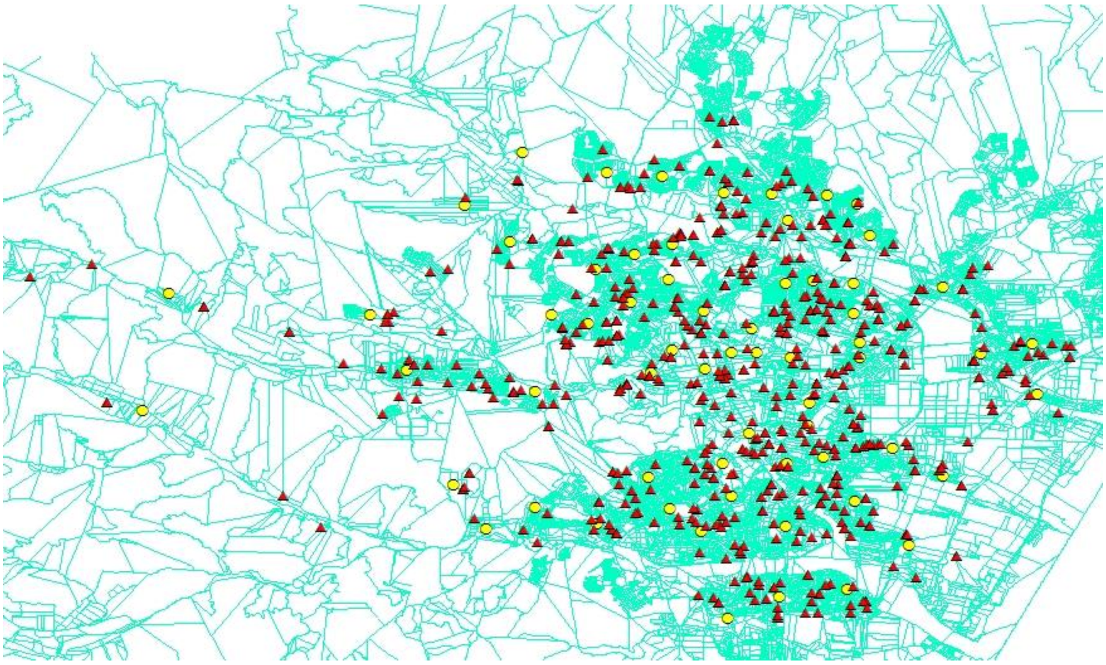
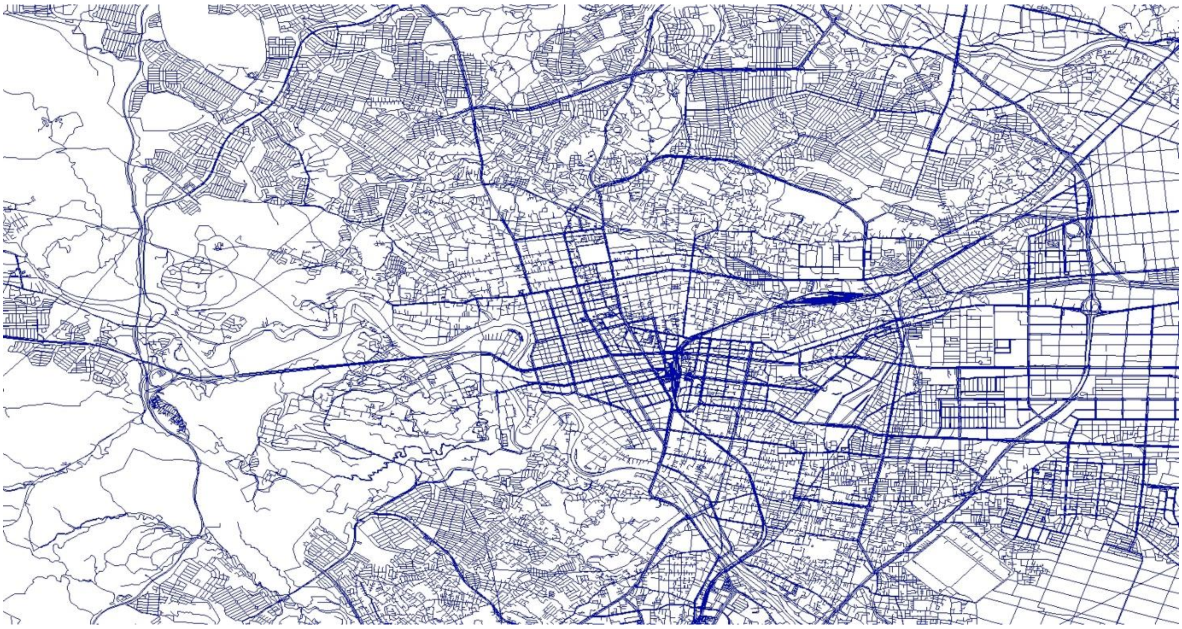


Figure 6.11 – Road Network Layer



With the rapid increase in the ageing population and the continuous decline of the working-age population, the layout of elderly care facilities should be immediately and rationally planned based on scientific population forecasting. This will help ensure the improvement of conditions in areas with insufficient elderly care resources and avoid the over-planning of facilities in sparsely populated areas. In this study, the results of the 2015 census published by the MIC were used to predict the requirements of regional elderly care services based on the predicted size and distribution patterns of the elderly population in the future and then estimate the approximate size and spatial layout of elderly care facilities required in the future. Additionally, some policy-making suggestions are also provided.

6.4.2 - Methods

The combination of the spatial analysis model and GIS is one of the widely used tools to analyse problems regarding the spatial allocation and location optimisation of public service facilities. This study uses the ArcGIS software network analysis module to conduct spatial comparison experiments to identify the areas of shortage in receiving elderly care services. The analysis attempts to build an improved gravity model that can comprehensively analyse the size of demand, travel costs, scale of facilities, and service capabilities related to elderly care. As mentioned in Chapter 2, the GIS software is a useful and efficient method for analysing facility locations. In this chapter, the model is further optimised to suit the characteristics of the analysis objective, and then used to provide theoretical and practical foundation for future optimisation layout and planning of elderly care services. This analysis is based on spatial analysis methods, comprehensively applies the theories and methods of economic geography and public health and integrates the spatial, statistical and medical data to conduct the research.

Based on the large-scale maps and spatial attribute data obtained from government agencies, the ArcGIS software was used to establish the basic database. This study used the network analysis modules on the ArcGIS software platform to conduct spatial comparison experiments. It then used ArcGis and QGIS to visually present the results and discuss the planning direction for optimising the coverage of elderly care services in Sendai in the future.

6.4.2.1 - Application of the Improved Gravity Model

The effectiveness and rationality of resource allocation cannot be determined based solely on a unilateral indicator, such as the number of institutional beds, to measure the abundance of elderly care facilities in different regional institutions. The preference of residents in choosing elderly care facilities is influenced by numerous factors. Generally, the elderly prefer to stay near their homes (Oguro and Hirakata, 2017). The distance between an elderly care facility and a place of residence is one of the factors that influences the elderly when choosing an elderly care facility. Spatial accessibility focuses on the distance barrier between supply and demand points. The gravity model considers demand factors (the number of elderly people), supply factors (the capacity of facilities), and the distance barrier between the supply and the demand points (the distance between a residential area and a facility). These three factors can better reflect and compare the difficulty of obtaining elderly care services in different regions. This chapter attempts to use the principle of gravity model to analyze the accessibility of elderly care facilities.

As discussed in Chapter 3, the traditional gravity model ignores the influence of different scales of public infrastructure facilities on residents' usage choice behaviour. Different levels/grades of public facilities in real life have different levels of attraction for residents. For example, public facilities such as intensive care homes and sanatorium medical facilities for the elderly requiring long-term care are characterized by the fact that older people who require long-term care can move in with low costs; such facilities are popular and generally have many people waiting to move in. Therefore, this study analyses these facilities' accessibility by dividing them into publicly and privately conducted facilities. Publicly conducted elderly care facilities are larger in size and have a higher level of nursing and medical management, which can often attract patients who live far away, especially those who have intractable diseases or require higher service quality. Privately conducted facilities are smaller and relatively less effective in terms of nursing and medical management, and usually provide basic elderly care services to nearby residents, thus offering only a limited attraction to older people living far away.

The impact of scale of public facilities on usage choice behaviour of residents is reflected in the travel time limit (distance) in this study, for example, the location of elderly care facilities from residential areas exceeding 30 minutes in travel time, is considered as no longer used by residents. Accordingly, we can use 'D_j' to represent the travel time limit (distance) of elderly care facilities, 'j'. Elderly care facilities of different levels have different values of 'D_j', and the higher the level of facilities, the larger the value of 'D_j'.

For the same public facility 'j', it is obvious that the smaller the distance 'D_{ij}' between the residential area 'i' and the facility 'j', the smaller the influence of distance on residents' usage choice behaviour. The closer the values of 'D_{ij}' and 'D_j', the greater this influence. When the value of 'D_{ij}' goes beyond 'D_j', it is concluded that residents no longer choose to use such facilities. In this study, the influence factor 'S_{ij}' is used to express the influence of public facilities 'j' on the utilization behaviour of residents in residential area 'i'. The improved gravity model is expressed as follows (Formula 6.1):

$$\mathbf{A}_i = \sum_{j=1}^{n} \frac{S_{ij} M_j}{D_{ij}^{\beta} V_j}$$

$$\mathbf{V}_j = \sum_{k=1}^{m} \frac{S_{kj} P_k}{D_{kj}^{\beta}}$$

$$\mathbf{S}_{ij} = 1 - \left(\frac{D_{ij}}{D_j}\right)^{\beta}$$

(Formula 6.1)

In formula 6.1, 'A_i' represents the spatial accessibility of the residential area 'i' to all accessible elderly care facilities (Accessibility refers to the convenience or inconvenience that residents experience in obtaining services, measured by the degree of difficulty to reach facilities (e.g., time spent, and distance travelled) and the quality and adequacy of services available within facilities); 'M_j' represents the service capacity of the facility 'j', that is, the maximum acceptable number of users; 'P_k' represents the population size of elderly people in the residential area 'k'; 'V_j' represents the population size impact factor; 'D_{ij}' represents the travel impedance factor (time or distance) between the residential area 'i' and the facility 'j'; 'S_{ij}' is a level/scale influence coefficient that represents the influence of the elderly care facility 'j' of different levels/scales on the utilization behaviour of users in residential area 'i'; 'D_j' represents the travel time limit (distance), as discussed above, facilities of different levels/scales can set a different value of 'D_j'; 'β' represents the travel friction coefficient; and 'n' and 'm' represent the number of elderly care facilities and residential areas, respectively.

For formula 6.1, if 'D_{ij}' ≥ 'D_j', then there the corresponding $S_{ij} \leq 0$, which means that the travel time limit (distance) is exceeded. In that case, the specific elderly care facility is not attractive to residents. In the calculation, all negative values of 'S_{ij}' are set to 0. It is not difficult to find that formula (6.1) is actually a model of the total amount of elderly care facilities' resources at all levels/scales available to each residential area. It takes into account the service capacity of facilities, the population size of residential areas, the relationship between facilities and residential areas, the travel impedance and the impact of different scales of facilities on users' utilization behaviour. Compared with the traditional gravity model, this improved model can better reflect the actual situation.

In this analysis, the distance barrier factor is expressed by the travel time cost from the geometric center point of a residential area to an elderly care facility. The time cost is calculated based on road traffic network grades. Different driving speeds are assigned to different grades of roads based on Articles 11 and 27 of the Road Traffic Act Enforcement Ordinance. Facility size (capacity) is calculated according to the number of beds in each elderly care facility. This analysis uses the number of elderly people over the age of 65 years in each residential area in 2015 to measure population size.

The gravity model contains the travel friction coefficient β. While different values can be chosen for β, which expands the scope of the model's application and also improves the accuracy of the measurement, choosing the most suitable value for β poses a difficult problem. Academics believe that β can have different mathematical expressions (such as linear, exponential, etc.) and the value of β varies with service type, population characteristics, etc. When choosing the value of β, it is ideal to determine the actual use of the facility, which can be done by the regression of the number of users at different distances from the facility. Reggiani et al. (2011) used regression analysis to calculate the value of β under different distance decay functions based on the daily commuting flow data of 439 regions in Germany from 2003 to 2007. However, this method often requires a large amount of data and is costly and difficult to implement. Therefore, in practical research, the method of multi-scenario analysis of multiple values of parameters is often used (Tao et al. 2014).

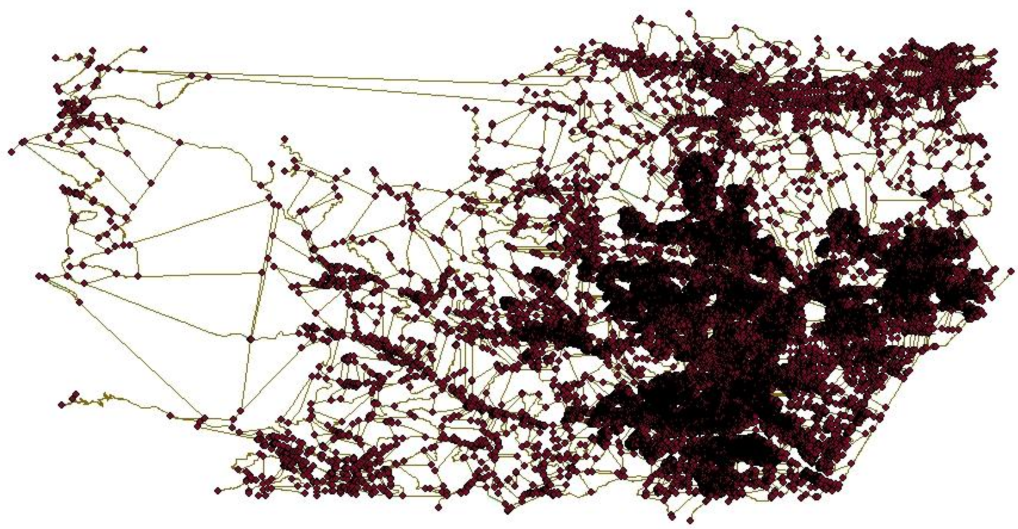
Based on the outcomes of previous studies, Peeters and Thomas (2000) found that the value is mainly between 0.9 and 2.29. Luo and Wang (2003) measured the spatial accessibility of basic medical services in the Chicago area and limited the value of β between 0.6 and 1.8 at intervals of

0.2. In addition, the authors found that the accessibility's mean, standard deviation, and maximum values increase with the increase of the β value but the minimum value decreases. Moreover, Wang and Luo (2005) used the gravitational polygon method to determine the service domain of hospitals in Shanghai and compared the two cases of β=1 and β=2. Given that β=1 means that the geographical effect is weak and that the service fields of the hospitals are large, the analysis considered β=2 to be suitable. Tao et al. (2014) analyzed the accessibility of institutional pension facilities in Beijing and believed that compared with medical facilities, elderly care facilities need not meet certain urgent medical needs. The author observed that the visiting frequency of elderly care facilities is smaller than that of medical facilities; thus, the spatial connection (between supply and demand) of an elderly care facility is weaker than that of a medical facility. Therefore, a β value of 1 is reasonable. The travel friction coefficient is affected by numerous aspects, thus determining the actual measurement is difficult. Reference range of values for existing research—scholars who have mostly valued β as 1.0 (Ortega et al. 2012; Ding et al. 2016), 1.5 (Suárez et al. 2012; Siegel et al. 2016), 1.8 (Reggiani et al. 2011) and 2.0 (Yang et al. 2016; Tong and Chen, 2017). In this study, these four values are substituted into Formula 6.1 for calculation, and the influence of different β values on the spatial accessibility to elderly care facilities is discussed.

6.4.2.2 - Implementation Path of Improved Gravity Model

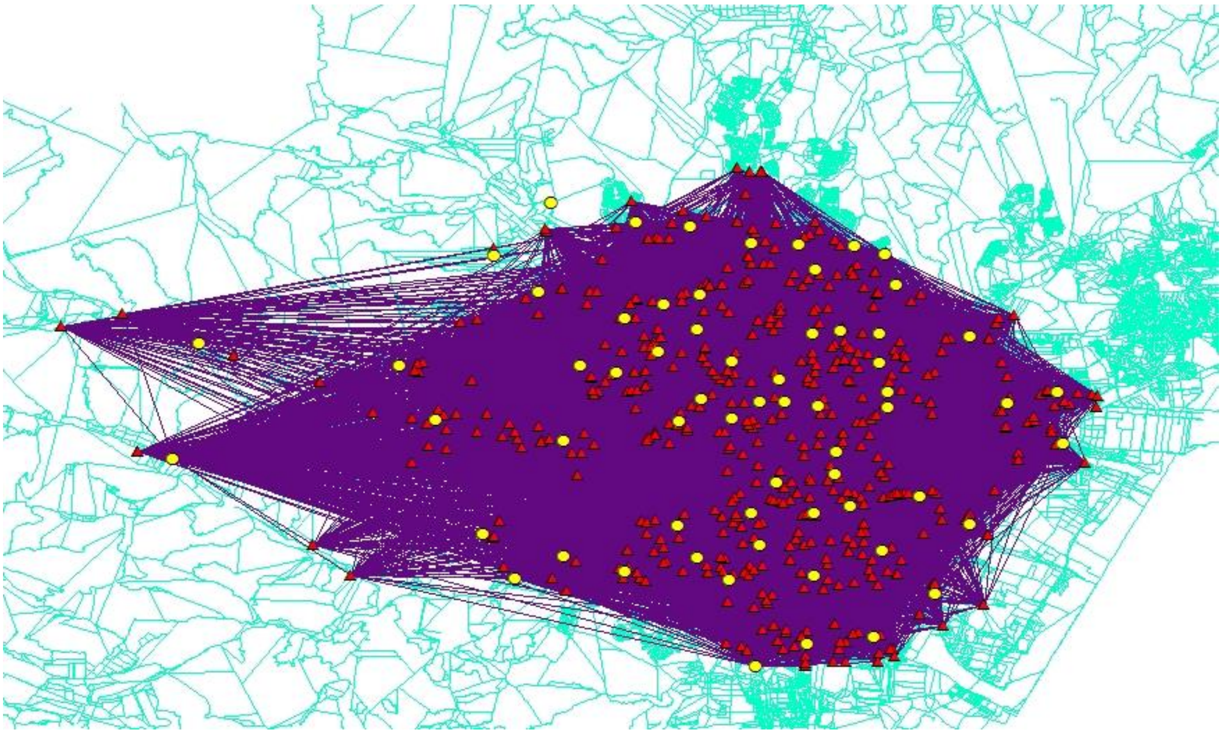
The OD Cost Matrix is established through the Network Analyst module. The travel speed was set based on the legal speed limitations and the road standards of Sendai City. The speed limits for different classes of roads are—national routes: 60km/h, prefectural roads: 60km/h, and municipal roads: 40km/h. For the feature data collection in the geodatabase, Sendai's road network is taken as the main body and a topology network of Sendai's road is established using the network path topology relationship (Figure 6.12).

Figure 6.12 – Road Network with Topological Relationships



Based on this network, the shortest network distance and network travel time from 63 residential areas to 605 elderly care facilities can be obtained and thus d_{ij} can be finalized. Then, an evaluation index system for the elderly service capability is established (Figure 6.13). Finally, the accessibility rates can be calculated in ArcGIS through functions, such as ‘Join’ and ‘Summarize’. The limit travel distance D_j of the Privately conducted elderly care facilities are set to 15min and the Publicly conducted elderly care facilities do not consider such impact and sets it to ∞ to ensure that each residential area will choose at least one of the nearest elderly care facilities for services.

Figure 6.13 – Operation Results of OD Matrix



The specific implementation steps through the GIS software are as follows (the friction coefficient β is set to 2 as an example):

1. Create a network dataset based on the Sendai City transportation network layer, activate the cost matrix tool, load the elderly care facility points as the destination locations, the residential points as the origin locations, click ‘Solve’, open the attribute table of the ‘Line’ layer, and export the O-D Cost.dbf table.

2. Add the field D_{ij} to the O-D Cost.dbf table, calculate $D_{ij}^{\wedge 2}$ according to D_{ij} = distance * 60 / 40000, add the field S_{ij}, and calculate $\mathrm{S}_{ij} = 1 - (\frac{d_{ij}}{d_j})^{\beta}$, export the result, and generate a new table S_{ij}.dbf.

3. Join the residential area layer with the new S_{ij}.dbf table together, add field V_j, calculate

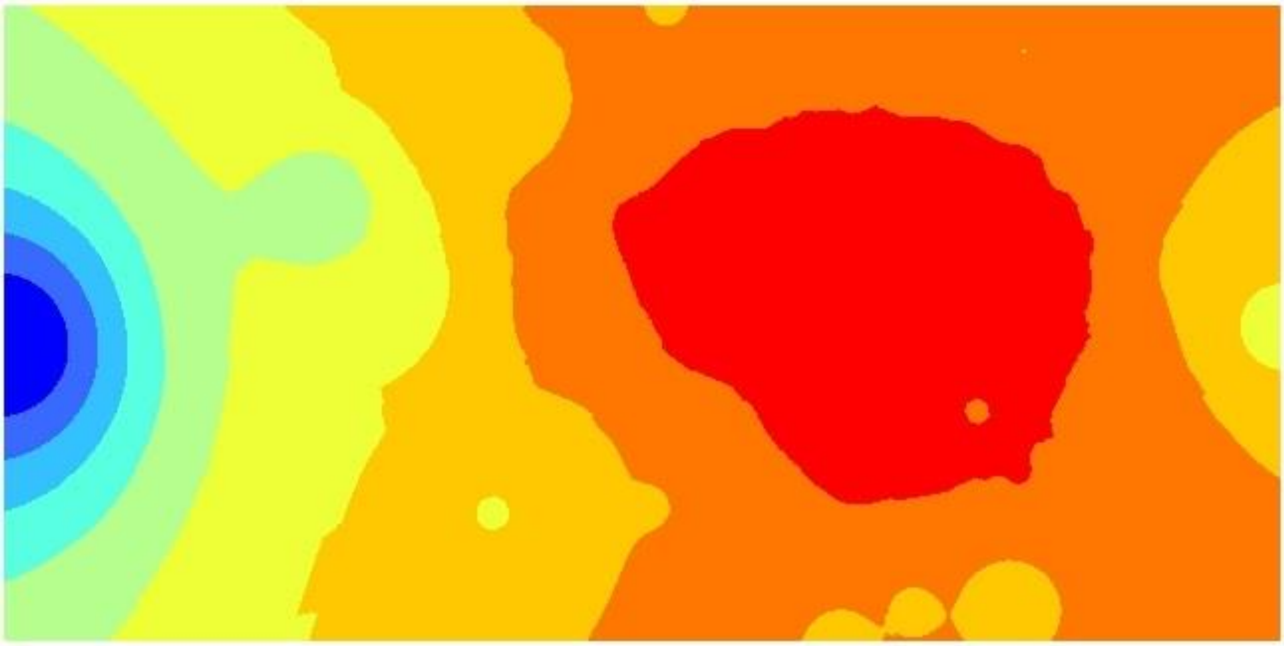
V_j = population * S_{ij}/D_{ij}^2 , summarize V_j according to the location of the elderly care facilities, and derive the data to obtain a new table Sum V_j.dbf.

4. Connect the table Sum V_j.dbf to the elderly care facility layer, add the field A_i, calculate $A_i = S_{ij}S_j$ / Sum V_j, and summarize A_i according to the location of the residential areas. Export the data to obtain the Sum A_i.dbf table;

5. Connect the Sum A_i.dbf table to the residential area layer to obtain the spatial accessibility value of each residential area to elderly care facilities, then represent outcomes via geographic visualization (Figure 6.14).

6. Repeat steps 2 – 5 to calculate the coefficient of friction β = 1, 1.5, and 1.8.

Figure 6.14 – Accessibility Rates' Distribution



Based on the accessibility measurement of the improved gravity model and the distance of the transportation network, the capacity of the facility service (accessibility) is calculated. This comprehensively reflects the actual allocation of resources for elderly care services. The model reflects scientifically the relationship between the convenience of receiving elderly care services and the capacity of providing elderly care services, residents' preferences for elderly care services, and to what extent the services are affected by distance. The results of the improved gravity model show the presence of considerable spatial differences in the accessibility values of each residential area as well as certain spatial regularities.

6.5 - IGM Outcomes

The descriptive statistical analysis results of different β values are shown in Table 6.1. It can be seen from the table that when the β value increases, the maximum value of accessibility increases, the minimum value decreases and the standard deviation increases. The distribution of the accessibility results gradually shows the characteristics of "divergence", which indicates that the accessibility evaluation results are highly sensitive to the value of β, and an appropriate value of β needs to be selected for calculation.

Table 6.1 – Accessibility Rates Comparison

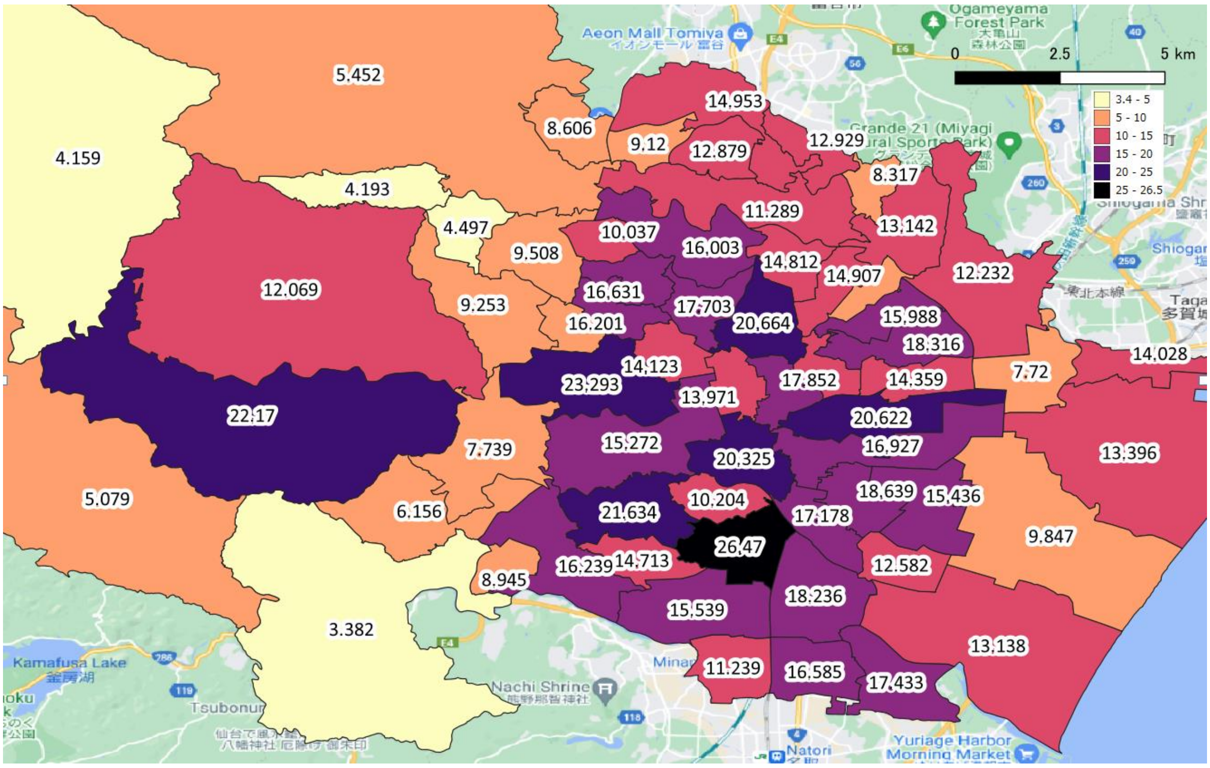
	β = 1.0	β =1.5	β = 1.8	β = 2.0
Min	4.442	3.652	3.394	3.382
Max	23.054	23.697	26.103	26.470
SD	2.176	2.435	2.734	3.638

From observing four sets of data, it was found that for Formula 6.1, β = 2.0 had a larger fluctuation range and greater dispersion degree than the other values. The results obtained with the other values of β were too concentrated and could not aptly reveal the differences in the spatial accessibility of elderly care services in different residential areas. Therefore, it was more appropriate to use β = 2.0 for the calculation of the spatial accessibility of elderly care services in Sendai.

The following were some of the outcomes obtained with β = 2.0: the minimum value is 3.382, the maximum value is 26.470, and the average value is 13.35. Residential areas with accessibility values below 10.00 accounted for 28.57%, and accessibility values above 17.00 accounted for 22.22%. Among the residential areas, the accessibility value of Nagamachi (長町) is the highest, and the accessibility value of Oide (生出) is the lowest. Besides the highest value, residential areas where accessibility values are higher than 21.00 include settlements Yagiyama (八木山), Hirose (広瀬), and Daiichi (第一).

Based on the above analysis, the results of the spatial accessibility of elderly care services calculated by Formula 6.1 with β = 2.0 can more accurately describe the status of elderly care service resources that can actually be obtained by residents in Sendai, and can better reveal the difference in the accessibility of elderly care services in each residential area. Therefore, in this section, the results with β = 2.0 are used to analyse the accessibility pattern of the services and determine areas of shortage in receiving the services (Figure 6.15). The accessibility rates of each residential area are shown in Figure 6.15. In Sendai, the accessibility rates present a core edge pattern centred around residential area Itsutsubashi (五橋, 20.325). Taking the central urban area as the centre, the accessibility rates within a 5 kilometres radius is significantly higher, and the accessibility rates along traffic roads and larger residential areas are relatively high.

Figure 6.15 – Accessibility Rates of the Study Area



However, accessibility is unequal across regions: that of the central area of Sendai is significantly higher than the city's average level (13.35), while that of the western peri urban area Kouryou (広陵, 4.159) and southwestern peri urban area Oide (生出, 3.382) is significantly lower than the city's average level. Combined with the population distribution of the existing residential areas in Sendai City, the residential areas in Oide are dense and largely populated, while the residential areas in area Kouryou are scattered and sparsely populated. Therefore, the phenomenon of lack of elderly care service resources is the most serious in residential area Oide.

Improving or even eliminating the service shortage area is a basic requirement of improving the elderly care service network. The residential area with better accessibility often receives more elderly care services, and the difference in accessibility is an important reason for the formation of the shortage area of elderly care services. In order to more intuitively show the regional differences in the accessibility to elderly care facilities, according to the ratio of the accessibility value of each residential area to the average accessibility value of the city, the spatial accessibility of elderly care facilities in Sendai was divided into five grades: poor (<0.50), fairly poor (0.50-0.99), fair (1.00-1.49), fairly good (1.50-1.70), good (>1.70). It can be seen from the Table 6.2 that the proportion of 'fair' and 'fairly good' grades is 49.2%, indicating that the spatial accessibility of elderly care facilities in near half of the residential areas is higher than the average of the whole city. However, the proportion of 'poor' and 'fair poor' grades is 47.6%. The cumulative ratio of these four grades exceeds 90%, indicating an obvious imbalance in the accessibility of the elderly care facilities in Sendai.

Table 6.2 – Grades of Accessibility Rates

	Poor (<0.50)	Fairly poor (0.50-0.99)	Fair (1.00-1.49)	Fairly good (1.50-1.70)	Good (>1.70)
Number	8	22	26	5	2
%	12.7	34.9	41.3	7.9	3.2

Additionally, two levels of differentiation can be observed in the accessibility of elderly care services in Sendai. The residential area with the highest accessibility value is almost 8 times the residential area with the lowest accessibility value. In addition, the distribution of elderly care service resources within the same ward is also uneven. For example, the accessibility value of Aoba ward ranks second in the whole study area, but 2 residential areas within it belong to the low accessibility value group, and thus the level of equalization of elderly care services is relatively low. In the context of the construction of a compact city, in the process of equalization of public services, it is necessary to focus on the balanced layout of internal elderly care service resources and to increase facilities and improve appropriately the level of service in areas with shortages.

6.6 - Disparities in Accessibility of Elderly Care Services

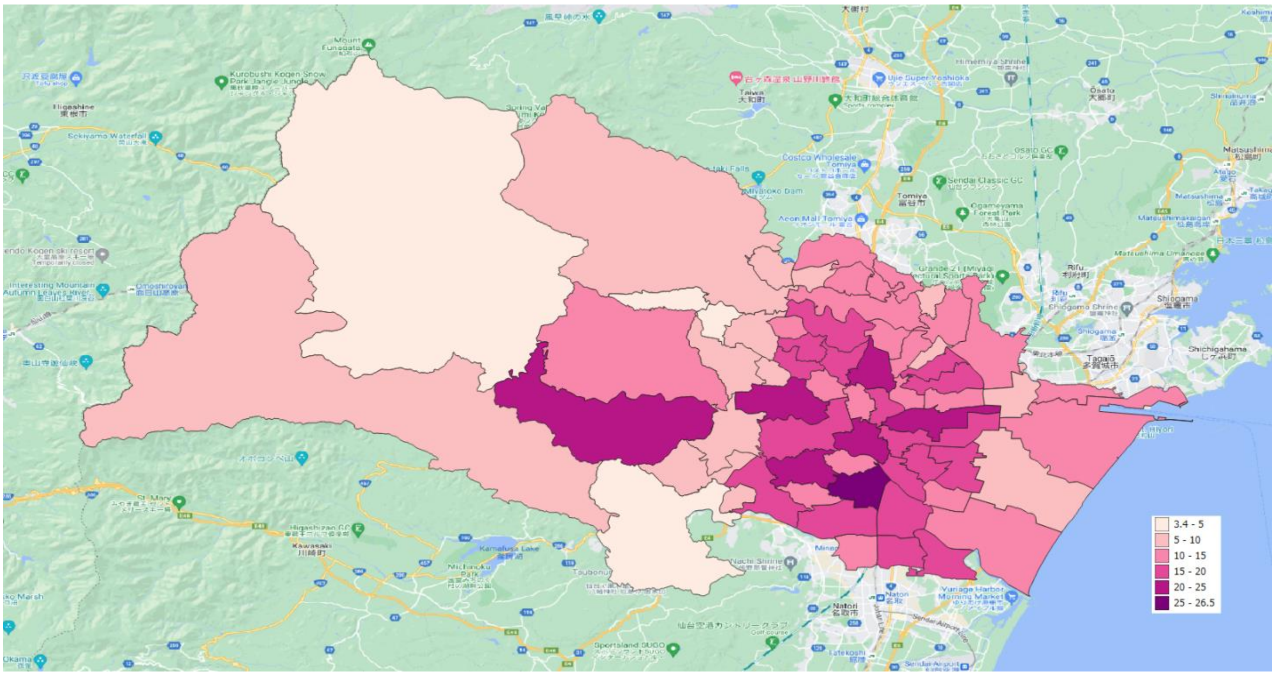
The scale and number of elderly care facilities in some residential areas in the central Sendai area have obvious advantages in attracting users and providing services, but there are situations where facilities of the same scale are arranged adjacently and elderly care service resources are relatively concentrated, such as in residential areas Miyagino (宮城野, 20.622) and Dainohara (台原, 20.664). Furthermore, As seen in Figure 6.15, the dark ring-shaped high-value areas are mainly concentrated in residential areas Miyagino and Dainohara, indicating that these two areas also have obvious advantages for obtaining elderly care services. Miyagino is a residential area that has 4 facilities that have service capacities of more than 30 people each, 6 publicly conducted facilities and 8 privately conducted facilities, forming a relatively complete hierarchical and diverse facility distribution. Residential area Dainohara has 3 publicly conducted facilities and 5 privately conducted facilities, which can provide residents with both efficient and high-quality elderly care services.

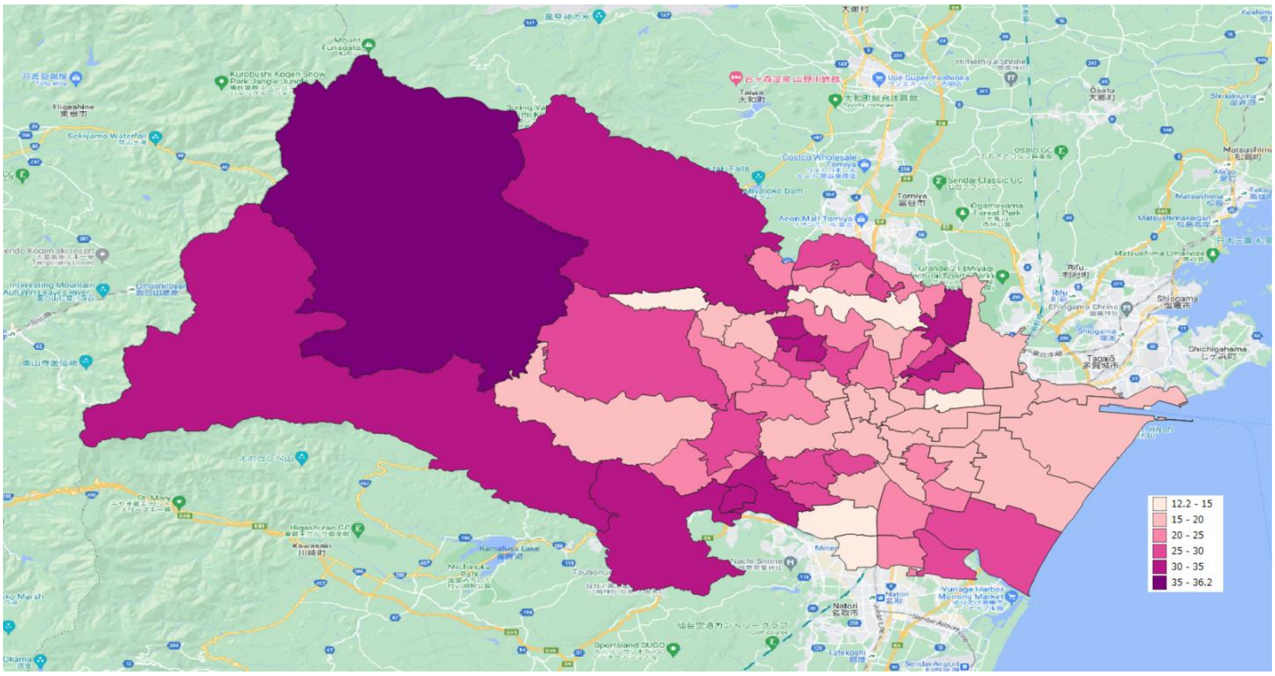
When a complete hierarchical system of elderly care facilities is arranged around a residential site, and the different care needs of elderly residents can be satisfied, it means that the overall spatial accessibility of elderly care services is superior. For the layout and planning of future elderly care facilities, it is necessary to consider not only the service scale of facilities, but also the distribution of existing facilities in order to establish a good hierarchical and diversified service provision model. At the same time, it is necessary to avoid the situation in which facilities of a similar scale and type are too close together, leaving some areas devoid of elderly service facilities, and reduce the duplication of construction and redundancy of resources as much as possible. Furthermore, in order to achieve harmony between supply and demand, the service capabilities of high-value areas of accessibility should be channelled and extended to low-value areas so that the accessibility of elderly care facilities is balanced to fairly provide services to the residents throughout the city. Highway Sendai nishi douro (仙台西道路) passes through Taihaku, Aoba and part of Izumi, effectively connecting various types of nearby elderly care facilities to each other so the residents along the route have higher spatial accessibility to elderly care services. This shows that excellent traffic conditions are conducive to improving the accessibility of elderly care facilities. The cooperation of rail transit and ground transportation services to provide more convenient travel routes can save travel time, provide residents with more opportunities to obtain elderly care resources and improve the utilisation rate of elderly care facilities and resources. Considering local governments' vigorous promotion of a "compact city" policy, optimising public transport transfer routes, strengthening the system connection of different public transport modes and filling blind spots will greatly improve the accessibility of elderly care facilities.

In the western and the northern parts of the region's peri-urban areas, some residential areas are small in number, scattered and slightly remote. They belong to the suburbs with certain development accumulation. Although the municipal infrastructure construction in the region is relatively complete, the elderly care facilities and public transportation services have not yet reached a level that matches the regional development and infrastructure construction. The spatial accessibility in these areas is relatively poor, so the residents often need to seek elderly care services in nearby areas. However, as the increasing trend of the elderly population in the region slows down and infrastructure is gradually equipped, the spatial accessibility of elderly care facilities for residents in the region is expected to improve accordingly.

If the accessibility rates of elderly care services in each residential area are compared with the ageing rates in each residential area, the results show that the distribution of accessibility rates does not match the distribution of ageing rates. As shown in Figure 6.16, in some regions with higher ageing rates, accessibility rates are lower. Conversely, in some areas with lower ageing rates, accessibility rates are higher. The residential areas with higher ageing rates and lower accessibility rates are mostly distributed in the western and northern peri-urban areas.

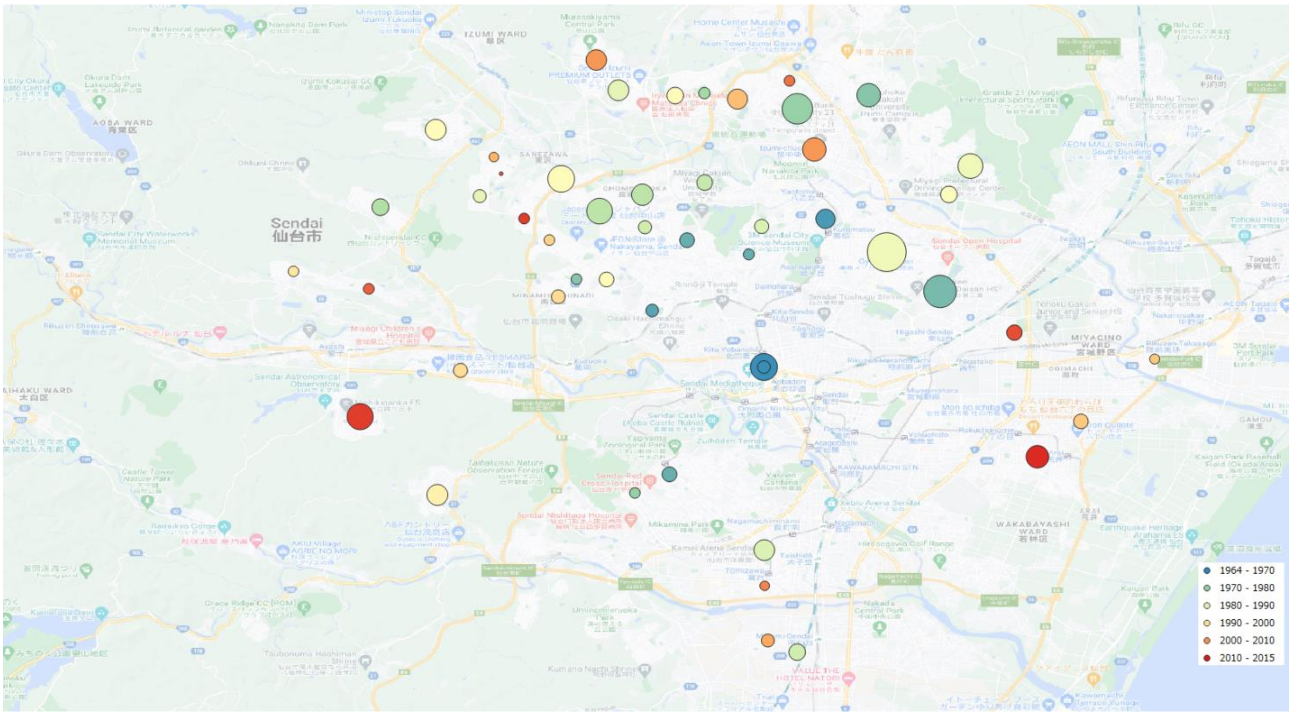
Figure 6.16 – Distributions of Accessibility Rates (above) and Ageing Rates (below) in 2015





This mismatch is due to the urbanisation of Sendai City. In Sendai City, the increase in population and housing demand after WWII has shifted the residential land development within the area of the old city area to the surrounding hills from the latter half of the 1950s. Due to the precarious food situation then, the paddy fields to the east side of the city were not converted into residential land, and the forested hills on the north and west sides were actively developed. Residential area development up to 1969 was centred around the development of private residential areas around the old city region and public residential areas in the Tomiya Hills bordering the Nanakita River (Koganezawa and Ono 2016). Due to the underdeveloped construction technology at that time, many residential areas were constructed on slopes. In the 1970s, with the advancement of construction technology, such as the introduction of large heavy machinery, hill flat residential areas created by cutting and embankment of slopes started being developed.

Figure 6.17 – Distributions of New Towns



Although the suburban residential areas developed in these hills vary in size, most have been developed as single-family residential areas where similar generations (households of similar age) tend to move in in large numbers during the same period. In such housing complexes, the residents are particularly motivated to settle down, and they remain there even after raising their children; hence, in many cases, the housing complex attains maturity with almost no new residents moving in (Koganezawa and Abe 2014). As a result, the elderly population within these areas has increased rapidly in recent years, with the ageing of the residents who were non-elderly at the time of moving in. Furthermore, the second generation flowing out of the residential areas is not uncommon due to schooling, employment, marriage, etc. Therefore, one of the characteristics of ageing in these suburban residential areas is "relative increase in the elderly population" because of the outflow of the second generation, in addition to the characteristic of "absolute increase in the elderly population" because of the ageing inhabitants.

Regarding these social backgrounds, studies have clarified the process of residential area formation in the Sendai area (Chiba 1994), the diffusion of residential areas to the suburbs (Masuda, 2014), and the research on the location of condominiums in the central city area (Koganezawa and Ono 2016). Particularly, Ito (2010) discusses the ageing of detached residential areas that have expanded to the suburbs. In the study, an age composition analysis of the housing complex in Sendai City reveals that the bias in population size of the first and second generations differs greatly depending on the housing complex. Attention is drawn to the fact that the ageing of the residential areas is progressing rapidly due to the ageing of the first generation and the outflow of the second generation since 2005.

Such ageing in the suburbs is attributable not only to the phenomenon of rapid progress but also to the differential ageing levels within the suburbs. The ageing rate of Sendai City is 22.1% in 2015 (MIC, 2015), and it is particularly high in the hills in the west and the old residential areas in the centre of Sendai City. Furthermore, the ageing of the population is conspicuous in areas where early-developed residential areas exist, such as Tsurugaya, Yagiyama (Koganezawa and Ono 2016). These housing complexes were created before the 1970s, and although there are differences depending on the living conditions, such as distance to subway stations and apartment locations, the older the development age, the faster the ageing progress. Many of these early-developed residential areas are residential areas created on slopes, restricting the elderly's behaviours and lives. As the ageing of residential complexes in hills progresses, the lives of the elderly are expected to be inconvenienced if the living environment and traffic conditions in the complex are inadequate. Thus, the difference in the development period of the housing complex and the characteristics of the slope level are considered to greatly influence the accessibility of residents to the public facilities. Similar to the situation in Tokyo that was discussed in Waley (2013), the value of old housing complexes built in the 1970s and 1980s in the fringe areas of metropolitans has been declining due to urbanisation policies. This has led to a spatial representation of social inequalities. It also indirectly leads to the inconvenience of transportation, which in turn impacts the convenience of residents in these areas to obtain public services.

Owing to the expansion of urban areas resulting from population influx during the high-growth period, housing construction expanded to the suburbs. Despite the increasing elderly population in the suburbs, transportation is inconvenient and several residential areas have slopes, which negatively affect elderly people who cannot drive or have weak legs. In areas where the population is declining significantly, there is a possibility that daily life will become inconvenient because of the withdrawal of grocery and convenience stores in residential areas and improper maintenance of lifelines such as roads and water services. Hence, to improve the traffic conditions in these areas, it will be indispensable to secure transportation within and between areas.

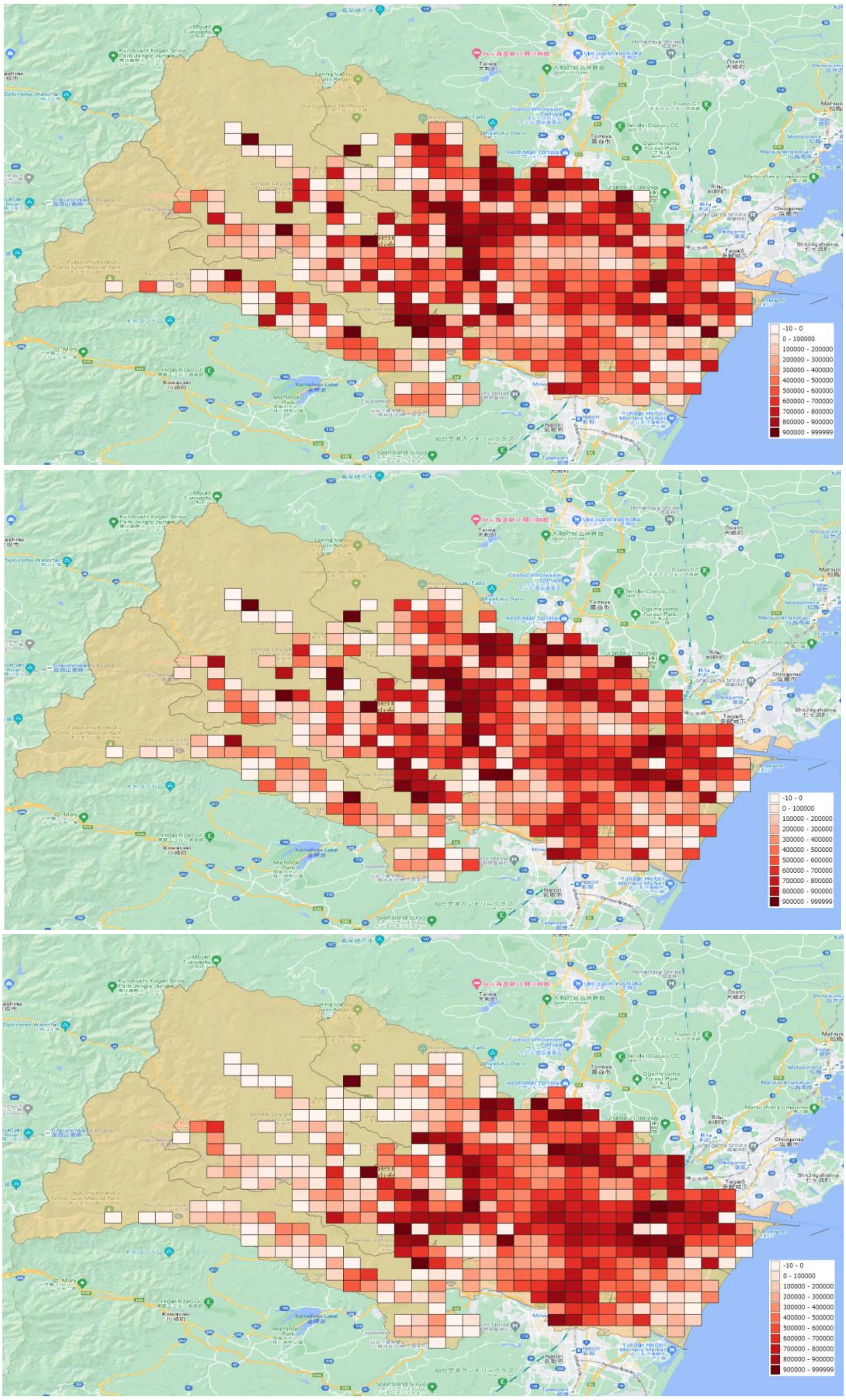
Similarly, the use of public transport, such as railways and buses, is declining due to the decrease in working-age population, and further decline is expected in the future. Furthermore, in areas where public transport usage is declining significantly, there are concerns related to deteriorating services such as increased usage fees and reduced bus services. There is also a possibility that the number of people with mobility difficulties will increase, especially elderly people who are forced to remain in an area and those who need to visit the hospital or need long-term care. To improve this situation, it is vital to maintain and secure services by promoting the conversion from personal to public transportation, by improving the transit of public transportation and promoting its use. Furthermore, transport infrastructure, including roads, rivers and parks, that have been developed in line with the expansion of urban areas will require renewal when the population declines. As the number of elderly people will increase in the future, it will be indispensable to switch to community development that is elderly-friendly to meet the demand for barrier-free access.

In addition, although the elderly population will increase in the north-western suburbs by 2030, it will decrease by more than 10% in most areas by 2050 (Figure 6.18). On the other hand, in the urban areas, the elderly population is expected to increase significantly from 2030 to 2050, mainly in the central area and also the city's eastern outer edge. Thus, the gap between the number of facilities and the amount of demand is expected to widen in the near future.

In this way, when considering the optimal layout of the elderly care facilities in Sendai, it is necessary to consider the imbalance in the current facility layout and also predict population changes in the sub-regional units. With the increase in the elderly population in the central and the eastern regions, there is a concern that the shortage of long-term care facilities will increase in the future. An analysis of the rationality of the facilities' locations should consider the uneven distribution and placement of the facilities, the regional differences in the increase and decrease of the elderly population by 2050, and the physical ageing of the facilities.

If the locations of the facilities remain the same as they are now, the service insufficiency will become stronger in the peri-urban areas, especially in the suburban area on the northwest side of the city. In addition, there will be areas where a sense of service insufficiency will occur even in the central region, which is currently generally satisfied. Furthermore, it can be expected that a large shortage will occur in the eastern side of the city and the suburbs located on the eastern outer edge of the city.

Figure 6.18 – Elderly Population Distribution in 2020 (above) and Predicted Elderly Population Distribution in 2030 (middle) and 2050 (below)



As mentioned above, Sendai, as a whole, is facing an inequality in the delivery of elderly care services. In addition, there is an imbalance in each region, and it is hoped that the number of facilities and their capacities can be increased in the future, mainly in the regions with strong shortages. The planning should be done in consideration of the changes in the distribution and the scale of the elderly population. In addition, between 2030 and 2050, some of the existing facilities will have to be demolished or rebuilt from the viewpoint of building life. It is necessary to renew the facilities based on the proper layout of the facilities, including the rebuilding and the relocation of the facilities or the consolidation and the abolition, while considering facility planning.

6.7 - Summary

The purpose of this chapter is to consider the efficiency and the effectiveness of the service provision through accessibility analysis by applying the improved gravity model and using the population data and the GIS data of the elderly care facilities in Sendai. In addition, while considering the future demographics of the elderly, how to efficiently arrange the elderly care facilities in the near future under the declining and ageing population has also been discussed. Sendai City, as the largest economic and cultural centre in northeast Honshu Island, is homogeneous in terms of natural and economic geography. This case study facilitates problem characterisation, model construction, simulation analysis and spatial planning of the accessibility of elderly care facilities, which is convenient to extract empirical research results into standardised theoretical research outcomes. Based on the perspective of spatial analysis, this chapter applies the improved gravity model to analyse the spatial accessibility of elderly care services in Sendai. The traditional gravity model considers comprehensively the elderly service capacity, the needs of the elderly and the spatial impedance but does not consider the effects of the different levels of facilities on residents' service selection behaviour. This study uses different spatial impedance coefficients for facilities of different scales to verify the sensitivity of spatial accessibility. This method evaluates and explains the accessibility and service shortage regions more reasonably.

The analysis outcomes show that: (1) A significant difference in the accessibility of elderly care service in Sendai exists. The accessibility presents a core-edge model centred on the central urban area, with higher accessibility along the main roads. The accessibility rates in the central urban area and the surrounding radius of 5 kilometres is significantly higher. The accessibility rates around traffic roads and large-scale residential areas are also relatively high. (2) The distribution of accessibility rates does not match the distribution of ageing rates. In some regions with higher ageing rates, accessibility rates are lower. Conversely, in some areas with lower ageing rates, accessibility rates are higher. (3) By summarizing time from the residential area to the elderly care facility, the accessibility of elderly care services in Sendai can be divided into five grades. The analysis results show that near half of residential areas are the service shortage ones in terms of elderly care. (4) Two levels of differentiation were observed. In addition to the regional difference in accessibility of elderly care services among wards, the distribution of elderly care service resources within a single ward is also uneven. In the process of developing the equalization of public services, the local government agencies need to focus on ensuring a balanced layout of internal service resources and increase facilities and improve service standards appropriately in areas with shortages.

In this chapter, I have also compared the current status and the future needs of each facility's service area with the current supply status of the facility, using the data on the current and the future forecast of the elderly population. As a result, while there is still a high shortage of facilities in the peri-urban areas and its suburbs, most of the facilities are currently located in the central city area (which roughly matches the distribution of the DID districts). In the future, while the shortage of the facilities will increase in the north-western and the eastern peri-urban areas and suburbs, shortage is also expected in the central urban area.

With a further increase in the number of elderly people in the future, it is expected that the need for elderly care facilities will continue to increase. Due to financial constraints, it is expected that the importance of improving the efficiency of services by further optimizing the layout of facilities, including the promotion of care and compact cities, will increase significantly. Moreover, it is expected that some existing facilities will become obsolete in the coming years. Therefore, it will be extremely important to select optimization, including reorganization and relocation of the facilities, and introduce private support. In addition, it is necessary to consider not only each facility unit but also the reorganization of the urban infrastructure. An important issue in the future will be the ability to contribute to the examination of the reorganization of the elderly care facilities by integrating them with roads, bridges, sewers, school education facilities, etc., which are the core facilities in cities and urban regions..

Proximity from the user side is important in the provision of elderly care services, and proximity to the other party that provides the service also leads to the improvement of efficiency on the supplier side. Also, even for occupancy-type facilities, it is better for them to be as close as possible to the users' homes, as that makes it easier for the families to visit the residents more frequently. If an environment can be created within walking distance where older people can enjoy support services that focus on living at home, including medical care, long-term care, and general stores, they will be encouraged to go out and improve their quality of life. It can be expected that it will lead to the prevention of long-term care and, at the same time, a reduction in the costs related to medical care and elderly care services.

Based on these facts, to promote 'Care Compact City', which is an attempt to efficiently and effectively provide services, such as medical care and elderly care, in intensive, high-quality housing and community spaces, it is important to evaluate the detailed effects of the optimal placement of facilities, taking into account the distance relationship between the long-term care facility and the consumer side, by predicting the number of people in each distance zone from places suitable as bases within the consolidation destination.

In addition, making active use of vacant houses and vacant lots in urban areas, which are expected to increase in the near future, is also related to elderly care facility planning. It is possible to consider positive relocation on the housing side, such as active relocation, after performing necessary remodelling for the elderly to move in or rebuilding to turn them into housing for the elderly. In this way, the local communities are likely to promote a more effective ‘comprehensive community care system’ and ‘compact city’ from the viewpoint of distance and positional relationship, including not only the supply side (facility) but also the demand side (older people). The realization of such measures will lead to the formation of effective policy planning and evaluation methods for the construction of the ‘Care Compact City’. At the same time, optimising the allocation of resources for elderly care services provides opportunities for obtaining depopulation dividends, that is, for achieving an efficient provision of elderly care services, and for creating a social environment that is friendly to the elderly.

As introduced in Section 6.3, there are various types of elderly care facilities in Japan, providing different services for the elderly with different care needs. The diversification of elderly care services also complicates the analysis of elderly care service supply. The limitation of the analysis in this chapter is that it does not examine the accessibility of different types of elderly care facilities separately. The reason lies mainly in the availability of relevant data and the operability of the model. This has led to limitations of the analysis results of this study. Some areas have higher accessibility rates; however, it does not mean that the older citizens living in these areas enjoy better elderly care service resources. For example, the higher accessibility rates in Aoba Ward can mainly be attributed to more facilities providing daily elderly care around this area. However, the older people living in this area who require long-term care facilities cannot avail of the necessary services. In other words, the analysis results of this chapter have limitations in fully demonstrating the matching of supply and demand for elderly care services in Sendai City. In future research, the analysis accuracy can be improved by setting different coefficients for different facilities in the model.

CHAPTER 7

SPATIAL INEQUITIES IN BASIC EDUCATION AND THE PLANNING APPROACH OF EDUCATION RESOURCES IN NAGANO CITY

7.1 - Introduction

The depopulation occurring in Japan is not just reflected as a decrease in the total population, the population structure itself is also experiencing changes due to ageing and the declining birth rate. Accordingly, the number of children is declining significantly. The impact of this is reflected in changes in the number of primary school students, which has decreased year after year since the second baby boom generation of 11.92 million in 1981. In 2021, the number of primary students dropped to 6.22 million, which is about half of the peak in the late 1950s. The number of students per class has decreased by about 20, from 43.8 in 1955 to 23.5 in 2018. Additionally, the number of primary schools has decreased from 26,988 in 1957 to 19,336 in 2021, a result of the integration of educational institutions due to the decrease in the number of children and students (MEXT, 2016).

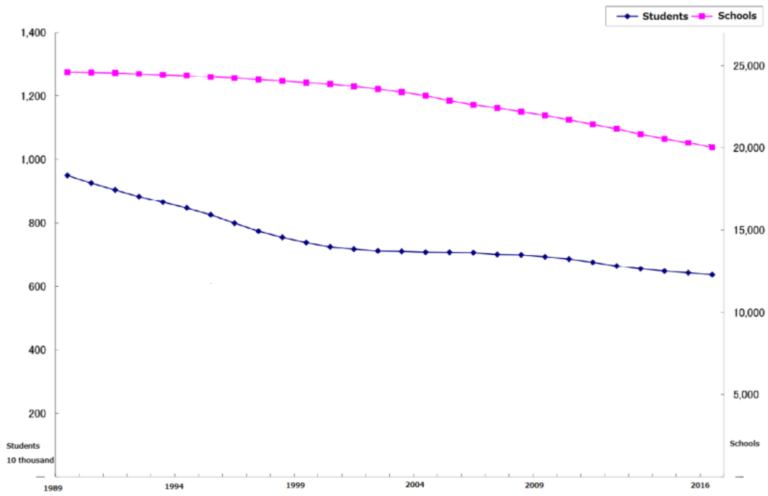
The integration of primary schools may increase the burden on students, particularly those who have to attend schools which are long distances from their homes. The decrease in the number of students may reduce the opportunities for children to work hard and grow while fostering sociality, making it more difficult for them to grow into independent and strong young people. In addition, the disappearance of primary schools due to institutional integration may possibly lead to depopulation, through the loss of the child-rearing generation's population, and may directly lead to the decline of the areas where primary schools are located.

Based on the abovementioned problem, this chapter examines the spatial distribution characteristics and layout efficiency of primary schools in the city of Nagano via accessibility analysis and provides suggestions for future school planning based on the analysis outcomes and government statistics. Section 7.2 presents a brief introduction of the geographical and historical background of Nagano prefecture to clarify its rationality as the research object. Section 7.3 introduces the current primary education situation in Nagano Prefecture. Sections 7.4 introduces the data used in the subsequent analysis and describes the distribution patterns of primary schools in Nagano City. This section also details the 2SFCA method applied in the accessibility analysis and the calculation process of key variables to provide the basis for further analysis. Section 7.5 shows the process and outcomes of the accessibility analysis. Section 7.6 discusses the possibility of improving the spatial layout of schools and provides policy making suggestions based on the findings of the accessibility analysis and population projection data. Finally, Section 7.7 summarises the chapter.

7.2 - Historical and Geographical Background

Figure 7.1 shows changes in the number of students and public primary schools. From 1989 to 2016, the number of children decreased from 9.5 million to 6.37 million, a decrease of 3.13 million; in other words, the number of children has decreased by 33% in 28 years. As the number of children decreases, so does the number of public primary schools. The number of public primary schools was 24,608 in 1989; however, this number decreased to 20,011 in 2016. In 28 years, the number of primary schools witnessed an 18.7% decrease—a total of 4,597 schools (MEXT, 2016). Overall, these figures demonstrate that the decrease in the number of primary school children and the consequent consolidation of primary schools are progressing at a considerable pace in Japan.

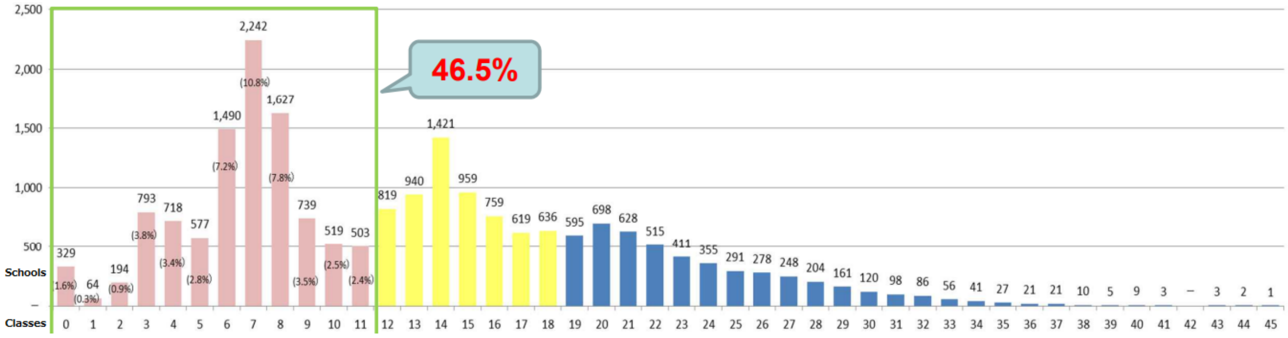
Figure 7.1 – Changes in the Number of Students and Public Primary Schools



Source: MEXT (2016)

Furthermore, changes are also happening inside schools. Japan's primary school establishment standards stipulate that the school scale should be 12 to 18 classes (Article 41 of the School Education Law Enforcement Regulations), that is, two to three classes per grade. In this study, primary schools with less than this standard (11 classes or less) are defined as small schools. Figure 7.2 shows that in 2016, 46.5% of primary schools had fewer classes than the appropriate scale of 12 classes (MEXT, 2016). In other words, nearly half of the primary schools are small schools that do not meet the appropriate scale stipulated by law.

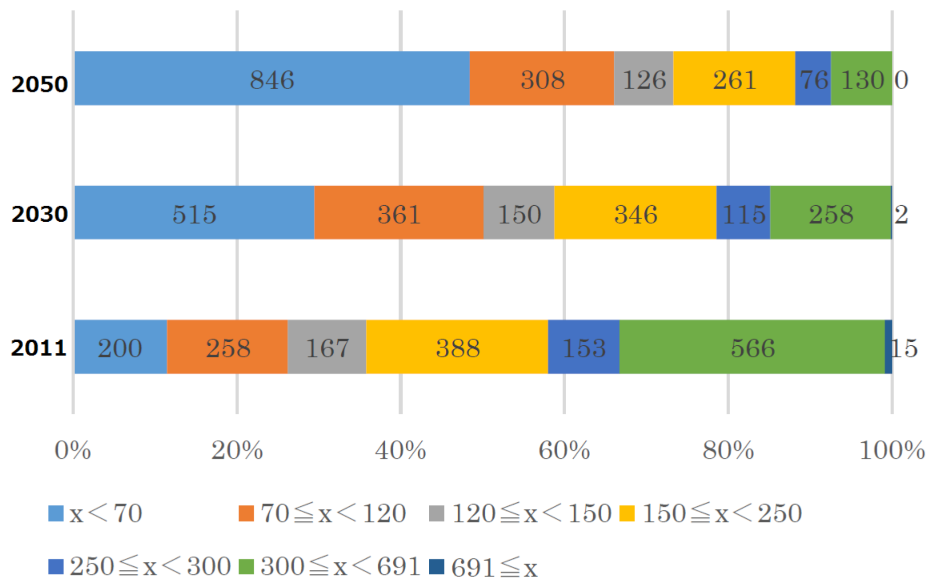
Figure 7.2 – Number of Schools by Class Size



Source: MEXT (2016)

Figure 7.3 shows the average number of children per primary school by city, estimated for 2030 and 2050 based on the changes so far. By 2050, the average number of children per primary school will be less than 70 in about half of the cities. A number of students less than 70 is the level at which one class cannot be maintained per grade (Hayo, 2017). While this figure displays the number of children, not the number of class sizes, it is evident that the size of the class is also expected to shrink.

Figure 7.3 – The Average Number of Children Per Primary School by City



Source: Hayo (2017)

As mentioned above, the number of small primary schools is about half at present, and the number of small primary schools may increase overwhelmingly in the future. In other words, there is concern that the scale down of primary schools will accelerate. Therefore, it is necessary to consider how to efficiently distribute primary school educational resources to respond to the coming era of small schools.

The subject of this study is public primary schools in Nagano City. The reason for taking up public primary schools is that public primary schools are compulsory education courses and are most closely linked to the community. Primary school is not just a place to teach children to study. More importantly, primary schools play various key roles such as subject education, fostering sociality, and cooperation with the community. These roles are made possible by the presence of a certain number of children and teachers, sufficient facilities for primary school education, and the cooperation of local people. However, as the population declines, it is easy to imagine that some areas will have insufficient resources such as people, goods, and facilities.

Nagano Prefecture is the fourth largest area in Japan. It is a vast mountainous prefecture with an area of 13,562 km2 and approximately 120 km east–west and 212 km north–south, is located at the centre of Honshu and borders eight prefectures. Mountains account for 84% of the total area, habitable area ratio is 24.43% and many traditional settlements exist in mountainous areas. Notably, 19 cities, 14 counties, 23 towns and 35 villages exist in the prefecture (Nagano Prefecture Board of Education, 2014). Amongst them, 8 cities, 8 towns and 21 villages are considered ‘depopulated areas’, as stipulated by the Act on Special Measures for Promotion for Independence for Underpopulated Areas (過疎地域自立促進特別措置法). Nagano Prefecture is surrounded by high mountains, such as the Northern and Southern Alps, where numerous rivers originate. Sai and Chikuma Rivers flow into the Sea of Japan, and Tenryu and Kiso Rivers pour out to the Pacific Ocean. The prefecture are divided into four areas, namely, Toushin (東信), Nanshin(南信), Chuushin(中信) and Hokushin(北信), according to these mountains and rivers, each region forms a community with its unique history, culture and economy.

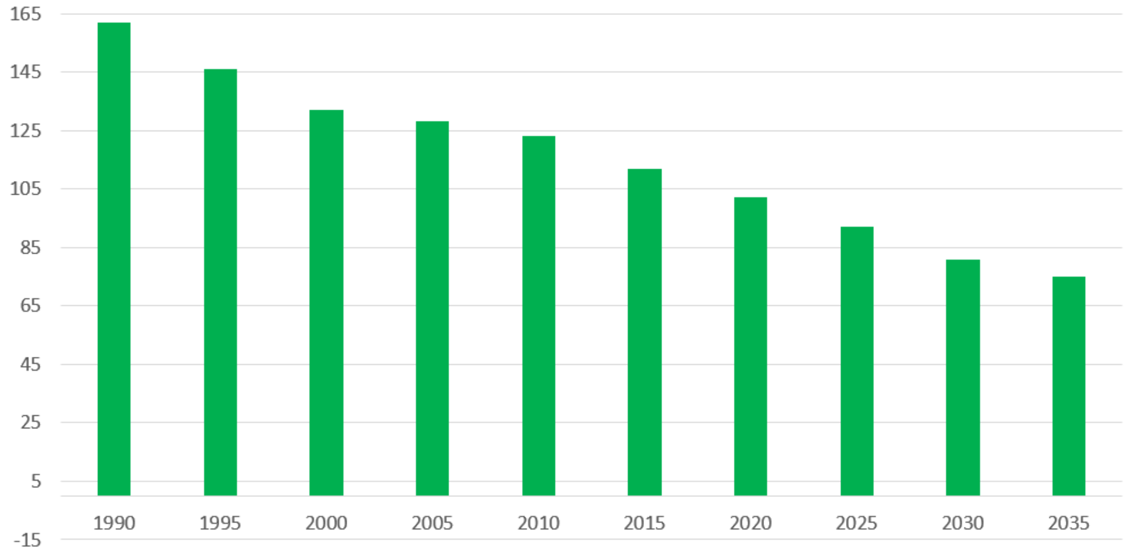
Nagano Prefecture featured the largest number of Terakoya (寺子屋, temple schools) in Japan during the Edo period, and the early Meiji period recorded the maximum school enrolment rate in Japan. In addition, children’s education has been given considerable importance because the majority of costs of former Kaichi (旧開智学校,kyūkaichi-gakkō) and Nakagomi (旧中込学校, kyū-Nakagomi gakkō) Schools built in the Meiji era were covered by donations from local residents (Nagano Prefecture Board of Education, 2014). However, since the 1980s, the decrease in the young population is large compared with the total population and many municipal boards of education only have one primary and one junior high school due to these geographical and demographic conditions. The inevitable downsizing of schools has led to the increasing adoption of measures, such as school consolidation and integrated education for primary and junior high schools, to improve the educational environment for students. Moreover, some local governments have even decided to outsource their junior high school education to adjacent local governments.

7.3 - Current Status of Primary School Education in Nagano Prefecture

Similar to that of the national situation, the population of Nagano Prefecture continues to decline and the young population is estimated to decrease significantly in rural areas. This section summarises the current situation of changes in primary school education in the Nagano Prefecture.

The number of students has been declining since the 1980s, with the number of primary school students peaking at 200,326 (1982), and this number has decreased to approximately 50% at present. As shown in Figure 7.4, the National Institute of Population and Social Security Research estimates that the number of primary school students will be approximately 75,000 in 2035, a reduction to around 70% of the present number. Additionally, the number of students in some rural areas is estimated to decrease rapidly to less than 30% of the current number; thus, the impact of depopulation on primary education is unavoidable.

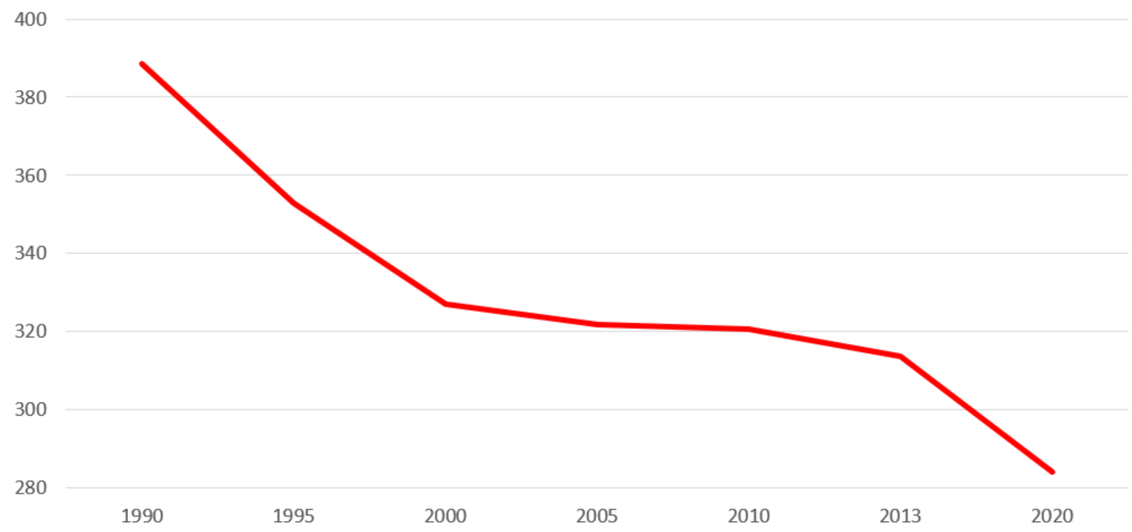
Figure 7.4 – Changes in the Number of Students and Future Estimates (Unit:1000)



Sources: School Basic Survey (2020), Ministry of Education, Culture, Sports, Science and Technology. Population Projection for Japan: 2016-2065 (2015), IPSS.

Notably, 365 primary schools (360 main and 5 branch schools) exist in 2020. As shown in Figure 7.5, the number of students per school decreased to 284.02 in 2020. Due to this, the number of schools has also been decreasing. Since the rate of decrease in the number of students is greater, a continuous decrease in the number of students per school has been sustained.

Figure 7.5 – Number of Students per School



Sources: School Basic Survey (2020), Ministry of Education, Culture, Sports, Science and Technology.

Tables 7.1 and 7.2 show the number of schools by the number of students and the number of schools by the number of classes in 2020, respectively. Table 7.1 shows that 79 primary schools (22.1%) have less than 100 students. The number of students varies widely, with the majority of primary schools having less than 300 students. Regional disparities have been observed in the continuous decline of birth rates, and the miniaturisation of schools has progressed significantly in rural areas.

Table 7.1 – The Number of Schools by the Number of Students

Students	>99	100-199	200-299	300-399	400-499	500-599	600-699	700<	Total
Schools	79	76	61	49	24	26	24	19	358
%	22.1	21.2	17	13.7	6.7	7.3	6.7	5.3	100

Sources: School Basic Survey (2020), Ministry of Education, Culture, Sports, Science and Technology.

Table 7.2 – The Number of Schools by the Number of Classes

Classes	>6	7-12	13-18	19-24	25<	Total
Schools	36	147	94	43	38	358
%	10	41.1	26.3	12	10.6	100

Sources: School Basic Survey (2020), Ministry of Education, Culture, Sports, Science and Technology.

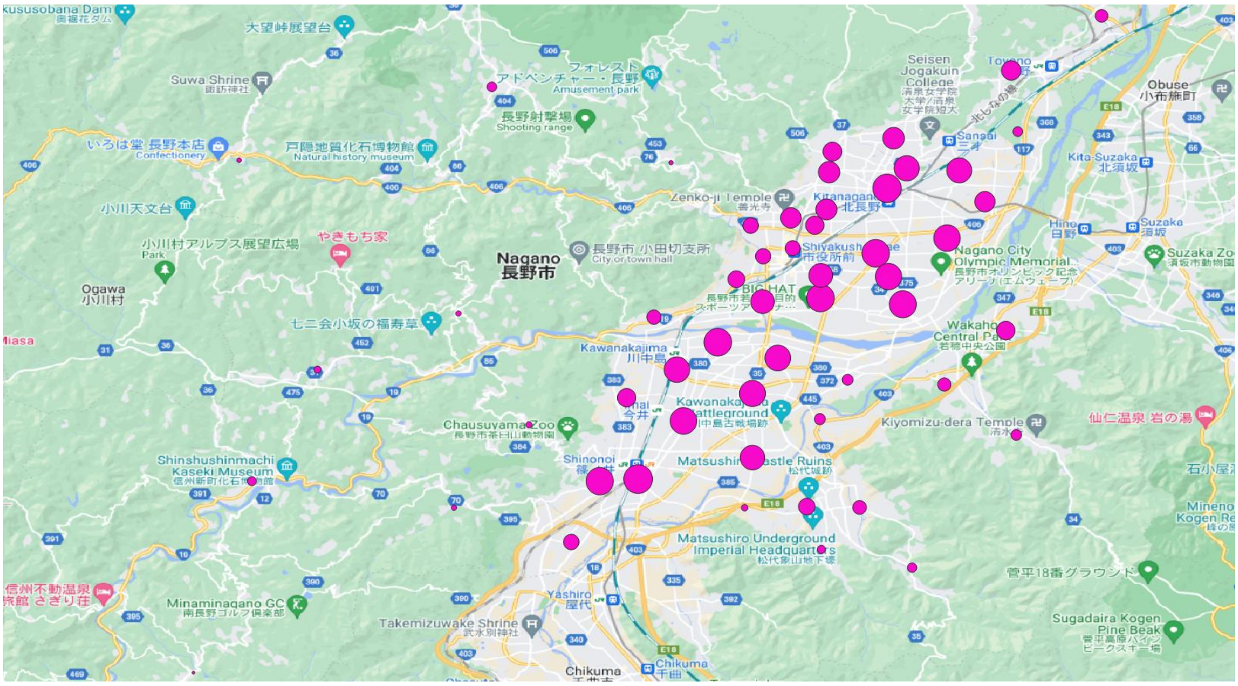
The average number of classes per school in 2020 (excluding special support classes) was 13.5. As shown in Table 7.2, the majority of primary schools in the Nagano Prefecture have 7–12 classes. However, a few primary schools only have one class for all grade levels.

7.4 - Data and Methodologies

The spatial data of primary schools in Nagano city were obtained from the National Land Numerical Information Database and the relevant population data were obtained from the 2015 National Census. The number of students and teachers in each primary school was obtained from the school education information site. Demographic data for each residential area was obtained by district and age from the demographics published by the Planning Division of Nagano City. The analysis method used in this study is the 2SFCA model. The basic principles of this method have been comprehensively discussed in Chapter 3. In this chapter's analysis, the first step of 2SFCA is to calculate the supply-demand ratio of each primary school's service area. Specifically, the search area is established with the primary school as the centre, and the distance from the primary school to the residential areas within the search area is restricted to the reach of the school service radius. The second step is to establish residential area-centred search areas. Each residential area may contain multiple primary schools within its limit distance. The analysis then sums up the supply and demand ratios to obtain schooling accessibility of each residential area.

Nagano City is promoting a "multipolar, network-type compact city" that connects the bases with transportation infrastructure by arranging sub-bases around the main base, Nagano Station. Through good transportation, the primary school has spread not only to the central area around Nagano Station but also to the surrounding regions, and the results are in line with the city's plan. Schools located in the central area are larger and relatively close to each other geographically, while schools located in peri-urban areas are smaller and more geographically dispersed. The Nagano City area has grown due to the wide-area merger, and even if it is difficult to reach the center around Nagano Station from the peripheral area, there is a possibility that the school can be accessed if it is near the "nearest sub-base." From Figure 7.6, it can be observed that the primary school distribution has proved the effectiveness of the "multipolar, network-type compact city" structure.

Figure 7.6 – Primary Schools Spatial Distribution



Sources: National Land Numerical Information database, produced by using QGIS.

The data used in this study are divided into spatial and non-spatial data. The spatial data include the current primary school layout in Nagano City, street divisions, community areas, and transportation networks. Non-spatial data include the 2015 permanent population data of various communities and basic data of primary schools (number of students, number of teachers, number of classes, floor space, etc.) in Nagano City and relevant background information.

Before the accessibility evaluation, the various spatial data obtained are pre-processed into the data format required by ArcGIS, that of the shapefile format. Then the location of primary schools and community units are abstracted into point data as the starting and end points of the analysis and are connected with road line features. The main techniques of the 2SFCA method include the extraction of residential areas, the creation of the OD cost matrix of the traffic network, the establishment of standards for non-spatial attributes of primary schools and the determination of distance thresholds. Non-spatial data are processed using the MS Excel tools, and the resulting table is connected with the spatial data attribute table in ArcGIS.

7.4.1 - Calculation of School-age Population

First, residential land is extracted based on the high-resolution OSM of Nagano City and urban land map and combined with actual survey data. Then, the residential area of each community is extracted from the entire area. The area to point tool in ArcMap is used to convert the area element file into a point element file, and the centroid of the community area is extracted as the residential area.

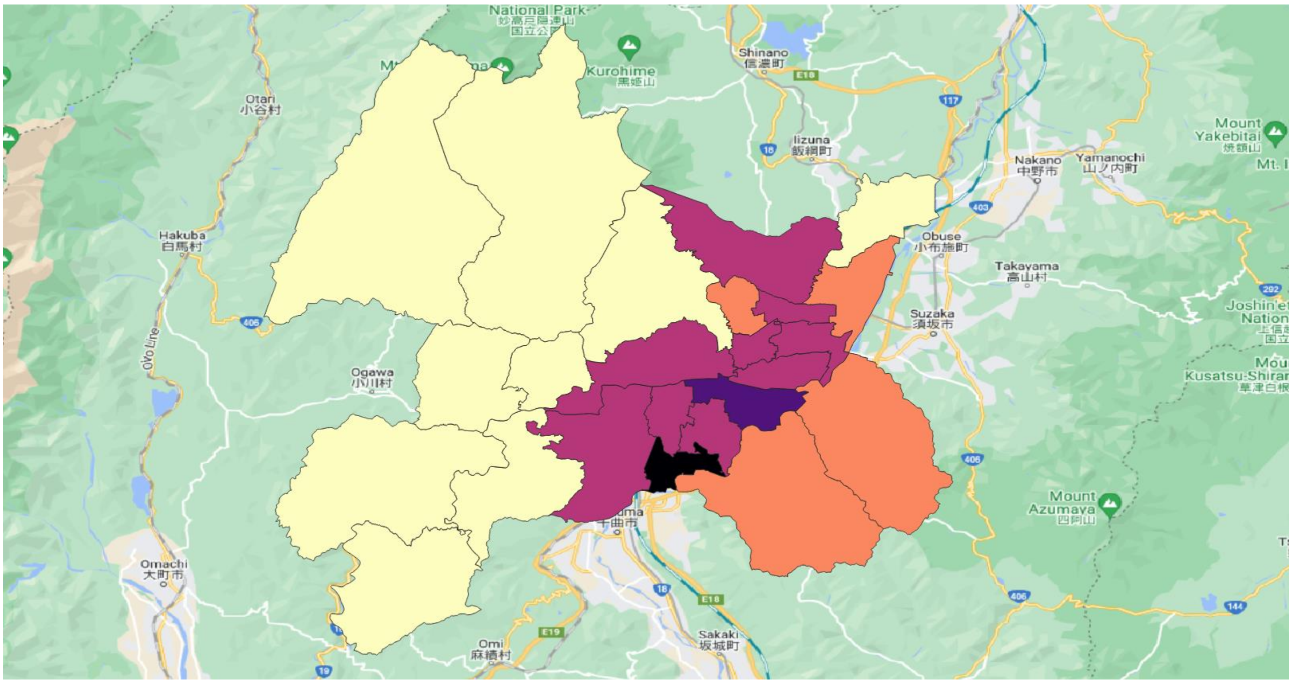
Second, the current population of each residential area is calculated. At present, the smallest unit of population statistics is at the municipal level, and obtaining the current permanent population of each residential area is difficult. Therefore, the following is used to calculate the population of residential areas.

$$\textbf{\textit{Residential area Population}} = \frac{\textbf{\textit{Area of Residential Point}}}{\textbf{\textit{Area of Municipality}}} \textbf{\textit{ X Total Population of Municipality}}$$

Finally, assign population attribute data to residential areas, and establish the distribution data of residential areas (.shp).

Regarding the calculation of school-age population (6–12 years old), the commonly used method is to multiply the number of permanent residents in each municipality by the proportion of the school age population to the permanent population in each municipality. The National Census has population statistics for each age group. The total population of 6–12 years old can be summarized and divided by the total permanent population to obtain the proportion of the school age population to the permanent population. Then the number of permanent residents in each municipality is multiplied by this ratio to obtain the total number of permanent school-age residents in each residential area. Through calculation and analysis of the population data of Nagano City in 2015, it is concluded that the population of 6–12 years old accounts for approximately 6.3% of the total permanent population.

Figure 7.7 – Distribution of Population Density



Before the main analysis, this section uses the analysis tool in ArcGIS to analyse the population density of each residential area. The purpose is to sort out the permanent population and school-age population size of each residential area at the end of 2015 and provide demographic information for subsequent analysis. The colour in the Figure 7.7 from lighter to darker represents the increase in density. As shown in Figure 7.7, relatively large differences in the density of the school-age population in various residential areas can be observed. On the whole, Shnonoihigashi (篠ノ井東) has the highest population density and Oooka (大岡) has the lowest population density. The population densities of Kouhoku (更北), Kawanakajima (川中島) and Susobana (裾花) are relatively balanced and significantly higher than in other areas, while the population densities in Kinasa (鬼無里), Naniai (七二会) and Shinkou (信更) are relatively low. From the perspective of demand, the density distribution of teaching capacity in primary schools should be roughly positively correlated with school-age population density. In the next section, the teaching quality of schools will be analysed.

7.4.2 - Evaluation of Primary School's Teaching Capacity

The selection of primary schools in Japan is based on three aspects. The first aspect is the advantages and disadvantages of the corresponding junior high school of the primary school, the second is the quality of the school's teaching and the third is the distance between the primary school and home. The first aspect belongs to the scope of opportunity and is not within the scope of this research. Therefore, the spatial accessibility evaluation of this research focuses on the second and third points. Among them, the supply capacity of primary schools indicates the quality of teaching.

According to the Primary School Establishment Standards (小学校設置基準), many rigid indicators can be found in the evaluation system for standardization construction of primary schools in Nagano City. Standards have been formulated from five aspects: planning and layout, school conditions, school management, teaching and characteristics. In the calculation of accessibility, some studies use indicators, such as the number of teachers, directly as the only basis for evaluating teaching quality. To improve the accuracy of calculation, this study sets a different weight value for each indicator to comprehensively calculate the teaching quality of primary schools and to improve the accuracy of calculation. Among the many indicators, three are selected: the number of teachers, the number of classes and the school building area.

The standards for each indicator are as follows. Primary school teacher-student ratio adopts the prefectural standard ratio in 2016. The urban primary school teacher-student ratio is 1:17.2. Based on the results of the School Basic Survey 2016, the class size of the primary school is determined to be 24 students/class. The index of area per student follows the corresponding index value of $12.5m^2$/student specified in the Primary School Establishment Standards. The specific standards are shown in Table 7.3.

Table – 7.3 - The Standards

Indicators	Standards	Weights
Number of Teachers	17.2 students/teacher	W_1
Number of Students	24 students/class	W_2
School Building Area	12.5m^2/student	W_3

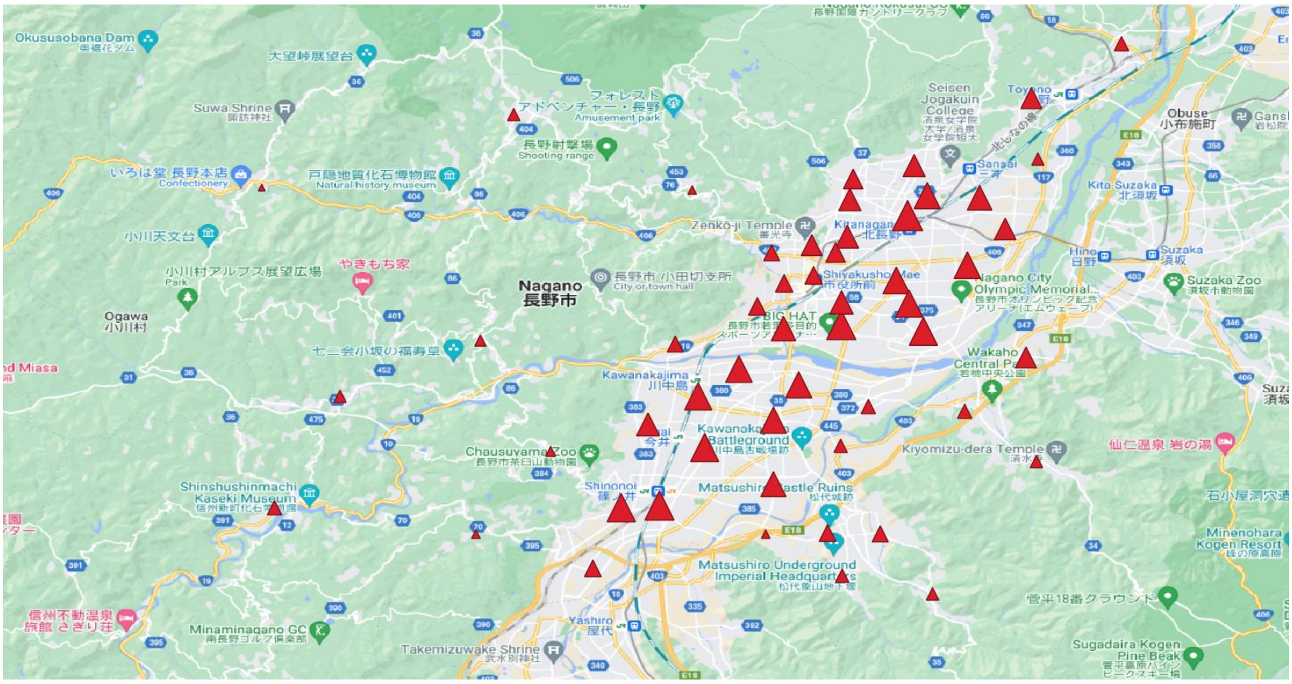
$$S = W_1 \times (A \times K_1) + W_2 \times (B \times K_2) + W_3 \times (C / K_3)$$

S: Teaching capacity;

K_1: Standard of teacher; K_2: Standard of class; K_3: Standard of area per student

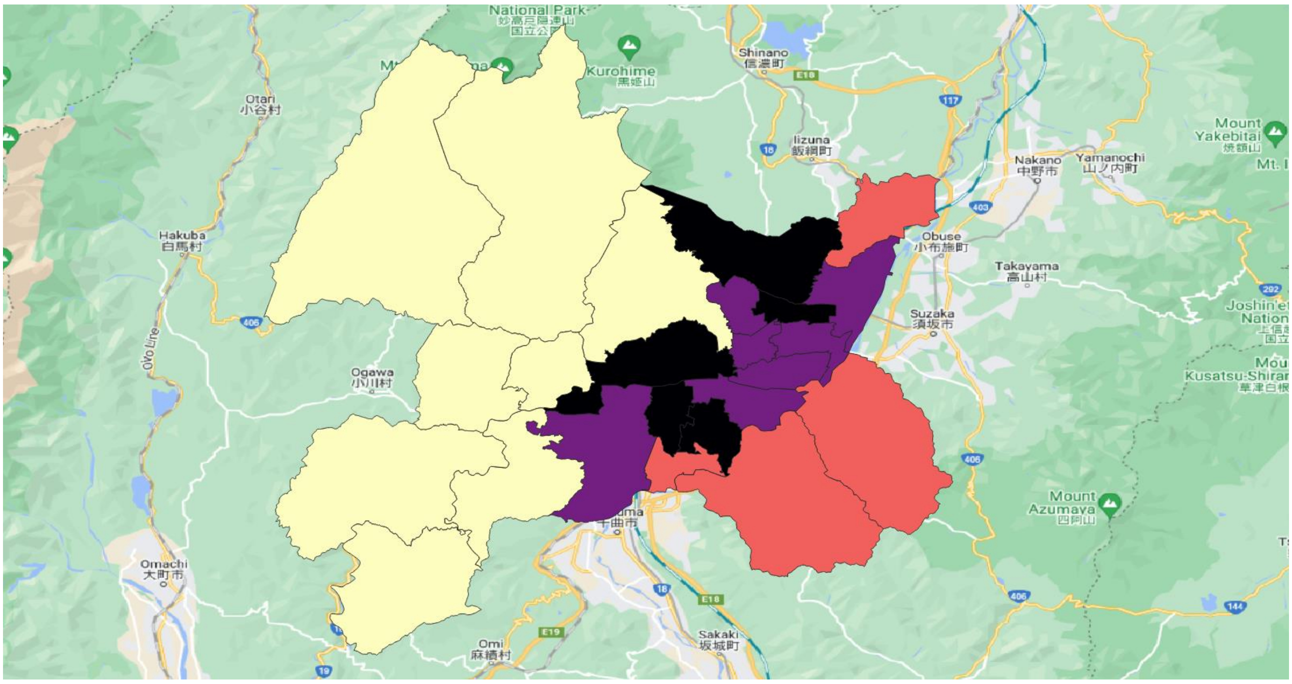
In the calculation, A, B and C represent the number of teachers, the number of classes, and the school building area. The weights are set according to the importance of each evaluation index, W_1=0.3, W_2=0.3, W_3=0.4. According to analysis, most schools in the region relatively lack floor space, and it will be difficult to expand in future adjustments, while the class size and teacher resources are easier to increase in the short term. Therefore, the weight of the floor area is 0.4, and the weight of the number of teachers and the number of classes is 0.3.

Figure 7.8 – Distribution of Teaching Quality (School)



The next step is to calculate the teaching quality of each primary school in the study area. The calculation result is shown in Figure 7.8. The figure shows that the education quality of primary schools Tsuumei (通明), Yoshida (吉田) and Sanbonyanagi (三本柳) is much higher than other primary schools. According to the above evaluation method, the teaching quality of each primary school in the study area can be quantified, and the outcomes can be used to draw a density map of the teaching quality. Figure 7.9 is a grading map of the teaching quality, it shows that the overall teaching quality of primary schools located in Kawanakajima (川中島), Susobana (裾花) and Toubu (東部) is the highest. The teaching quality of primary schools in Koutoku (広徳) and Shinonoinishi (篠ノ井西) areas is relatively high while the teaching quality of primary schools located in Kinasa (鬼無理) and Oooka (大岡) areas is generally low. Generally speaking, primary schools with better teaching quality are located in the middle of the study area, and primary schools at the edge of the study area are relatively low in quantity and quality.

Figure 7.9 – Distribution of Teaching Quality (Region)



Based on the analysis of the density of the school-age population and the density of primary school teaching quality, it can be seen that in the study area, primary school education resources have generally met the demand. Educational resources have achieved a reasonable match, especially for areas with strong demand for education, such as Kawanakajima (川中島) and Susobana (裾花) areas. However, for some areas with relatively high educational needs, such as Sairyou (犀陵) and Hokubu (北部) areas, the teaching quality is relatively poor, and leaves room for improvement. In Shinkou (信更) area, the uneven distribution of educational resources is more serious. Thus, determining how educational resources can be allocated more reasonably will be an urgent issue in these areas.

7.4.3 - Determination of Distance Threshold

The most important technical parameter in this study is the distance threshold. The previous studies (Lavy, 1996; Killeen and Sipple, 2000; Luo and Qi, 2009) indicate that the service radius of primary schools should not be greater than 700 meters. The planning for supporting facilities in residential areas requires that the design of primary schools should take into account the number of residents in the planned area, and the layout of educational service facilities must be planned following the requirements of the educational service radius. Moreover, according to the Guidance on proper scale and placement of public primary and junior high schools (公立小学校・中学校の適正規模・適正配置等に関する手引), the maximum service radius of urban primary schools should be 4000 meters, and the time for primary school students to go to school should be controlled at about 15 minutes. This study takes into account the actual situation in the research area and refers to previous studies on educational resource space. The analysis concludes that under the premise of the road network range, the coverage area can be maximized when the service radius of the primary school is 600 meters. Therefore, the standard travel distance threshold is set to 600 meters.

In the actual analysis, when the distance threshold is 600 meters, more than 50% of the residential areas' accessibility value is 0, which is not conducive to the comparative analysis of the overall layout within the study area. Therefore, this study made the following adjustments to the analysis. Using the existing road OD cost matrix, the shortest distance OD path from each residential area to the primary school was extracted. Using this method yielded 210 shortest paths. Then, the maximum distance value of all paths is taken as the distance threshold. The unit of the Distance field is in meters. Through further calculation using MS Excel, the average shortest distance is 718.37 meters, of which the minimum is 21.33 meters, and the maximum is 2394.37 meters. Therefore, the distance threshold in the analysis is 2400 meters. In addition, to ensure the objectivity of the experiment, two other distance thresholds, 1000 and 1500 meters, are also selected.

7.4.4 - Application of the Two-step Floating Catchment Area Methods

Radke (2000) proposed a two-step floating catchment area method (referred to as 2SFCA model), which is based on both demand points and supply points and moves the search area twice. The first step of the 2SFCA is to determine the utilization level of the primary schools, that is, the ratio of supply and demand in the service scope of each school. The first step is to set up a search domain with the each school as the centre. The distance from the school to the residential area in the search domain is limited to the ranges of d_0.

The second step is to set up a search domain centred on the residential area. The residential area may correspond to multiple primary schools within the threshold of d_0, which would imply the presence of multiple facilities that provide services for a certain residential area. In this case, the accessibility of a certain residential area can be obtained by aggregating the supply-demand ratio of all schools. The 2SFCA method considers the supply-demand relationship in the study area and the results show that the calculated accessibility of each demand point is different.

However, as discussed in Chapter 3, the 2SFCA model does not consider the influence of distance attenuation. The model assumes that the spatial accessibility of each demand point is equivalent within the travel distance limit, ignoring the difference between the spatial accessibility of different demand points. In order to overcome this shortcoming, this study considers the influence of the traffic distance between the residential area and the primary school, so as to accurately distinguish the difference between the spatial accessibility of different supply points. The improved 2SFCA is actually a combination of the 2SFCA model and the gravity model discussed in Chapter 6. The improved 2SFCA model has the following expressions (formula 7.1):

$$A_i^F = \sum_{j \in (d_{kj} \le d_0)} R_j = \sum_{j \in (d_{ij} \le d_0)} \frac{a_j S_j}{d_{ij}^{\beta} \sum_{k \in (d_{kj} \le d_0)} P_k}$$

Equation 7.1

In this study, 'a_j' is the scale factor of the primary schools; the supply volume 'S_j' of the primary schools is represented by the facility scale or the number of teachers ets.; 'β' is the travel friction coefficient, and the traffic impedance 'd_{ij}' is expressed by the travel time; 'P_k' is the population of residents in the search area; and the distance threshold 'd_0' obtains spatial reachability by selecting different threshold intervals and setting weighted summation.

The significance of d_0 is that when the distance from the residential area to the primary school is less than the threshold ($d_{ij} \le d_0$), the residents will choose to attend the school. Meanwhile, when the distance from the residential area to the facility is greater than the threshold ($d_{ij} \ge d_0$), the residents will not attend such school's services. d_0 is related to many factors, including age, health status, income level, social status, and other personal attributes. Hence, the actual calculation should be set according to the actual data situation and research purpose.

7.4.5 - Implementation Path of the Two-Step Floating Catchment Area (2SFCA) Method

The 2SFCA method applied in this research includes three factors: supply point, demand point and road network spatial information. The supply point is the primary schools, and the demand point is the residential areas of various communities in the Nagano city. The road network is drawn based on the open street map of the Nagano city. These three elements are indispensable and are interdependent in the analysis. This study made the following improvements in the accessibility analysis of primary schools.

(1) Integrated research on the current status of the schools and future planning: The accessibility rate of each residential area was calculated by applying the 2SFCA method based on the current primary schools' spatial layout. This analysis also applied the Huff model based on the results of the accessibility analysis to make suggestions for future school spatial layout planning.

(2) Road network distance instead of Euclidean distance: GIS road network analysis is used to obtain the OD cost matrix. The matrix is then employed to calculate the distance from each residential area to the surrounding primary school.

(3) Refined the processing of the non-spatial attributes of supply points and demand points: School data (number of teachers, number of classes, school building area) is used to evaluate the school teaching capacity, and the data of the school age population in residential areas are collected and processed to improve the rationality of the results.

(4) Step-by-step evaluation of distance threshold optimization: In the common 2SFCA method analysis, the distance threshold value is determined according to the relevant standards of the research area. However, in the experimental results of this study and based on relevant standards, more than 50% of schools have an accessibility of 0. Evaluating the accessibility of the entire region from a comprehensive perspective is difficult. Therefore, in this study, the existing road OD cost matrix was used to extract the shortest OD path from each residential area to the corresponding primary school point. With this method, 210 shortest paths were obtained. The longest distance 'd_m' in these paths was then taken as the distance threshold. Moreover, to further ensure the objectivity of the experiment, this study also takes the values between 600m and d_m to conduct calculation and compare the outcomes.

In the following sections, this study evaluates and analyses the accessibility of primary schools in Nagano City based on the spatial attributes, non-spatial attributes, and transportation network data between primary schools and residential areas. The purpose is to provide evidence for basic education planning through quantitative analysis. The specific implementation steps of the analysis are as follows:

(1) Data preparation and pre-processing. This step consists of two parts: the first part involves collecting and sorting the data to identify the population data and spatial location of the residential area, the spatial location and education data of the primary school (number of students, number of teachers, number of classes, floor space). The second part involves building a road network layer, a street partition layer (Figure 7.10), a primary school point layer with non-spatial attributes (Figure 7.11) and a residential area layer with non-spatial attributes (Figure 7.12) in the ArcMap.

Figure 7.10 – OSM Layer

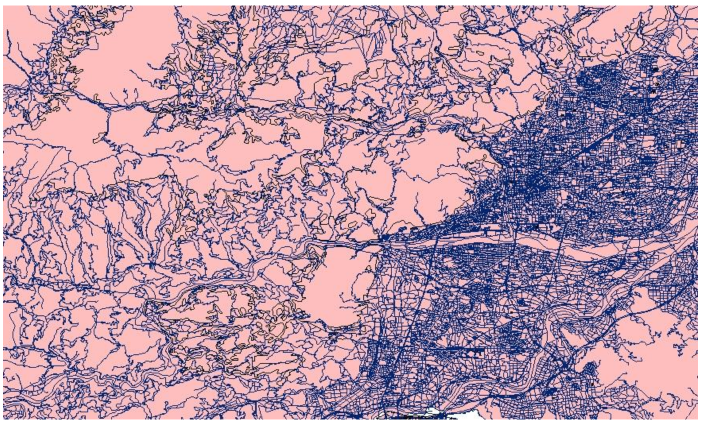


Figure 7.11 – Primary School Layer

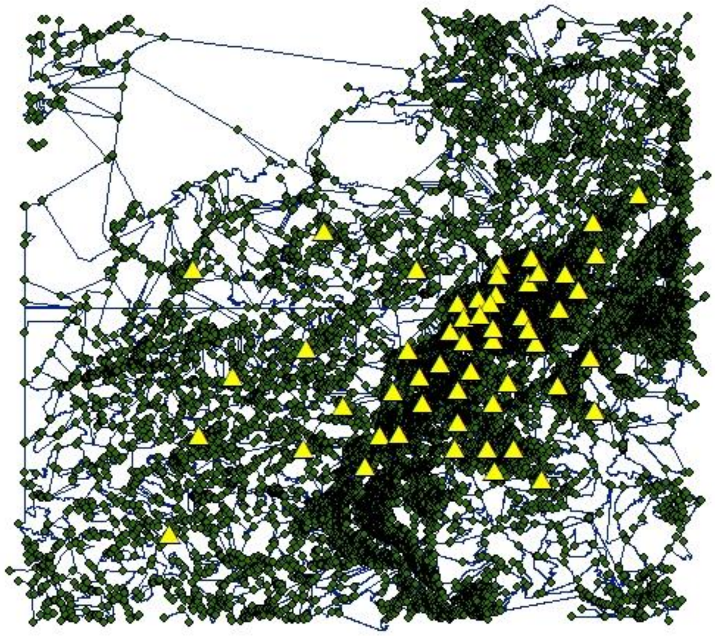
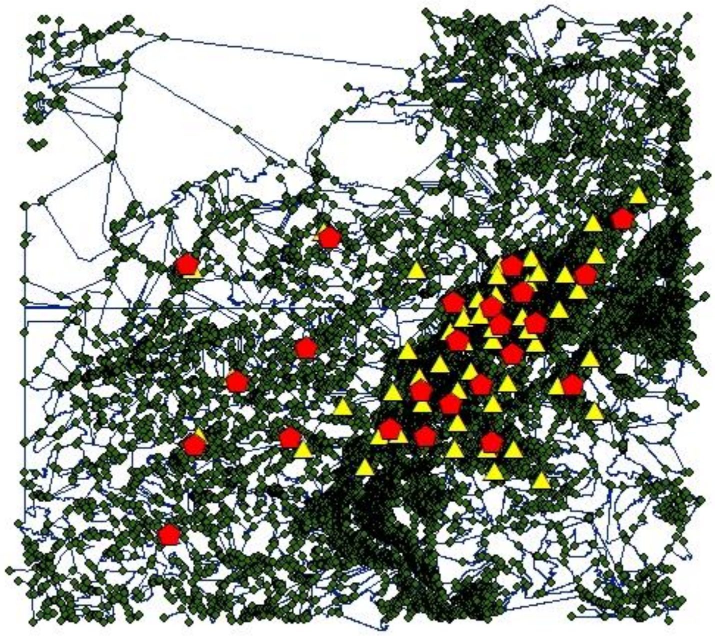


Figure 7.12 – Residential Area Layer



(2) Build a network data set of the road network. A spatial road network data set is established in ArcCatalog and the GIS network analysis tool is used to obtain the OD cost matrix. First, a new 'Geodatabase' named 'Nagano Road Network' is created in GIS. Then, a new 'Featuredataset' is created in the new geodatabase and a new feature (.shp) in the feature dataset, which is named as 'Nagano road network'. Second, the roads are drawn based on the OSM of Nagano City, and

then the current roads are interrupted to ensure that each road intersection will automatically turn (Figure 7.13). In this study, walking distance is used to define the distance between schools and residential areas. The grade of roads is not considered here. Although the road network includes the city's main roads, secondary roads and part of the community roads, when constructing the road network, roads of different levels are represented by the same line. Finally, the GIS Network Analyst tool is loaded and a new network data set is created in the element data set of the road network of Nagano City. Then, the new OD cost matrix tool is used to calculate the actual distance between the schools and the residential areas (Figure 7.14). Those works can provide extreme distance information based on the transportation network for the next step of the analysis (Figure 7.15).

Figure 7.13 – Road Network Layer

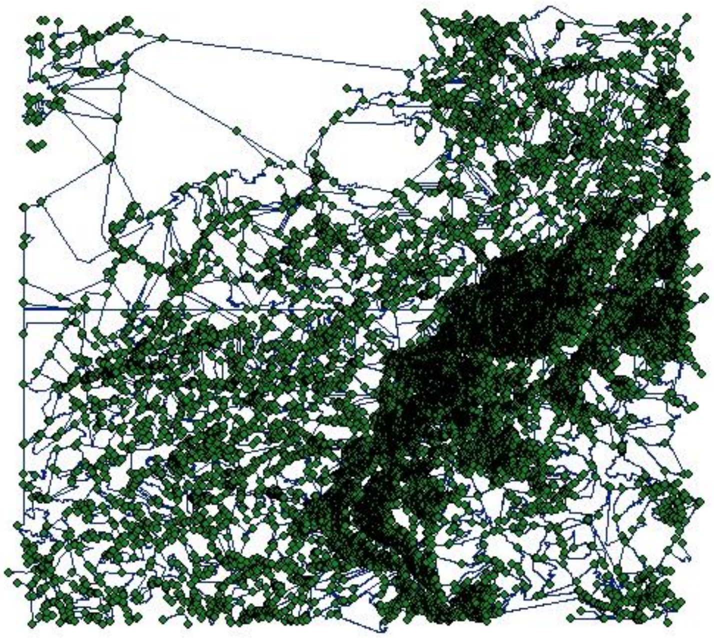


Figure 7.14 – OD Cost Matrix

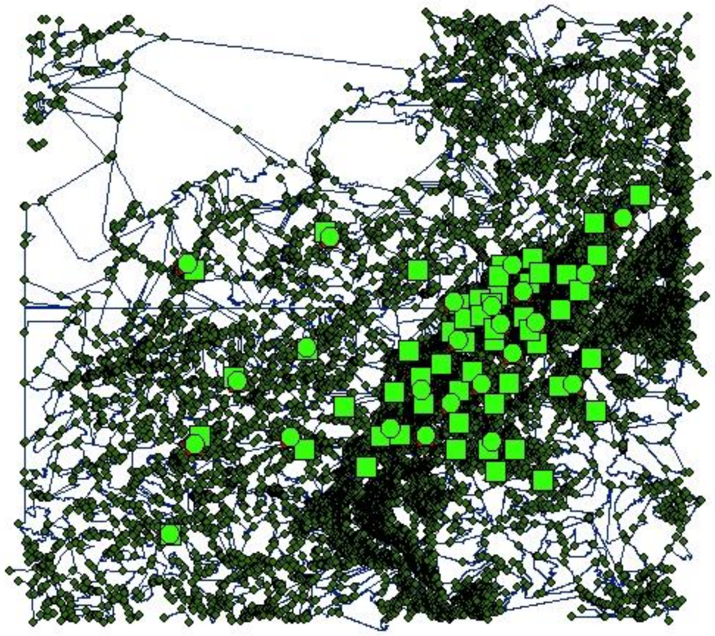
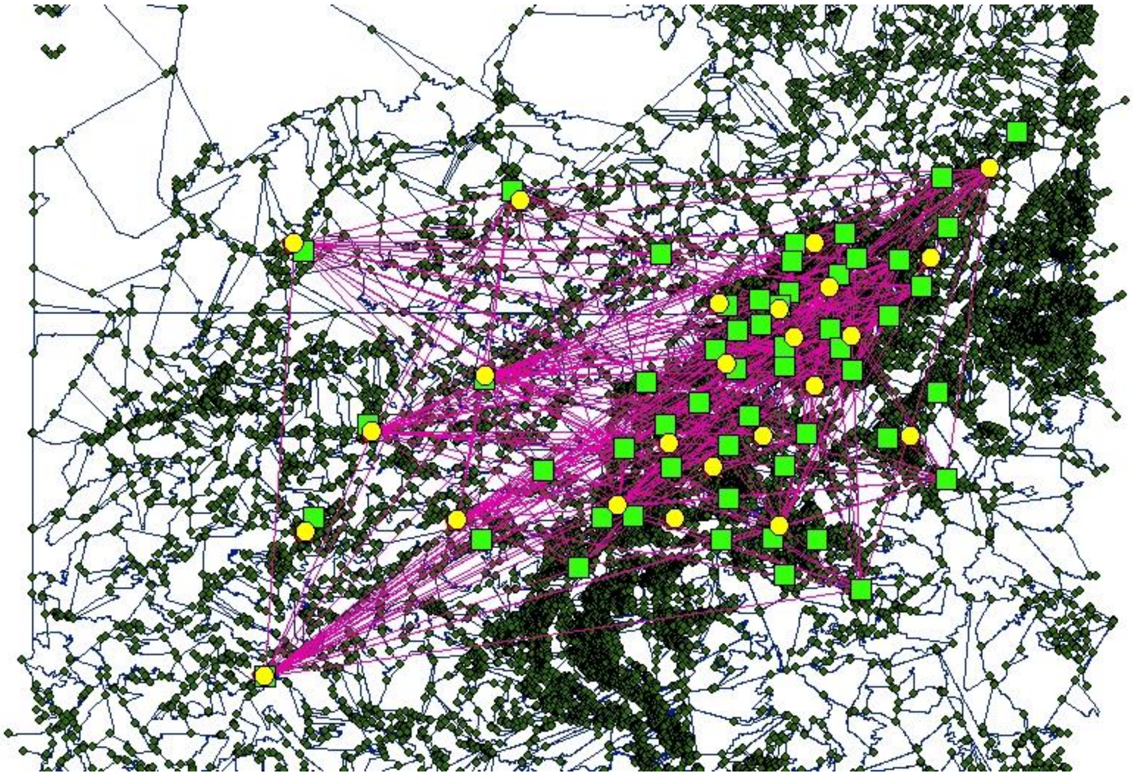


Figure 7.15 – Operation Results of OD Matrix



(3) Extract objects within the distance threshold. In the attribute table of the OD matrix, the objects that meet the distance threshold range are filtered out.

(4) Link the attributes of the primary school point and the residential area to the attribute table of the distance threshold. Then, based on the primary school name and residential area name fields,

the primary school point layer and the residential area layer are connected to the distance table.

(5) Perform the first search and calculate the supply-demand ratio. The population of school-age children within the threshold of each primary school point is summarized. Then, obtain the ratio of the number of teachers in the primary school to the number of school-age children and calculate the supply-demand ratio.

(6) Perform the second search and calculate the accessibility of residential areas. The supply and demand ratios of all primary schools within the threshold range of each residential area are summarized to obtain the accessibility of each residential area.

(7) Draw a graded accessibility evaluation chart. The accessibility attribute table of residential areas and the community layer are connected then the symbol system in the GIS attribute is used to draw an accessibility evaluation map of all residential areas (Figure 7.16).

Figure 7.16 – Accessibility Rates' Distributions

7.5 - 2SFCA Method Outcomes

Four sets of analyses are conducted in this study, and the distance thresholds were set as 600m, 1000m, 1500m and 2400m. Based on the above analysis outcomes, the accessibility evaluation map of primary schools in the Nagano City under different distance thresholds are drawn in Figures 7.17 – 7.20. According to the calculation results, the accessibility evaluation values are divided into five levels: excellent, good, average, fair and poor. The dark red part in the figure indicates the area with excellent accessibility, the red part indicates the area with good accessibility and the light red part indicates the area with poor accessibility. Within the same distance threshold, if the accessibility level is excellent/good, it means the supply of primary education resources in a certain residential area is relatively sufficient. On the whole, the accessibility of educational resources is relatively unbalanced. As the distance threshold increases, the demand for primary education resources in the majority of residential areas tends to balance, and the pressure on schooling in some areas has also been eased, also within a certain distance threshold, the accessibility shows a trend of optimization.

Nagano City has a greater demand for primary education resources. As far as the current situation is concerned, there are fewer areas with excellent accessibility level. When the distance threshold is 600m, residential areas with good accessibility account for 29.2% of the total number of residential areas. When the distance threshold is set to 1000m, residential areas with good accessibility account for 37.5% of the total number of residential areas. When the distance threshold is 1500m, 41.2% of residential areas reach a good level of accessibility. On the whole, residential areas with poor accessibility are located in the western part of Kinasa (鬼無里), Oooka (大岡), and Shinkou (信更) areas. The residential areas with good or higher accessibility are concentrated mainly in the middle part of Kawanakajima (川中島) and Susobana (裾花) areas.

The accessibility level of some residential areas in the west of Naniai (七二会) area increases as the distance threshold increases, indicating that the pressure on schooling in these residential areas can be relieved to a certain extent when the service scope of the primary school becomes increases, indicating that the imbalance between the supply and demand for educational resources in these areas is relatively large. This situation has also occurred in some areas such as Togakushi (戸隠) and Shinshuushimachi (信州新町) areas.

Figure 7.17 – 600-meters Distance Threshold Accessibility Evaluation

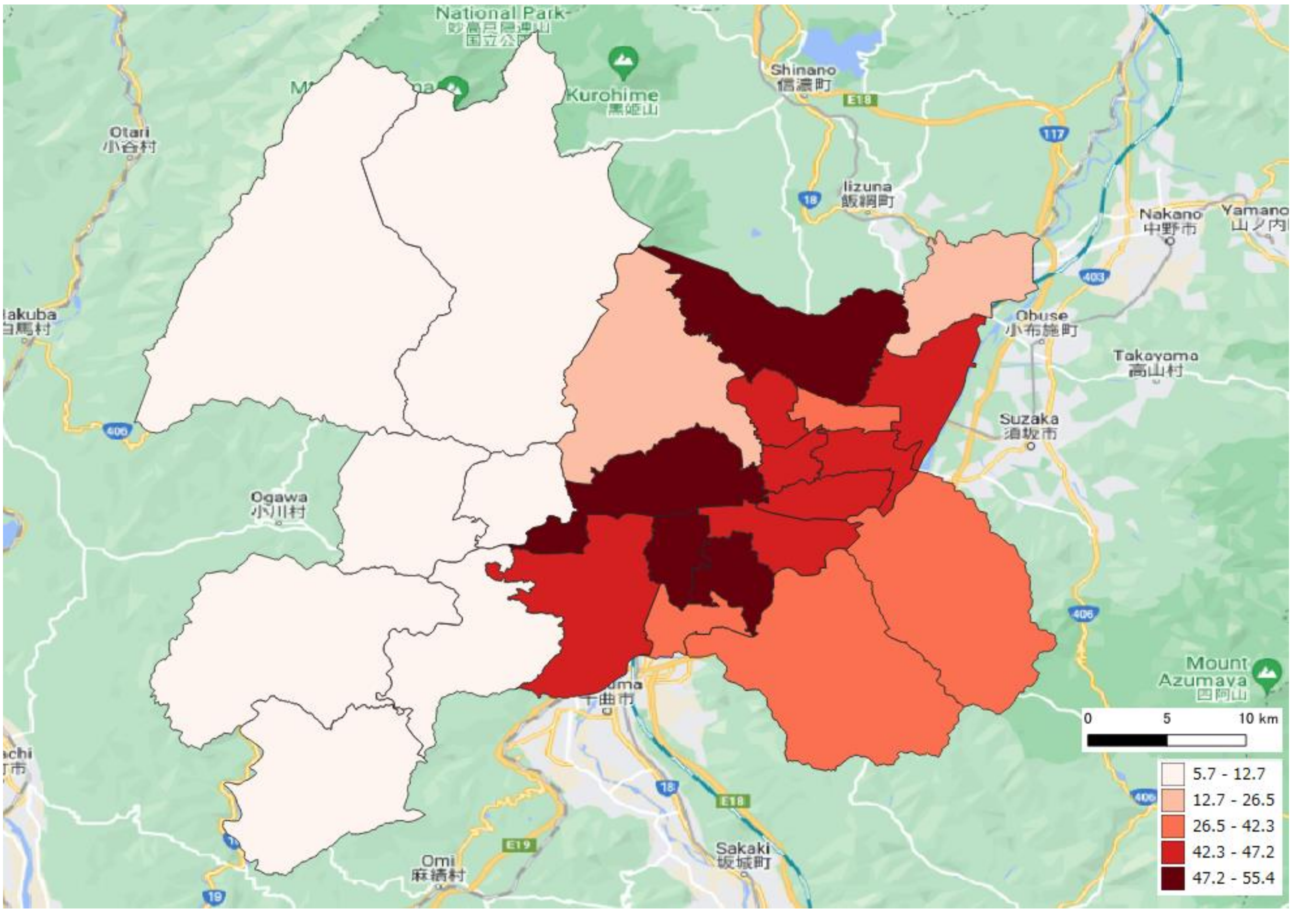


Figure 7.18 – 1000-meters Distance Threshold Accessibility Evaluation

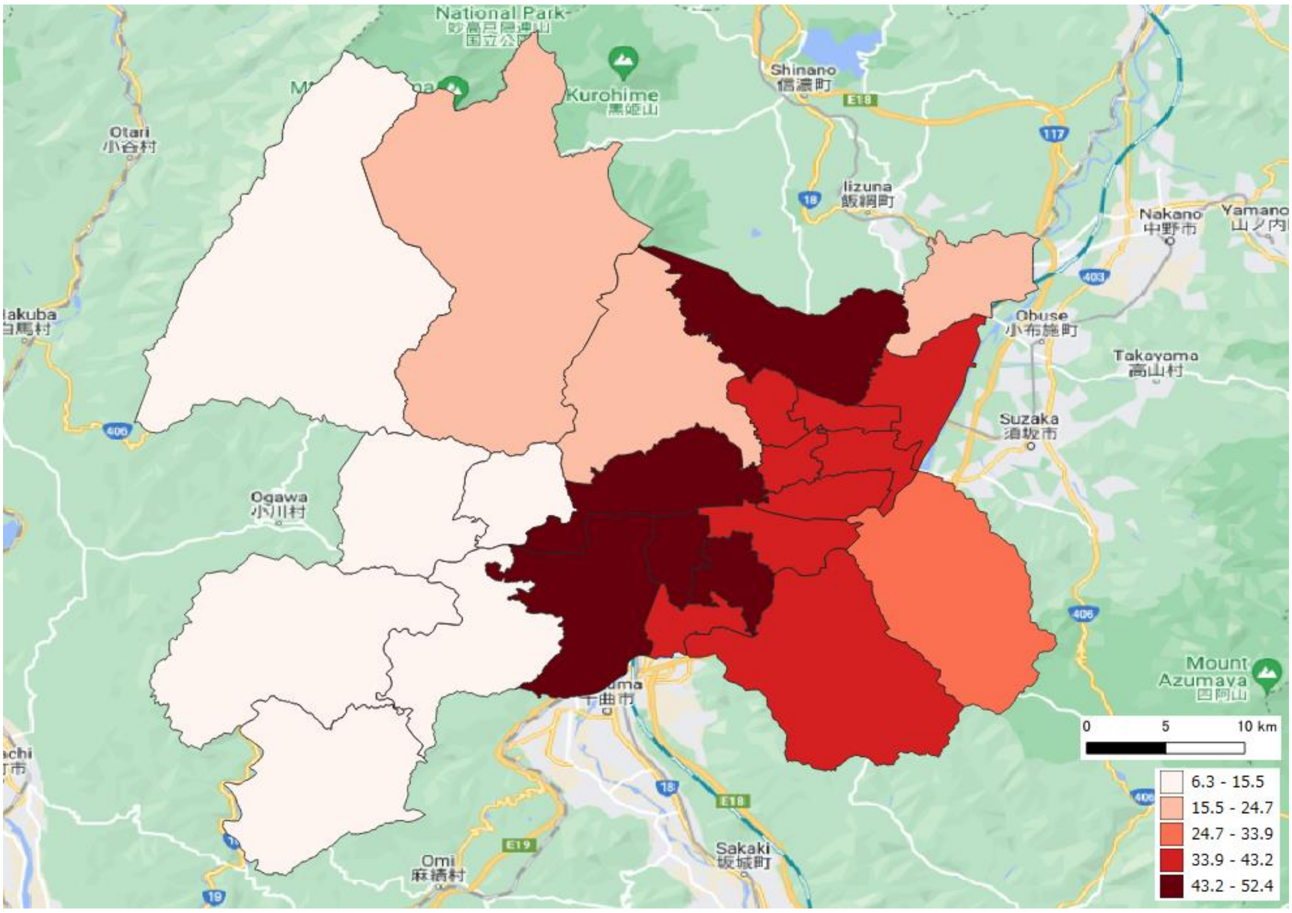


Figure 7.19 – 1500-meters Distance Threshold Accessibility Evaluation

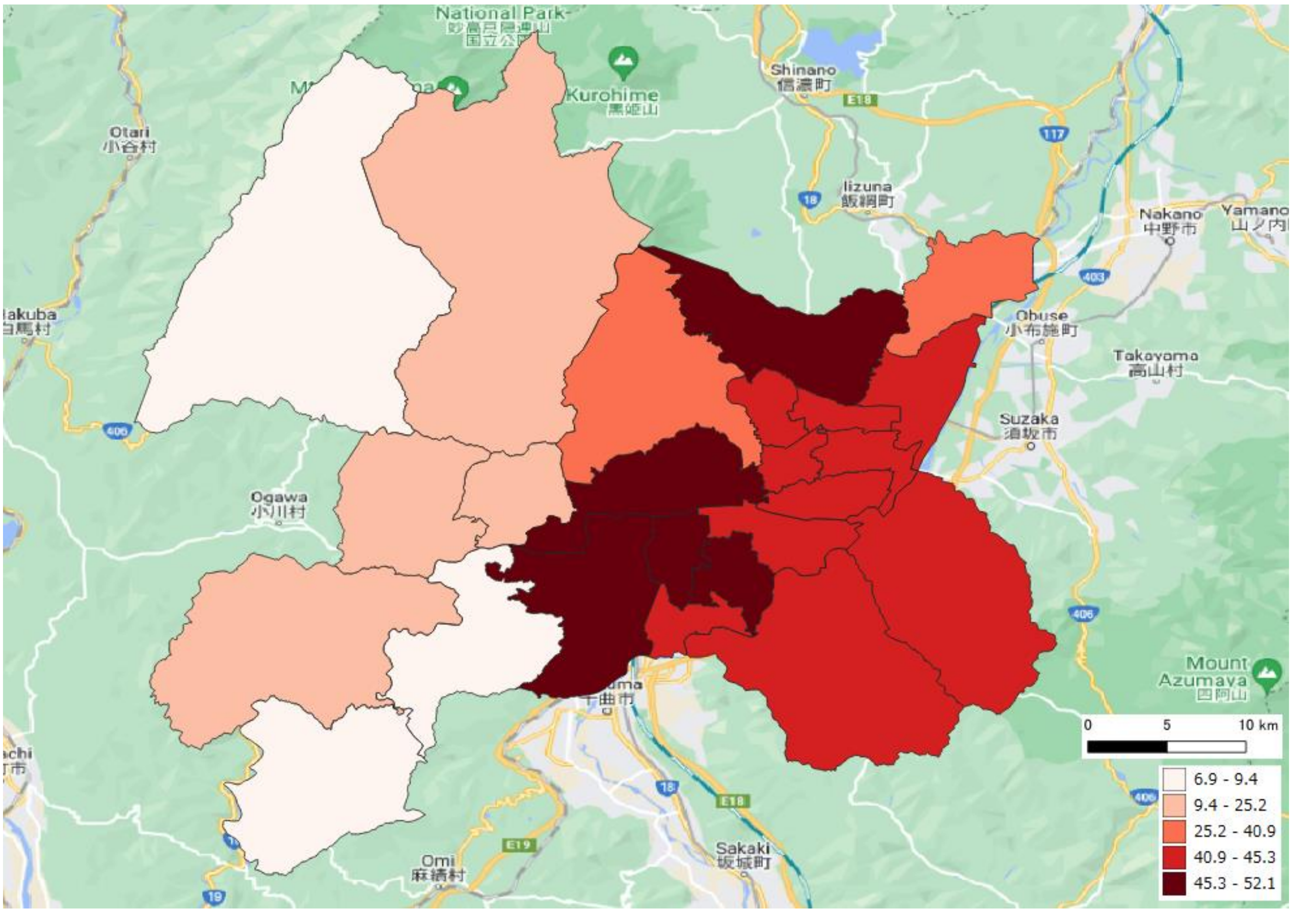
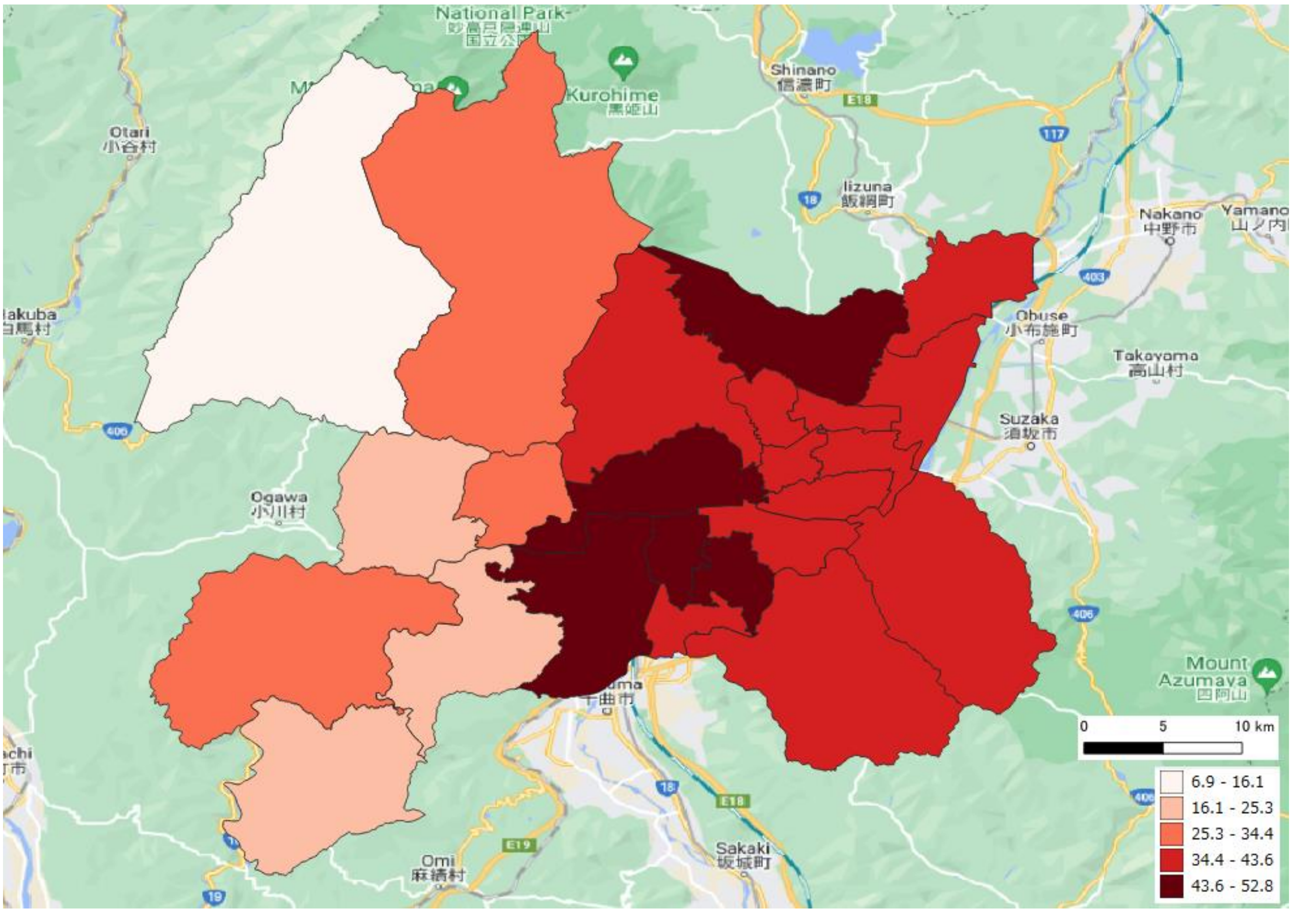


Figure 7.20 – 2400-meters Distance Threshold Accessibility Evaluation



Based on the above analysis, the following conclusions can be drawn for the current accessibility situation of primary schools in the Nagano City.

From a whole perspective, the overall accessibility is polarised, and a significant gap in the level of the supply-demand relationship among different residential areas exists. As the distance threshold increases, the overall accessibility level increases and then decreases, the accessibility level among municipalities tends to be balanced, and the regional difference in accessibility is reduced.

From a municipal perspective, the accessibility levels within each municipality vary greatly. As distance threshold increases, the internal accessibility levels of some municipalities tend to be balanced, while internal accessibility levels of some municipalities still have obvious gaps.

From a residential area perspective, for different residential areas, as the distance threshold changes, the level of accessibility presents different trends. Most residential areas have decreased pressure on schooling, and some residential areas have reached a balance between supply and demand at a critical point. A few residential areas also have a trend of surplus educational resources. It can be seen that in the process of increasing the distance threshold, a certain distance value will appear, indicating that the overall accessibility is optimal. However, in the case of unlimited increase of distance threshold value, residential areas with high-quality educational resources will have worse accessibility, and residential areas with backward educational resources will have better accessibility. The next section proposes suggestions for layout optimization from qualitative and quantitative perspectives.

7.6 - Improvement for Primary School Layout

Combined with the above analysis (section 7.5), the teaching quality of the current primary schools cannot fully meet the needs of the school-age population in the study area. Based on the current layout of primary schools, analysis in this section optimises the quality and quantity of primary schools. The specific measures are as follows.

7.6.1 - Qualitative Perspective

Adjust the scale of primary schools and narrow the gap in teaching quality among schools. Obvious differences are observed in the teaching quality of primary schools among residential areas in Nagano City. The choice of schools makes some primary schools' educational resources tight, whereas some primary schools are less attractive, resulting in a waste of educational resources. Therefore, formulating corresponding adjustment plans for primary schools at different levels is necessary. Encouragement measures should be taken for primary schools with high teaching quality. These primary schools have excellent educational resources and reputation. Giving full play to the advantages and expanding the scope of their education are necessary. Under the circumstance of ensuring normal operation, a part of the educational development land can be reserved to cope with the rapid decline of student resources, such as the primary schools located on Kawanakajima, Susobana areas. For primary schools that are located in areas where the overall layout is relatively sparse and have relatively weak hardware facilities and soft power, such as the schools on Kinasa area, renovating the surrounding environment and construction level, improving teaching level and strengthening educational attraction to the surrounding school-age population are necessary.

Remove and merge primary schools. The main targets of the merger are primary schools located in areas with a dense layout or good teaching quality. For primary schools that are less attractive, have insufficient student resources and occupy a small area, they can be merged into the surrounding schools with higher teaching quality, thereby increasing the utilisation of educational resources, expanding the advantages of high teaching quality schools and improving the regional basic education level. Primary schools with unreasonable locations and lower teaching quality can be considered to be closed. To minimise the negative impact of school closures and ensure normal primary education activities in the area, the principle of build before demolishing must be followed. For example, primary schools located in Kinasa, Oooka and Shinkou areas, because of their low educational level and scale, may consider combining several schools to improve the efficiency of teaching resources.

Build new schools or expend current schools. For areas where the quality and quantity of education are low, population density is high and urban land use is redundant, building new primary schools can be considered. In areas with sufficient land conditions, primary schools with good student resources can be expanded to a certain scale without affecting the overall function of the area. The layout of primary schools should be planned in new urban areas or urban renewal projects by setting higher construction standards and reserving some educational land to establish high-quality primary schools.

7.6.2 - Quantitative Perspective

Although the optimisation of the spatial layout of primary schools can improve the balance of educational resources to a certain extent, in some areas, the supply and demand of education are imbalanced because of the unscientific division of school districts. To ensure the balance of educational resources and enable each residential area to have decent primary school accessibility, this study uses the Huff model to divide the primary schools in the study area quantitatively and provide a reference for the formulation of future planning plans and the division of primary school districts. The purpose is to maximise the demand points within the service radius at the same time.

The division of primary school districts should consider the supply capacity and service scope of the school itself. Given that the urban space in Nagano City is constantly changing and the population continues to decrease, the division of school districts should consider the changes in the school-age population around the school. The division of school districts should maintain a certain degree of flexibility and scientificity. According to the changing trend of the school-age population in the area, the scope of the school district should be adjusted in time to coordinate the relationship between educational resources and the service population to achieve dynamic balance.

However, in the actual operation process, the re-division of school districts may bring about some conflicts. For example, some families may have purchased the school district housing, but the change of the school district in the next year will cause social problems. Therefore, the re-division of school districts needs to follow acceptable principles, and the education department and planning department need to integrate the opinions of residents. In the adjustment process, ensuring that the teaching quality of the schools after the re-division is equivalent or higher than that of the original schools is necessary to avoid conflicts and improve the level of allocation of educational resources.

School district optimisation based on the Huff model. The Huff model considers the educational quality of the school, the spatial demand of the school-age population in the community and the attenuation of schooling distance. The Huff model is widely used to calculate the accessibility probability of each residential area to a school, the attractiveness of a school to each residential area and the potential teacher-student ratio to obtain the degree of difficulty for schooling in each residential area and use this as a basis for the school district division. The Huff model can accurately simulate the enrolment probability of students in each residential area when choosing different schools to provide an objective basis for the division of school districts.

The principle of the Huff model used in this study is relatively simplified. Unlike the traditional Huff model that obtains multiple values to evaluate accessibility (Shen, 2005; Slagle, 2001), this study aims to consider how to allocate educational resources more balanced through reasonable service area division. The basic idea is that, if the residents of a community have the highest probability of going to a certain primary school, then this community has the strongest interaction with the primary school; thus, this community can be classified into the school district of the primary school. The specific calculation process is shown as follows.

$$\boldsymbol{A_{ij}} = \frac{\boldsymbol{S_j}}{\boldsymbol{d_{ij}^{\beta}}}$$

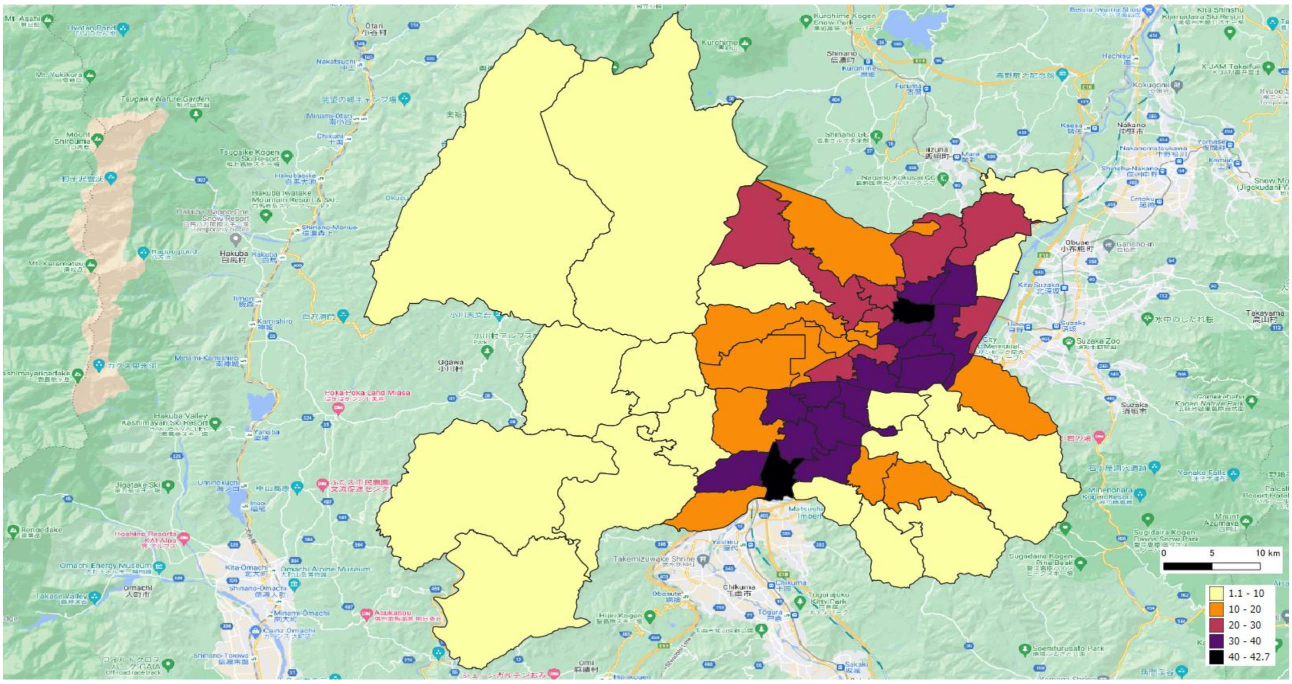
$$\boldsymbol{P_{ij}} = \boldsymbol{A_{ij}} \ \boldsymbol{X} \ \frac{\mathbf{1}}{\sum_{j=1}^{n} \boldsymbol{A_{ij}}}$$

Equation 7.2

The Huff model calculation process is divided into four steps: (1) establish the road network OD matrix, find all the shortest paths from residential areas to primary schools based on the road network and save the results in the data table; (2) connect school element and residential area element to the OD matrix table based on the road network, add the field ‘Potential’ to the attribute table and then calculate the attractiveness of each school to each residential area according to the Equation 7.2; (3) use Equation 7.2 as the calculation formula of the Huff model, where A_{ij} represents the attraction of the j-th school to the students of the i-th residential area, P_{ij} is the probability of schooling from the i-th residential area to the j-th school, S_j is the j-th school's teaching quality (considered via the number of teachers, number of classes and school building area), and d_{ij} is the cost from i to j, that is, the distance expressed by the shortest distance based on the transportation network in Equation 7.2, additionally β=2; (4) filter out the maximum value in the 'Potential' field of each primary school, which indicates the most attractive situation for students from a certain residential area to schooling. According to the operating mechanism of the Huff model, such residential area can be divided into school districts.

The attractiveness index calculated in this study is only a relative numerical concept and does not have a unit itself. With reference to the calculation results of the Huff model, all primary schools' districts can be drawn, as shown in Figure 7.21. The residential area representatives in different colours in the picture belong to different schools. The overall school districts are relatively compact. Most schools provide services to surrounding residential areas. Some schools only serve their residential areas, and few schools provide cross-community teaching.

Figure 7.21 – Adjusted School Districts



7.6.3 - Principles and Ideas for Optimizing Primary School Layout

When optimizing the layout of primary schools, it is necessary to consider comprehensively the effect of the student source distribution, traffic conditions in surrounding areas. It is necessary to adhere to the first principle of balanced development, combine the scientific and reasonable prediction of planning department and analysis of the actual problems of the education department and formulate reasonable and feasible plan to meet school-age population's school needs and achieve a balanced distribution of educational resources. It is also necessary to continue to support the development of high-quality schools while improving educational conditions of poor-quality primary schools so that high-quality educational resources can be distributed evenly.

A good practice plan requires good theoretical support. The optimization and adjustment of primary school land layout must be planned first, then constructed, removed and merged. The accelerated demographic shrinkage has brought about continuous changes in the urban spatial pattern and population structure. The spatial layout of primary schools in urban areas also has problems that need to be resolved, such as substandard school construction and uneven distribution of resources. Basic education facilities should be integrated with urban planning, considering different planning strategies and priorities in the near and future, not only to propose feasible solutions to short-term problems but also to meet the potential educational needs of the nearby areas in the long term. At the same time, it is necessary to comprehensively consider factors, such as geographical environment, population changes and policy implementation, formulate reasonable norms and standards, predict the number and spatial changes of the school-age population, conduct a practical and experimental multi-faceted analysis of service radius of educational facilities and make reasonable adjustments and planning of primary school’s layout.

The optimization and adjustment of the primary school’s spatial layout is a process of dynamic change. In the actual implementation process, it is difficult to solve all problems simultaneously within a short time. In actual work, changes in the spatial layout of educational facilities will involve many problems in the city, and thus, most optimization plans tend to start with improving teaching quality. Optimizing the layout of primary school land requires comprehensive consideration of multiple factors. When formulating educational facilities planning, it is particularly important to deal with districts and adjust measures to local conditions. Special consideration shall be given to functional zoning and land use when planning, and gradual transformation shall be carried out to adjust the layout of educational facilities. In areas with sufficient land space and a high degree of freedom in spatial layout, high-standard layouts can be carried out, and a part of the land can be reserved for future educational development at the same time.

At present, the spatial layout of primary schools in Nagano City is manifested mainly in the obvious polarization of school accessibility. More than 50% of residential areas have different levels of insufficient supply of educational resources, showing an uneven distribution of overall educational resources. The number of primary schools in Nagano City is small, but there are obvious differences between schools. Thus, proposing feasible and effective optimization measures according to actual conditions of different communities is necessary to improve current problems more efficiently. The purpose of optimizing the spatial layout of primary schools is to balance the supply and demand for educational resources in the region and achieve the goal of educational equity.

Optimise the implementation strategy of school district division

(1) Clarify the construction mode and the main body of responsibility

According to the traditional location theory, the construction of primary schools is compatible with urban residential space. In an idealised situation, the central location of each residential space should be equipped with primary schools, reducing transportation costs on the one hand and improving the efficiency of resource allocation on the other hand. However, in the actual land transfer process, the main body responsible for the construction of the primary school may be the construction unit. Under this condition, the primary school will become a public service resource. On the condition that the responsible subject is a private developer, the schools will become educational resources that only serve specific areas.

The population of Nagano City continues to decrease, and the degree of declining birth rate in the future will have an impact on the layout of primary schools. Therefore, clarifying the main body of responsibility for school construction and adjustment is important. When the main body of responsibility is the construction unit, the construction standards and service quality of the primary school will be guaranteed. However, when the main body of responsibility is the developer, to maximise the profit of the land, problems such as delaying construction, shrinking building standards and private adjustment of land use will occur. These problems will cause a great waste of urban land resources and negatively impact the balanced layout of educational facilities throughout the region.

To ensure the utilisation of educational resources, in the implementation of the primary school land layout plan, a mechanism with the government as the main body of responsibility should be established to control the initiative effectively and clarify the land acquisition method and ownership relationship. As a result, a complete supervision system can be established to supervise the specific construction and implementation work and ensure that the construction of the primary school is reasonably matched with the residential area. Relatedly, Wayley (2007) presented that commercial companies play an increasingly crucial role in Japan’s urban development, such as urban governance and the transformation of urban living spaces. In the future planning of primary schools, private capital should be considered and used more effectively to achieve a rational allocation of social resources, especially when building new schools or demolishing old ones under the financial constraints of local government departments.

(2) Balance school education resources and strengthen the construction of the teaching staff and the mobility of teachers

The rational implementation of the optimisation plan for primary school land use is not only affected by government decision-making, capital investment and planning factors, but also the more important factor, which is human resource, that is, teachers who guarantee the quality of primary school teaching. The population decline has also had an impact on the age structure of teaching staff. At present, the division of teachers in Nagano City is serious. Schools with high teaching quality can attract teachers easily, whereas schools with unsatisfactory facilities can hardly attract high-qualified teaching staff. To balance educational resources, teaching ability can be optimised from the following aspects: (1) conduct regular assessments of the incumbent teachers to ensure the steady improvement of teaching skills; (2) establish a talent pool in Nagano City and strengthen the flow of teachers among schools to narrow the gap among schools, ensure a balanced allocation of regional teachers and thus meet the increasing teaching requirements of students; (3) broaden teacher recruitment channels and provide a steady stream of resources for the existing teaching team; and (4) for outstanding teachers, give certain honours and rewards to encourage talents, attract potential high-quality teacher resources in the region and create favourable learning atmosphere among teaching staff.

(3) Formulate reasonable and scientific planning proposal

Combined with the accessibility analysis results in Section 7.5, a reasonable planning scheme is found to optimise the layout of the primary school. From an overall perspective, the educational resources of primary schools can be balanced to a large extent. The land layout planning of primary schools is a dynamic process. To ensure the implementation of the plan, proposing planning strategies from both short-term and long-term perspectives is necessary. From the perspective of near-term planning, the government can put forward a feasible plan to solve the current contradictions in the development of primary schools and problems such as insufficient land and large class size through the merger and construction of primary schools. When selecting construction indicators, referring to national standards and making a certain range of flexible adjustments according to the actual conditions of each region are necessary. From the perspective of long-term planning, meeting the potential educational needs of the surrounding areas, maintaining the primary school land layout at a high standard and reserving a part of the educational land for the adjustment of primary education in the future are necessary.

(4) Optimising the schooling path

This research mainly optimises the spatial layout of primary schools. However, in the actual schooling process, in addition to factors such as teaching quality and transportation costs, which greatly impact the optimisation of primary schools, the safety of students cannot be ignored. Currently, a number of students go to school across blocks because of the uneven distribution of primary education resources and limitations of school district division. Combined with the above analysis, the current spatial layout of primary schools does not provide residents with a basic guarantee of education within the prefectural standard service radius. Hence, in future planning, relevant departments can consider designing a dedicated slow-moving system for students or designing urban greenways combined with landscape requirements. On one hand, it can strengthen the systemic connection of urban pedestrian traffic and enrich the spatial pattern of the city. On the other hand, it also guarantees the safety of students to the greatest extent.

7.6.4 - Suggestions for Future Planning

In fact, many primary schools have been forced to consolidate due to a lack of resources, especially in depopulated areas. In the case of a consolidation, children who cannot walk to school often go to school by bus or other public transportations. However, if there are children who are too far away to commute to school by bus, or if there are strong voices that do not want to consolidate schools in the area, the local governments have to consider ways to maintain the primary school by means other than consolidation. In this regard, the number of communities with such problems will increase rapidly in the future. Therefore, this section considers strategies to maintain a primary school with a small number of resources, taking into account the background of the era of depopulation.

The most important role of primary school is to foster the healthy growth of children. This includes not only the growth of academic abilities such as learning grades but also physical and mental growth. As a side outcome, primary schools also play a role in creating and maintaining solidarity in local communities. Primary schools are familiar as the school of the "local area", and people in the same primary school’s service area have a sense of solidarity as the "local people". Many primary school events involve local people, and many communities are conscious of watching over primary school students in Japan. Additionally, the existence of primary schools at least prevents the outflow of child-rearing households.

Due to the declining birth rate, the number of students has reduced; thus, in some cases, it is not possible to change classes in each grade. The inability to change classes restricts the relationships between children and limits their opportunities to interact with various people and foster sociality, which may lead to the formation of limited relationships. Furthermore, in the case of combined classes, while teaching one grade, the other grade has to self-study. Thus, different levels of content have to be taught at the same time, and teachers will require special teaching skills. Additionally, siblings may be present in the same class, which causes problems in life guidance. Therefore, problems arise in the development of sociality and academic ability in the learning process.

Overall, primary schools need a certain number of teachers and clerks, as well as facilities, and the same applies to small schools as well. However, small schools inevitably have higher maintenance costs per schoolchild than regular schools, and this becomes a heavy administrative burden. Therefore, due to this financial burden, small schools have a lower priority for rebuilding and repairing than other schools even if they are old. Consequently, many small schools are becoming a learning environment that is not suitable for primary school students with dilapidated school buildings, narrow grounds, poor requited air conditioners, etc. However, although small schools largely suffer from such issues, it is difficult for them to take effective measures due to financial constraints.

To improve this imbalanced distribution of educational resources, the first solution that comes up for small schools is the consolidation with neighbouring primary schools. Consolidation makes it possible to maintain a certain scale and solve problems caused by scale. Educational problems can at least be solved, and financial benefits are expected to improve.

However, there is a possibility that some children will have to attend from afar due to consolidation. If the distance is too far to walk, the guardians will have to pick up and drop off their children or a school bus will have to be operated. In this case, the walking distance of the children is greatly reduced; consequently, problems such as a tendency to lose physical strength and become obese emerge; additionally, financial problems will reignite in the case of school bus operation. Furthermore, local people have expressed that they do not want the primary school to disappear, which tends to be a bottleneck in consolidation. It is no exaggeration to say that the disappearance of primary schools, which are symbols of the region and prevent the outflow of child-rearing generations, means the decline of the region. Therefore, many communities express a strong sense of resistance against the disappearance of primary schools. Even if the government tries to consolidate for financial reasons, it may not be possible to consolidate due to such resistance. The following sections consider the initiatives that can be taken without consolidation on the school, community and nation levels.

The first initiative involves setting up vertical division activities that go beyond grades. By doing so, students will be able to interact with children from other grades, thus leading to the formation of a wide range of relationships. However, the vertical division activity is not a special event because it is also carried out in large-scale primary schools that allow class changes in all grades. Another proposed initiative involves prompting interactions with local people by utilizing the total time. The school may ask local people for their cooperation, benefiting from their expertise, such as cooking, farming, and work experiences, to create opportunities for children to go out of school to foster their sociality.

Furthermore, it can be expected that the possible advancements in the education sector will be further expanded by the active movement of local governments. The first initiative is the utilization of the community school system. A community school system is a school management council consisting of parents, local people, and members of the board of education. It is a mechanism that allows members to share opinions on the management policy and the appointment of faculty and staff of primary schools. Overall, 1,919 community schools have been designated nationwide in 2014 (MEXT, 2016).

According to the Ministry of Education, Culture, Sports, Science and Technology, the introduction of community schools has made it possible for schools and communities to share information, has promoted a change in the awareness of faculty and staff, and has solved problems in student guidance, including bullying and school refusal. In particular, cooperation within the region has strengthened notably. Ultimately, this system can be utilized to realize high-quality school education even in small schools without large financial burdens. However, although the introduction of community schools is progressing nationwide, the actual situation seems to vary considerably from school to school. In the future, it will be necessary to implement a mechanism to accumulate and share know-how on how to operate the system to improve the quality of education rather than just introducing the system.

The second initiative is the operation of one-stop school management. This is a school format in which kindergartens, welfare facilities, social education facilities, etc. in a certain area are set up next to the school, the services provided by each are integrated, and each function is deepened through mutual exchange. The one-stop approach has a strong advantage of utilizing existing resources, and it does not pose a new financial burden. An example of this is in Mugi Town, Tokushima Prefecture. In Mugi Town, primary schools, junior high schools, nursery centres, and community facilities that were originally located in different locations have all been consolidated on a hill because of the deterioration of the facilities and the decrease in the number of children and to avoid the danger of a tsunami. Additionally, efforts are being invested to enhance the learning process; for instance, nursery school, primary school, and junior high school teachers give classes with mutual participation, and senior citizens and fishermen participate in the classes as ‘teachers’.

The third initiative is the introduction of a school choice system. The school choice system is a system that collects the opinions of parents to use as references when deciding which primary school to attend. In Japan, normally, the primary school to attend is automatically decided by the place of residence; however, if the local government introduces the school choice system, parents will have freedom of choice. Then, parents who favour small-group education can send their children to small schools. However, if a school selection system is introduced, the desire to enrol may be biased toward a certain school, and if this issue is not addressed, it will be difficult to maintain the survival of small schools. While this system is not impossible as one option, it may be difficult to implement as a measure for small schools at the current stage. If the education of the small school itself is unique and there are a certain number of people who want to receive education only at the small school, then this approach may be viable.

At the national level, two measures can be taken by changing national policies. The first is the use of online education in primary schools. In Japan, online education is not actively recognized as compulsory education by law. However, in modern times, the Internet-based communication environment has become prevalent, and high-quality online education is employed in higher education. However, since the age of primary school students is a time when personal relationships that they come into direct contact with affect personality growth, it would be problematic to make everything online. Nonetheless, it may be possible to introduce some subjects in the upper grades.

However, since the introduction of the infrastructure for online education itself is costly, generating the necessary financial resources for the initial introduction will be an issue. Therefore, to resolve this problem, the government can implement a policy in which it provides subsidies and establishes a foundation for online education in primary schools. By developing the infrastructure for online education nationwide, it will be possible to provide online education even between regions that are far apart. It can also serve as a useful communication tool for children in remote areas to interact with each other, which has a great advantage in that they develop various relationships. Since nationwide development is a task that the national government should undertake, it seems appropriate for the national government to provide subsidies.

The second measure is the introduction of a small-group education system for school education. Under the current school education system in Japan, it is ideal for primary schools to maintain a certain size, and small-scale class composition is treated as an exception. However, if it is expected that the number of small schools will increase, it is possible to introduce the small-group education system itself as a formal system. For example, the government agency organizes a curriculum with two systems: one is for the traditional scale education and the other is for the small-group education system. Then, local governments can be allowed to choose between traditional education and small-group education.

Implementing this may be unrealistic because it is quite burdensome to establish a new system. However, considering the future population decline, it is inevitable that the number of communities that will require small-group education will increase. Therefore, it may be viable to think of a curriculum that takes advantage of the benefits of small-group education. Now that the harmful effects of uniform guidance are being called out in Japan, there is plenty of room for consideration.

7.7 - Summary

In Japan, school management will inevitably become difficult because of the combination of the declining population and the shrinking economy. Primary schools, as basic education service facilities, are an important part of improving people's livelihood and the urban functional system. A scientific and reasonable layout of primary school is of great significance for improving the balanced allocation of educational facilities, efficient use of land resources and achievement of educational equity. This study uses spatial analysis as the starting point with the help of ArcGIS analysis software and takes Nagano City as the research object to study the rationality of the current primary school layout. The purpose is to provide a theoretical basis for undeveloped measures for the balanced development of basic education in the near future. Through this research, the following conclusions can be drawn:

At present, the overall allocation of educational resources in Nagano City is unbalanced. Through a 2SFCA analysis, it can be concluded that the main reasons for the uneven distribution of educational resources are: constraints of the urban spatial pattern, limitations of the planning layout, and reduction of student sources. After distance threshold optimization, the 2SFCA method can be applied to the accessibility analysis of the spatial layout of educational facilities. Combined with the actual situation of the study area, it is possible to comprehensively evaluate and analyse the trend of and reason for change in accessibility under different distance standards. Effective urban planning methods can improve the balance of the school layout. The second half of this chapter examined the spatial layout of the primary school planning. The suggested planning scheme is feasible and can optimize areas with poor accessibility while further balancing the level of regional accessibility. Through the integration and abolition of schools, it is possible to improve the quality of teaching and provide better education for fewer students, which is also an opportunity for obtaining a depopulation dividend, providing a cornerstone for the inheritance of knowledge and the orderly development of society.

Main innovations of this chapter: From the perspective of geospatial data analysis, by using quantitative research methods combined with ArcGIS software the spatial layout of educational facilities was evaluated and analysed from a demographic perspective. According to the results of the accessibility analysis, an empirical basis is provided for future spatial layout planning and the feasibility of the planning scheme is discussed. Corresponding policy implementation suggestions are also provided. The Huff model is used to optimize the primary school district, and the outcomes of the accessibility analysis are used as the basis for optimization. Previous studies mostly made theoretical suggestions for optimization, rarely technical ones. This study fills this gap.

The findings of this study also provide directions for future research. The land layout of educational facilities is closely related to the balanced distribution of educational resources. The research process needs to consider many factors, such as society, economy, culture, history and geographic technology. The content of this study is only a part and cannot be analysed from the overall situation. Specifically, this study still has the following limitations. In the analysis of the spatial layout of the current primary schools, quantitative technical means are mainly used. Surveys on current primary schools' land occupation and facility configuration and interviews with relevant personnel in primary schools and residential areas are insufficient. The collection of information/data regarding historical, cultural and land use in the study area is incomplete. In the follow-up study, I will attach importance to this aspect of work and then analyse the current situation of educational facilities more realistically.

This research focuses on the impact of the supply point's service quality, the demand point's demand scale, and the transportation distance. In the follow-up research, it is necessary to analyse and evaluate the impact of more influencing factors – the influence of socioeconomic factors, transportation convenience, and population structure – on school choice. When using the 2SFCA method and the Huff model, the road network distance is taken as an important reference factor. However, in actual situations, the choice of transportation modes will also affect the residents' school behaviour. This factor will be discussed in more depth in follow-up research. Land layout planning for educational facilities is a systematic and complex long-term process. In the future, it is necessary to explore how to better combine theoretical research with technical methods.

CHAPTER 8

THE IMPACT OF POPULATION CHANGE ON HOUSING DEMAND IN JAPAN THEORY AND EMPIRICAL TEST

8.1 - Introduction

By benefitting families with stable homes and enabling them to access myriad other services such as education and healthcare, public housing makes a vital contribution to the public infrastructure of a nation. The housing problem concerns both the family as well as the country. It is the basic responsibility of a government to make housing available to its residents and find solutions to any and all housing issues that arise. For citizens, without a house, a family cannot form a home. Housing is a basic right belonging to every citizen, and which, since antiquity, has been regarded as a fundamental necessity for survival and development of each person. The population, as the main working force of society, is engaged in reproduction of both people and materials. Housing is the foundation of, and guarantees, all such production. Therefore, demographic changes are bound to affect housing demand.

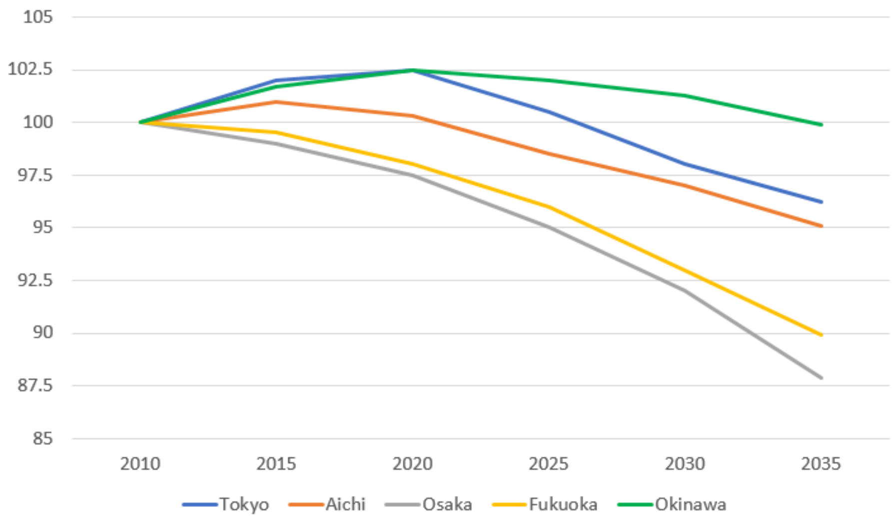
Population in Japan is declining and ageing at a rate never experienced by any of the major developed countries. Japan only had about 30 years to grow from a young society to an ageing one. This demographic transition in other developed countries had taken hundreds of years. The rapid population transition has brought upon a huge impact on social and economic development. The rich demographic dividend has played a role in promoting economic growth, but the rapid population reduction has also presented challenges to social development. Japan's population has also undergone other structural changes: declining birth-rate, ageing population, smaller family structure, increased education level, diversification of occupational structure, increasing floating population, etc. Population affects housing demand not only through changes in quantity but also through changes in structure. Based on the changes in size and structure of Japan’s population in recent years, this chapter analyses the impact mechanism of population changes on housing demand and discusses the principle of housing demand changes with population factors through empirical results.

This chapter consists of the following sections: First, the background and significance of the research are introduced, while the demographic transition theory, life cycle theory and supply-and-demand theory are cited to provide theoretical support for the analysis. Section 8.4 summarizes the relevant research results in detail and points out the shortcomings of the existing research and the direction in which this research attempts to develop. Section 8.5 describes the variables and models used in the analysis. Then section 8.6 explains theoretically the impact of different attributes of the population on housing demand and analyses the impact mechanism. Then, on the basis of these analyses, panel data, mixed models, fixed effects, random effects and other methods were applied for comparative analysis. The Kanto, Kinki and Chubu regions were then investigated. Finally, Section 8.7 puts forward relevant policy suggestions based on the findings of the empirical analysis. The shortcomings of this study and future research directions are also prospected.

8.2 - Background

Japan's population has been declining since peaking around 2008. According to the future forecast of the National Institute of Population and Social Security Research, medium birth/death forecast, it is estimated that Japan’s total population will decrease from 110.92 million in 2040 to 99.24 million in 2053 before dropping further to 88.08 million in 2065. As shown in Figure 8.1, comparing the future population in 2045 with the population in 2015 by prefecture, it is predicted that only Tokyo will not experience depopulation. The whole country is predicted to experience a population decrease of 16%, and some regions will even experience a decrease of more than 40%.

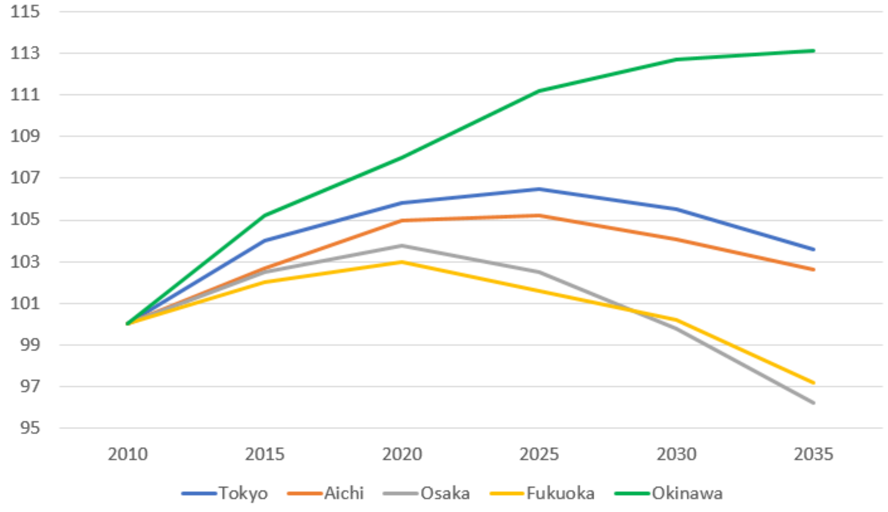
Figure 8.1 – Population Forecast (2010 = 100)



Source: National Institute of Population and Social Security Research, 2010.

Changes in the number of households are also an important factor when considering the relationship between demographics and housing demand. Except for two-generation homes, one home is generally required for each household. Figure 8.2 shows that the change in the number of households in Japan is different from that of the population, and it is predicted that it will not decrease significantly for a while. From 2015 to 2040, for an increasing number of prefectures—such as Okinawa, Tokyo, Aichi, Shiga and Saitama, and even in most rural areas of these prefectures—the rate of decrease will remain less than 10%.

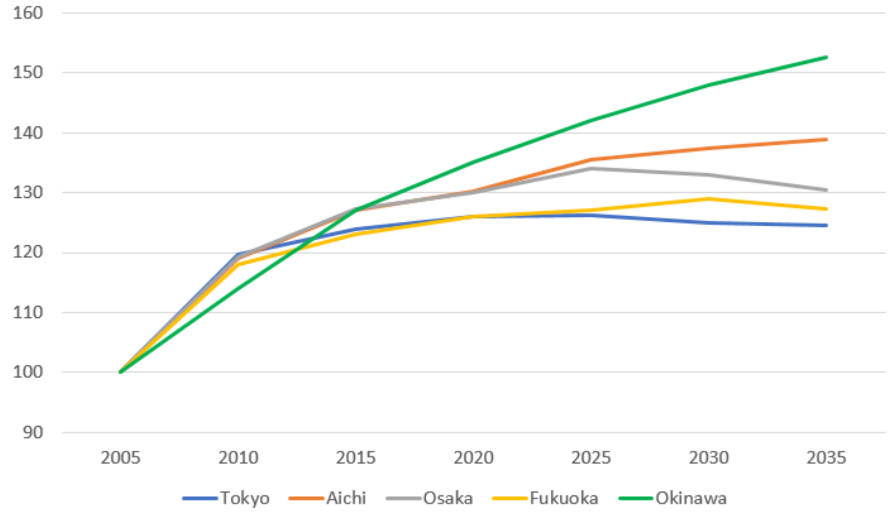
Figure 8.2 – Forecast of the Number of Households (2010 = 100)



Source: National Institute of Population and Social Security Research, 2010.

As shown in Figure 8.3, the number of single households will increase significantly in most prefectures from 2015 to 2040. The increase will even occur in some prefectures in the north Tohoku region, where the population is predicted to decrease by more than 30% and the number of households to decrease by more than 15% during the same period. The trend of ageing population will likely increase the number of single households. Moreover, late marriage and increase in the number of divorces have also had great impact on the increase in the number of single households. While the number of single people is expected to increase in the future, the number of single households is expected to increase even further. Based on these grounds, we can expect the number of single households to continue to increase in the future, which will support housing demand.

Figure 8.3 – Forecast of the Number of Single Households (2005 = 100)



Source: National Institute of Population and Social Security Research, 2010.

Changes in population and its structure have caused various impacts for the housing market with low supply elasticity. As urbanisation progressed at a stretch due to the high economic growth after the World War II and the subsequent remodelling of the archipelago, social problems emerged, such as housing shortages and soaring land prices from the 1970s to the 1980s. Furthermore, when baby boomers entered the housing market, they created the largest housing demand after World War II and became one of the factors that created the real estate bubble during the mid-1980s (Shimizu and Watanabe, 2010). Under such circumstances, the construction of section-owned apartment buildings was promoted. Since the 1970s, condominiums have been built in earnest mainly in urban areas. Given that supplying a large amount of housing whilst conserving land resources is possible, condominiums became general residences in Japan, which has a small land area. Condominiums function as an infrastructure that supports the population increase and economic growth of Japan. However, similar to other public infrastructure, such as roads and bridges, the ageing of condominiums has begun to progress, and their maintenance and management are expected to develop as major social problems.

The Japanese housing market has provided housing services centred on new housing to the public. In particular, during the high-growth period and the bubble period, the number of new constructions increased significantly, and this brought about a boom in the housing market. However, after the bubble economy burst, the number of new constructions has decreased considerably. Compared to the mid-1990s, only about half the number of new constructions has been supplied in 2010. According to the Statistics on Building Construction Started, the number was 400,000 in 1960, then grew rapidly to 1.86 million in 1972, but then began to decline and remained around 1.1–1.2 million in the first half of the 1980s. When the bubble period began soon after, the number jumped to 1.7 million in 1987. From the latter half of the 1980s to 1996, a consistently high level of 1.5–1.6 million was observed. However, when the Asian financial crisis hit in 1997, construction again began to decline, with the number remaining around 1.0–1.2 million until 2008. After the Lehman crisis of that year, construction decreased even further, with only about 0.8–1.0 million new constructions reported.

The time lag between population decline and changes in the number of new constructions resulted in a large stock of vacant houses, especially in the rural areas. According to "People's Awareness Survey on Land Issues" (Ministry of Land, Infrastructure, Transport and Tourism 2013), 41% of the respondents reported "vacant houses/vacant lots and closed stores" as the most familiar and conspicuous land issue in their daily life. Furthermore, according to the Ministry of Land, Infrastructure, Transport and Tourism's "Long-term Outlook for the Land," it is estimated that the number of vacant houses will increase to 11.3 million in 2030 and 15.5 million in 2050. Assuming that the number of houses is about 60 million in 2015, one in five houses will be vacant by 2030 and one in four houses will be vacant by 2050. Such mass outbreak of ‘vacant lots’ and ‘vacant houses’ has developed into a social problem, mainly in local cities. It is the result of the distortion of resource allocation in the housing market. The existence of unmanaged homes can give areas external diseconomies. The area around a vacant house not only worsens but also spreads, debilitating the entire region.

After the high-growth period, urban area expansion resulted from the dramatic increase in population density. To respond to the large influx of population into urban areas, government agencies promoted housing supply by increasing the construction of public housing. Currently, due to the declining population, Japanese housing stock has remarkably exceeded the number of households in several areas, and the number of uninhabited houses is continuously increasing. Moreover, the population and the number of households in the suburbs are expected to further decrease in the future, with a potential risk of a greater number of uninhabited houses and lots than the present. Additionally, in densely populated urban areas of Japan, the ratio of wooden rental housing to the total number of units is high, and as many of the residents are elderly, severe damage is expected in case of a disaster. In the next 25 years, the number of households with elderly people and one-person elderly households is expected to account for 40% and 20% of the total number of households, respectively. Since cities have been designed with the working generation in consideration, steps and stairs in buildings and houses have hindered the movement of the elderly. Therefore, there will be an increased requirement for housing and community development in the future to ensure the safety of elderly people.

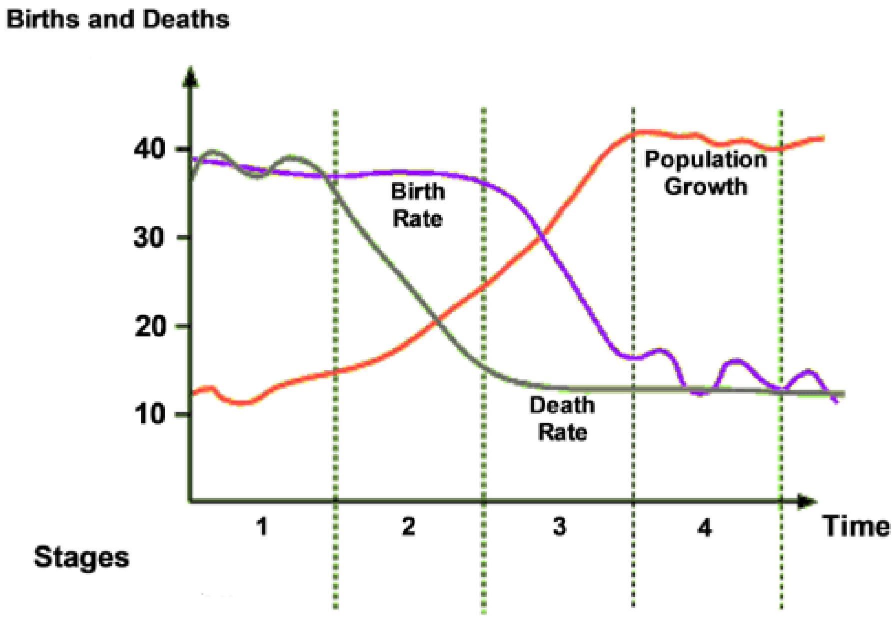
8.3 - Theoretical Framework

8.3.1 - Demographic Transition Theory

In the mid-twentieth century, the theory was first coined by Frank W. Notestein, but it has since been elaborated and expanded upon by many other scholars. Changes in a country's population size can be explained by the natural growth rate of changes in fertility and mortality, and cross-border migration. Based on the experience of Europe and North America, the model that explains the population change from the changes in the fertility rate and mortality rate is the "demographic transition model" (Figure 8.4). In this model, population changes are divided into four stages based on the levels and changes in fertility and mortality rates. The first is the "high fertility and high mortality" stage in which both the fertility and mortality rates are high. The second is the "high fertility and low mortality" stage in which the mortality rate decreases prior to the fertility rate. The third stage is the "low fertility and low mortality" in which the fertility rate declines. The fourth is the "stable stage" in which the fertility and mortality rates are stable at low levels.

The first stage of the demographic transition is a phase with high fertility mortality rates. Populations are volatile and fluctuating, and at risk of high mortality due to weather and illness. The second is the stage in which the mortality rate declines ahead of the fertility rate due to improvements in living standards and hygiene. The third stage is the decline in fertility, which follows the decline in mortality. In this stage, the gap between the fertility rate and the mortality rate is narrow, and the population growth rate declines. In the final stage of the demographic transition, the fertility and mortality rates are balanced at a low level and the population size becomes stable.

Figure 8.4 – Demographic Transition Model



8.3.2 - Life Cycle Hypothesis

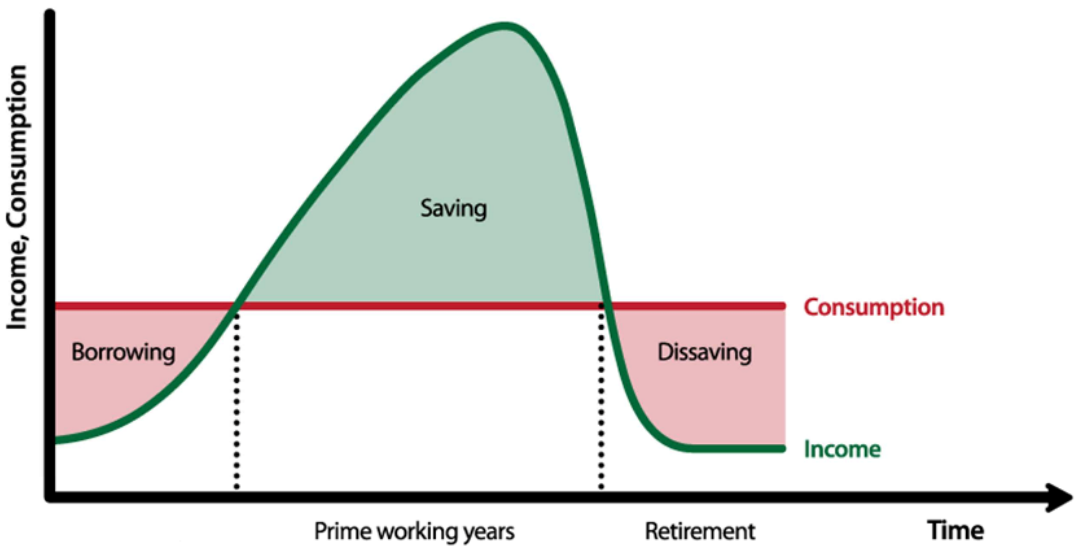
In the process of demographic transition, it has been argued that an increase in the proportion of the working-age population increases the domestic savings rate during the demographic dividend period and that the domestic savings rate declines during the process of population ageing. Demand for housing is related to population change from a consumption perspective, as lower savings rates can lead to lower housing investments. This section examines the impact of population change on housing demand using the "life cycle hypothesis model", taking into account the relationship between population changes and consuming behaviour (Franco Modigliani, 1957).

The life cycle hypothesis believes that the distribution of personal consumption and savings is determined by lifetime income, and that people save for old age during work and withdraw after retirement. Figure 8.5 illustrates the life cycle hypothesis model. The horizontal axis shows age, and the vertical axis shows consumption and income levels; it is composed of a consumption curve, which is almost parallel to changes in age, and a mountainous income curve. The gap between these two curves represents the income shortage and income surplus at each time point, and life can be divided into the following three periods.

The first period is from birth to adolescence. People start consuming activities immediately after they are born. Food and clothing costs are indispensable for sustaining life, and education costs are added when a certain age is reached. However, since income does not occur until employment is obtained, there is an income shortage from birth until around the age of 20. This shortfall is generally covered by family members and relatives. The second period is the period from adolescence to retirement. When people reach adolescence and get a job, the income shortage disappears. Then, at some point, income exceeds consumption, and income surplus is created. Part of this surplus is used for child support, and the rest is saved for the future. The level of savings is influenced by income levels, the degree of spending on consumption, the number of children, and the social security system. The third period is old age after retirement. Income levels decline with age, and income declines rapidly when retirement age is reached. Although there are individual differences, income will eventually fall below consumption, and again, there is a shortage of funds, which increases over time. The shortfall is basically covered by the savings that have accumulated during the working period or by family and social security services.

By accumulating this individual life cycle hypothesis model and expanding it on a national basis, it is clear that the savings rate will decline as the proportion of older people rises. In Japan, the savings rate is declining. Japan's domestic savings rate fell from 34% in 1990 to 25% in 2005. The household savings rate fell from 16% in 1990 to 7% in 2003 and then to 3% in 2010 (Kamio, Inagaki and Kitazaki, 2011).

Figure 8.5 – Life Cycle Hypothesis Model

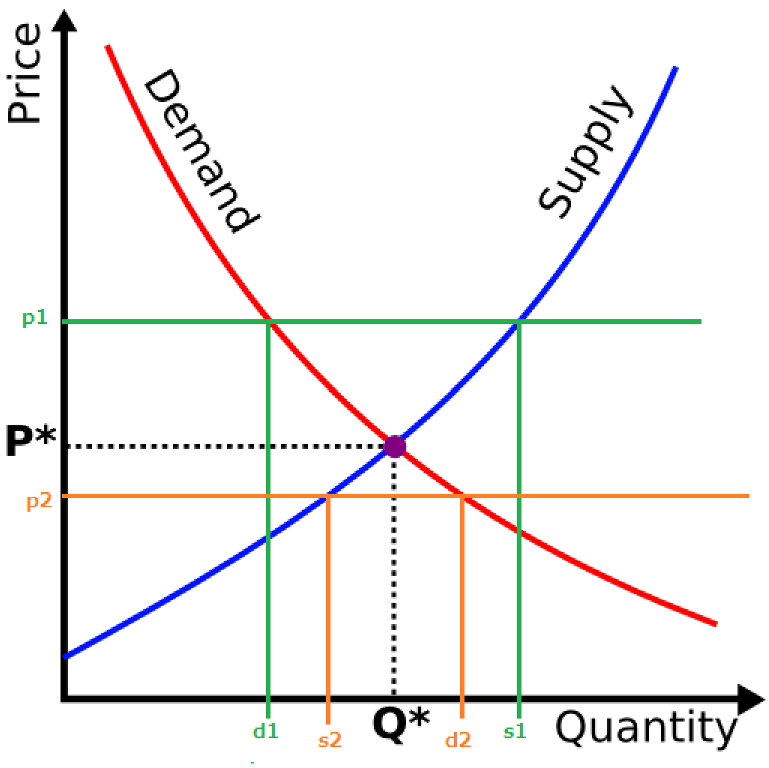


8.3.3 - The Classical Theory of Supply and Demand

The market price and trading volume of commodities are determined by supply and demand in competitive markets. The demand for a good decreases as the price increases. That is, the demand function D = f (p) is a decreasing function of price. As shown in Figure 8.6, if the vertical axis is price and the horizontal axis is quantity, the demand curve is a downward-sloping curve (DD curve). Since the supply amount increases as the price increases, the supply function S = g (p) is an increasing function of the price, and the supply curve becomes an upward-sloping curve (SS curve).

Now, if the price is at the level of p1, the demand will be d1 and the supply will be s1; supply will exceed demand. The excess d1s1 at this stage is called the excess supply. When excess supply occurs, competition on the supply side lowers prices, resulting in a decrease in supply. If the price drops to p2, the supply will be s2 and the demand will be d2. Now, demand will exceed supply. This excess s2d2 is called the excess demand. When excess demand occurs, competition on the demand side raises prices, resulting in a decrease in demand. Through such a process of trial and error, the price reaches P*, which equalizes the amount of demand and the amount of supply. The price P* at which the demand and supply are equal is called the equilibrium price, and the transaction quantity Q* at that time is called the equilibrium supply and demand. The essence of this process is that "excess demand raises prices and excess supply lowers prices", but conversely, price can change demand and supply, leading both to equal amounts. In economics, this effect of price is called "adjustment effect" or "price parameter function". Such price action can be hampered by government interference with the market and other socioeconomic factors.

Figure 8.6 – Supply and Demand Curve



Why does this matter? When we consider housing as a kind of infrastructure, as pointed out by Diewert and Shimizu (2016a, 2016b), three factors cause their deteriorating and thus affect its demand. The first is physical depreciation in which the function of the structure itself declines. The second is economic depreciation, which is brought about by the obsolescence of the building by improving its performance itself. The third is ageing due to loss. Specifically, the depreciation rate of Japanese houses is high, as the life of Japanese houses is short.

Ageing buildings likely bring external diseconomies to the entire area. The ageing of buildings obstructs the landscape, and when slums progress, it brings strong external diseconomies to the region. The quality of housing stock (vacant houses) may deteriorate faster than that of ordinary housing. Such deterioration of housing quality leads to that of housing services received by residents; a concern that poor living environments may lead to further external diseconomies also emerges. Such external diseconomies are great when poor stocks are spatially close together. Therefore, the deterioration of the regional environment varies greatly depending on the density and concentration of ageing condominium stock. Such deterioration due to the increase in ageing condominium stock is dictated by the population size and structure of an area. In addition, the increase in condominium stock itself defines the character of a region. That is, the increase in condominium stock and the demographic composition of the region interact with each other. For this reason, carefully observing the interaction between population change and the ageing condominium stock on a regional basis is necessary. Two types of scenarios are expected.

The first is the simultaneous progress of population ageing and the accumulation of ageing condominium stock. Currently, ageing housing estates represented by housing complexes and ageing residents are being taken up as major housing problems in the peri-urban areas. These problems can be regarded as those of regional management, which has emerged due to the occupancy of many residents with a biased age structure. The construction of housing complexes has been implemented as a direct housing supply policy by the Nihon Jyuutaku Koudan (日本住宅公団), currently the Urban Renaissance Agency (都市再生機構, Toshi Saisei Kikou) amid the growing shortage of housing shortly after the World War II. The ageing of condominiums and the population are progressing at the same time. The ageing of the population may lead to further deterioration of the condominium stock. Elderly people after retirement can be regarded as residents with a short remaining life. These residents are expected to have limited maintenance and renewal investment in housing stock. The increase in the number of elderly people acts in the direction of degrading the condominium stock. In this case, the real estate value of a condominium declines; thus, stock renewal is expected to be further difficult. This tendency may be amplified by the fact that the residents of the abovementioned suburban housing complexes are limited to the low- and middle-income groups from a policy view. That is, many residents have limited raise funds for stock regeneration.

The second is the strengthening of the negative impact of declining population on ageing stock. Specifically, the decrease in working-age population will have a strong negative impact on the housing market (lower housing demand), as the number of elderly people supported by it is expected to increase rapidly (Tamai, Shimizu and Nishimura, 2016; Saita et al. 2016). Theoretically, such decline in housing demand may result in less housing stock and lower housing prices through quantity and price adjustments. However, adjusting the quantity of goods such as houses that have a long physical service life is difficult. Specifically, this tendency likely appears remarkably for condominiums that require the consent of all residents to resolve the divisional ownership relationship. If the demand declines due to such a declining population, then price adjustments are expected to progress extremely. As the demand for housing and residential land is declining due to the declining population, land prices and rental prices are expected to stagnate. If housing demand drops significantly, then vacant homes will increase sharply. In addition, as owners age, house maintenance and repair are no longer actively carried out, and house ageing is progressing. When the real estate value declines significantly due to sluggish land prices or house ageing, inheritance may be abandoned and old housing may be left unattended. Furthermore, house ageing not only damages real estate value but also adversely affects land prices in surrounding areas. Such low real estate prices can lead to an influx of low-income and low-capital residents. That is, population decline in areas with large amounts of condominium stock likely leads to regional slums. As Yasumoto, Jones and Shimizu (2014) revealed, amenities that bring negative externalities are actively concentrated in areas where low-income earners live, whereas amenities that bring positive externalities are concentrated and distributed near areas where high-income earners live. Such a situation of environmental inequality is being created in Japan. If the numbers of old condominiums and low-income earners increase at the same time, not only will rebuilding condominiums be difficult but also the risk of regional environmental deterioration and slums will arise.

Population change and land price formation are polarised into areas where population grows and land prices rise, including areas where population decreases and land prices fall. Large cities, such as Tokyo and its surrounding areas, belonged to former areas. Surrounding areas outside large cities correspond to latter areas.

8.4 - Literature Review

Ermisch (1996) found that a decline in birth rate and an increase in elderly population can lead to a decline in housing demand. Lindh and Malmberg (2008) explored the relationship between population age structure and housing construction rate. They also observed a linear relationship between the two, that is, a positive (negative) relationship between the number of young (old) population and housing construction rate; an increase in young population leads to an increase in housing demand, whereas an increase in elderly population leads to a decrease in housing demand. Levin and Montagnol and Wright (2009) analysed the relationship between ageing and housing demand in England and Scotland by improving the Mankiw–Weil model. Their results showed that an increase in the degree of ageing can inhibit housing demand. Malmberg (2012) studied the relationship between the ageing of the Norwegian population and the housing market. An increase in the degree of population ageing can inhibit the development of the housing market, resulting in a decline in housing demand. Lim and Lee (2013) found that the number of people in different age groups has different effects on housing demand. Through the analysis of the relationship between the age structure of the Korean population and housing demand, they revealed that the elderly in South Korea prefer large houses, and the increase of the elderly population can offset the trend of declining housing demand caused by population decline. Thus, ageing has a positive effect on housing demand.

Based on the Mankiw–Weil model, Lim and Lee (2013) observed that an increase in the degree of ageing is conducive to an increase in housing demand. Andrea and Kerstin (2014) investigated the relationship between the age structure of the German population and housing demand. Their results indicated that Germany is obviously affected by the second demographic transition, as the demand for multistorey housing and single-family housing is affected by the changes in population age structure. Lerbs and Hiller (2015) found that ageing is not conducive to increasing demand for urban housing. Saita, Shimizu and Watanabe (2016) explored the relationship between demographic factors and housing demand. Taking Japan and the US as examples, their analysis showed that housing demand is inversely proportional to population ageing and proportional to population size. In addition, housing demand in Japan is more affected by demographic factors than that in the US. Kanghyun and Sol (2017) took South Korea as an example to study the relationship between population ageing and the housing market. They revealed that an increase in the number of elderly households has a positive impact on the increase in demand for small and medium-sized apartments. On the basis of an overlapping generation model, Day (2018) found that the sale of houses by retired seniors aggravates the negative effect of population ageing on housing demand. Beatrice (2019) found that population ageing can lead to a decrease in demand for large-sized housing and an increase in demand for small-sized housing.

Meng (2000) found that demographic factors have significant impacts on the housing market through an investigation of the relationship between the age structure of the Chinese population and the housing market. The 30–45-year-olds are the driving force in buying houses. The decrease in this age group and the increase in the elderly population lead to a significant reduction in housing demand. Liu (2004) indicated that an increase in elderly population can lead to an increase in demand for apartment-type housing for the elderly. Jiang and Ren (2005) predicted the future housing demand according to changes in population age structure. Their results showed that when the population growth rate lagged behind the growth rate of the household number, taking 2015 as the time node, no huge changes in housing demand was observed before 2015. However, after 2015, an increase in the elderly population caused a decline in housing demand. Wang and Zhang (2005) found that people of different age groups have different needs for housing due to their differences in social concepts and behavioural habits, such as different needs for house sizes and functions.

Wang (2014) shared that different age groups have different demands for housing, and the deepening of population ageing is not conducive to the growth of housing demand. Chen, Xu and Tan (2012) predicted the impact of population ageing on housing demand in a 12-year period after 2013. They found that the increase in the degree of ageing can cause the housing demand in China to show a downward trend. Chen and Chen (2013) found that population ageing in China will have a negative effect on housing demand. Nevertheless, with the advancement of urbanisation and the reduction of the average family size, this negative effect will not appear until 30 years later. Chen, Li and Zhou (2013) predicted that an increase in the degree of ageing will weaken the upward trend of housing prices by applying an intergenerational overlap model. Xiao and Song (2014) claimed that the old-age dependency ratio has a negative effect on housing prices, whereas the young dependency ratio has a positive effect on housing prices. Zou (2015) found that the inhibitory effect of population ageing on housing prices is affected by the degree of housing demand of young people.

In a relative manner, the relationship between demographics and land price formation has been elucidated theoretically and empirically, including Shimizu, Kawamura and Nishimura (2015), Shimizu and Watanabe (2016), and Tamai et al. (2016). In the existing literature, population density and the ageing rate are positioned as long-term demand factors. As the population declines, land demand declines and land prices fall. Previous studies indicate that the increase in the ageing rate will work to weaken land demand. As Shimizu and Watanabe (2016) pointed out, demand for owned houses declines sharply after the age of 65. Additionally, the proportion of households aged 65 and over who are single increased, and the demand for land area per household decreased accordingly.

In some previous studies, the phenomenon that population decline and ageing lower the land price level has been verified mainly using data at the municipal level. Since the early 2000s, the time when the population declined and the ageing progressed coincided with the time when the land price fell, the empirical result that the land price becomes an increasing function of the population density and a decreasing function of the elderly ratio has been supported. However, the population changes that occur inside local cities are not as monotone as in large cities. These diverse vitalities can create various relationships between population change and housing demand.

Apart from the demand factors through vital statistics, supply factors such as the macroeconomic environment also have a great influence on land price formation. Shimizu, Kawamura and Nishimura (2015) pointed out the importance of expansion and contraction of bank credit as a macroeconomic environment for land price formation. Furthermore, regarding land price fluctuations caused by changes in the macroeconomic environment, the decline in land prices from the early 1990s is strongly a reaction to the rise in land prices that occurred in the Japanese economy as a whole in the latter half of the 1980s. Moreover, if the land supply environment in the centre of the city is improved by the compact city policy, the impact of the increase in housing demand due to the increased internal migration may be offset and the increase in housing demand may not occur straight. It is expected that further research will be able to accurately grasp the impacts of these macroeconomic environments and supply factors in each region.

8.5 - Methodologies

8.5.1 – Model

To scientifically examine the impact of population change on housing demand, this study selected panel data from 1995 to 2015 as the analysis sample. Different from the data types used in chapters 5 and 6, the panel data are the same cross-sectional data of the survey over a period of time, with spatial and temporal characteristics. The advantages of panel data include the control of individual heterogeneity, the increase of the degree of freedom and the reduction in the collinearity amongst explanatory variables and the suitability for studying dynamic changing processes. To make the research results more accurate, this study selects three models of a static panel for comparative research, namely, mixed effects model, fixed effects model and random effects model. Furthermore, the study selects the best regression results for interpretation. The model is as follows:

$$\boldsymbol{Y_{it} = C_i + \beta X_{it} + \lambda_i + \varepsilon_{it}}$$

In the model, 'i' and 't' represent the region and year, respectively, Y_{it} represents the housing demand in region i during period t, that is, the housing sales area in each prefecture, C_i is the same intercept among individuals and β is the undetermined coefficient; X_{it} is the vector of explanatory and control variables; λ_i is the regional effects, which is used to control the fixed effects of prefectures; ε_{it} is the residual term.

According to the different restrictions on the intercept term and explanatory variable coefficient, the static panel data model can be divided into the constant coefficients model without individual influence, variable intercept model and variable coefficient model. Among them, the constant coefficients model assumes that the intercept term and the explanatory variable coefficient are the same for all individual members of the section. That is, it is assumed that neither an individual influence nor structural changes exist on the members of the section. The constant coefficients model is also called the mixed model. The variable intercept model assumes that the intercept terms of the section members are different, and the coefficients of the explanatory variables are the same. That is, it is assumed that individual influences exist on the section members without structural coefficient changes. The variable coefficient model assumes that the intercept term and explanatory variable coefficient of the individual members of the section are different. That is, it is assumed that individual influences and structural coefficient changes exist on individual members. According to the different forms of individual influence, variable intercept and variable coefficient models can be divided into fixed effects model and random effects model.

On the validity of the regression model setting, the static panel data analysis needs to test the validity of the mixed effects model, the fixed effects model and the random effects model. Therefore, the covariance F test and the Hausman test are required.

For mixed and fixed-effects models, we can use the F test to determine their validity. The null and alternative hypotheses of the F test are as follows:

H0: The model intercept terms of different individuals are the same (mixed effects model).
H1: Different individuals have different model intercept terms (fixed effects model).

$$\mathbf{F} = \frac{(S_1 - S_2)\ /\ (N-1)}{S_2\ /\ (NT-N-k)}$$

In the formula, S_1 represents the constrained model, that is, the residual sum of squares of the mixed effects model. Moreover, S_2 represents the unconstrained model, that is, the residual sum of squares of the fixed effects model. The unconstrained model has N-1 more estimated parameters than the constrained model; N is the number of cross-section individuals, T is the number of periods and k is the number of explanatory variables.

When F is greater than the critical value, the null hypothesis is rejected. We consider that individual fixed effects exist. When F is less than the critical value, the null hypothesis is accepted, and mixed effects exist.

Moreover, a Hausman test is required to determine whether the fixed-effects or random-effects model should be applied. The null and alternative hypotheses are as follows:

H0: Individual effects are independent of regressors (random effects models).
H1: Individual effects are correlated with regressors (fixed effects models).

When the test value is greater than the critical value, or the corresponding probability is less than expected, the null hypothesis is rejected, and the fixed-effects model is selected. Otherwise, the random-effects model should be selected.

8.5.2 - Variables

In the existing literature, indicators to measure housing demands include the housing area used by Chen et al. (2012) and real estate prices employed by Oliver and Norbert (2015). Most studies believe that the per capita housing living area in big cities is significantly smaller than those in small- and medium-sized cities and neither the housing area nor real estate prices can fully measure the actual housing demand. Therefore, this study utilised the product of the absolute value of the housing contracted area and unit sales price, i.e., the total transaction volume of housing as the dependent variable to measure housing demands. When the demand is strong and supply is limited, the rise in house prices will be indicated in the sales amount depicting an increase; when the demand is sluggish and supply is large, the decline in house prices will reflect the decrease in demand through the decline in sales amount. The absolute value of the housing contracted area (in square meters) refers to the total contracted area of commercial housing sold during the reporting period (i.e. the building area determined in the formal sales contract signed by the buyer and seller).

The explanatory variables are divided into two parts: attention and control variables. The attention variables include demographic indicators. According to theoretical analysis and data availability, this study selected the population size, age structure, average family size, education level, marital status, population density, the proportion of labour force and the proportion of internal migration as attention variables.

The population age structure indicator used in this study is the young-age dependency ratio (**YDR**) and old-age dependency ratio (**ODR**). The former is calculated by the ratio of the population of children aged 0–14 to the number of the labour population aged 15–64. Then, the latter is calculated by the ratio of the population of elderly people aged 65 and above to the number of labour population aged 15–64 in each prefecture.

The indicator of household size is measured by the average household size (**HHS**) in each prefecture. The household size has an impact not only on the size of the housing but also on the structure of the housing.

The educational level is expressed by the average years of education of the population aged 6 and above in each prefecture (**EDU**). Its calculation formula is as follows: (Number of people educated in primary school * 6 + Number of people educated in junior high school * 9 + Number of people educated in high school * 12 + Number of people educated in higher education * 16) / Population aged 6 and over. Education has different degrees of influence on people’s housing concept and housing awareness.

The total population comprises of the basis of housing consumption demands, and the impact of population size on housing demand is direct. When there are more people working and getting married in a certain area and period of time, the demand for housing will naturally increase. Economists such as Mankiw have demonstrated the view that when baby boomers reach their marriageable age, the demand for housing will greatly increase, thus, leading to a rise in housing prices. In other words, the growth of the population size will bring about the growth of housing demand, especially the demand for rigid housing, which will have an impact on the sales volume of residential commercial housing. This study selected the population size (**PS**) of each prefecture to analyse its actual impact.

Additionally, the population density (**PD**) was added owing to the issue of overweight economic functions in big cities as well as the depopulation of rural areas being actively discussed in Japan.

The quantitative indicator of marriage structure is the proportion of the population with spouses, which is expressed by the proportion of the population aged 15 and above with spouses (**MAR**) in each prefecture. People with different marital statuses have varying housing needs, so changes in the marital status in the overall social environment may also affect changes in housing demands.

The labour force rate is measured by the proportion of labour force (**LAB**) in each prefecture.

The flow structure of the population refers to the proportion of internal migration (**MIG**) to the resident population. The new population flowing in from other prefectures needs housing, which will affect the housing demand in inflow areas.

In addition to demographic variables, this study also selected some control variables, including the following: per capita income growth rate (**INC**), gender income gap (**GIG**), land prices (**PRI**), area of new construction (**ANC**) and interest rates (**r**). The growth rate of per capita income is the ratio of the current year's income increment to the previous year's income. The level of income directly determines the affordability of purchasing a house and thus is one of the economic factors affecting housing demand. With the increase of income, consumption concepts and patterns will also change. The increase in the level of disposable income will impact the housing demand from three aspects: meeting the rigid demand for housing, promoting the replacement of high-quality or large-area housing, and generating investment housing demand. The gender income gap represents the ratio of the wage level of women to the wage level of men (male = 100). Existing studies prove that income disparity is an important factor affecting consumption. Housing demand is an aspect of consumption demand, and thus, the influence of the gender income gap remains to be verified. Land price refers to the average sales price per square meter of residential buildings in each prefecture. From an economic point of view, high prices increase the vacancy rate of properties by inhibiting purchasing behaviour, whereas low prices may lead to a shortage of housing supply by stimulating buying behaviour. As discussed in section 7.3, general demand theory indicates that housing demand is not only affected by demand factors but also by supply factors. The area of newly started construction affects changes in regional housing prices and then the housing demand. As a monetary policy, interest rates have an impact not only on national economic development but also on housing consumption.

$$\boldsymbol{Q_{it}} = \mathbf{C} + \boldsymbol{\beta_1 YDR_{it}} + \boldsymbol{\beta_2 ODR_{it}} + \boldsymbol{\beta_3 HHS_{it}} + \boldsymbol{\beta_4 EDU_{it}} + \boldsymbol{\beta_5 PS_{it}} + \boldsymbol{\beta_6 PD_{it}} + \boldsymbol{\beta_7 MAR_{it}} + \boldsymbol{\beta_8 LAB_{it}} + \boldsymbol{\beta_9 MIG_{it}} + \boldsymbol{\beta_{10} INC_{it}} + \boldsymbol{\beta_{11} GIG_{it}} + \boldsymbol{\beta_{12} PRI_{it}} + \boldsymbol{\beta_{13} ANC_{it}} + \boldsymbol{\beta_{14} r_{it}} + \boldsymbol{\lambda_i} + \boldsymbol{\varepsilon_{it}}$$

8.5.3 - Data

The data sets for the analysis were gathered from the following statistics: Population Census（国勢調査）published by the Ministry of Internal Affairs and Communications, Housing and Land Survey

（住宅土地統計調査）, Statistics on Building Construction Started（建築着工統計調査）, National Land Numerical Information（国土数值情報）published by the Ministry of Land, Infrastructure, Transport and Tourism.

8.6 - Results

8.6.1 - Effects of Population Natural Attributes on Housing Demand

The analysis results of the effects of population natural attributes on housing demand are shown in Table 8.1. Given that the F test and the Hausman test reject the null hypothesis, the fixed effects model is the optimal choice. The results show that in Equation 1, when only the young-age dependency ratio and the old-age dependency ratio are included in the regression, the young-age dependency ratio has a significantly negative effect and the old-age dependency ratio has a significantly negative effect on housing demand. After adding the control variables into Equation 2, the effect of the young-age dependency ratio on housing demand is still negative, and the absolute value of the influence coefficient decreases from 0.125 to 0.042, that is, for every percentage point drop in the young-age dependency ratio, housing demand will increase by 4.2%. The effect of the old-age dependency ratio on housing demand is still negative, and the coefficient of influence drops from 0.148 to 0.093, that is, for every percentage point decrease in the old-age dependency ratio, housing demand will increase by 9.3%. In addition, the growth rate of per capita income, land price and area of newly started construction have significantly positive effects, gender income gap has a significantly negative effect and the interest rate has no significant impact on housing demand.

Table 8.1 – Effects of Population Natural Attributes on Housing Demand

	Equation 1			Equation 2		
	Pool	FE	RE	Pool	FE	RE
YDR	-0.064*** (0.006)	-0.125*** (0.007)	-0.121*** (0.005)	-0.001 (0.003)	-0.042*** (0.005)	-0.007 (0.006)
ODR	-0.231*** (0.019)	-0.148*** (0.014)	-0.153*** (0.015)	0.058*** (0.008)	-0.093*** (0.012)	-0.067*** (0.011)
INC	-	-	-	0.014* (0.007)	0.011** (0.005)	0.017** (0.005)
GIG	-	-	-	-0.016 (0.035)	-0.173*** (0.061)	-0.061 (0.041)
PRI	-	-	-	0.197*** (0.044)	0.468*** (0.061)	0.237*** (0.052)
ANC	-	-	-	0.807*** (0.017)	0.414*** (0.026)	0.721*** (0.021)
r	-	-	-	-0.004 (0.011)	-0.008 (0.007)	-0.012 (0.008)
_cons	15.122*** (0.342)	17.727*** (0.236)	17.601*** (0.284)	0.633 (0.497)	6.151*** (0.671)	1.895*** (0.0574)
R sq	0.4941	-	-	0.9250	-	-
Within	-	0.7487	0.7488	-	0.8797	0.8359
Between	-	0.3470	0.3507	-	0.7460	0.9624
Overall	-	0.4421	0.3507	-	0.7854	0.9208
F	F(30, 370)=70.68		-	F(30, 365)=13.21		-
	Prob>F=0.0000		-	Prob>F=0.0000		-
Hausman	-	Chi2(2)=66.17		-	Chi2(7)=307.25	
	-	Prob>Chi2=0.0000		-	Prob>Chi2=0.0000	

***, **, * indicate that the statistics are significant at the significance level of 1%, 5% and 10%, respectively.

8.6.2 - Effects of Population Social Attributes on Housing Demand

The results of the effects of population social attributes on housing demand are shown in Table 8.2. The F test and the Hausman test reject the null hypothesis that the fixed effects are still the optimal model. Equation 1 only includes demographic indicators, and the regression results show that the average household size has a significantly negative effect. Average years of education, population size and population density have significantly positive effects. The proportion of married population has no significant effect on housing demand. After adding the control variables in Equation 2, the average household size still has a significantly negative effect on housing demand, the absolute value of the influence coefficient decreases from 0.779 to 0.327 and the average years of education have significantly positive effects on housing demand; the influence coefficient also decreases. The positive effects of population size and population density on housing demand are still significant, but their coefficients have decreased. The effect of the proportion of the married population on housing demand becomes significant and positive. Moreover, the growth rate of per capita income and area of newly started construction have significantly positive effects on housing demand, whereas gender income gap, land prices and interest rates have no significant effects on housing demand.

Table 8.2 – Effects of Population Social Attributes on Housing Demand

	Equation 1			Equation 2		
	Pool	FE	RE	Pool	FE	RE
HHS	-2.376*** (0.166)	-0.779*** (0.163)	-1.171*** (0.172)	-0.483*** (0.103)	-0.327*** (0.123)	-0.475*** (0.117)
EDU	0.319*** (0.057)	0.312*** (0.081)	0.327*** (0.076)	-0.023 (0.033)	0.142** (0.065)	0.013 (0.045)
MAR	-0.049*** (0.014)	0.23 (0.015)	0.015 (0.015)	-0.011 (0.007)	0.031*** (0.012)	0.009 (0.008)
PS	0.018*** (0.006)	0.073*** (0.007)	0.053*** (0.007)	0.003 (0.004)	0.039*** (0.005)	0.005 (0.003)
PD	-0.063*** (0.005)	0.066*** (0.008)	0.036*** (0.008)	-0.012*** (0.005)	0.041*** (0.008)	-0.007 (0.004)
INC	-	-	-	0.014*** (0.007)	0.016*** (0.005)	0.018*** (0.007)
GIG	-	-	-	0.012 (0.047)	-0.015 (0.067)	0.017 (0.057)
PRI	-	-	-	0.256*** (0.073)	0.051 (0.094)	0.298*** (0.084)
ANC	-	-	-	0.779*** (0.026)	0.492*** (0.027)	0.663*** (0.026)
r	-	-	-	0.001 (0.011)	-0.007 (0.008)	-0.013 (0.008)
_cons	26.551*** (1.569)	10.508*** (1.682)	13.978*** (1.674)	4.073*** (1.287)	3.074*** (1.302)	3.507*** (1.356)
R sq	0.6892	-	-	0.9219	-	-
Within	-	0.7302	0.7181	-	0.8716	0.8342
Between	-	0.3633	0.4583	-	0.7093	0.9496
Overall	-	0.4107	0.4902	-	0.7433	0.9137
F	F(30, 366)=34.87		-	F(30, 361)=12.46		-
	Prob>F=0.0000		-	Prob>F=0.0000		-
Hausman	-	Chi2(5)=6264.53		-	Chi2(10)=21.26	
	-	Prob>Chi2=0.0000		-	Prob>Chi2=0.0194	

***, **, * indicate that the statistics are significant at the significance level of 1%, 5% and 10%, respectively.

8.6.3 - Effects of Population Geographical Attributes on Housing Demand

The results of the effects of population geographical attributes on housing demand are shown in Table 8.3. The F test and the Hausman test reject the null hypothesis that fixed effects are still the best choice. Equation 1 only includes the proportion of the labour force and the proportion of internal migration. The proportion of the labour force has a significantly positive effect, whereas the effect of the proportion of internal migration on housing demand is significantly negative. After adding the control variable into Equation 2, the effect of the proportion of the labour force on housing demand is still positive. The influence coefficient has dropped from 0.135 to 0.051, that is, for every 1 percentage point increase in the proportion of the labour force, housing demand increases by 5.1%. The effect of the proportion of internal migration on housing demand is still negative, with an influence coefficient of −0.023, that is, for every 1 percentage point increase in the proportion of internal migration, housing demand decreases by 2.3%. In addition, amongst the control variables, per capita income growth rate, land price and area of newly started construction have significantly positive effects on housing demand, whereas gender income gap and interest rate have significantly negative effects on housing demand.

Table 8.3 – Effects of Population Geographical Attributes on Housing Demand

	Equation 1			Equation 2		
	Pool	FE	RE	Pool	FE	RE
LAB	0.045*** (0.007)	0.135*** (0.005)	0.128*** (0.004)	-0.006* (0.004)	0.051*** (0.008)	-0.003 (0.002)
MIG	-0.014 (0.008)	-0.021*** (0.003)	-0.021*** (0.003)	-0.011*** (0.004)	-0.023*** (0.004)	-0.015*** (0.003)
INC	-	-	-	0.013** (0.007)	0.013** (0.006)	0.019*** (0.005)
GIG	-	-	-	-0.085** (0.041)	-0.291*** (0.065)	-0.157*** (0.049)
PRI	-	-	-	0.473*** (0.067)	0.463*** (0.087)	0.539*** (0.075)
ANC	-	-	-	0.853*** (0.018)	0.451*** (0.028)	0.761*** (0.022)
r	-	-	-	0.006 (0.011)	-0.017** (0.007)	-0.012 (0.008)
_cons	14.211*** (0.201)	10.184*** (0.182)	10.547*** (0.270)	-1.033*** (0.474)	3.871*** (0.542)	0.078 (0.496)
R sq	0.2236	-	-	0.9201	-	-
Within	-	0.7468	0.7468	-	0.8722	0.8293
Between	-	0.1647	0.1646	-	05638	0.9644
Overall	-	0.2227	0.2227	-	0.6344	0.9162
F	F(30, 370)=114.11		-	F(30, 365)=13.18		-
	Prob>F=0.0000		-	Prob>F=0.0000		-
Hausman	-	Chi2(2)=45.39		-	Chi2(7)=145.96	
	-	Prob>Chi2=0.0000		-	Prob>Chi2=0.000	

***, **, * indicate that the statistics are significant at the significance level of 1%, 5% and 10%, respectively.

This section has investigated the influence of population change on housing demand from three aspects: natural, social and geographical attributes of the population. The findings show that amongst the population natural attributes, the children dependency ratio has a significantly negative effect, and the old-age dependency ratio has a significantly negative effect on housing demand. Amongst the population social attributes, the average family size has a significantly negative effect, and the proportion of married population, population size and population density have significantly positive effects on housing demand. Amongst the population geographical attributes, the proportion of labour force has a significantly positive effect, and the proportion of internal migration has a significantly negative effect on housing demand. However, in the regression results of the three aspects, the effects of control variables on housing demand are different, and the effects of interest rates are inconsistent. To make the research results more representative and scientific, the next section puts all concerned and control variables into the models for a comparative analysis.

8.6.4 - Comparative Analysis

After incorporating the natural, social and geographical attributes of the population into the model, the F test and the Hausman test reject the null hypothesis, and the fixed effects model is still the optimal model. As shown in Table 8.4, Equation 1 indicates that the young-age dependency ratio has a significantly negative effect on housing demand. For every 1 percentage point drop in the young-age dependency ratio, the housing demand increases by 5.1%. The old-age dependency ratio has a significantly negative effect on housing demand. For every 1 percentage point drop in the old-age dependency ratio, the housing demand increases by 10.6%. Average family size, average years of education and the proportion of married population have no significant effects on housing demand. Population size and population density have positive effects on housing demand. For every 1 percentage point increase in the population size, the housing demand increases by 3.2%, and for every 1 percentage point increase in the population density, the housing demand increases by 2.9%. The proportion of labour force has a significantly positive effect. For every 1 percentage point increase in the proportion of the labour force, the housing demand increases by 5.1%. The effect of the proportion of internal migration on housing demand is insignificant.

Equation 2 includes control variables from economic and social perspectives, making the analysis results more integrated. The young-age dependency ratio has a significantly negative effect on housing demand. For every 1 percentage point drop in young-age dependency ratio, the housing demand increases by 2.3%, compared with 5.1% in Equation 1; the rate has dropped by more than half. The old-age dependency ratio has a significantly negative effect on housing demand. For every 1 percentage point drop in the old-age dependency ratio, the housing demand increases by 5.2%, which is about half of the rate of 10.6% in Equation 1. The declining birth rate increases the demand for housing, whereas the population ageing decreases the demand for housing.

The average household size has a significantly negative effect on housing demand, with a 1-person decrease in average household size, increasing housing demand by 37.6%. As mentioned in the previous theoretical analysis, traditional concepts have been affected by with the change of society, and family size has become smaller in Japan. As the downsizing of households continues, future housing demand may increase further. The average number of years of education has no significant effect on housing demand, which indicates that regardless of the level of education, there exists a demand for housing, and no difference exists in quantity, but there might be differences in the demand for housing quality. The effect of the proportion of married population on housing demand is insignificant, which can be explained from the following aspects. First, the proportion of the married population in this study is the proportion of the married population of all age groups in the total population, not only the proportion of the married population amongst young people. Second, relatively, the high proportion of the unmarried population does not necessarily increase the housing demand, because many unmarried people live with their parents, and their personal economic conditions also determine that buying a house independently is difficult for them. Third, the proportion of divorced and widowed population is generally small, and their effect on the housing market is limited.

The total population has a significantly positive effect on housing demand. For every 1 percentage point increase in the former, the latter will increase by 2.5%, which is slightly lower than the 3.2% in Equation 1. The effect of population density on housing demand is also positive. For every 1 percentage point increase in the former, the latter will increase by 2.1%, which is slightly lower than the 2.9% in Equation 1.

The effect of the proportion of the labour force on housing demand is still positive. For every 1 percentage point increase in the proportion of the labour force, housing demand increases by 2.6%. The proportion of internal migration has a significantly negative effect on housing demand. For every 1 percentage point increase in the proportion of internal migration, the housing demand drops by 1.3%. Thus, most of the current internal migrants choose not to buy or face the difficulty of buying a property in the place of employment, which also indirectly reflects the difficulty of integrating the floating population into the local life.

Among the control variables, the growth rate of per capita real income has no significant effect on housing demand. It shows that housing demand is not driven by income growth but is dominated by residents' rigid needs. The gender-income gap has a significant negative effect on housing demand; that is, housing demand decreases as the income gap widens. The area of newly started construction also has a significantly positive effect on housing demand. The effects of land prices and interest rates on housing demand are not significant. From the perspective of the demand curve, if the price rises, the quantity demanded will fall, but if the rigid demand is strong, the demand may rise instead. Therefore, the effect of land prices on housing demand is not significant. Interest rates may act on housing demand through both income and substitution effects. Changes in interest rates first affect the real value of a given savings, which in turn affects the consumption ratio of a given income. Rising interest rates first lead to an increase in the real value of given savings, which in turn causes residents to increase the consumption ratio of the given income, which may lead to an increase in housing demand. Changes in interest rates may also affect savings by affecting the cost of consumption. Rising interest rates mean that the cost of household consumption rises, which in turn causes residents to reduce consumption within a given income; this may lead to a reduction in housing demand. Therefore, the impact of interest rates on housing demand is difficult to determine.

Table 8.4 – Effects of Population Change on Housing Demand

	Equation 1			Equation 2		
	Pool	FE	RE	Pool	FE	RE
YDR	0.004 (0.008)	-0.051*** (0.009)	-0.048*** (0.008)	0.009 (0.006)	-0.023*** (0.008)	-0.002 (0.005)
ODR	-0.161*** (0.018)	-0.106*** (0.016)	-0.133*** (0.017)	0.042*** (0.012)	-0.052*** (0.015)	-0.049*** (0.014)
HHS	-1.956*** (0.226)	-0.248 (0.156)	-0.668*** (0.177)	-0.719*** (0.128)	-0.376*** (0.131)	-0.667*** (0.132)
EDU	0.546*** (0.053)	-0.051 (0.082)	0.182*** (0.083)	0.108*** (0.036)	0.037 (0.073)	0.165*** (0.046)
MAR	-0.059*** (0.015)	-0.003 (0.011)	-0.005 (0.012)	-0.022*** (0.007)	0.008 (0.011)	-0.009 (0.008)
PS	0.024*** (0.004)	0.032*** (0.008)	0.031*** (0.007)	0.009*** (0.002)	0.025*** (0.007)	0.015*** (0.003)
PD	-0.052*** (0.008)	0.029*** (0.006)	0.006 (0.007)	-0.008 (0.004)	0.021*** (0.006)	-0.003 (0.006)
LAB	-0.027*** (0.007)	0.051*** (0.008)	0..16* (0.007)	-0.015*** (0.005)	0.026*** (0.008)	-0.020*** (0.004)
MIG	0.003 (0.008)	-0.004 (0.006)	-0.004 (0.005)	-0.012*** (0.003)	-0.013*** (0.005)	-0.014*** (0.005)
INC	-	-	-	0.005 (0.005)	0.006 (0.006)	0.011* (0.005)
GIG	-	-	-	-0.004 (0.041)	-0.179*** (0.061)	-0.006 (0.053)
PRI	-	-	-	0.398*** (0.075)	0.075 (0.091)	0.437*** (0.077)
ANC	-	-	-	0.701*** (0.026)	0.386*** (0.029)	0.592*** (0.027)
r	-	-	-	0.004 (0.009)	-0.003 (0.008)	-0.008 (0.007)
_cons	22.881*** (1.735)	13.282*** (1.243)	15.374*** (1.541)	4.815*** (1.214)	7.821*** (1.322)	4.575*** (1.301)
R sq	0.7700	-	-	0.9354	-	-
Within		0.8437	0.8251	-	0.9006	0.8648
Between		0.2872	0.4623	-	0.6061	0.9577
Overall	-	0.3658	0.5267	-	0.6623	0.9291
F	F(30, 363)=47.45		-	F(30, 358)=14.05		-
	Prob>F=0.0000		-	Prob>F=0.0000		-

Hausman	-	Chi2(9)=829.63	-	Chi2(14)=1536.17
	-	Prob>Chi2=0.0000	-	Prob>Chi2=0.0194

***, **, * indicate that the statistics are significant at the significance level of 1%, 5% and 10%, respectively.

8.6.5 - Regional Effects of Population Change on Housing Demand

The effects of population changes on housing demand have been analysed above from the national level. In view of the differences in economic and social development and population conditions in different regions, in this section, regressions are performed for different regions to determine the relationship between variables in different social and demographic settings. According to the division method used by government officials for statistical and other purposes, the country is divided into eught regions, This study analyzes the following three regions: Kanto, Kinki and Chubu. Given the small sample size of each region, excessive independent variables may affect the regression results. Therefore, only the variables in the overall regression that have significant effects on housing demand are selected here. The regional regression results are shown in Table 8.5. Given that the results of the F test and Hausman test reject the null hypothesis, the fixed-effects model is still the optimal choice. Therefore, the following explanations are based on the results of the fixed effects model for Kanto, Kinki and Chubu.

The analysis of the population natural attributes indicate that the effect of population change on housing demand varies in different regions. The young-age dependency ratio in Chubu has a significantly negative effect on housing demand. For every 1 percentage point increase in young-age dependency ratio, the housing demand drops by 2.4%. The effect of young-age dependency ratio on housing demand in Kanto and Kinki is insignificant. The old-age dependency ratio in Kanto and Kinki has a significantly negative effect, whereas the old-age dependency ratio in Chubu has a significant positive effect on housing demand. When the old-age dependency ratios in Kanto and Kinki regions drop by 1 percentage point, the housing demand increases by 4.8% and 7.5%, respectively. By contrast, the negative effect of the young-age dependency ratio on housing demand in Chubu is slightly larger than the national average. The old-age dependency ratio in Kanto has a smaller effect on housing demand than the national average, whereas the old-age dependency ratio in Kinki region has a larger effect on housing demand than the national average. The data in 2015 show that the average value of the old-age dependency ratio in each region is ranked from high to low: Chubu, Kinki, national average, and Kanto. The data reflect that the higher the old-age dependency ratio is, the larger the coefficient of influence on housing demand will be. Hence, its negative effect on housing demand will aggravate as the population ages.

Population social attribute variables in different regions have different effects on housing demand. The average household size in Kinki and Chubu regions has no significant effect on housing demand. The average household size in Kanto has a significantly negative effect on housing demand. The housing demand increases by 57.7% for every one person reduction in the average household size in Kanto. The change in the average household size in Kanto has a larger coefficient of influence on housing demand than the national level. Hence, the current increase in housing demand in Kanto is obviously affected by the miniaturisation of households to a larger extent. In Kanto, the coefficient of population size is positive but not significant. On the other hand, the coefficient is significantly positive in in Kinki and Chubu.

Changes in the labour force rate have a significantly positive effect on housing demand in Kanto and Chubu but have no significant effect on housing demand in Kinki region. For every 1 percentage point increase in the labour force in Kanto, housing demand increases by 1.7%, and for every 1 percentage point increase in the labour force in Chubu, housing demand increases by 7.3%. The proportion of internal migration in Kanto and Kinki regions has no significant effect on housing demand, while the proportion of internal migration in Chubu has a significantly negative effect on housing demand. The possible reason is that the migrants in Chubu often choose to go back to their hometowns to buy houses after earning funds. The effects of the control variables on housing demand also vary across regions. The gender-income gap in all three regions has no significant effect on housing demand, which is different from the overall situation in the whole country. The possible reason is that the income in Kanto, Kinki and Chubu regions is quite different but relatively small within each region. The area of newly started construction in all regions has a significantly positive impact on housing demand.

Table 8.5 – Regional Effects of Population Change on Housing Demand

	Kanto		Kinki		Chubu	
	FE	RE	FE	RE	FE	RE
YDR	-0.014 (0.011)	0.006 (0.007)	-0.011 (0.007)	-0.002 (0.007)	-0.024** (0.011)	-0.033*** (0.010)
ODR	-0.048** (0.021)	-0.053*** (0.014)	-0.075*** (0.024)	-0.098*** (0.017)	0.014*** (0.027)	0.077*** (0.027)
HHS	-0.577** (0.236)	-0.124 (0.151)	0.068 (0.221)	0.025 (0.176)	-0.157 (0.189)	-0.601*** (0.195)
PS	0.007 (0.008)	0.006 (0.005)	0.031** (0.014)	0.026*** (0.009)	0.026** (0.012)	0.023* (0.016)
PD	0.007 (0.013)	0.003 (0.008)	0.011 (0.012)	-0.013* (0.007)	0.078*** (0.011)	0.016 (0.011)
LAB	0.017* (0.008)	0.003 (0.005)	0.008 (0.011)	0.008 (0.006)	0.073*** (0.015)	0.017 (0.013)
MIG	-0.008 (0.007)	0.003 (0.003)	-0.006 (0.005)	-0.009 (0.004)	-0.017*** (0.008)	-0.008 (0.007)
GIG	0.064 (0.223)	0.427*** (0.102)	-0.017 (0.131)	-0.317*** (0.088)	-0.128 (0.085)	-0.137 (0.093)
ANC	0.623*** (0.048)	0.867*** (0.032)	0.745*** (0.077)	0.887*** (0.042)	0.232*** (0.037)	0.346*** (0.042)
_cons	6.307*** (1.325)	0.075 (0.787)	1.853 (1.657)	0.734 (1.118)	9.887** (1.122)	11.377*** (1.232)
Within	0.9077	0.8852	0.9656	0.9627	0.8935	0.8147
Between	0.6705	0.9946	0.9322	0.9778	0.5117	0.9906
Overall	0.7478	0.9513	0.9366	0.9651	0.6072	0.9448
Hausman	Chi2(9)=55.71 Prob>Chi2=0.0000		Chi2(9)=135.42 Prob>Chi2=0.0000		Chi2(9)=42.39 Prob>Chi2=0.0000	

***, **, * indicate that the statistics are significant at the significance level of 1%, 5% and 10%, respectively.

The analysis in this section reveals the various effect of the old-age dependency ratio on housing demand through the empirical analysis of panel data. In Kanto and Kinki, old-age dependency ratio has a significantly negative effect on housing demand. However, in Chubu, the population ageing is working to raise housing demand. The possible reasons are as follows. First, with the development of the economy and society, the number of nuclear families has increased, and the proportion of the elderly living separately from their children has increased. Therefore, the housing occupancy rate of the elderly is also increasing. Thus, ageing will not always decrease housing demand and may even have different effect in different regional and demographic settings. However, from the regression results of subregions, the analysis shows that the influence coefficient of population ageing on housing demand in Kanto is smaller than that in Kinki, whereas the population ageing in Kinki is more serious than that in the Kanto, which shows that the effect of population ageing on housing demand may tend to speed up in near future.

The significantly negative effect of young-age dependency ratio has on housing demand can be explained from demand and supply aspects. On the one hand, children do not have the ability to purchase property; thus, expressing their housing needs is difficult for them. Although children's housing needs can be met by their parents, many young parents choose to purchase property before the child is born; hence, the possibility of additional purchasing is relatively small. On the other hand, a low young-age dependency ratio implies a high social savings rate and an increase in the investment rate; hence, the investment in the real estate market increases accordingly. As a result, the supply of housing increases, and the demand decreases accordingly. Therefore, whether from the perspective of demand or supply, the young-age dependency ratio has a negative effect on housing demand. This negative effect also indicates that the current intensification of low birth rate is one of the reasons for the increase in housing demand.

The average household size has a significantly negative effect on housing demand. With the popularisation of the separation living style and the intensification of low birth rate, the degree of family miniaturisation will continue to deepen. Therefore, the negative effect of family structure on housing demand will increase in near future.

In Kanto and Chubu, the coefficient of the proportion of labour force is significantly positive. However, the increase in the proportion of internal migration has not brought about an increase but a decline in the housing demand in Chubu. At present, the floating population is still mainly individuals, and majority of them still choose not to purchase real estate in the place of their employment. However, the effect of the proportion of internal migration on housing demand may change due to changes in the size of the structure of the floating population.

8.7 - Conclusion and Discussion

This chapter is an empirical study of the effects of population changes on housing demand. After a brief literature review, a housing demand model is derived. Then, the empirical test method, variable selection and data source are introduced. Thereafter, according to the natural, social and geographical attributes of the population, the effects of population changes on housing demand are analysed. Finally, a comparative study is conducted by subregions. The results show that the old-age dependency ratio has a negative effect on housing demand at national level, and the young-age dependency ratio has a negative effect on housing demand. The average family size has a negative effect on housing demand, and the population size and population density have positive effects on housing demand. The proportion of labour force rate has a positive effect on housing demand, but as the population ages, its positive effect tends to weaken. The proportion of internal migration has a negative effect on housing demand, which may change in the future due to changes in the floating population structure.

This study analyses the impact of population change on housing demand from both theoretical and empirical perspectives. The innovation is mainly reflected in the following aspects: First, the innovation of research methods. Previous studies were mainly based on theoretical analysis or time series data, and rarely used panel data. This study employs panel data to examine the impact of population changes on housing demand, and it examines the impacts by region, which was rarely covered in previous studies. Second, the innovation of research perspective. Previous studies on population attributes mainly involved the age structure, family structure, or urban-rural structure. This study examines the impact of population change on housing demand from the natural, social and geographical attributes of the population, which broadens the research perspective. Third, the innovation of research results. This study found that population ageing has a positive impact on housing demand in Chubu region, and the negative impacts in Kanto and Kinki show an upward trend; the proportion of floating population has negative impact on housing demand, which is rarely found in previous studies.

As we have seen above, the estimation results of the panel data using the five-time points from 1995 to 2015 do not necessarily confirm the tendency that housing demand decreases with the increase in old-age dependency ratio. From these estimation results, the normal relationship between housing demand and demographics may have collapsed. In other words, the standard estimation result that housing demand fall due to the ageing population may not be robust for urban policies that change the functions and population allocation in cities. Due to the complexity of population change, it is difficult to policy-guide the functioning and population relocation within the city as advocated by the compact city policy. There are limits to the policy options available at each city level, and policies need to be developed by wide-area administration in metropolitan areas, including cities and their adjacent areas. It should be noted that the validity of the prediction that housing demand will fall due to the ageing of the population will be influenced by urban policies. There is room to develop a compact city policy in areas where population decline is significant. However, since the compact city policy is by no means all-purpose, it may be necessary to take additional measures to address the problems raised by that policy. As is proven from the analysis, the optimal policy options for each region will depend largely on the relationship between the demographic settings and housing demand at the regional level. It can be seen that the positive gains brought about by population decline (and ageing) are conditional. Government departments need to implement policies tailored to the size and structure of the regional population to maximise the depopulation dividend.

CHAPTER 9

CONCLUSION AND DISCUSSION

9.1 - Introduction

Since the opening of the country in the Meiji era, modern infrastructure development in Japan has progressed in keeping with the industrialisation of society, and after World War II, development in Japan has also been aimed at achieving economic recovery. During the post-war reconstruction period, efficient maintenance was required due to the absolute shortage of infrastructure. The development of a certain amount of infrastructure necessitated qualitative improvement, along with balanced regional and national development. In this way, Japan's infrastructure has been developed with enormous public investment during the growth period. However, now that the economic growth has entered the maturity stage, it is difficult to expect additional economic growth simply by updating the existing infrastructure. In the era of depopulation, the burden per person is expected to increase if infrastructure planning is carried out as it is.

This thesis examines research questions from the socio-demographic perspective: Are Japan’s infrastructure planners responding appropriately to Japan’s demographic shrinkage? The primary purpose of this study is to analyse to what extent the changes in population size and structure that substantially affect material infrastructure planning as well as the types of infrastructure facilities are affected by these demographic changes. The analysis applied improved gravity model (Chapter 6), The two-step floating catchment area (2SFCA) method (Chapter 7), fixed effects model, random-effects model and mixed-effects model (Chapter 8), combined with the ArcGIS and QGIS visualisation function, quantitatively analysed the data of elderly care facilities, primary schools and housing published by the Ministry of Internal Affairs and Communications and the Ministry of Land, Infrastructure, Transport and Tourism.

This chapter draws together the main findings and contributions of this study. It presents a succinct view of the evidence of the impacts of the magnitude of changes in population size and structure on infrastructure planning. Additionally, the direction of future research is discussed. Finally, the relevance of these findings to policy debates is addressed, and policy-making suggestions are provided.

9.2 - Main Findings and Contributions

The aging population has increased worldwide, whereas fertility rates have reduced to exceedingly low levels. This, in turn, has simultaneously resulted in aging and shrinking populations across the globe (Jarzebski, Elmqvist, Gasparatos. et al, 2021). In Japan, along with the ageing and declining population, there is concern that the infrastructure facilities developed during the high-growth period will be ageing and becoming excessive in near future. The present study selects three types of infrastructure facilities (elderly care facilities, primary schools and housing) related to ageing, declining birthrate and shrinking population, then conducts quantitative analysis on the impact of population change on the infrastructure planning. Consistent with the chapter structure, this section outlines the main findings of each main chapter, then the underlying reasons and academic contributions are summarised.

As anthropologist Ruth Benedict notes, during the World War II era, the elderly in Japan were cared for by their families due to the Confucian tradition of respecting the elderly. Today, schools are still teaching Confucianism about respecting the older people, and the country also has a public holiday honouring elderly citizens annually, but in the eyes of most Japanese people, caring for the elderly is no longer a necessary responsibility of the family, but a social one. The dramatic growth of the number of elderly requires a higher demand for care services (Rudnytskyi and Wagner, 2019). Elderly care facilities are an important part of public service infrastructure. Their reasonable layout will not only help the elderly to receive care but also improve the overall medical level of the region.

Chapter 6 measures the geographic accessibility of elderly care facilities in Sendai by using the improved gravity model and obtains the numerical spatial distribution map of the accessibility rate of elderly care facilities of different levels. Generally, the overall accessibility level of the elderly care facilities in Sendai is unbalanced and the spatial accessibility features are significant. It is the highest in areas Itsutsubashi and Nagamachi and gradually decreases in the surrounding areas. At the same time, it presents the characteristics of unequal spatial distribution of accessibility value. According to the accessibility value and population distribution, the service grade of the elderly care facilities in Sendai can be divided into the following types: poor, fairly poor, fair, fairly good, and good. The facilities of the good and fairly good grades are mostly distributed around the city centre, where elderly care facilities are concentrated, population density is high, and traffic is developed. The fair-grade facilities are mainly distributed in the junction of areas with high-accessibility values, whereas those with low-accessibility values and are in the edge areas are of a fairly good grade. The facilities of the fairly poor grade are distributed in a limited range and cover a small population size, and poor-grade facilities are mainly distributed in the western and southwestern peri-urban areas. The uneven distribution of elderly care service resources in Sendai is also reflected in the fact that in some areas with higher ageing rates, the accessibility value is lower, while in some areas with lower ageing rates, the accessibility value is higher. Generally speaking, in Sendai, residents in central areas enjoy convenient and high-quality elderly care resources, while the provision of elderly care services in urban fringe areas is not satisfactory. Future planning should gradually narrow the geographical gap in elderly care services and improve the convenience of fringe areas.

The impact of the population decline has inevitably spilled over into the operations of primary schools in Japan. About 400-500 primary and secondary schools in Japan are closed every year (School basic survey 2020). The biggest reason for this is the decline in the number of school-age children due to declining birth rates throughout the country. The bustling scene of overcrowded schools in the past is gone, and the empty classrooms are particularly conspicuous. Chapter 7 investigates the spatial distribution characteristics and layout efficiency of primary education resources in Nagano City. The analysis adopts the 2SFCA method, The Huff model and the visualisation function of ArcGIS. By examining the accessibility value, the spatial distribution fairness and service area coverage efficiency of primary education resources at the residential area scale were analysed quantitatively. The results show that from the perspective of the whole prefecture, the polarisation of primary school service is significant, and the comprehensive service efficiency is low. The spatial layout of existing primary educational resources should be improved according to the size and distribution of the school-age population.

Specifically, the coverage and repetition of the primary school service area in Nagano City show an obvious divergent and decreasing trend from the central street to the peripheral area, and a strong positive correlation exists between the coverage and the repetition rate of the educational resource layout. The primary schools located in the central area have high school attendance and large service area coverage, but as the repetition rate is high, educational resources are wasted. In the areas far away from the central area, the number of primary schools is relatively small, and the number of schools should be appropriately increased to improve the existing spatial layout. Areas Kawanakajima and Susobana have the most abundant education resources in the entire study area. However, due to the large number of schools and the close spatial distance, the school service areas overlap, which leads to severe resource wastage, which is more serious than in other areas. Generally, the educational resources of Kouhoku and Susobana should be optimised and adjusted between schools and within them on the premise of maintaining the existing educational quality (such as the merger of schools). Other regions, especially in Kinasa and Oooka, should increase the quality of teaching in existing schools while adding a certain number of new schools.

Population decline might, in the long run, lead to a decrease in housing demand due to the decline in the number of people and the number of households. But at the same time, the supply of housing influences the opportunities for population increase through immigration and the opportunities for citizens to form new households (Mulder, 2006). In order to examine this two-sided relationship, Chapter 8 uses panel data and selects mixed models, fixed effects, and random effects models to analyse the impact of population change on housing demand across Japan. The differences in this impact are analysed with reference to the Kanto, Kinki, and Chubu areas. The regression results show that the young-age dependency ratio negatively and significantly affects housing demand; that is, as the young-age dependency ratio decreases, housing demand will rise. A significant negative effect of the old-age dependency ratio on housing demand was also observed; that is, as the old-age dependency ratio rises, housing demand will decline. In the sub-regional analysis, the old-age dependency ratio in the Chubu area was found to have a significant positive effect on housing demand, which is inconsistent with the nationwide results.

The nationwide regression results also show that average household size has a significant negative effect on housing demand. In other words, current household downsizing has a positive impact on rising housing demand. When analysing the impact of population change on housing demand, the innovations of this study include the following: (1) Innovation in research methods. Previous studies on the impact of population change on housing demand are often based on theoretical analysis or use time series data and relatively use panel data. Chapter 8 analyses the impact of population change on housing demand theoretically, uses panel data to examine the impact, and conducts sub-regional investigations, which have not been extensively covered in previous studies. (2) Innovation in research perspectives. In previous studies, demographic variables mainly include age structure, family structure, and the urban–rural structure. Chapter 8 examines the impact of population structure on housing demand from the broader context of the population structure, natural population structure, social structure, and regional structure, which broadens the research perspective in this field. (3) Innovation in research results. The analysis results show that population ageing in the Chubu area has positively affected (boosted) housing demand, and the proportion of internal migration has negatively affected (slowed down) housing demand. These findings have not been reported in studies using nationwide data as the analysis unit.

9.3 - Inspirations for Other East Asian Countries from Japan's Experience

In a society with a growing population, funding for simple government-led infrastructure development using long-term, low-interest funds through mechanisms such as the Fiscal Investment and Loan Program (FILP) has been uniformly ensured throughout Japan (Uto, Kitazume and Asami et al. 2013). In a society with a declining population, it is difficult to maintain the conventional system from the viewpoint of financial constraints and a decline in the number of users. Therefore, to induce public and private funds for infrastructure development, it is necessary to allow fund procurement and business management according to business risks and profitability. By doing so, it is possible to diversify and mitigate the impact of population decline on the infrastructure business and enhance the sustainability of infrastructure planning.

It is impossible to plan diverse infrastructure facilities by utilising the same ideas and methods. Given the declining population, optimising infrastructure levels promptly and appropriately is necessary. Therefore, “time management” is an important factor. The main purpose of time management is to skilfully control the time difference between the rates of population decline and infrastructure renewal. Time management is also closely related to space management. However, efforts to mitigate population decline should be initiated first in certain cases, and it is better to downsize infrastructure facilities in several cases. In scenarios where future population recovery is unlikely, abolishing infrastructure and shifting the resident population to other habitable areas may reduce social costs compared to the costs associated with renewing infrastructure.

As infrastructure generally has a long service life, it is difficult to flexibly change service levels in alignment with demographic trends. Therefore, it is realistic to use renewal timing as an opportunity to optimise service levels. Even if this is the case in principle, consolidation will instantly result in lower lifecycle costs for overall infrastructure maintenance and management if it takes a long time to update. In such a case, it is necessary to artificially degrade the infrastructure. In this context, time management initiatives must consider how much and when it is reasonable to implement this degeneration appropriately. Moreover, as consideration must be given to aspects such as convenience, human resources, technology and the environment, in addition to financial considerations, a highly detailed infrastructure optimisation plan is required.

In addition, although it relates to the technical theory, the basic policy of current infrastructure technology development is to extend the service life. In regions where population decline is rapid, long-lived infrastructure will no longer be needed after several decades. In this case, only the infrastructure will be left. Relatively, if the infrastructure is needed for only 20 years, one must strive to build infrastructure that will last for only 20 years, and if its construction and maintenance costs are lower, then that infrastructure facility is preferable (Uto, Kitazume and Asami et al. 2013). From this point of view, it is necessary to formulate an infrastructure development plan after considering for how many years the infrastructure in the region will be needed and when to downsize.

As a discussion that considers the time axis, it is necessary to consider the provision of infrastructure services over time after predicting the population decline trend (Buhr, 2007). In addition, it has been argued that it is necessary to establish a time axis when formulating a plan that considers the rate of population decline and the financial burden (Taira, 2005). In a sense, it is desirable to proceed with such infrastructure degeneration plans with the consent of residents and planners. However, in reality, planners encounter severe obstacles when downsizing infrastructure and services. In particular, it is difficult to gain the understanding of residents regarding the consolidation and abolition of infrastructure facilities and the decline in service standards. Securing this understanding is a major issue in promoting infrastructure planning in the context of population decline.

9.4 - Implications for Future Research

In Chapter 6, when analysing the accessibility of elderly care facilities, to avoid bias for a single measurement method, the population scale coefficient and facility-level influence factor were added to the model. This was done after examining the different ‘β’ values and under the premise of considering the effect of distance attenuation. Then, in combination with the distance of the road network, the accessibility level of elderly care facilities was measured by applying the improved gravity model. In future research, we can consider adding residents' socioeconomic attributes (occupation, income level, and education level) to the existing model and analyse the impact of these variables on the demand for elderly care services. Moreover, the existing model equalises the needs and does not take into account the diverse needs of older people with varying disease and age attributes with regard to elderly care services. In reality, these demanders have diverse needs for elderly care services in different times and spaces, and discussing their spatial dependencies has important practical significance for the study of elderly care needs and the planning and improvement of the layout of elderly care facilities.

The concluding analysis in Chapter 7 provides a reference for future research directions in this field. First, it is necessary to use more comprehensive school data covering all districts of Nagano Prefecture to study the allocation of basic education resources in the entire prefecture, so as to further analyse the spatial distribution characteristics and layout efficiency of primary schools. Second, the analysis method could be improved to increase the accuracy and credibility of the model by adding a coefficient to measure the difference in the quality of primary education in the model. Finally, when applying the 2SFCA method to measure the spatial accessibility of schools, there is still room for improvement in the selection and calculation of population impact factors. In future research, more accurate population data can be considered to further optimise the analysis results, as it would help grasp the characteristics of population distribution in the region. Additionally, the 2SFCA method and the Huff model used in Chapter 7 are expected to be applied to other types of public service facilities (refuge facilities, general hospitals, etc.) through transformation and analysis.

When analysing the impact of population change on housing demand, in future research, a more in-depth study should be conducted on the effect of the old-age dependency ratio on housing demand. Moreover, the circumstances under which population ageing will have a positive effect on housing demand, when and why the impact will appear, etc., remain to be explored. Most studies, including this study, focus on the impact of population change on the quantity of housing demand, without specifically considering the impact of demographic factors on the structural demand for housing. In future research, the impact of ageing on the demand for housing structure and the impact of changes in family structure on the demand for housing structure can be considered. The results of this analysis can then be combined with existing findings to further analyse the impact mechanism of population changes on housing demand.

The housing needs of Japanese people will diversify depending on the life stage. Family households generally require big homes, but as the inhabitants get older, the needs of elderly members and their convenience regarding shopping and hospitals will increase rather than their requirement for big houses. Moreover, the number of residents who want to continue living in the place where they presently live is expected to increase as they get older. In response to these changes, government agencies urgently need to establish a mechanism that enables citizens the choice of their residence according to their needs. In this regard, it is conceivable to create a mechanism to eliminate less used, uninhabited houses, extend the life of condominiums and promote reconstruction.

Additionally, this study aims to discuss the impact of population decline on infrastructure planning. In Japan, infrastructure planning is inextricably linked with political activity. Thus, future research could consider exploring the relationship between political activities and infrastructure planning within the context of depopulation.

Japan's infrastructure development and maintenance have a long history. Infrastructure planning has always depended on the social conditions of each era and the relationship between the national and local governments, as well as between the public and private sectors. When considering infrastructure planning in the era of population decline, it thus becomes crucial to seek the most efficient and effective ways to respond to the demands of the times.

Deciding where and how to develop infrastructure in order to maintain and improve people's living standards is one of the important responsibilities of those involved in political activities. As discussed in Chapter 2, traditional research on political activity and infrastructure development has focused primarily on how politicians and bureaucrats have used social infrastructure development projects as political means. In other words, guiding the development of social infrastructure in the constituencies is a "local benefit" that political parties and politicians use in order to win the election.

However, infrastructure development in the local community does not directly benefit the local community. Although some people do benefit from it, some others do not. If a local burden is required for such infrastructure development, consensus building in the local community is even more necessary. Population decline can be anticipated to cause changes in the political environment, which would also complicate the relationship between balancing political activities and facility planning, thus creating new issues. Then the following questions arise: Who creates "local benefits" in the era of depopulation and how? Further, how will the form of "local benefits" change depending on the bearer? These issues should be investigated by future studies.

9.5 - Implications for Practice

Japan's population peaked in 2008 after a period of modern growth and has since been hit by an unprecedented decline. By 2050, the total population will almost certainly fall below 100 million in Japan, and the retiring baby boomer generation and its junior generation are expected to push the percentage of older people aged 65 and over to nearly 40%. After that, the population will continue to decline, possibly reaching 88 million in 2065, which was the size of the population in 1955. However, the age structure will be significantly different: The percentage of elderly people in 1955 was 5.3%, but by 2065, it will be 38.4%. Additionally, the working-age population in 2065 will be 45 million, which means the Japanese economy will have to be supported by about half of its population (MIC, 2015). The government has begun to tackle the declining birthrate, ageing population, and pension issues, and the media and public opinion are interested in these issues. However, there is little debate about how to manage, operate, and improve infrastructure that has achieved post-war reconstruction, supported high economic growth, and responded to the rapid increase in urban population in a society experiencing rapid depopulation. As Japan reached the maximum point of the population curve ahead of the rest of the world from increase to decrease, the infrastructure planners in Japan need to re-examine the meaning of sustainable development and tackle the following two issues regarding the infrastructure planning in the context of population decline:

What should be the basis of the idea of infrastructure planning suitable for a depopulating society and the mechanism for consensus debating?
What should be the social space (regional) design necessary to maintain vitality, ensure safety, and maintain a country rich in nature under a declining population?

There are uncertainties about vital estimation, but Japan has been on the path of long-term population decline since at least 1974, when total fertility rate dipped below 2.1 children per woman for the first time. It has remained below 2.1 since then, a period of 48 years. Applying the conventional way of social infrastructure development based on the premise of population growth to a depopulating society will make for a fundamental mistake. Additionally, social infrastructure development, including the consensus process and financial measures, takes a long time. It is too late to respond after the population declines and problems arise. Further, as discussed in Chapter 1, the peak of renewal period of the existing infrastructure facilities will come in the next 20 years, which is another reason why immediate action is required. Needless to say, it is necessary to clarify the direction of this response and make efforts to repair various conflicts such as environmental problems that occurred in the infrastructure planning during the period of rapid population growth. On the other hand, the world population is said to exceed 10 billion in the 21st century, and there are concerns about further deterioration of global environmental problems. Actually, we are already facing an environmental catastrophe, and human economic development is the cause. However, it is estimated that the global population increase will be about to converge around 2100. In such forecasts, efforts to create a society that maintains vitality under a declining population and is safe and coexists with nature are unexplored and common challenges for humankind. If successful, it can contribute to the survival and development of all people. It is said that Japan achieved an "economic miracle" in the 20th century, and, in the 21st century, Japan has potential to achieve a "social and space design miracle" and lay the foundation for becoming a country that is globally respected.

The results of this study to a certain extent prove the rationality and possibility of realisation of the depopulation dividend theory proposed by Matanle and Sáez-Pérez (2019) and Matanle, Sáez-Pérez, Li and Buehler (2022). The depopulation dividend indicates the achievement from peaceful and non-coercive human depopulation of positive gains that contribute to socio-cultural, political-economic, and environmentally sustainable living. This concept has guiding significance for future infrastructure planning in Japan. The decline in population size is conducive to the formation of a compact and efficient social production model and an intensive urban structure. This is similar to the conditions for obtaining demographic dividends argued in Bloom et al. (2003). Under a certain size and structure of the population composition, the necessary condition for obtaining positive gains of depopulation for sustainable socio-economic development is that the government agencies implement support policies that are conducive to the development of the population composition. In this way, the government plays a guiding role, so that the positive impact of population decline can be exerted to a greater extent.

Starting from this consideration, based on the conclusions and inspirations obtained in the empirical analysis chapters, this study finally discusses the reasonable methods and ideas of infrastructure planning under the condition of population decline.

The fairly rapid and long-term population decline that is expected to emerge after the rapid population growth of Japan is the first in modern history. Regarding infrastructure planning, not only the amount/size of population decline, but also its speed, spatial distribution, and population composition are important. Enormous maintenance, management, and renewal costs will be required to address the ageing of infrastructure that has been centrally maintained during the high-growth period, but in many cases, this response has been postponed. For Japan, which is already operating on the premise of accumulating a huge amount of infrastructure, when maintenance, management, and renewal are postponed and the infrastructure deteriorates to a serious level and suddenly becomes unusable on a large scale, the loss is immeasurable. As renewing the country’s infrastructure in a short period of time is impossible, it is necessary to formulate a plan for several decades and respond step by step.

Population growth and a heavy use of resources are the root causes of environmental problems, but, even during population decline, environmental problems do not disappear naturally, and it is necessary to reaffirm the environment. In addition to the economic contraction after the burst of bubble economy, under the condition of long-term population decline under environmental constraints, Japan needs to create a new vibrant civilization while accepting contraction and withdrawal from society that has continued to demand quantitative expansion. The direction and lifestyle need to be changed. Based on the highly uncertain population decline estimates, it is necessary to form an agreement on "strategic choices" that are more difficult than during the period of population growth and to create a new society.

Although it is difficult to estimate the transition of the spatial distribution of the population in the country, it has an important meaning together with the total population in terms of spatial design and planning. During infrastructure planning, it is necessary to draw up and examine some scenarios of whether the population will decrease uniformly or partially and tackle the problems that arise with the relocation of the population. It is important to aim to improve the quality of both the living and the natural environment. Japan may restore the over-expanded city to a compact form, change the idea of quantitative expansion of social infrastructure, and harmonize with the natural environment and production areas while effectively using the existing infrastructure facilities. It is also necessary to set a planning time axis that considers both the rate of population decline and the renewal period of infrastructure facilities that brings about a financial burden.

Based on the trend of population changes in every country, it is important to improve Japan's infrastructure planning from a long-term and wide-area perspective. In Japan, during the declining population, cooperation with the international community is becoming important for solving problems such as food supply, security, and climate change. International coordination with a global perspective and leadership are required for Japan. Among the modernized countries, Japan stands on the frontier of the phenomenon of population decline and thus has the potential to establish a new social design and space design concept and play a leading role in solving problems common to all humankind.

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