A study on urban vacant dwellings and the efficiency of transportation system in the context of urban shrinking

その他（別言語等）のタイトル	都市縮小に伴う空き家と交通システムの効率化に関する研究
著者	HA Thi Khanh Van
学位名	博士（工学）
学位の種別	課程博士
報告番号	甲第503号
研究科・専攻	工学専攻
学位授与年月日	2022-09-26
URL	http://doi.org/10.15118/00010872

A Study on Urban Vacant Dwellings and The Efficiency of Transportation System in The Context of Urban Shrinkage

by

Ha Thi Khanh Van

A Dissertation Submitted to
the Division of Sustainable and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy
in the Course of Advanced Sustainable and Environmental
in the Muroran Institute of Technology

Approved by:

Prof. Makoto Nakatsugawa

Prof. Katsutoshi Kimura

Prof. Mikiharu Arimura

August - 2022

DECLARATION

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgment of collaborative research and discussions.

ABSTRACT (日本語)

近年、空き家は多くの国にとって大きな課題の 1 つになっています。 2018 年の日本の空き家総数は 849 万戸に達し、総住宅ストックの 13.6%を占めています。 OECD 諸国と比較して、この数字は最も高く、社会の高齢化と低い出生率により、将来さらに増加すると予想されていました。

住宅市場を安定させるためには、空き家の比率を一定の水準、通常は 5%未満に抑える必要があります。実際の空室率がこのしきい値を超えると、需給関係の不均衡を反映するだけでなく、都市の持続可能な開発に悪影響を与える可能性があります。これらの悪影響には、近隣の不動産の価値の低下、空室率と犯罪率の増加の刺激、劣悪な衛生状態と景観、税収の減少、および輸送システムの非効率的な運用が含まれます。したがって、空き家の発生のメカニズムを理解し、その影響を制御することが不可欠です。

これらの問題を解決するために、この研究は 2 つのポイントを目指しています。まず、空き家とその決定要因の空間分布を調べます。次に、住宅利用との関係における輸送システムの効率を評価します。これらの目的のケーススタディとして、北海道札幌市が選ばれました。局所空間的自己相関分析、部分最小二乗回帰（PLSR）、およびデータ包絡分析（DEA）を実行することにより、研究の目的が達成されます。

結果は、高い住宅空室が中央地区と密集した地域に集中する可能性が高いことを強調しています。その後、空室レベルは、市内中心部までの距離が長くなるにつれて減少します。影響を与える特徴の中で、人口統計学的特性が最も強力な決定要因でした。その中で、空き家を刺激する上で、単身世帯の数は他の世帯を上回りました。同様に、人口の減少に伴う住居の供給過剰は、空室の増加に集中的な影響を及ぼしました。対照的に、住宅所有率の増加と建物内の統合駐車場は、空き家の数を減らすでしょう。また、DEA の分析によると、札幌市、特に駐車場やエリアの交通サービスの余剰は、住宅の充填率の不足によるものである。研究の結果は、文献だけでなく、持続可能な開発を達成するための政策立案にも貢献するでしょう。

ABSTRACT (English)

In recent years, vacant houses have become one of the major challenges for many countries. In 2018, the total number of vacant houses in Japan reached 8.49 million units, accounting for 13.6% of the total housing stock. Compared to OECD countries, this figure was the highest and was expected to further increase in the future due to social aging and the low fertility rate.

For a stable housing market, it is necessary to keep the ratio of the unoccupied dwellings within a certain level, usually less than 5%. When the real vacancy rate exceeds this threshold, it may not only reflect the imbalance in the supply-demand relationship but also negatively affect the sustainable development of the urban. These negative influences include the neighbouring properties' value reduction, stimulation of the increased vacancy and crime rates, poor sanitation and landscape, decline in tax revenue, and the inefficient operation of the transportation system. Therefore, it is essential to understand the mechanism of vacant dwellings occurrence and to control its effects.

To solve these problems, this study aims at two points. First, it examines the spatial distribution of vacant houses and their determinants. Second, it evaluates the transportation system's efficiency in the relationship to housing utilization. The city of Sapporo, Hokkaido, was chosen as a case study for these objectives. By conducting the local spatial autocorrelation analysis, partial least squares regression (PLSR), and data envelopment analysis (DEA), the study's objectives are achieved.

The results highlight that the high housing vacancy would likely concentrate in the central district and the dense areas. The vacancy level then decreases with the increase in the distance to the city's centre. Among the affecting features, the demographical characteristics were the strongest determinants. In which, the number of single households outperformed the other in stimulating the vacant houses. Likewise, the oversupply of dwellings along with the decline of the population had an intensive effect on the rise of vacancy. By contrast, the increase in the housing ownership ratio and the integrated parking lots in the buildings would reduce the number of vacant dwellings. Moreover, the DEA analysis shows that the shortfall in the housing filling rate accounted for the surplus in transportation services in the city of Sapporo, especially the car parking sites and areas. The outcomes of the study would contribute to not only the literature but the policymaking in achieving sustainable development.

ACKNOWLEGEMENTS

It’s not easy to count the people who supported and encouraged my efforts to complete this dissertation.

First and foremost, I would like to express my deepest appreciation to my supervisor, Professor Mikiharu ARIMURA for your patience, enthusiasm, kindness, guidance, and constant support. I have learnt greatly from you. It is not only your immense knowledge but also your lifestyle through the way of great treatment with all lab members. I am deeply grateful that you took me on as a research student and continued to have faith in me over the years.

This endeavour would not have been possible without Associate Professor Takumi ASADA, who inspired me to pursue this research topic. Without your advice and encouragement, this research and dissertation would not have happened.

I’m extremely grateful to the members of my dissertation committee, including Professor Makoto NAKATSUGAWA and Professor Katsutoshi KIMURA. Their insight, feedback and advice were essential in this dissertation's fulfilment.

Special thanks to Dr. TRAN Vinh Ha, who has always stood by me for the past 18 years, for his enthusiastic guidance to help me access the research process more easily. His experience and advice were fundamental throughout the research and dissertation-writing process. Besides, I am also grateful to the members of the ARIMURA and ASADA laboratories, who always accompany me in all laboratory activities and supported me so much in my life at Muroran.

I would like to extend my sincere thanks to all the staff of the Centre for International Relations, Muroran IT. Many thanks to Mr. Jinro ENDO, Ms. Hatsuki NODA, Mr. Sangyub BAEK, Ms. Mai IKEDA, and Ms. Kozue TAKEKAWA for your support with my family in the life. And especially thanks to Professor Naoko YAMAJI and Associate Professor Masatsugu ONO, who inspired me to love more the Japanese language, culture, and people.

Thanks to all my friends and colleagues in Construction College No.1 who directly or indirectly helped me to complete this PhD. course.

At last, but not least gratitude, I would like to towards my parents and my son with a deep sense of reverence, who have always stood behind me and supported me unconditionally.

TABLE OF CONTENTS

DECLARATION II

ABSTRACT (日本語) III

ABSTRACT (ENGLISH) IV

ACKNOWLEGEMENTS V

TABLE OF CONTENTS VI

LIST OF FIGURES IXx

LIST OF TABLES X

LIST OF ABBREVIATIONS XIi

CHAPTER 1. INTRODUCTION 1

1.1. Background 2

1.2. Research objectives 8

1.3. Dissertation structure 8

References 10

CHAPTER 2. VACANCY DWELLINGS SPATIAL DISTRIBUTION–THE DETERMINANTS AND POLICY IMPLICATIONS 15

Abstract 16

2.1. Introduction 16

2.2. Literature review 18

2.2.1. Housing allocation and housing market equilibrium 18

2.2.2. Demographic features 19

2.2.3. Neighbourhood characteristics 20

2.2.4. Housing characteristics 21

2.3. Material and methodology 23

2.3.1. Research area 23

2.3.2. Material 23

2.3.3. Local spatial autocorrelation 28

2.3.4. Partial least squares regression 28

2.4. Results 30

2.4.1. Vacant dwellings spatial autocorrelation 30

2.4.2. PLSR models 31

2.4.3. The determinants of vacant dwellings 32

2.5. Discussions 34

2.5.1. Spatial distribution of the vacant dwellings 34

2.5.2. Demographic factors 35

2.5.3. Neighbourhood characteristics 38

2.5.4. Housing characteristics 40

2.5.5. Policies implications 43

2.6. Conclusions 44

Appendixes 45

References 48

CHAPTER 3. ASSESSING THE TRANSPORTATION SYSTEM EFFICIENCY IN THE RELATIONSHIP TO THE UTILIZATION OF URBAN HOUSING 57

Abstract 58

3.1. Introduction 58

3.2. Material and methodology 60

3.2.1. Research area 60

3.2.2. Material 61

3.2.3. DEA models 64

3.3. Results 68

3.3.1. Selection of variables 68

3.3.2. Data envelopment analysis 68
3.4. Discussions 73
3.4.1. Achieving efficiency 73
3.4.2. Productivity scale implications 77
3.5. Conclusions 78
Appendixes 79
References 81
CHAPTER 4. CONCLUSIONS 88
4.1. Summarise of the dissertation findings 89
4.2. Limitations 90
4.2. Future works 91

LIST OF FIGURES

Figure 1.1. Housing stock, Vacant housing stock, and Vacancy rate in Japan Vacant dwellings in OECD countries 5
Figure 1.1. Vacant dwellings in OECD countries 6
Figure 1.2. The rank of vacant dwelling rates in OECD countries 6
Figure 1.3. The statistic for homeless 7
Figure 1.4. Dissertation structure 9

Figure 2.1. The spatial distribution of resident dwellings 27
Figure 2.2. The distribution of vacant dwellings 27
Figure 2.3. Local spatial autocorrelation Gi* clusters map (significant level 95%) 30
Figure 2.4. PLSR models training outputs 31
Figure 2.5. The change in population and housing supply in the city of Sapporo 40
Figure 2.6. The housing stock by structure in the city of Sapporo 41

Figure 3.1. Transportation facility indexes by sub-district zones 62
Figure 3.2. CFAR, HFAR, and housing filling rate distribution 63
Figure 3.3. CCR and BCC frontier visualization (produced by the authors) 65
Figure 3.4. Efficient score and return-to-scale status by zone 69
Figure 3.5. Distribution of input excess and output shortfall 71

LIST OF TABLES

Table 2.1. Vacant houses ratio in Japan and some metropolises 23
Table 2.2. Summary of the data set 25
Table 2.3. Summary of vacant houses in the three clusters 31
Table 2.4. PLSR models training results 32
Table 2.5. Top high influence variables 34

Table 3.1. Data statistics summary 64
Table 3.2. Results of the linear regression models 68
Table 3.3. Summary of efficiency analysis 69
Table 3.4. Summary of input reduction and output improvement 72
Table 3.5. Frequency of references 73
Table 3.6. Summary of transportation and housing indexes by efficiency rank 74
Table 3.7. Summary of transportation and housing indexes by efficiency RTS status . 77

LIST OF ABBREVIATIONS

BCC	Banker-Charnes-Cooper
BRT	Bus Rapid Transit
CBD	Central Business District
CCR	Charnes-Cooper-Rhodes
CFAR	Commercial Floor Area Ratio
CRS	Constant Return-To-Scale
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
DRS	Decreasing Return-To-Scale
DRT	Demand-Responsive Transport
FAR	Floor Area Ratio
HFAR	Housing Floor Area Ratio
IRS	Increasing Return-To-Scale
LRT	Light Rail Transit
MaaS	Mobility-as-a-service
MRL	Multiple Linear Regression
OECD	Organisation for Economic Co-operation and Development
PR	Poison Regression
RTS	Return-To-Scale
TOD	Transit-Oriented Development
VIF	Variance Inflation Factor

CHAPTER 1

Introduction

1.1. BACKGROUND

In recent years, vacant dwelling is one of the great concerns of scholars because of their rapid increase and popularity in many countries across all continents of the world. In Europe, the number of unoccupied conventional houses reached about 38 million in 2011 (Feantsa & Foundation Abbé Pierre, 2016); some countries, such as Greece, and Croatia, had a vacant house rate of over 30%. Meanwhile, the U.S is mentioned as a typical case of a vacant house crisis in the Americas. According to Oversight & Reform (P.14, 2012), between 2000 and 2010, the number of vacant houses increased by 44%, equivalent to 4.5 million units, and the number of nonseasonal vacancies is 3 million units, up 51%, even over 70% in 10 states. The same situation also occurs in Asia nations, especially the developed economies. Countries that have a high vacancy rate are Japan (13.6% in 2018) and Taiwan (17.6% in 2000) (Hsueh et al., 2007; Statistics of Japan, 2018). Remarkably, the severity of the housing vacancy does not appear to be decreasing in such cases listed above. Therefore, understanding the mechanism of this problem remains a major challenge in the scholar community.

According to basic economic theory, to maintain the stability of the housing market, a certain number of exceeded dwellings is essential. It occupies a certain percentage of the housing stock and is known as the natural vacancy rate[1]. As a rule of thumb, the threshold vacancy value is 5%, as introduced by Gentili and Hoekstra (2019) and Glock and Häussermann (2004). Nevertheless, this rate may change when applying to a country or specific region depending on the housing market characteristics. For instance, the ratio is 2.5% in the UK (2008), 5% in the U.S., 1-1.5% in Swiss, etc. (Couch & Cocks, 2013; Hoekstra & Vakili-zad, 2011; McDonald, 2000; Thalmann, 2012). If the real vacancy rate is greater than the natural vacancy rate, it may not only reflect an imbalance between supply and demand, but also has negative effects on urban sustainability.

In terms of socioeconomic, many researchers state that vacant houses cause value reduction in the nearby properties, stimulate the increase of total abandoned dwellings (Han, 2014, 2019; Immergluck, 2015), or adversely affect the neighbourhood landscape (Deng & Ma, 2015). Moreover, inefficient abandoned houses management can lead to social problems such as a rising crime rate, poor sanitation (Yamada & Uosaki, 2007), high collapse risk, and

[1] The natural vacancy rate is determined as the average percentage of rental properties that are not occupied with tenants when there is balance in demand and supply. It also calls by other names such as frictional vacancy or structural vacancy.

reduced tax revenue (Gu et al., 2019; Han, 2014; Keenan et al., 1999; Martinez-Fernandez et al., 2012). For transportation, an increase in vacancy rate in an area subsequently decreases the number of passengers using the area's services, which then runs under capacity. While investment and maintenance in transportation infrastructure are costly, the inefficient operation of the system can cause great pressure on the budget of the local government. Therefore, the management of vacant house problems requires urgent attention. And quantitative examinations to fill this knowledge gap are essential.

Since the second half 20th century, vacant dwellings have been mentioned in numerous studies as an aspect of globalization, suburbanization, depopulation, deindustrialization, and the economic downturn (Gu et al., 2019; Haase et al., 2014, 2016; Martinez-Fernandez et al., 2012; Newman et al., 2016; Radzimski, 2016; Xie et al., 2018). Nevertheless, it has just been evaluated as a symptom rather than an urban disease (Accordino & Johnson, 2000), and no timely response measures. As a result, a large excess of vacant houses has become a challenge not only in urban areas but also nationwide, particularly in developed countries.

At present, clearly understanding the mechanism and effectively controlling the rise of housing vacancy remains a major challenge in the academic community as well as policy makers. In most studies, the scholars focus on vacant houses on the aspects of demographic features, neighbourhood, and building characteristics.

In the aspect of demographic features, the adverse change in demographic (such as depopulation, low fertility rate, and the high elderly population) is claimed as one of the main causes of housing vacancy (Cohen, 2001; Glaeser & Gyourko, 2005; Huuhka, 2015; V. Morckel, 2014; Newman et al., 2019). In many studies, depopulation reflects the direct consequences of the shrinking urban phenomenon, also known as suburbanization. This refers to an inevitable stage that occurs after the urbanization process (Berg et al., 1982; Weaver et al., 2016). Depopulation, either natural or migratory increase, or both, led to a decline in housing demand and an imbalance in the housing market. Moreover, the lack of effective measures (such as policies and restrictive local budgets) has resulted in a substantial accumulated number of vacant dwellings. In addition, the high proportion of elderly increases in society also reflects the risk of vacant dwellings in the future. When they pass away, there are no more heirs to the property. Further, the change in the structure of traditional households significantly affects the appearance of empty houses (Jeon & Kim, 2020; Kubo & Mashita, 2020; Mayumi, 2020). The scale of family sizes is smaller, consisting of one or two generations instead of as many as in the past. In the short term, it motivates the housing demand, but in the long term, when fertility continues to remain low, there is a high probability of vacant houses (Kubo & Mashita, 2020; Mayumi, 2020; Seirin-Lee et al., 2020; Sophie, 2010).

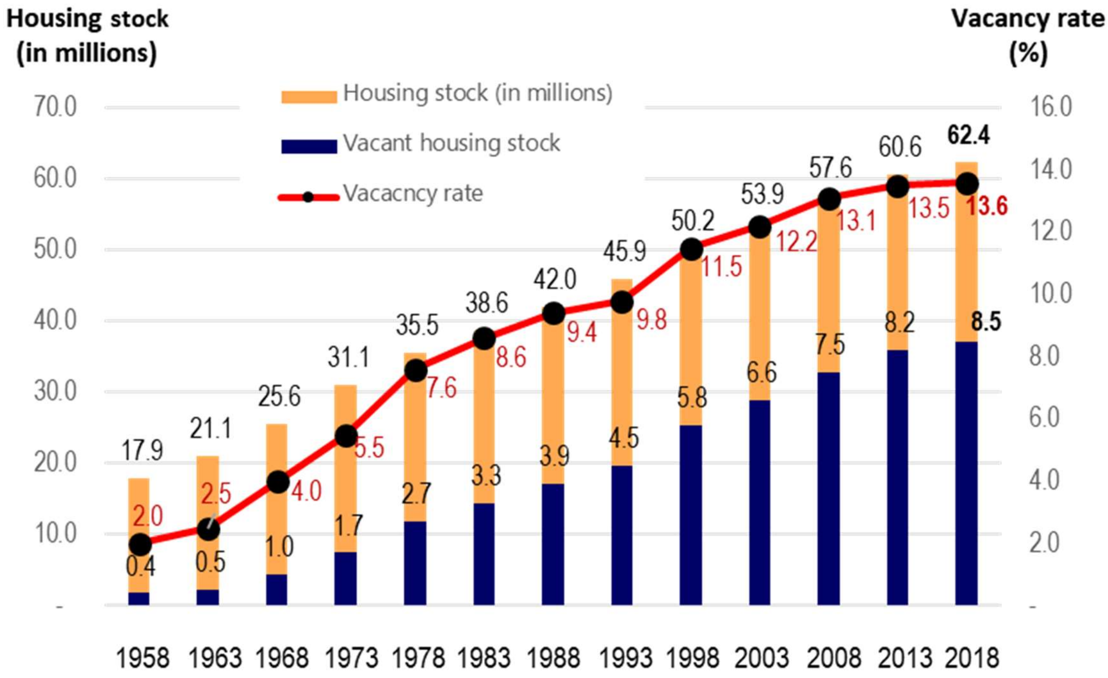
Regarding the neighbourhood characteristics, some factors such as natural environment conditions, unemployment, radical and ethnic composition, and poverty are argued to relate to the increase in vacant houses. While the radical and ethnic composition, unemployment, and poverty factors appear to be more prevalent in studies in Western countries and the U.S (Appel et al., 2014; V. Morckel, 2014; Newman et al., 2019); natural environmental factors such as steep slopes and low land are observed more in some Asian countries, such as Japan and South Korea (Kanayama & Sadayuki, 2021; Kubo & Mashita, 2020; Park, 2019; Wuyts et al., 2020). In addition, the houses that have poor conditions of built-up infrastructure or are close to the industrial zone, or with low accessibility to grocery stores can become abandoned (Jeon & Kim, 2020; Wuyts et al., 2020). Nevertheless, to my best knowledge, the relation between public facility quality and housing vacancy was not much concern in the previous studies.

The ownership, building structure and types, and size, are common factors that have been found in the literature related to housing characteristics. Most studies found a high rate of vacancy in the private ownership sector. The major cause is stated to be related to the financial situation of the owner (tax debt, mortgage) in the US, (Durst & Ward, 2015; Immergluck et al., 2012; V. Morckel, 2014), and the loss of population due to the economic decline from the post-industrial stage in England (Couch & Cocks, 2013). Meanwhile, some scholars argue that an aging population, reduced demand for ownership in younger generations as well as oversupply are the key drivers in Japan (Kubo & Mashita, 2020; Mayumi, 2020; Xu & Zhou, 2019a). Likewise, building structure and types, as well as sizes, have significantly affected the vacancy rate. For instance, the high vacancy rate in apartments found in the UK and Japan (Couch & Cocks, 2013; Xu & Zhou, 2019a), whereas detached houses predominate in Finland. Housing with wood, block, stone structure, and small areas was more likely to be vacant (Baba & Asami, 2017; Park, 2019). Furthermore, the factors of high-price, poor maintenance, and age are also stated to associate with the vacancy situation (Baba & Hino, 2019; V. Morckel, 2014; Nishiyama, 2020; Wuyts et al., 2020).

For Japan, the total number of vacant dwellings across the nation reached 8.49 million units in 2018 (Statistics of Japan, 2018) and 8.46 million units in 2020 (Vérité, 2021). Although this increased slower than in 2013 (0.08 percentage points), the vacancy rate still remains at a high level, accounting for 13.6% of the country's housing supply (Statistics Bureau of Japan, 2018) and has the highest rank compared with other countries in OECD (Figure 1.1 and Figure

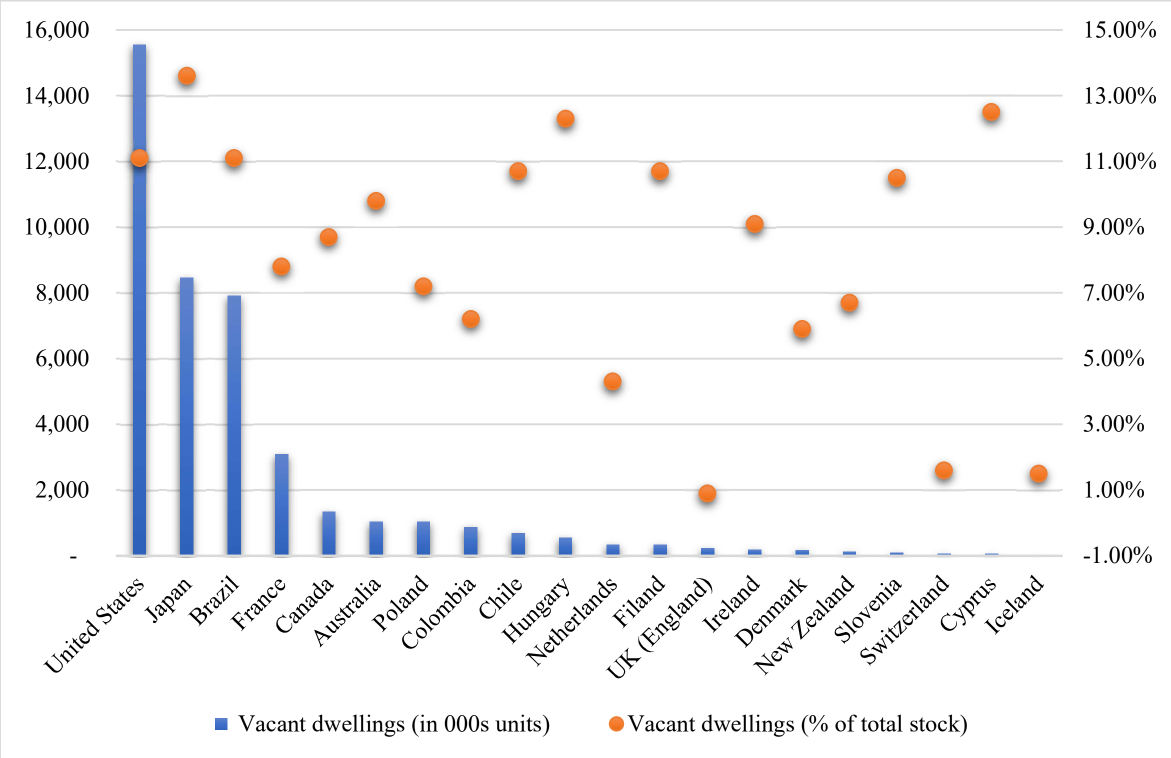
1.2). Vacant dwellings appear not only in small and medium-sized cities or in out and inner suburbs of the metropolitan but also spreads into the major city center (Kubo, 2020b; Park, 2019). As reported in a survey from Japan's Ministry of Internal Affairs and Communications (Statistics of Japan, 2018), the average vacant house ratio in the major metropolis was about 12.44%, with some cities hitting extremely high values such as Osaka (17.07%) and Kitakyushu (15.80%) or Sapporo (11.93%). This figure is expected to continue increasing in the future as the country is facing a stage of super-aging society and depopulation (Arimura et al., 2020; Muramatsu & Akiyama, 2011).

1



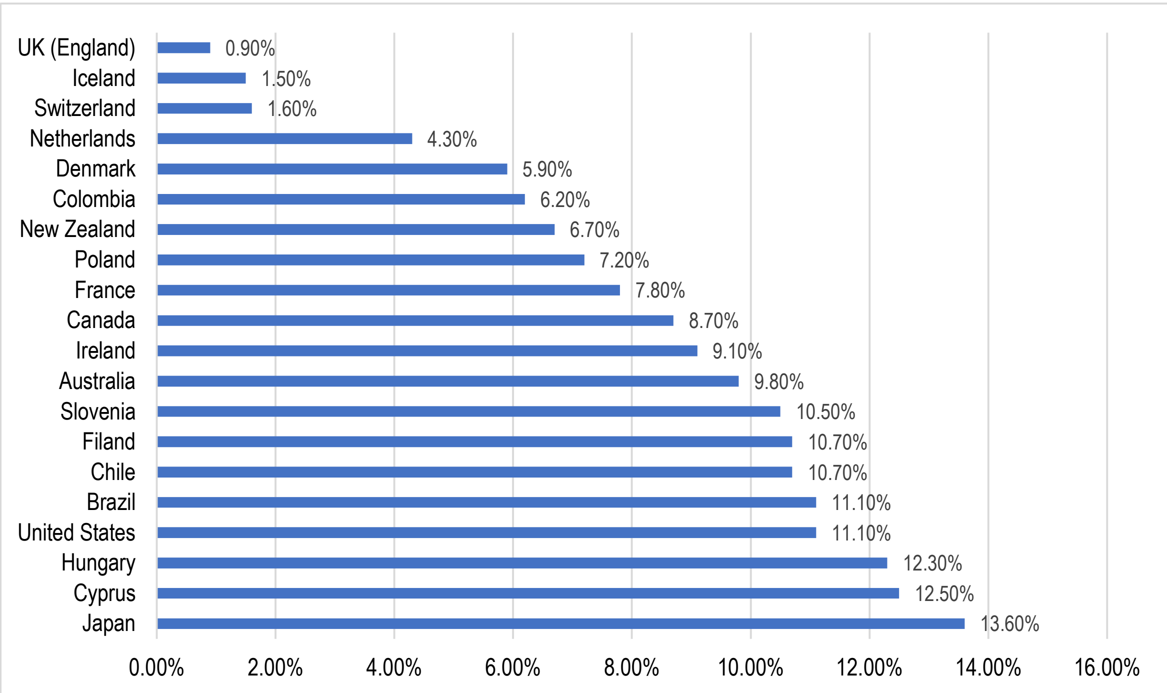
(Source: Statistics of Japan Housing and Land Survey, 2018)

***Figure 1.1**. Housing stock, Vacant housing stock, and Vacancy rate in Japan*



(*Source: Organization for Economic Cooperation and Development (OECD), 2021*)

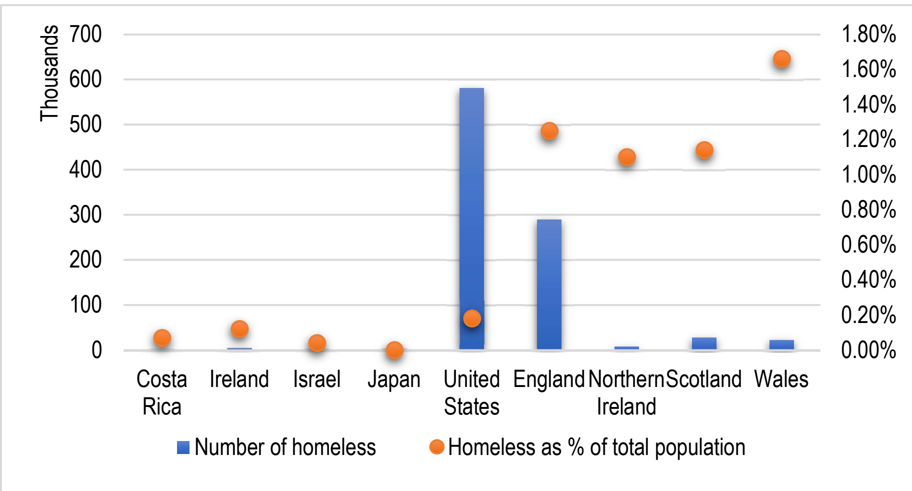
Figure 1.2. *Vacant dwellings in OECD countries*



(*Source: Organization for Economic Cooperation and Development (OECD), 2021*)

Figure 1.3. *The rank of vacant dwelling rates in OECD countries*

In response to the stated problem, many studies have been carried out. Similar to studies outside of Japan, the population decline, out-migrating, and massive public housing supply are the major causes of vacant dwellings (Hattori et al., 2017; Kobayashi, 2015; Xu & Zhou, 2019b). Meanwhile, policies related to the property tax, and growth-oriented housing meant to stimulate economic growth are believed to account for the rise of the vacancy rate (Kobayashi, 2016; Xu & Zhou, 2019b; B. Zhang, 2020). And, regarding distribution estimation of vacant houses, researchers mainly concentrate on describing or identifying the spatial distribution, as well as estimating the occurrence of vacant dwellings by using the suspension water supply status (Nishiyama, 2020; Yamashita & Morimoto, 2015), applying the Geographic Information System (GIS) (Ishikawa et al., 2016, 2017; Miyazawa, 2020). These works are meaningful when they can help to detect the vacant house and its location, however, the mechanism of how it appears is remaining obscure. Notably, the studies mentioned above limit in just describing the vacant house phenomenon and its negative effects, in which the vacancy determinants are investigated in small separate groups. This may lead to limited findings while there are still many hidden factors that need to unveil, e.g., geographical conditions, the public facilities quality, or the capacity of transportation infrastructures. In addition, though Japan has a high vacant housing ratio, its proportion of homeless people is the lowest compared with the OECD nations (OECD, 2021a). In 2020, the homeless population in Japan was 3,992, which was even approximately equal to or less than that of some European cities, such as Brussels (5,313), Paris (3,601) (FEANTSA and the Abbé Pierre Foundation, 2021) (Figure 1.3). This raises the question that the vacancy problem in Japan may have distinct characteristics. Hence, clarifying these characteristics is necessary.



(*Source: Organization for Economic Cooperation and Development (OECD), 2021*)

***Figure 1.4.** The statistic for homeless*

1.2. RESEARCH OBJECTIVES

This study aims to address the following three points:

First, the present study examines the spatial distribution of vacant dwellings in the city of Sapporo by clusters, including Hot-spot, Cold-spot, and Random.

Second, identifying the determinants of vacant houses in terms for each cluster of both direction and magnitude.

Third, assessing the efficiency of transportation services in the city and give the recommendations to improve the efficiency of transportation system in the context of rising of housing vacancies.

To archive these purposes, the primary objectives of this dissertation can be listed as follows:

- Using the Local Autocorrelation or Gentis-Ord Gi* statistic or Hot spot analysis to determine the spatial distribution of vacancy level into three clusters: Hot-spot (area with concentration high vacancy grids), Cold-spot (area with concentration low vacancy grids), Random (area with high and low vacancy grids)
- Employing the Partial least squares regression (PLSR) to identify the determinants of vacant dwellings in both direction and magnitude
- Implementing the Multiple Linear Regression model to choose suitable features for Data Envelopment Analysis (DEA) models
- Applying the Data Envelopment Analysis (DEA) models, including Banker-Charnes-Cooper (BCC) and Charnes-Cooper-Rhodes (CCR) models, to measure the efficiency of the transportation system in the relationship with urban housing. Besides, the study provides policy implications that support decision-making to ease the surplus of vacant houses and its impact on urban sustainability.

1.3. DISSERTATION STRUCTURE

This dissertation is organized into four chapters (Figure 1.4) with a concise summary as follows:

Chapter 2 explores the determinants of vacant dwellings in the context of urban shrinkage in Sapporo. Vacant dwellings were clustered in three spatial clusters (Hot-spot, Cold-spot, and Random) by the local spatial autocorrelation method. After that, the study uses the partial least regression (PLSR) method to identify the determinants of vacant dwellings in each cluster and across the city. Research results show that a high proportion of vacant houses is concentrated in the city core. The number of single households has the strongest influence on the increase in the vacancy rate in the city. The Children variable is a new finding that has a positive effect on empty houses, besides the elderly factor. Additionally, the surplus in housing supply and the disadvantage of geographical conditions have an intense effect on the proportion of uninhabited houses. On the other hand, a large percentage of private share, road network density, and the integrated parking size of the building are the major factors that can detain the low rate of empty houses. The findings of this work provide a helpful contribution to the literature on housing vacancy as well as policy implications that would be helpful for decision-making to alleviate the surplus of vacant houses and their impact on urban society.

In chapter 3, I implemented research on assessing the efficiency of the transportation system in the context of rising vacant houses in Sapporo using the Data Envelopment Analysis (DEA) method. This is a superior tool for estimating the efficiency of decision-making units in benchmarking and has been applied widely in many fields, including transportation. The population decline in the urban areas resulted in transportation services operating under capacity. While excess investment in the transportation system can intensely pressure local governments' budgets. Therefore, this study used the DEA models to measure the spatial efficiency of Sapporo city's transportation system. The finding shows that two-thirds of the urban area were running below capacity and the shortfall in the filling rate of housing was high at 3.82%. Based on the analysis results, some recommendations for city policymakers are introduced to improve the city's overall efficiency.

Chapter 4, finally, summarises the main findings and limitation of this dissertation. In addition, proposals and future works are also presented in this chapter.

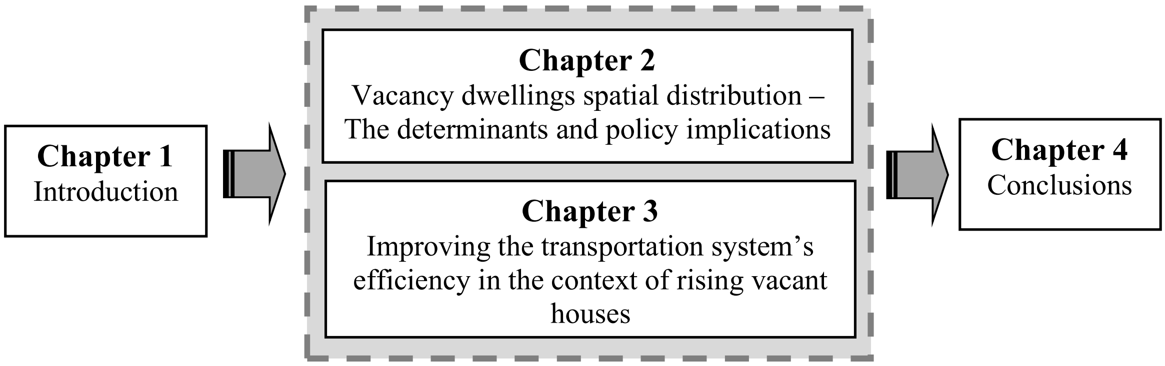


Figure 1.5. *Dissertation structure*

REFERENCES

Accordino, J., & Johnson, G. T. (2000). Addressing the vacant and abandoned property problem. *Journal of Urban Affairs*, *22*(3), 301–315. https://doi.org/10.1111/0735-2166.00058

Appel, S. U., Botti, D., Jamison, J., Plant, L., Shyr, J. Y., & Varshney, L. R. (2014). Predictive analytics can facilitate proactive property vacancy policies for cities. *Technological Forecasting and Social Change*, *89*, 161–173. https://doi.org/10.1016/j.techfore.2013.08.028

Arimura, M., Vinh Ha, T., Kimura, N., & Asada, T. (2020). Evacuation awareness and behavior in the event of a tsunami in an aging society: An experience from the 2018 Hokkaido Eastern Iburi earthquake. *Safety Science*, *131*(July), 104906. https://doi.org/10.1016/j.ssci.2020.104906

Baba, H., & Asami, Y. (2017). Regional Differences in the Socio-economic and Built-environment Factors of Vacant House Ratio as a Key Indicator for Spatial Urban Shrinkage. *Urban and Regional Planning Review*, *4*(0), 251–267. https://doi.org/10.14398/urpr.4.251

Baba, H., & Hino, K. (2019). Factors and tendencies of housing abandonment: An analysis of a survey of vacant houses in Kawaguchi City, Saitama. *Japan Architectural Review*, *2*(3), 367–375. https://doi.org/10.1002/2475-8876.12088

Berg, L. van den, Drewett, R., Klaassen, L. H., Rossi, A., & Vijverberg, C. H. T. (1982). *Urban Europe a study of growth and decline* (First Edit). Pergamon Press.

Cohen, J. R. (2001). Abandoned housing: Exploring lessons from Baltimore. *Housing Policy Debate*, *12*(3), 415–448. https://doi.org/10.1080/10511482.2001.9521413

Couch, C., & Cocks, M. (2013). Housing Vacancy and the Shrinking City: Trends and Policies in the UK and the City of Liverpool. *Housing Studies*, *28*(3), 499–519. https://doi.org/10.1080/02673037.2013.760029

Deng, C., & Ma, J. (2015). Viewing urban decay from the sky: A multi-scale analysis of residential vacancy in a shrinking U.S. city. *Landscape and Urban Planning*, *141*, 88–99. https://doi.org/10.1016/j.landurbplan.2015.05.002

Durst, N. J., & Ward, P. M. (2015). Lot vacancy and property abandonment: colonias and informal subdivisions in Texas. *International Journal of Housing Policy*, *15*(4), 377–399. https://doi.org/10.1080/14616718.2015.1090095

FEANTSA and the Abbé Pierre Foundation. (2021). *Sixth overview of housing exclusion in Europe*.

Feantsa, & Foundation Abbé Pierre. (2016). *Filling Vacancies - Vacant Real Estate: Seizing the Opportunity To Find Affordable Housing Solutions in Europe*. https://ec.europa.eu/futurium/sites/futurium/files/long_version_en.pdf.pdf

Gentili, M., & Hoekstra, J. (2019). Houses without people and people without houses: a cultural and institutional exploration of an Italian paradox. *Housing Studies*, *34*(3), 425–447. https://doi.org/10.1080/02673037.2018.1447093

Glaeser, E. L., & Gyourko, J. (2005). Urban decline and durable housing. *Journal of Political Economy*, 30.

Glock, B., & Häussermann, H. (2004). New trends in urban development and public policy in eastern Germany: Dealing with the vacant housing problem at the local level. *International Journal of Urban and Regional Research*, *28*(4), 919–929. https://doi.org/10.1111/j.0309-1317.2004.00560.x

Gu, D., Newman, G., Kim, J. H., Park, Y., & Lee, J. (2019). Neighborhood decline and mixed land uses: Mitigating housing abandonment in shrinking cities. *Land Use Policy*, *83*(February), 505–511. https://doi.org/10.1016/j.landusepol.2019.02.033

Haase, A., Bernt, M., Großmann, K., Mykhnenko, V., & Rink, D. (2016). Varieties of shrinkage in European cities. *European Urban and Regional Studies*, *23*(1), 86–102. https://doi.org/10.1177/0969776413481985

Haase, A., Rink, D., Grossmann, K., Bernt, M., & Mykhnenko, V. (2014). Conceptualizing urban shrinkage. *Environment and Planning A*, *46*(7), 1519–1534. https://doi.org/10.1068/a46269

Han, H. S. (2014). The Impact of Abandoned Properties on Nearby Property Values. *Housing Policy Debate*, *24*(2), 311–334. https://doi.org/10.1080/10511482.2013.832350

Han, H. S. (2019). Exploring Threshold Effects in the Impact of Housing Abandonment on Nearby Property Values. *Urban Affairs Review*, *55*(3), 772–799. https://doi.org/10.1177/1078087417720303

Hattori, K., Kaido, K., & Matsuyuki, M. (2017). The development of urban shrinkage discourse and policy response in Japan. *Cities*, *69*, 124–132. https://doi.org/10.1016/j.cities.2017.02.011

Hoekstra, J., & Vakili-zad, C. (2011). High vacancy rates and rising house prices: The spanish paradox. *Tijdschrift Voor Economische En Sociale Geografie*, *102*(1), 55–71. https://doi.org/10.1111/j.1467-9663.2009.00582.x

Hsueh, L., Tseng, H., & Hsieh, C. (2007). Relationship Between the Housing Vacancy Rate, Housing Price, and the Moving Rate at the Township Level in Taiwan, in 1990 and 2000. *International Real Estate Review*, *10*(1), 119–150.

Huuhka, S. (2015). Vacant residential buildings as potential reserves: a geographical and statistical study. *Building Research and Information*, *44*(8), 816–839. https://doi.org/10.1080/09613218.2016.1107316

Immergluck, D. (2015). Examining Changes in Long-Term Neighborhood Housing Vacancy During the 2011 To 2014 U.S. National Recovery. *Journal of Urban Affairs*, *38*(5), 607–622. https://doi.org/10.1111/juaf.12267

Immergluck, D., Lee, Y. S., & Terranova, P. (2012). Local Vacant Property Registration Ordinances in the U.S.: An Analysis of Growth, Regional Trends, and Some Key Characteristics. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2130775

Ishikawa, M., Matsuhashi, K., Ariga, T., Kanamori, Y., & Kurishima, H. (2016). Estimation of current and future distribution of vacant dwellings within municipalities - With a focus on the difference between the numbers of dwellings and households. *Journal of the City Planning Institute of Japan*, *51*(3), 833–838.

Ishikawa, M., Matsuhashi, K., Kanamori, Y., & Ariga, T. (2017). Method of grasping detailed regional distribution of vacant dwelling based on the number of dwellings and households. *Journal of the City Planning Institute of Japan*, *52*(3), 689–695.

Jeon, Y., & Kim, S. (2020). Housing abandonment in shrinking cities of East Asia: Case study in Incheon, South Korea. *Urban Studies*, *57*(8), 1749–1767.

https://doi.org/10.1177/0042098019852024

Kanayama, Y., & Sadayuki, T. (2021). What types of houses remain vacant? Evidence from a municipality in Tokyo, Japan. *Journal of the Japanese and International Economies*, *62*(August), 101167. https://doi.org/10.1016/j.jjie.2021.101167

Keenan, P., Lowe, S., & Spencer, S. (1999). Housing abandonment in inner cities-the politics of low demand for housing. *Housing Studies*, *14*(5), 703–716. https://doi.org/10.1080/02673039982687

Kobayashi, M. (2015). Housing and demographics: Experiences in Japan. *Housing Finance International*, *Winter*, 32–38.

Kobayashi, M. (2016). The Housing Market and Housing Policies in Japan. In *SSRN Electronic Journal* (Issue 558). https://doi.org/10.2139/ssrn.2752868

Kubo, T. (2020b). Shrinking suburbs in Tokyo. In *Divided Tokyo* (pp. 111–125). http://doi.org/10.1007/978-981-15-4202-2_6

Kubo, T., & Mashita, M. (2020). Why the Rise in Urban Housing Vacancies Occurred and Matters in Japan. In *The Rise in Vacant Housing in Post-growth Japan* (pp. 3–22). https://doi.org/10.1007/978-981-13-7920-8_1

Martinez-Fernandez, C., Audirac, I., Fol, S., & Cunningham-Sabot, E. (2012). Shrinking Cities: Urban Challenges of Globalization. *International Journal of Urban and Regional Research*, *36*(2), 213–225. https://doi.org/10.1111/j.1468-2427.2011.01092.x

Mayumi, K. T. (2020). Aging Population, Vacant Dwellings and the Compatibility Problem Between Human and Exosomatic Populations. In *Sustainable Energy and Economics in an Aging Population Lessons from Japan* (pp. 123–141). https://doi.org/10.1007/978-3-030-43225-6_6

McDonald, J. (2000). Rent, Vacancy and Equilibrium in Real Estate Markets. *Journal of Real Estate Practice and Education*, *3*(1), 55–69. https://doi.org/10.1080/10835547.2000.12091569

Miyazawa, H. (2020). Distribution of vacant homes in Tama city in the Tokyo metropolitan area: Estimation using GIS and small area statastics. In *The Rise in Vacant Housing in Post-growth Japan* (pp. 87–109). https://doi.org/http://doi.org/10.1007/978-981-13-7920-8_6

Morckel, V. (2014). Predicting abandoned housing: does the operational definition of abandonment matter? *Community Development*, *45*(2), 121–133. https://doi.org/10.1080/15575330.2014.892019

Morckel, V. C. (2014). Spatial characteristics of housing abandonment. *Applied Geography*, *48*, 8–16. https://doi.org/10.1016/j.apgeog.2014.01.001

Muramatsu, N., & Akiyama, H. (2011). Japan: Super-aging society preparing for the future. *Gerontologist*, *51*(4), 425–432. https://doi.org/10.1093/geront/gnr067

Newman, G., Gu, D., Kim, J. H., Bowman, A. O. M., & Li, W. (2016). Elasticity and urban vacancy: A longitudinal comparison of U.S. cities. *Cities*, *58*, 143–151. https://doi.org/10.1016/j.cities.2016.05.018

Newman, G., Lee, R. J., Gu, D., Park, Y., Saginor, J., Van Zandt, S., & Li, W. (2019). Evaluating drivers of housing vacancy: a longitudinal analysis of large U.S. cities from 1960 to 2010. *Journal of Housing and the Built Environment*, *34*(3), 807–827. https://doi.org/10.1007/s10901-019-09684-w

Nishiyama, H. (2020). A Problem of Vacant Housing in Local Cities: Utsunomiya City, Tochigi Prefecture Case Study. In *The Rise in Vacant Housing in Post-growth Japan* (pp. 123–146). Springer Nature Singapore Pte Ltd. https://doi.org/http://doi.org/10.1007/978-981-13-7920-8_8

OECD. (2021a). HC3.1 Homeless population [estimates]. *OECD Affordable Housing Database*, 1–12.

Oversight, S., & Reform, G. (2012). Vacant properties: Growing number increases communities' costs and challenges. In *No One Home: Challenges and Costs of Vacant Properties* (Issue November).

Park, J. Il. (2019). A multilevel model approach for assessing the effects of house and neighborhood characteristics on housing vacancy: A case of Daegu, South Korea. *Sustainability (Switzerland)*, *11*(9), 9–12. https://doi.org/10.3390/su11092515

Radzimski, A. (2016). Changing policy responses to shrinkage: The case of dealing with housing vacancies in Eastern Germany. *Cities*, *50*, 197–205. https://doi.org/10.1016/j.cities.2015.10.005

Seirin-Lee, S., Nomata, M., & Mukunoki, M. (2020). Mathematical modeling and regionality-based optimal policy to reduce empty houses, Akiya, in Japan. *Japan Journal of Industrial and Applied Mathematics*, *37*(2), 365–382. https://doi.org/10.1007/s13160-019-00400-3

Sophie, B. (2010). From shrinking cities to toshi no shukusho: Identifying patterns of urban shrinkage in the Osaka Metropolitan Area. In *Berkeley Planning Journal* (Vol. 23, Issue 1, pp. 132–155).

Statistics Bureau of Japan. (2018). *Housing and Land Survey*. https://www.stat.go.jp/english/data/jyutaku/index.html

Statistics of Japan. (2018). *Housing and Land Survey*. Statistics Bureau, & Ministry of Internal Affairs and Communications.

Thalmann, P. (2012). Housing market equilibrium (almost) without vacancies. *Urban Studies*, *49*(8), 1643–1658. https://doi.org/10.1177/0042098011417902

Vérité, C. (2021). *In Japan, 14% Homes Vacant, More Than 42 Million Empty Places In The World*. https://www.newsendip.com/japan-world-million-homes-permanently-vacant-oecd/

Weaver, R., Bagchi-Sen, S., Knight, J., & Frazier, A. E. (2016). Shrinking Cities. In *Shrinking Cities: Understanding Urban Decline in the United States*. Routledge. https://doi.org/10.4324/9781315757582

Wuyts, W., Sedlitzky, R., Morita, M., & Tanikawa, H. (2020). Understanding and managing vacant houses in support of a material stock-type society-The case of Kitakyushu, Japan. *Sustainability (Switzerland)*, *12*(13). https://doi.org/10.3390/su12135363

Xie, Y., Gong, H., Lan, H., & Zeng, S. (2018). Examining shrinking city of Detroit in the context of socio-spatial inequalities. *Landscape and Urban Planning*, *177*(May 2017), 350–361. https://doi.org/10.1016/j.landurbplan.2018.03.002

Xu, H., & Zhou, Y. (2019a). Public housing provision and housing vacancies in Japan. *Journal of the Japanese and International Economies*, *53*(January). https://doi.org/10.1016/j.jjie.2019.101038

Xu, H., & Zhou, Y. (2019b). Public housing provision and housing vacancies in Japan. *Journal of the Japanese and International Economies*, *53*(January), 101038.

https://doi.org/10.1016/j.jjie.2019.101038

Yamada, H., & Uosaki, K. (2007). National Report of Japan. *Third United Nations Conference on Housing and Sustainable Urban Development*, *July*, 1–15. http://habitat3.org/wp-content/uploads/Habitat-III-National-Report-Japan-final.pdf

Yamashita, S., & Morimoto, A. (2015). Study on Occurrence Pattern of the Vacant Houses in the Local Hub City. *Journal of the City Planning Institute of Japan*, *50*(3), 932–937.

Zhang, B. (2020). Why is japan's housing vacancy rate so high a history of postwar housing policy. *Social Science Japan Journal*, *23*(1), 65–77. https://doi.org/10.1093/ssjj/jyz041

CHAPTER 2

Vacancy dwellings spatial distribution– the determinants and policy implications

ABSTRACT

In this chapter, we examined the spatial distribution and determinants of vacant dwellings in the context of the aging society in Sapporo. Research results show that a high proportion of vacant houses is concentrated in the city core. The demographic change was the strongest influence on the increase in the vacancy rate in the city, especially in the number of single households. And the Children variable is a new finding that has a positive effect on empty houses. Additionally, the surplus in housing supply and the disadvantage of geographical conditions have an intense effect on the proportion of uninhabited houses. On the other hand, a large percentage of private share, road network density, and the integrated parking size of the building are the major factors that can detain the low rate of empty houses. The findings of this work provide a helpful contribution to the literature on housing vacancy as well as policy implications that would be helpful for decision-making to alleviate the surplus of vacant houses and their impact on urban society.

Keywords: *Vacant dwellings, spatial distribution, local spatial autocorrelation, Partial least squares regression, urban housing policy, vacancy determinant, shrinking city, Sapporo.*

2.1. INTRODUCTION

In the context of the ongoing housing vacancy crisis in many developed countries, Japan appears as a representative. In 2018, the ratio of vacant dwellings across the nation reached 13.6% (Statistics of Japan, 2018). This is significantly higher than in some other countries, such as 2.6% in England, 12.3% in the U.S., and 4.3% in Hong Kong (RVD, 2019; The U.S. Census Bureau, 2020; Wilson et al., 2018). This figure is expected to continue increasing in the future as the country is facing a stage of a super-aging society and depopulation (Arimura et al., 2020; Muramatsu & Akiyama, 2011). Further, the unoccupied dwelling problem appears not only in small- and medium-sized cities or in out and inner suburbs of the metropolitan but also spreads into the major city centres (Kubo, 2020b; Park, 2019). As reported in a survey from Japan's Ministry of Internal Affairs and Communications (Statistics of Japan, 2018), in 2018, the average vacant house ratio in the major metropolis of Japan was about 12.44%, with some cities hitting extremely high values such as Osaka (17.07%), Kitakyushu (15.80%), or Sapporo (11.93%). Thus, the need to control the rise of vacant houses in urban areas becomes urgent.

In Japan, many studies on vacant housing have been carried out. Almost previous works focused on key points including the adverse changed demographic, housing policies and vacant dwellings distribution estimation. As the research results of Hattori et al., (2017), Kobayashi (2015), and Xu & Zhou (2019) argued that declined population, out-migrating, and massive public housing are major causes of vacant dwellings. Meanwhile, policies related to property tax and growth-oriented housing meant to stimulate economic growth are believed to account for the rise in the vacancy rate of property tax or using the housing market as a tool to stimulate economic growth are believed to account for the rise in the vacancy rate (Kobayashi, 2016; Xu & Zhou, 2019a; B. Zhang, 2020). Regarding the location of vacant houses, researchers mainly concentrate on describing or identifying the spatial distribution, as well as estimating the occurrence of vacant dwellings. For example, Nishiyama, (2020) and Yamashita & Morimoto (2015) use the suspension water supply status to estimate the number of abandoned houses in Utsunomiya city. Likewise, Ishikawa et al. (2016, 2017) and Miyazawa (2020) apply the Geographic Information System (GIS) based method to assess the occurrence of vacant dwellings in areas. These works are meaningful when they can help to detect the vacant house and its location, however, the mechanism of how it appears is remaining obscure.

Notably, the studies mentioned above limit in just describing the vacant house phenomenon and its negative effects, in which the vacancy determinants are investigated in small separate groups. This may lead to limited findings while there are still many hidden factors that need to unveil, e.g., geographical conditions, the public facilities quality, or the capacity of transportation infrastructures. In addition, though Japan has a high vacant housing ratio, its proportion of homeless people is the lowest compared with the OECD nations (OECD, 2021a). In 2020, the homeless population in Japan was 3,992, which was even approximately equal to or less than that of some European cities, such as Brussels (5,313) and Paris (3,601) (FEANTSA and the Abbé Pierre Foundation, 2021). This raises the question that the vacancy problem in Japan may have distinct characteristics. Hence, clarifying these characteristics is necessary.

To fill this gap, the present study proposed to conduct a spatial autocorrelation and regression analyses to identify the determinants of vacant dwellings the city of Sapporo, one of the largest metropolises in Japan. Specifically, the present study aims to address the following research questions: 1) Where and how much level of vacant houses in the city? 2) Among neighbourhood, demographic, and housing features, which have a relationship with the vacant dwelling occurrence? and 3) To what extent do these features influence the rise of unoccupied housing in both direction and magnitude? We suppose that the outcomes would not only contribute to the literature but also support the policy-making process in controlling the vacant housing problem.

2.2. LITERATURE REVIEW

Since the second half 20th century, the vacant dwelling has been mentioned as an aspect of globalization, suburbanization, depopulation, deindustrialization, and the economic downturn in many studies (Gu et al., 2019; Haase et al., 2014, 2016; Martinez-Fernandez et al., 2012; Newman et al., 2016; Radzimski, 2016; Xie et al., 2018). Remarkable, there is no consistency in vacant house definition in the past studies, especially in the U.S.; one country that has contributed a lot of scholarly literature on this issue (Cohen, 2001; V. C. Morckel, 2014). It causes difficulty in identifying the amount of the entity and executing the policies. To ease this issue, this study used the Japanese definition and classification of vacant dwellings, which divides them into four categories: for rent, for sale, a second housing, and other types of vacant dwellings, e.g., abandoned, or seasonal use. So, the terms vacant, empty, unoccupied, and abandoned houses can be used interchangeably. Besides, the influence factors were classified into three groups: demographic, neighbourhood, and building characteristics, which are popularly used in other studies.

2.2.1. Housing allocation and housing market equilibrium

A fundamental theory in housing allocation was the bid-rent curve, first introduced by Von Thunen in 1826, which modelled agricultural land use with the market as the center. The model assumes that land is homogeneous and an increase in distance from the market would decrease the land rent and vice versa. In later decades, Alonso (1964), Muth (1969), and Mills (1972) developed the bid-rent curve model for urban housing, commercial, industry, and other firms. Philip McCann (2013) summarized the patterns of residential urban land allocation in the five models considering the different income groups. For the first model, the low-income tends to be highly allocated in the central city to reduce the commuting cost, while the high-income prefers the outskirts because it meets their demand for space. Likewise, the second model splits the high-income into two sub-groups: the young and the older. The young high-income would prefer to live in the center because they seem to have lower demand for space but higher demand for work location accessibility. The author suggested that this model is suitable for the financial and international metropolitan areas.

Contrary to the first model, the third model reverses the pattern when the high-income concentrate in the central city and the low-income move to the periphery. This pattern suggests that the opportunity cost of travel time is very high. Cities that illustrate this pattern are small, compact, and highly congested, such as Bangkok and Manila. The fourth and fifth models integrate environmental factors or amenities into the basic model. In these models, the high and medium-income would keep a distance from the central city and the high density of the low-income. This shift may reflect the concerns about pollution from industrial activities and social risks, such as crime. In these cases, the poor would occupy the entire city center. Though the housing allocation theory does not directly explain the housing vacancy problem, it is helpful to understand the urban structure and the housing market operation.

Later, a study by Wheaton provided a macro view of the housing market operation (Wheaton, 1990). The study reveals the relationship between the housing price, the vacancy rate, and the change in household characteristics by applying the searching model. The author suggested that the prices determined by production costs, market activities, or turnover can explain the structural or natural vacancy in different places. Also, a small vacancy would cause a poor match possibility and, thus, cause housing prices to increase significantly by inducing. When the vacancy increases, the matching process improves and thus shortens the sale time. Nevertheless, if the vacancy rate rises beyond a certain threshold, it will cause a longer time of sales and lower prices.

One worthy thing drawn from the study of Wheaton is that a healthy housing market needs equilibrium. That means all population groups can obtain a house that meets their preferences and ability to pay. Nonetheless, such housing markets do not exist because of their elastic and dynamic characteristics of both supply and demand. In the following sub-sections, we review these influence factors into three groups: demographic, neighbourhood, and building, which are popular in previous studies.

2.2.2. Demographic features

Many scholars have agreed that the change in demographics is one of the major causes of housing vacancy. From the early 21st century, Cohen (2001); Glaeser & Gyourko (2005) indicated that substantial population decline accounted for the vacant housing issue in U.S. cities. Meanwhile, Morckel (2014b) and Newman et al. (2019) reported that the population change affected the increase of vacancy, but was inconsistent or even insignificant. Similarly, Huuhka (2016) claimed that the vacant house rate has a negative relationship with the population but a positive relationship with the elderly population in the Finish cities. Likewise, the proportion of empty single-family houses was commonly high at about 10% and even ran up to 25-30% in some municipalities in Denmark and Sweden (Jensen, 2016; Wilhelmsson et al., 2011).

Depopulation reflects the direct consequences of the shrinking urban phenomenon, also known as suburbanization. In urban development theory, shrinkage refers to an inevitable stage that occurs following the urbanization process (Berg et al., 1982; Weaver et al., 2016). As a result, the issue led to the decline in housing demand and the imbalance in the housing market. In addition, the lack of effective measures (such as policies and restrictive local budgets) has resulted in a substantial accumulated number of vacant dwellings.

Another facet of urban shrinkage is the aging population and the change in household structure. As life longevity rises, the proportion of the elderly increases, and when they pass away, there is no one to take over the entire house, and it will be vacant (Jeon & Kim, 2020; Kubo & Mashita, 2020; Mayumi, 2020). Further, it is stated that the increase in household quantity reflects the vacant house problem. The rise in the number of households comprises the rise in nuclear families, which detached from the traditional household and elderly households. In the short term, it motivates the housing demand, but in the long term, the high possibility of vacant houses will appear (Kubo & Mashita, 2020; Mayumi, 2020; Seirin-Lee et al., 2020; Sophie, 2010). Meanwhile, Appel et al. (2014) report that the bigger the family size, the lower possibility of vacant houses in the area. Another factor that may reduce the vacancy ratio is the population of young people (Baba & Asami, 2017; Nam et al., 2016).

For Japan, since the end of World War II, the country experienced two baby booms, in 1947-1949 and 1971-1974, then the fertility rate decreased and has not yet recovered. The change in socioeconomic aspects and a low birth rate have significantly affected the demographic structure. An aging society with an increasing elderly population and single-family households seems to be the hallmarks of Japan today. And these factors can strongly affect housing vacancy. Therefore, in this study, demographic characteristics are mentioned in the analysis, especially age and household structure.

2.2.3. Neighbourhood characteristics

Besides demographic factors, neighbourhood characteristics are believed to associate with housing vacancy rates. In developed countries, the racial and ethnic composition and the high rates of unemployment and poverty have a close association with the housing vacancy problem.

For example, Morckel (2014b) indicated that the high proportion of African American population in the area would stimulate the rise of vacancy, while Newman et al. (2019) found that the non-white populations may have reduced the vacant houses in the U.S. cities recently. Likewise, though the severe unemployed was found to be vacant houses determinant in U.S. cities, it did not affect the rise of vacant houses in Columbus, Ohio (Appel et al., 2014; V. Morckel, 2014; Newman et al., 2019). Nevertheless, these factors haven't been found in any literature on vacant dwellings in Asia. And in Japan, the unemployed rate is also significantly lower (less than 3%) than in OECD countries (OECD, 2021b). Meanwhile, natural environmental conditions also appear as strong determinants of housing vacancy in Asian countries with a high rate of aging societies such as Japan and South Korea. Kubo & Mashita (2020) claimed that houses located in disadvantaged topography statuses are more likely to be vacant due to barriers for residents when they age. Consistent with this statement, areas situated on the high slope, on lowland or on highland appeared to associate with high probabilities of vacancy (Kanayama & Sadayuki, 2021; Park, 2019; Wuyts et al., 2020).

Relating built-up environment attributes, Jeon and Kim (2020) stated that the poor conditions of built-up infrastructure may cause abandoned dwellings, especially for the small houses in fragment lots. In addition, areas with a high density of houses and close to the industrial zone are more likely to have a high housing vacancy ratio (Wuyts et al., 2020). Also, in the study of Wuyts et al. (2020), the authors did not find any association between the occurrence of a vacant house and the accessibility to public facilities, e.g. bus stops, hospitals, or schools. Meanwhile, another study conducted by Baba and Asami (2017) declared that the high number of grocery stores in areas may reduce the vacancy rate.

Remarkably, the relation between public facility quality and the housing vacancy was not much concern in the previous studies. This study hypothesis that though a public facility may represent a service, it cannot satisfy the residents without the quality and capacity. This issue will be clarified in the next sections.

2.2.4. Housing characteristics

There is high agreement that there is a relationship between housing ownership status and its vacancy. As Couch and Cocks (2013) reported, in England, the major proportion of vacant houses was privately owned. Meanwhile, in Japan, though the number of rental vacant dwellings is higher than those of vacant private dwellings, the relative increase in private vacancies is much higher than in rental vacancies (Mayumi, 2020). Hence, this study will verify whether this phenomenon is true in the chosen city.

Besides the ownership status, building type and constructions are also major variables in the vacancy problem. According to Couch and Cocks (2013), the number of vacant apartments in England was almost two times that of abandoned houses. In Japan, the proportion of vacant departments and detached houses accounted for 67.8% and 32.2% of vacancies, respectively (Xu & Zhou, 2019a). Interestingly, in Finland, Huuhka (2016) found that the number of vacant detached houses was larger than the number of vacant blocks, or flats, but the overall floor space was lower. Meanwhile, in Japan and South Korea, Baba and Asami (2017) and Park (2019) claimed that houses with more floors and larger floor areas are less likely to be vacant. According to the authors, buildings with wood, block, or stone structure were more likely to be vacant.

Regarding the property value and condition, Morckel (2014b) and Park (2019) reported that the high price of land and houses would increase high vacancy, but Baba and Asami (2017) claimed the high-priced houses have an inverse relation to the vacancy ratio. Another reason that causes the high-priced properties to become vacant is that the buy-to-leave super-rich buyers invest in these properties as a safe deposit box rather than for living or renting. This phenomenon happens in global cities such as London and New York (Fernandez et al., 2016). By contrast, houses in poor condition are more likely to be abandoned (Morckel, 2014b).

Finally, building age is stated to have a positive relationship with the rise of the vacancy ratio. Different researchers declared that older properties are more likely to become vacant than newer because of outdated technology or structures, high maintenance and refurbishment cost, or residential preference change (Baba & Hino, 2019; Nishiyama, 2020; Wuyts et al., 2020). Furthermore, buildings with high age are also the major factor that drive the rise of vacancy in the decline cities. As Glaeser and Gyourko (Glaeser & Gyourko, 2005) stated, in the US cities, the housing supply increased higher than housing demolition because of the durability. Also, the depopulation caused by the out-migration, economic downturn, employment loss led to the decrease in demand. The join effect would push the vacancy rise significantly.

In the present study, besides verifying the above influence features, I proposed to investigate the other factors that may associate with the likelihood of vacancy. They included the integrated facilities in the buildings and the mixed-use characteristics. We suppose this supplement would help to further understanding the housing vacancy problem.

2.3. MATERIAL AND METHODOLOGY

2.3.1. Research area

The city of Sapporo is the capital of Hokkaido, the largest and coldest prefecture in Japan. Located on the Ishikari plain, Sapporo has typical characteristics of the mixed topography conditions. Most of the city area is flat, with a decreasing elevation from the South-East to the North-West. Besides, the city is one of the earliest aging demographics in Japan. In 2019, the city's elderly ratio was nearly 27% (approximately 533,000 people). This figure is expected to increase to 32% by 2030 (City of Sapporo, 2020).

Similar to other Japanese major cities, Sapporo is facing the problem of vacant houses across the city. Table 2.1 exhibits the housing vacancy in some Japanese metropolises from 1973 to 2018 (Statistics of Japan, 2018). As the data illustrate, before a decrease in 2018, most cities saw a gradual increase in the vacancy rate from 1973 to 2013. Among nine metropolises, Sapporo has a rank sixth vacancy rate (11.93%) and ranks fourth in the number of vacant houses (125,400 units). So, besides representing a high vacancy problem, Sapporo also has inclusive characteristics of the topographic, weather, and demographic. Thus, the city can be the representative for investigating the vacant house determinants in Japan.

Table 2.1. *Vacant houses ratio in Japan and some metropolises*

Year	Sapporo	Yokohama	Nagoya	Kyoto	Osaka	Kobe	Fukuoka	Kitakyushu	Kawasaki	Japan
1973	4.66	5.42	6.88	5.12	6.79	6.31	5.35	7.98	6.21	5.54
1978	6.82	6.46	10.68	8.36	10.55	9.37	8.96	8.45	7.63	7.56
1983	9.34	7.07	11.41	10.51	12.52	11.80	10.62	10.03	8.40	8.55
1988	11.21	6.78	11.65	11.40	13.91	11.26	11.57	12.38	7.33	9.38
1993	10.48	8.41	10.68	10.88	13.29	10.02	10.03	11.43	9.02	9.76
1998	11.98	9.96	12.64	13.59	15.91	14.40	9.96	12.07	10.85	11.47
2003	12.14	9.68	13.71	13.25	17.52	12.77	10.91	12.84	10.30	12.23
2008	13.76	9.66	13.18	14.12	16.67	13.50	14.65	15.30	10.13	13.14
2013	14.08	10.09	13.16	14.03	17.18	13.05	12.24	14.34	10.42	13.52
2018	11.93	9.71	12.71	12.91	17.07	13.32	10.54	15.80	9.49	13.60
VC*	125,400	178,300	156,900	106,000	286,100	109,200	94,200	79,300	73,800	8,488,600

(*) Total vacant dwellings in 2018

2.3.2. Material

In this study, the data was acquired from four sources: (1) the Zenrin data package (a commercial data based on the field survey produced by ZENRIN Co. Ltd.), (2) National land numerical information from the Ministry of Land, Infrastructure, and Transport (MLIT), (3) Sapporo city planning basic survey data, and (4) the Sapporo statistics data. From the Zenrin data set, the number of vacant houses is extracted as the dependent variable. Combining the first and the third data source, the research derived the building's characteristics, such as the structure (the fireproof level) and the purpose of the rooms. The demographic status and public facilities and infrastructure indexes were extracted from the city's statistical data and planning survey data, respectively. Note that the data are mainly collected in the year 2019.

From the literature review and the availability of data, the present study divided the variables into three groups: neighbourhood characteristics, housing attributes, and demographic status. The first group contains categories including geographical conditions and public facilities indexes. Relate to the geographical features, my research used three indicators, consisting of the average elevation and slope, and inundated area. In terms of public facilities, my study split it into two sub-categories that represent the quantity and the accessibility to those facilities. The former category stands for the number of each facility in the 500m radius area from the building, which is equal to about 7–8-minute walk based on the comfortable speed of 1.2-1.4m/s. Meanwhile, the latter estimates the shortest distance from the building to those amenities. The public facilities here represent education and health care institutions, public transport stations, or leisure places. Besides, for transportation indexes, the present study calculated the density of road, bus, and rail networks for the specific area where the building situates.

Regarding the building's characteristics, the present study summarized the following information: parking area inside/belonging to the building, fireproof level, and the age of the building. Further, several indicators were extracted including the number of rooms (for all use purposes) and the number of private residence rooms and offices. Finally, the demographic characteristics include four variables. With population features, this study focused on the total number of children and elderly people in each area. Meanwhile, the household index comprises the indicators of the number of households that own a dwelling and the number of single homes.

As stated in the previous sections, the present study aims to investigate the spatial distribution of vacant dwellings. Thus, instead of using an individual building as an observation, my research employs the spatial grid. Besides the advantage of covering the entire city's area, the spatial mesh approach also allows controlling the data size via the grid scale. In this study, the dimension of a grid equal to 250m on each side was set up. This figure is small enough to grasp the information about the location's characteristics and to avoid the mixing of an extensive number of buildings. After creating the mesh over the city's boundary, the information was assigned for each grid by following these steps.

For variables that contain numerous entities in a grid, the value is estimated using equation (1)

$$X_{ij} = \frac{\sum f_{ijk} x_{ijk}}{\sum f_{ijk}} \quad (1)$$

Where: X_{ij} – the target variable's value i of grid j. This includes average elevation, slope, flood area, and average building age; f_{ijk} – the sub-area k for the variable i in grid j; x_{ijk} – the value of variable i for sub-area k in grid j

For variables relate to density, the value is estimated as follows:

$$X_{ij} = \sum f_{ijk}\, x_{ijk} \quad (2)$$

Where: X_{ij} – the target variable's value i of grid j. This includes number of children, and number of elderly people; f_{ijk}; x_{ijk} are similar in equation (1)

The final data set is illustrated in Table 2.2 presents. Figures 2.1 and 2.2 visualize the distribution of dwellings and vacancy houses over the city area. Figure 2.1 shows that high-density housing is primarily found in the city core and along subway lines. Intuitively, it's easy to recognize that there is a relation between the empty house ratio and housing density. High-density housing areas are likely to have a high rate of vacant dwellings. A detailed explanation will be introduced in the upcoming part.

Table 2.2. *Summary of the data set*

No	Variable	Description	Unit	Type	Min	Median	Mean	Max
Dependent variable								
1	zenVCrooms	Number of vacant dwellings	-	Int	0	41.00	118.73	1,457
Explanatory variable								
Neighborhood characteristics								
Geographic conditions								
1	ElevAv	Average elevation	m	Num	2.30	20.01	41.99	375.51
2	SlopeAv	Average slope	%	Num	0.00	0.61	1.93	27.54
3	FloodArea	Flood area	100m2	Num	0.00	0.00	38.75	625.06
Public facilities in 500m radius area								
4	R5ParkingA	Car parking area	1000m2	Num	0.00	15.55	17.40	73.00
5	R5Hosp	Number of hospitals	-	Int	0	0	0.55	6
6	R5Clinic	Number of clinics	-	Int	0	5	7.18	182
7	R5Welf	Number of welfares	-	Int	0	2	3.02	16
8	R5Cult	Number of cultural facilities	-	Int	0	1	1.43	13
9	R5RailS	Number of railway stations	-	Int	0	0	0.29	13
10	R5BusS	Number of bus stops	-	Int	0	4	4.47	37
11	R5Fuel	Number of fuel stations	-	Int	0	0	0.69	6
12	R5Univ	Number of universities	-	Int	0	0	0.08	11
13	R5HighS	Number of high schools	-	Int	0	0	0.13	3

No	Variable	Description	Unit	Type	Min	Median	Mean	Max
14	R5Junior	Number of junior schools	-	Int	0	0	0.29	3
15	R5Ele	Number of elementary schools	-	Int	0	1	0.56	3
16	R5Kind	Number of kindergartens	-	Int	0	0	0.40	3
Nearest facilities distance								
17	HubPark	Distance to the nearest park	100m	Num	0.02	1.45	1.64	10.06
18	HubCultura	Distance to nearest cultural facility	100m	Num	0.11	4.12	4.60	20.29
19	HubHospita	Distance to the nearest hospital	100m	Num	0.07	6.10	7.13	36.11
20	HubClinic	Distance to the nearest clinic	100m	Num	0.01	2.14	2.62	17.04
21	HubWelfare	Distance to nearest welfare facility	100m	Num	0.00	2.83	3.25	16.69
22	HubRailS	Distance to nearest rail station	100m	Num	0.25	10.39	16.82	167.32
23	HubBusS	Distance to the nearest bus stop	100m	Num	0.02	1.87	2.06	10.23
24	HubPking	Distance to the nearest car parking area	100m	Num	0.01	0.88	1.22	8.97
25	HubFuelS	Distance to nearest fuel station	100m	Num	0.14	5.28	6.25	42.93
26	HubUniv	Distance to nearest university	100m	Num	0.36	22.76	24.75	136.02
27	HubHighs	Distance to the nearest high school	100m	Num	0.24	11.38	12.61	103.82
28	HubJunior	Distance to the nearest junior school	100m	Num	0.10	7.03	7.38	23.53
29	HubEle	Distance to the nearest elementary school	100m	Num	0.14	4.96	5.29	20.72
30	HubKind	Distance to the nearest kindergarten	100m	Num	0.15	6.20	7.24	88.34
Infrastructure index								
31	RoadDen	Road density	km/km2	Num	0.00	23.49	22.27	46.27
32	BusDen	Bus route density	km/km2	Num	0.00	4.62	14.16	377.75
33	RailDen	Rail line density	km/km2	Num	0.00	0.00	0.41	16.68
Building characteristics								
34	ParkingA	Total car parking area in the buildings	100m2	Num	0.00	6.62	12.68	1,276.94
35	woodA	Total wood structure floor area	1000m2	Num	0.00	11.71	11.71	68.10
36	semifireA	Total semi-fire structure floor area	1000m2	Num	0.00	1.00	1.54	23.29
37	fireproofA	Total fireproof structure area	1000m2	Num	0.00	1.45	12.13	391.03
38	AgeFloorAv	Average age of floor area	year	Num	1.06	26.58	25.98	90.00
39	zenPriRoom	Total private apartments	-	Int	0	128	128.17	758
40	zenOffRoom	Total office rooms	-	Int	0	5	10.65	544
Demographic characteristics								
41	Children	Total children	person	Int	0	48	51.75	267
42	Elderly	Total elderly	person	Int	0	123	123.09	680
43	HHowner	Total households that own dwelling	household	Int	0	103	105.10	528
44	HHsingle	Total single households	household	Int	0	41	88.54	1,363

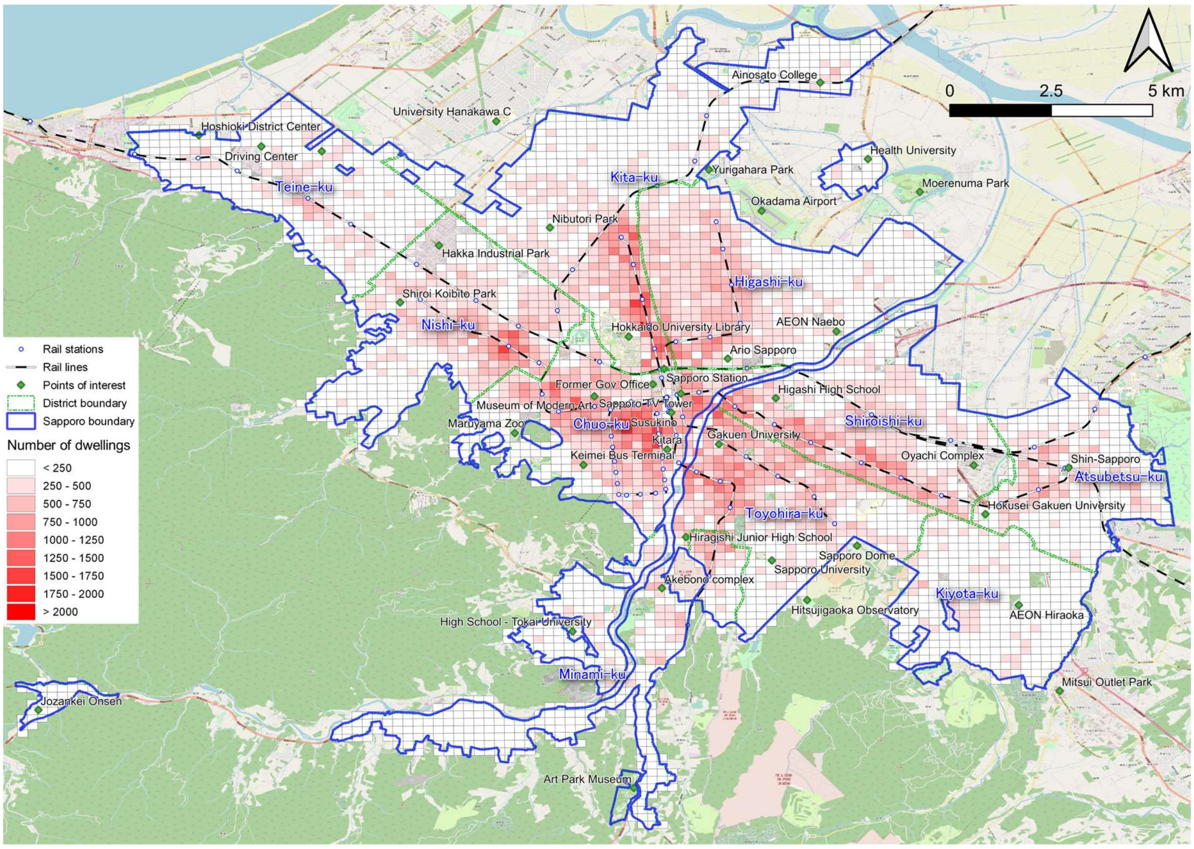


Figure 2.1. *The spatial distribution of resident dwellings*

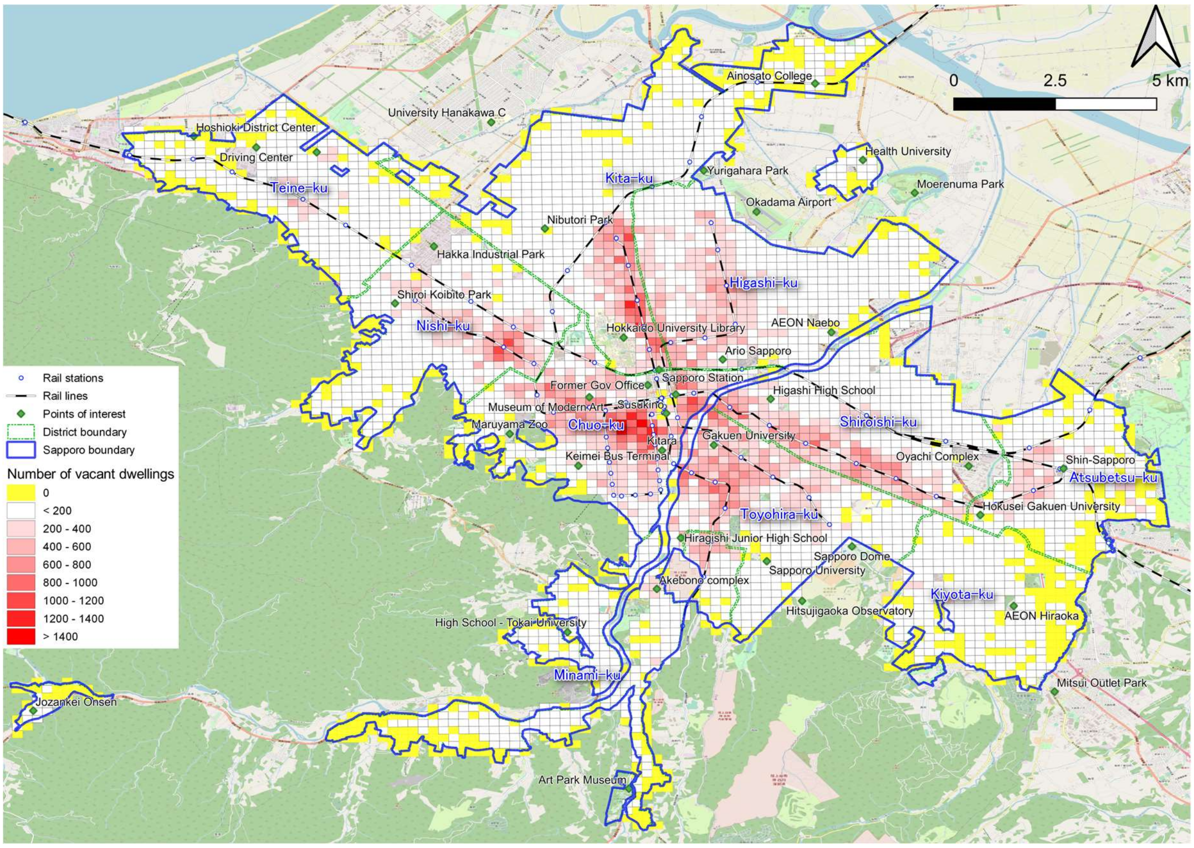


Figure 2.2. *The distribution of vacant dwellings*

2.3.3. Local spatial autocorrelation

To examine the spatial distribution of the vacant houses, this study proposed to conduct the local spatial autocorrelation analysis, Gentis-Ord Gi*, introduced by Getis and Ord (Getis & Ord, 1992; Ord & Getis, 1995). Getis-Ord Gi* statistics or hot spot analysis is a effective tool that maps similar (high or low) or dissimilar (random) feature in the study area. The application of Gi* is very prevalent in many research fields, such as agriculture, epidemiology, urban study, or social science (Khan et al., 2017; Mondal, 2020; Peeters et al., 2015; Rossi & Becker, 2019).

In the present study, the G_i^* statistic of grid i is defined by equation (3).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \bar{x}\sum_{j=1}^{n} w_{ij}}{S\left\{\frac{n\sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2}{n-1}\right\}^{\frac{1}{2}}} \tag{3}$$

Where x_j is the number of vacant houses of grid j, w_{ij} is the spatial weight between grid i and j, n is the number of grids, $\bar{x}$ and S are calculated using equations (4) and (5):

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n} \tag{4}$$

$$\mathrm{S} = \left\{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{x})^2\right\}^{\frac{1}{2}} \tag{5}$$

Based on the value of G_i^* and the statistical significance level ($p<0.05$), the present study defined the three clusters of vacant houses, including Hot-spot (area with concentration high vacancy grids), Cold-spot (area with concentration low vacancy grids), and Random (area with high and low vacancy grids). The study then examined these three clusters to identify the vacant house determinants and their variation across the city.

2.3.4. Partial least squares regression

To address the second and third research questions, the present study used partial least squares regression (PLSR), one of the popular regression methods used in chemometrics, bioinformatics, ecology, or social sciences (Boulesteix & Strimmer, 2006; Hulland, 1999; Wold et al., 2001), to clarify the effect of the vacancy determinants. PLSR has characteristics of principal component analysis (PCA), multi-linear regression (MLR), and canonical correlation analysis (Jia et al., 2009). Compared with PCA, PLSR uses the least components obtained from independent variables that best explains the dependent variable. Meanwhile, PCA identifies the number of components that best explains the independent variables. Thus, PLSR usually outperforms PCA in predicting the independent variable. A detailed description and interpretation of PLSR can be found in the studies of (Boulesteix & Strimmer, 2006; Wold et al., 2001).

To find the optimal number of components for the final PLSR model and to control the over-fitting problem, we employed the cross-validation (CV) technique in the training process. First, we used 80% of the data to train the model with a 5-fold CV and 100 repetitions. By scoring the root-mean-square error (RMSE), the optimal number of components was the components that had the lowest RMSE value. We then used the remaining 20% of the data set to test the model's performance.

Concerning the characteristics of the determinants, this study extracted the variable's importance and coefficient from the final model. Since the model's coefficients alone do not reveal the role of the variable in mapping both independent and dependent variables (Wold et al., 1993), we used them to illustrate the direction of influence. A positive or negative coefficient implies the variable correlates to the dependent variable positively or negatively, respectively. Likewise, the variable importance index represents the influence level of the independent variable. This index is more stable and reliable than the model's coefficients (Mehmood et al., 2012; Wold et al., 1993).

Several methods produce the variable importance in PLSR, including Variable Importance in Projection (VIP) (Wold et al., 1993), Selective Ratio (SR) (Rajalahti et al., 2009), or Significance Multivariate Correlation (sMC) (Tran et al., 2014). Of these three methods, SR outperforms sMC in identifying the most significant variable in a PLSR model (Kvalheim, 2020). Likewise, VIP is more reliable than SR in scoring variables for the raw data (Farrés et al., 2015). Thus, the study applied the VIP method in the current study. Equation (6) expresses the VIP value of the jth variable (Mehmood et al., 2012).

$$VIP_j = \sqrt{P\frac{\sum_{a=1}^{A} SS_a w_{aj}^2}{\sum_{a=1}^{A} SS_a}} \quad (6)$$

Where P and A are the number of variables and components, respectively. w_{aj}^2 represents the contribution of variable j in component a, and SS_a stands for the sum of squares explained by component a.

Since the average squared of VIP is equal to 1, this value is usually used as a threshold to judge whether the variable is important (Duan et al., 2020; Mukherjee et al., 2015; Onderka et al., 2012). Nevertheless, a lower value of VIP (0.80) is also considered the threshold in several studies (Nash & Chaloud, 2011; Vinzi et al., 2010; Yang et al., 2015). In the present study, we used a VIP value of 0.9 to identify the significant variables.

2.4. RESULTS

2.4.1. Vacant dwellings spatial autocorrelation

Figure 2.3 expresses the Gi* local spatial autocorrelation. As illustrated in the graph, the Hot-spot covered the central city. This area comprises Chuo-ku, the Central Business District (CBD), and parts of the districts, Nishi-ku, Kita-ku, Higashi-ku, Shiroishi-ku, and Toyohira-ku. Meanwhile, the Cold-spot placed mainly in the outskirt districts, including Teine-ku, Kiyota-ku, and Minami-ku. The Random-spot allocated in the areas lies between the Hot- and Cold-spot.

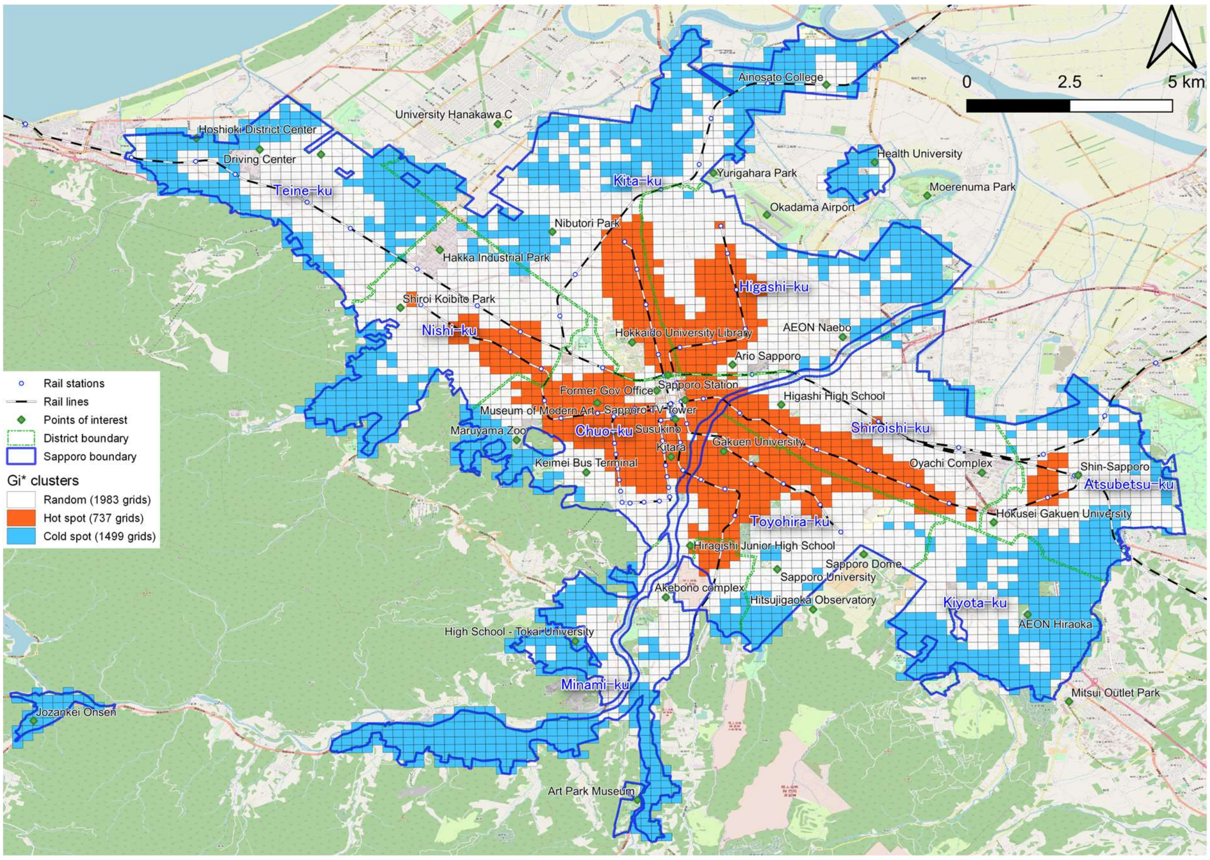


Figure 2.3. *Local spatial autocorrelation Gi* clusters map (significant level 95%)*

Table 2.3 summarizes the vacancy of the three clusters extracted from Appendix A. Among the three clusters, the Hot-spot had the lowest proportion of girds (17.5%) but the highest mean of vacant houses per grid (407.7 units). The random cluster took the highest part of the grids and had a medium value of vacancy, accounting for 47.0% and 89.41 units/grid.

Meanwhile, the Cold-spot had about one-third of the grids and its vacancy level was the lowest compared with the other clusters.

Table 2.3. *Summary of vacant houses in the three clusters*

Cluster	Min	Median	Mean	Max	Total grids	Percentage
Overall	0	41	118.7	1,457	4,219	100.0%
Hot-spot	0	379	407.7	1,457	737	17.5%
Cold-spot	0	5	15.41	231	1,499	35.5%
Random	0	61	89.41	678	1,983	47.0%

2.4.2. PLSR models

Figure 2.4 presents the outputs of the training PLSR models process. As expressed in the graph, the RMSE decreased significantly while the number of components increases at a small value. In the Hotspots, and Random-spot, the value of RMSE became stable when the number of components reached about 8 to 9. By contrast, the Cold-spot model saw an increase in RMSE when the number of components excesses 6.

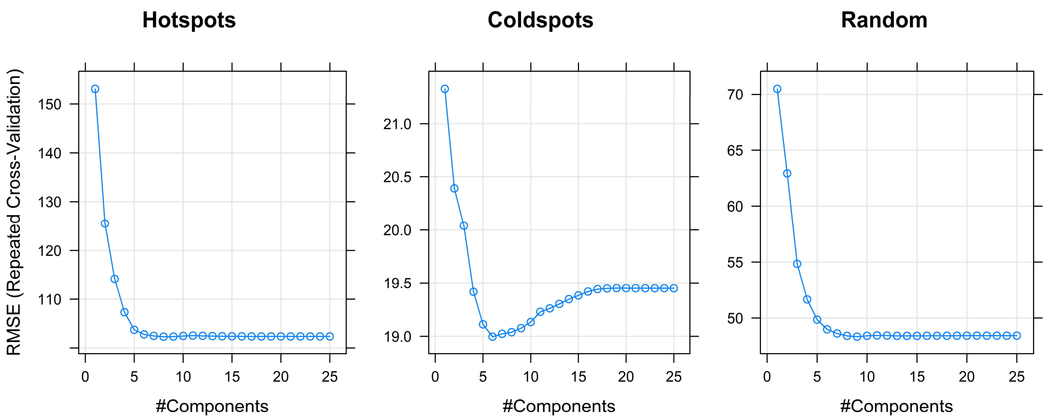


Figure 2.4. *PLSR models training outputs*

Table 2.4 expresses the detailed outputs extracted from the training process. The optimal number of components for Hot-spot, Cold-spot, and Random are 8, 6, and 9, respectively. Of the three models, the Hot-spot had the highest performance with the cross-validated R2 value of 0.80, followed by the Random with the cross-validated R2 value of 0.74, respectively. The performance of the Cold-spot was lowest when the cross-validated R2 reached just 0.40. Notably, the R2 values on the testing data set of all models approximated their values on the training data. This indicates the over-fitting and under-fitting problem did not exist in the models.

***Table 2.4.** PLSR models training results*

# Components	1	2	3	4	5	6	7	8	9
Hot-spot									
VC. Exp	56.32	72.61	78.30	81.15	82.47	82.71	82.87	82.96	
RMSE (CV)	153.14	125.56	114.18	107.35	103.80	102.85	102.56	102.40	
R2 (CV)	0.54	0.69	0.74	0.78	0.79	0.79	0.80	0.80	
RMSE (Test)								89.15	
R2 (Test)								0.89	
Cold-spot									
VC. Exp	22.03	33.52	38.99	42.89	44.09	45.06			
RMSE (CV)	21.33	20.39	20.04	19.42	19.11	19.00			
R2 (CV)	0.22	0.31	0.35	0.38	0.39	0.40			
RMSE (Test)						16.42			
R2 (Test)						0.46			
Random									
VC. Exp	47.34	64.61	72.54	75.43	76.81	77.29	77.54	77.74	77.78
RMSE (CV)	70.48	62.90	54.84	51.64	49.85	49.00	48.63	48.42	48.35
R2 (CV)	0.45	0.59	0.68	0.71	0.73	0.74	0.74	0.74	0.74
RMSE (Test)									45.24
R2 (Test)									0.72

2.4.3. The determinants of vacant dwellings

Table 2.5 shows the significant variables and their affecting direction on the vacant houses in each model (extracting from Appendix B). As the results indicate, the number of significant variables in the Hot-spot, Cold-spot, and Random was 14, 19, and 16, respectively. The study found that twelve variables appeared in all models. These features are HHsingle, HHowner, Elderly, Children, zenPriRoom, fireproofA, woodA, ParkingA, HubRailS, HubPking, HubClinics, and R5Clinic. Four variables were significant in two models: semifireA in the Hot-spot and Random, zenOffRoom in the Hot-spot and Cold-spot, R5ParkingA and RoadDen in the Cold-spot and Random. Five variables appeared in only one model, including HubUniv, HubHighs, HubKind, ElevAv in the Cold-spot, and R5BusS in the Random.

Among independent variables, demographical features were the most influential factor. Specifically, HHsingle stood at the first rank with a positive sign. Its VIP values ranged from 2.62 (in the Cold-spot) to 3.61 (in the Hot-spot). The Elderly had a positive effect in the Hot-spot but a negative effect in the Cold-spot and Random-spot. Also, the impact level of the Elderly was higher in the Hot-spot than in the Random and Cold-spot. The Children had a positive influence with a 2nd, 7th, and 14th rank in the Random, Hot-, and Cold-spot, respectively. Meanwhile, HHowner's impact was negative. Its influence level decreased from the Cold-spot (3rd rank) to the Random and Hot-spot (5th and 6th grade, respectively).

Most housing characteristics significantly correlated with the vacancy except for AgeFloorAv. All housing structure types positively affected the vacancy. Of these three types, the influence of fireproofA was stronger than that of semifireA and woodA. The VIP rank of fireproofA was 2nd, 3rd, and 4th in the Cold-spot, Random, and Hot-spot, respectively. Likewise, the influence level of semifireA was higher in the Hot-spot (2nd rank) than in the Random (13th rank). Meanwhile, the woodA’s effect decreased from 7th in the Cold-spot to 9th in the Random and 10th in the Hot-spot.

For the other housing characteristics, zenPriRoom and zenOffRoom were significant factors with an inverse effect. While the influence of zenPriRoom was negative, the effect of zenOffRoom was positive. The zenPriRoom's rank reduced from 5th in the Hot-spot to 6th and 9th in the Random and Cold-spot, respectively. Meanwhile, the influence level of zenOffRoom was highest in the Hot-spot and was lower in the Cold-spot. Finally, the study found ParkingA had a negative effect in the Hot-spot and Random-spot but a positive effect in the Cold-spot.

As the results showed, only clinics significantly affect the vacancy. This study found that R5Clinic's effect was positive in the Cold-spot but negative in the other models. Its rank decreased from the Hot-spot (at 11th grade) to the Cold-spot (at 13th grade) and Random-spot (at 15th grade). Meanwhile, HubClinic had a negative effect in the Cold-spot but a positive impact in the other two clusters. The influence level of HubClinic increased from the Hot-spot to Cold-spot and Random.

Regarding transportation features, R5ParkingA was positive in the Cold-spot and Random-spot with an influence level of 4th and 8th, respectively. In contrast, HubPking affected the vacancy negatively in all clusters. Also, its influence ranking varied from 10th grade in the Cold-spot to 12th grade in the Hot-spot.

For rail stations, the HubRailS was negative in all clusters. The effect level of HubRailS was highest in the Hot-spot (rank 9th and was lower in the Random and Cold-spot, with a ranking of 12th and 15th, respectively. For bus services, R5BusS had a significant effect in the Random cluster. Likewise, the effect of RoadDen was negative in the Cold-spot and Random with an influence level of 6th and 7th, respectively.

Regarding educational institutions, the results expressed the negative relationship between the vacant houses and HubHighs, HubKind, and HubUniv in the Cold-spot. The influence level of these variables was on the 16th, 17th, and 19th, respectively.

Eventually, ElevAv had a significantly positive influence in the Cold-spot, with a VIP value of 0.92.

Table 2.5. *Top high influence variables*

No	Variable	Hot-spot			Cold-spot			Random		
		VIP	Sign	Rank	VIP	Sign	Rank	VIP	Sign	Rank
1	HHsingle	3.61	+	1	2.62	+	1	3.17	+	1
2	semifireA	1.87	+	2				1.01	+	13
3	Elderly	1.61	+	3	1.25	-	8	1.53	-	4
4	fireproofA	1.44	+	4	1.72	+	2	1.64	+	3
5	zenPriRoom	1.44	-	5	1.24	-	9	1.47	-	6
6	HHowner	1.29	-	6	1.61	-	3	1.49	-	5
7	Children	1.27	+	7	1.02	+	14	1.71	+	2
8	zenOffRoom	1.24	+	8	1.11	+	11			
9	HubRailS	1.18	-	9	1.01	-	15	1.02	-	12
10	woodA	1.16	+	10	1.31	+	7	1.07	+	9
11	R5Clinic	1.14	-	11	1.06	+	13	0.93	-	15
12	HubPking	1.11	-	12	1.24	-	10	1.03	-	11
13	HubClinics	1.06	+	13	1.09	-	12	1.05	+	10
14	ParkingA	1.00	-	14	1.40	+	5	1.00	-	14
15	R5ParkingA				1.44	+	4	1.17	+	8
16	RoadDen				1.38	-	6	1.22	-	7
17	HubHighs				0.98	-	16			
18	HubKind				0.97	-	17			
19	ElevAv				0.92	+	18			
20	HubUniv				0.90	-	19			
21	R5BusS							0.92	-	16

2.5. DISCUSSIONS

2.5.1. Spatial distribution of the vacant dwellings

The high concentric vacancy in the city center of Sapporo corresponds to the cases of Changshu, China (Pan et al., 2020) and Sao Paulo, Brazil (Nadalin, 2014). In both these cases, the decline in the central cities and out-migration accounted for the rise in vacancy. Specifically, the new towns and residential areas attracted people to move in by providing good facilities and services, as in the city of Changshu. Likewise, for Sao Paulo, the problem came from the fast population growth in the past, which left a large volume of low-quality housing, slums, flophouses, and homeless people in the center. As a result, the wealthy households moved to the new districts, and the lower income took over the historical center. This shifting would likely be consistent with the theories presented in previous studies (Edel, 2001; Glaeser & Gyourko, 2005). Nonetheless, the situation for Sapporo is dissimilar. The central districts, such as Chuo-ku, Higashi-ku, and Kita-ku, have increased in population, while the suburban has declined in recent years (refer to Appendix C). Thus, the study suggests the high vacancy in the center would be more likely associated with the disequilibrium housing market rather than the population change.

Regarding housing allocation patterns, the city of Sapporo is likely to match the second model introduced by McCann, where the central city is a favorable area for the low- and young high-income. Specifically, the number of low-income households in Chuo-ku and Kita-ku ranged from 52.45 to 57.40 thousand. Meanwhile, these figures for the suburbs were about 15.79, 22.59, and 21.70 thousand for Kyota-ku, Atsubetsu-ku, and Teine-ku, respectively. In addition, the number of high-income single- and couple households in the CBD was about two to four times higher compared to other districts.

However, compared to the suburbs, the rental and land prices in the CBD were about 10% to 30% and four times higher, respectively (see Appendix C). Besides, the travel cost, converted to primary earner commuting time, was comparable between districts. As expressed in Appendix C, people seem to spend more commuting time in Chuo-ku than in some areas, such as Atsubetsu-ku and Minami-ku.

As expressed in section 2.2, Sapporo has various sub-centers at the subway and rail stations, representing a transit-oriented development (TOD) approach. Hence, the city would likely be a mix of monocentric and polycentric patterns, which differs from the bid-rent curve theory. This development model substantially shortens the travel time from the suburbs to the downtown. Besides, each sub-center can provide reasonable amenities for its surroundings. Seemingly, the price discrepancy and equal travel costs would restrain the low-income from moving into the city center. This effect may influence the housing market when a segment of houses for these expected customers is stagnant.

2.5.2. Demographic factors

As expected, demographic features were the major vacant houses determinant, in which the number of single households was the strongest influence factor.

Single households, by theory, represent the elasticity of housing demand. Specifically, single households are highly mobile because of their changes in housing preferences caused by marriage status, family members, or working locations. Hence, an area that has a high density of tenants would seem to have a high proportion of rental housing, which could be more likely to be vacant when the renters move. The study's results are consistent with earlier research

(Accordino & Johnson, 2000; K. Wang & Immergluck, 2019; Wegmann, 2020). Moreover, this reflects the progress of Japanese societal change.

The present study argues that this phenomenon is related to the characteristics of the demographic and housing market of Japan in the late 1990s. As reported by Kubo (2020a) and Kubo and Yui (2011), there have been many condominium projects constructed since the significant rise of the single-house demand from the young or marginalized people emerged. To adapt to the need of customers who live alone, the developers quickly provided an extensive number of mini-flats with basic amenities. Eventually, these compact houses became less attractive and surplus because of various reasons, e.g. the oversupply, lack of facility, and a rise in estate market price. Notably, at the beginning of this stage, there was about 70% of owners were single women in their 30s and 40s. Three decades later, this group of people may have moved out after marriage or stayed as single households, resulting in a high likelihood of vacancy.

Regarding the elderly population, the result is partly consistent with the findings of Nam et al. and Park et al. (Nam et al., 2016; Y. Park et al., 2021; Yoo & Kwon, 2019) when both studies found a positive relationship between the elderly population and the vacancy at province and national scale in South Korea. Nevertheless, in the present study, the positive impact of the elderly appeared only in the Hot-spot but the negative effect in the Random and Cold-spot. This difference may present the mobility and housing preference of the elderly group.

Most studies explain the relationship between the elderly population and vacancy by stating that after the death of the elderly, their houses become unoccupied (Jeon & Kim, 2020; Kubo & Mashita, 2020; Yoo & Kwon, 2019). However, a proportion of mobile aging people would seem to affect the vacancy. For example, the independent and open-minded elderly would be more likely to move to a new residence since they still have sound physical health and financial status (Filipovič Hrast et al., 2019). Also, regarding housing preference, the elderly and pre-seniors who are non-metropolitan residents prefer to live in rural or suburban areas (Andersson et al., 2019; Jancz & Trojanek, 2020). Besides, when the elderly decide to change their accommodation, there is a trend of reducing housing consumption, shifting from owning to renting, from detached houses to flats (Abramsson & Andersson, 2016; Angelini & Laferrère, 2012). These characteristics are similar to the single households that induce the vacancy. Nonetheless, most aging people are reluctant to change their accommodations

(Angelini & Laferrère, 2012). This immobility characteristic would remain the housing occupied rate and thus reduce the vacancy.

For Sapporo city, the problem appears to become more stressful. Besides the high proportion of single households, the city also had a large aged population, which may cause the rise of vacant houses. According to statistical data, in 2018, the total household units of Sapporo were 920,900, of which single and elderly single households were 377,000 (40.93%) and 112,400 (12.21%), respectively. These figures increased by 16.65% for single homes and 41.38% for single elderly households, compared to 2013. Additionally, in 2018, there were 167,900 single homes between the ages of 30 and 64 and 96,000 double-aged households. This volume will be the supplement to the total single aged household in the upcoming years and make the problem even more problematic.

Compared to the household status, the ratio of household home-ownership is noteworthy when it can reduce the vacancy rate, though the effect is weak. This outcome is consistent with the findings of other studies. While Immergluck (2016) found the relationship between the high rate of house ownership with low vacancy, Baba and Hino (2019) argued that the abandoned houses associate with the unknown ownership status. From the view of the demand side, when families decide to purchase a home, it implies that they aim to stable their living place. Like the elderly, they become less mobile and hence reduce the vacancy.

As the statistical data illustrate, the ownership rate in Japan in 2013 was 61.5%, which is lower than the average value of the OECD countries, at a value of 69.7% (OECD, 2018). This figure is even lower in Hokkaido and Sapporo, with a value of 57.5% and 49.3%, respectively (Sapporo City (b), n.d.; Statistics of Japan, 2018). The proportion of rental households seems to increase in the future when young people are less likely to purchase their own homes. This issue probably comes from the previous generation (the second baby boom in Japan), which prefers to be independent of their child and saves for their retirement. The next generation then cannot buy housing due to the lack of finances, especially in and after the post-economic bubble collapse of the 1990s (Druta & Ronald, 2018). In addition, the movement of working location in Japanese culture may discourage the employees from purchasing outright accommodation when they are expected to move to a new working place after a few years (Arimura et al., 2020; Druta & Ronald, 2018). Thus, we argue that policy should be introduced not only to subsidize finances for the young people but to stabilize their workplace as discussed in the studies of Druta and Ronald (2018) and Hirayama (2010).

One of the interesting findings is the children's variable, which has a significant impact on housing vacancies. We suggest that this matter connects with the housing preference of child-rearing families. The concerns about the child-rearing amenities may make them mobile, and thus, this is supposed to influence the rise of vacancy. Essentially, families with children prefer to live near public facilities, such as educational institutions, commercial districts, and public transportation hubs (Andrade et al., 2017). They are also willing to pay more to rent an apartment in a better neighborhood for a high-quality school (Kuroda, 2018). As a result, these places typically provide various housing options for young families with children. With time, the declining birth rate has resulted in a decline in housing demand for child-rearing households. However, they are still more likely to dwell in locations with high accessibility to public facilities. For Sapporo city, the birth rate has declined gradually since the 1980s. The proportion of infants dropped from 3.6% in 2015 to 3.4% in 2020 (Sapporo city (d), 2021). This fall suggests the problem will be more severe.

2.5.3. Neighbourhood characteristics

Consistent with previous studies, the findings showed an association between the elevation and vacant houses. Nonetheless, this relationship appeared in the outskirt areas, implying the effect of the highland residing in the southwest part of the city. Located on the Ishikari Plain, the northwest side area is low and suitable for agriculture. Thus, during the fast development of the economy, particularly in the late 1960s and before the 1972 Sapporo Winter Olympics, the city expanded mainly to the southwest side of the city's center, which is a rugged area. Over time, houses in these places hinder the elderly from accessing the center and urban facilities, and thus, they become more likely to be vacantant.

In terms of transportation facilities, most of these features had a negative effect on the vacancy, except the parking scale in the cold and random spots. As expected, a good index of these facilities would increase the amenities of the areas and thus reduce the vacancy.

For the rail station, the short distance to the rail station represents the commuting satisfaction level of the area. Note that the accessibility distance to the station is between 2 and 3 km can still induce the growth of the nearby population (SUZUKI & MUROMACHI, 2010). Housing prices in this location may be affordable for low- and mid-income people since the walking time is acceptable. In Sapporo, the median distance to the subway station is about 1 km (refer to table 2). Thus, it is a favorable factor for owning a house in this area.

As the results indicated, bus stops and road density did not affect the vacancy in the central city. Though the proximity to bus stops and main roads would improve the accessibility to the center and increase the nearby property's value (Y. Wang et al., 2015), this effect seems to appear in the outskirt areas. As shown in Appendix A, the indexes of these two features decreased gradually from the center to the city boundary. Moreover, in the center, the distribution of these facilities was more likely to be evenly dispersed. Thus, they would affect the vacancy higher in the outskirt area than in the central city.

Regarding car parking facilities, there was an inverse effect on the vacancy between parking proximity and parking scale. As expected, the convenient access to the parking site would enhance the amenity of the houses, making them more attractive to the buyers. Thus, it can reduce the possibility of vacancy. By contrast, the study suggests that, outside the central city, the large parking sites are placed mainly around commercial zones or near points of interest. These areas commonly provide massive apartments or mansions at a relatively high price. Thus, the disequilibrium in housing may occur in these places, which leads to an increase in vacancy.

Similar to transportation facilities, good educational services can significantly contribute to housing amenities. These services would likely be more important in the suburbs, which have limited resources. For Sapporo city, the mean distance to the educational facilities was higher in the Cold-spot than in the Hot- and Random-spot (see Appendix A). This distinction may account for the impact variation across areas. Besides, the difference in target customers of the housing market surrounding these institutions is also a reason. For instance, for universities, rental housing for students makes up a larger proportion. Based on the statistical data (Sapporo city (d), 2021), in Sapporo, the number of students increased by 6% within six years, from 46,935 students in 2014 to 49,665 students in 2019. Notably, the proportion of foreign students increased by 42% in the same period. Thus, the demand for student housing is stable and is expected to grow for at least some coming years.

The study expected that the accessibility to clinics and their quantity would increase the nearby housing amenities and thus decrease the vacancy. Studies from the UK and Poland report that the elderly consider accessibility to healthcare services as one of the critical factors in their living area (Jancz & Trojanek, 2020; Mulliner et al., 2020). For Japan, clinic services play an integral role in the healthcare system when the number of clinics per 100,000 people was 131.1, while the figure for hospitals was 6.6 (Statistics Bureau of Japan, 2020).

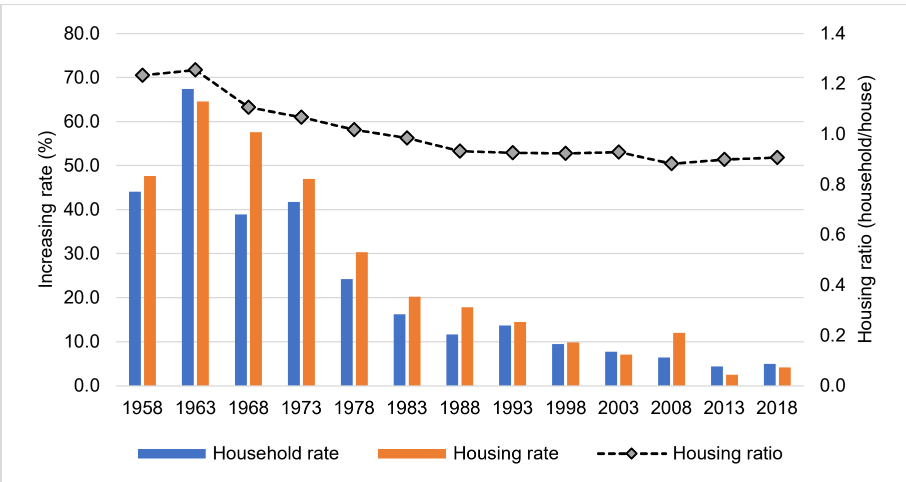
Nevertheless, the results did not fully support our hypothesis. Thus, this problem needs further investigation.

2.5.4. Housing characteristics

The effects of the housing structures are partly consistent with the previous studies, which indicated houses constructed of traditional materials have a higher vacancy rate (Baba & Asami, 2017; Huuhka, 2015; Park, 2019). For Sapporo city, all housing structures positively associated with the vacancy. We argue that the major causes of the problem are housing oversupply and the housing inelasticity per se.

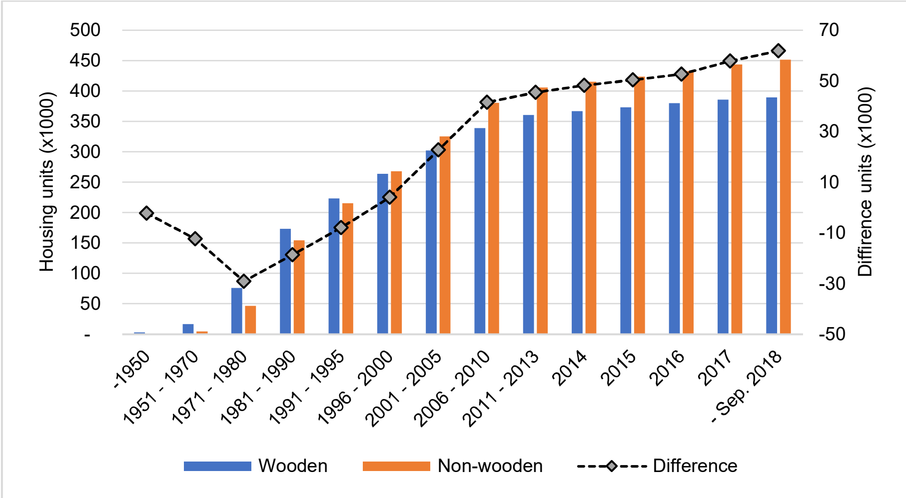
For the first issue, Figure 2.5 illustrates the increased rate in housing, population, and the change of average dwelling size in the city of Sapporo since 1958. Even the two trends of population and housing supply variation are comparable, the supplement housing rate was higher in 30 years from 1963 to 1993. This process resulted in a significant reduction in housing ratio size, which dropped from 1.26 households per house (in 1963) to around 1 household per house (in 1978). After that, the figure continued to decrease and remained at a value of 0.9 households per house by the year 2018. Also, in 1978, Sapporo saw a significant increase in empty dwellings, accounting for 9.34% of total housing stock (refer to table 1). This evidence demonstrates the excess in the overall housing stock in the city.

For the second point, the structure's function and advantages represent the differences in housing elasticity levels. It is stated that concrete or steel structures outperform wood structures in load-bearing, sound, and heat insulation and are suitable for high-rise buildings. Nevertheless, these features cause the houses to be difficult to rebuild or reform. Thus, the solid structure is more likely to be vacant than the light structure, as the results expressed.



(Note: The value of 1958 is compared with the year 1953) (Source: Sapporo city (Sapporo city (d), 2021))

Figure 2.5. *The change in population and housing supply in the city of Sapporo*



(Note: Number of units does not include the unknown structure house) (Source: Statistics of Japan (Statistics of Japan, 2018))

Figure 2.6. *The housing stock by structure in the city of Sapporo*

The wooden houses, however, would seem to be a significant source of vacancies. Although a wood building is expected to be obsolete in 30 years and lasts for about 40 to 50 years (Kubo, 2020b; Nishiyama, 2020), the proportion of this type of housing in Japan is still large. As wooden houses can withstand the earthquake and provide a better atmosphere for the family thanks to their spaciousness of function spaces, wooden houses remain popular (Ohba et al., 2020). The data shows that before the year 2000, the number of wooden houses was greater than the number of other structures (refer to Figure 2.6). Even when the increased supply of wooden houses on the market slowed down two decades later, its share was still high in the city of Sapporo.

In contrast to the other research, the age of the house did not associate with the vacancy in Sapporo city. As stated in the study by Glaeser and Gyourko (2005), the joint effect of urban decline and durable housing causes a significant rise in vacancy. For the city of Sapporo, this relationship would seem to be weak because the average age of buildings is still low, at about 26 years (refer to table 2). Moreover, the population decline is likely to be at the beginning stage. The statistics show that though the natural birth rate was negative since 2009, immigration still increased by about 10,000 people each year in the last decade (Sapporo city (d), 2021).

Nonetheless, the study argue that this situation would be more likely to change soon. Aside from the theory, the buyer's preference when purchasing accommodation is one reason that may cause the old houses to be vacant. As one of the most vulnerable countries to natural disasters (i.e., floods, earth-quakes, and tsunamis), the Japanese people put a priority on owning a reliable dwelling that could stand for such an extreme event. Hence, they prefer buying a new house since they believe the old house's structure has degraded. In addition, the expensive costs of demolition and renovation cause the old houses to be less attractive.

In addition, the current financial support policy is also responsible for the stagnation of the used house market. Under this program, the buyer can get the benefit of income tax reductions if they purchase a new or under 20 years old house using a home loan (Kubo & Mashita, 2020). Hence, people mostly prefer to buy a new house instead of the old one. According to statistics (Sapporo city (d), 2021), the number of housing units in Sapporo city that are over 30 years old accounts for about 35% of the total residences. This proportion is expected to rise to nearly 58% by 2030, implying a worsening problem in the future.

Regarding the housing ownership status, we found a similar statement in the study of Xu and Zhou (2019). The authors declared that the large proportion of public housing links to a high vacancy rate. This issue may present a difference in elasticity on the supply side between public and private housing.

Basically, housing provided by the government or related public agencies has the advantage of low prices. And in the early stage of the housing development program in Japan, the public houses were insufficient for the applicants. Since the favorable economic growth, people who have an income higher than the regulation threshold cannot access these types of housing, and those who are now living in these apartments are also asked to leave (Kobayashi, 2016). Besides, as reported in the study of Kobayashi (2016), public houses constructed in this period are of low standard and undersized, failing to suit the needs of modern life. Meanwhile, the private sector provides a diversity of housing forms with greater amenities, flexible time contracts, and straightforward procedures that satisfy the residents' budget and personal preferences. Because of this distinction, the private home has an advantage over the public house.

Contrary to the private housing factor, the concentration of offices in the Hot- and Cold-spot correlates with the increase in vacant houses. We suggest this state represents cost-effectiveness in the property market. Commonly, the high-density office locates in the center of the business district, where the property price is excessively high. This price range mainly suits the high-income who may own these houses as second dwellings or for investment, as discussed in the study by Fernandez et al. (2016).

For the attached parking lots, principally, this factor reflects the mobility habit of the Japanese. As reported by the Japan Automobile Manufacturers Association (JAMA, 2020), the ratio of a private passenger car in Japan reached about 105 units per 100 households, expressing the heavy dependence on the car when commuting. The values for Hokkaido and Sapporo are still around 100 and 60, respectively. Notably, one condition for owning a car in Japan is to have a parking lot certification. The availability of car parking when finding new accommodation is essential. Besides, even if the public parking area is nearby the house location, it is not as convenient as indoor or attached parking lots in the building. This element is even more fruitful in Hokkaido because of the extreme winter weather, with annual snowfall of 484.8cm and an average temperature of 5.7 degrees Celsius within the past 30 years (JMA, 2021). Thus, buildings with a combination of parking lots are more attractive than ones without them. However, attached parking lots are more likely in apartments in the central city and its surroundings. Meanwhile, in the suburbs, they denote detached houses. Thus, it may appear in a reversed impact direction.

2.5.5. Policies implications

For years, besides the depopulation influences, the free housing market operation and the outdated housing policy have resulted in a mass of houses in the death stock. Responding to this problem, the Japanese government enacted the 'Vacant Property Management Limited Measure Act' in 2014. Through this act, municipalities can force property owners to destruct their dilapidated buildings if necessary (Hattori et al., 2017). As a result, the vacancy rate declined nationwide, and in most metropolises (refer to table 1). However, we argue that this seems to be unsustainable when the burden of cost shifts from the private to the public sector. This, thus, will cause pressure on the local city budget. We propose that the decision-maker should consider the active approach with the following suggestions.

To begin, the city should implement a property tax on vacant houses simultaneously with a conventional tax. According to Segú (2020), this tax handled a 13% decline in vacancy rates in France, particularly on long-term vacancies. Besides, the second option is to change the tax rate to narrow the gap between the vacant land and empty house taxes. These two adjustments would influence the owner to demolish their deteriorated houses themselves or transfer them to a new owner. The third suggestion is to mandate registering the owner of the vacant house. This will solve the situation of an unknown owner or "ghost house" in the city. On the one hand, it will support the tax system for vacant properties; on the other hand, it helps the management agency to decide an alternative to the derelict houses—to either destroy or renovate.

Second, we argue that there is a need for quality inspection conduct to classify the old houses. For the re-useable accommodations, a refurbishment or renovation program can enable them to return to the housing market. From that, the in-charge agency will release a certification or guarantee that it fulfills the construction standard to give customers more confidence when purchasing a used property. Meanwhile, the no longer improper houses for a living can move to the conservation purpose, with vernacular historic buildings, or demolition.

Third, all new development projects should be thoroughly assessed, with an emphasis on enhancing the current environment. As Jeon and Kim (2020) indicate, while the new town with better public facilities would attract the people to move in, the cancellation of the reconstruction projects would dissatisfy the local resident. Consequently, this problem creates the push-and-pull effect, the people would leave the old to move to new areas.

Finally, policy implications should focus on easing the negative effect of the depopulation. Specifically, government should continue to improve the neighborhood conditions to increase the rate of child-rearing household as stated in the study of Andrade et al. (2017). Besides, it is necessary to boost up local economic programs which involve the young people as the center subject. This can provide the diversity and large scale of job that attract not only the young but the immigrations people and encourage them to stay.

2.6. CONCLUSIONS

In conclusion, the present study has examined the determinants of vacant houses' spatial distribution in the city of Sapporo. The outcomes highlight the high vacancy cluster that occurred in the central city. In contrast to the other cities, the vacancy in Sapporo would seem to link to the disequilibrium housing market rather than the urban decline. The results indicate that the influence factors varied over city areas in magnitude and direction. Demographic features were the substantial factors, followed by housing and neighborhood characteristics. Specifically, areas with a high density of single households and children are more likely to experience a high vacancy. Contrary, a high percentage of household ownership and the elderly (in suburban) would reduce the vacancy. Notably, a group of mobile elderly would increase the vacancy in the central city.

Regarding housing characteristics, the study argues that the surplus in housing supply stimulated the vacant houses intensively. Further, the elasticity in housing structures causes the different influence levels of the house to increase from flexibility to hardness. The study also identifies the high percentage of private shares as a primary factor that can keep the low rate of empty homes, especially in the central city and its surrounding. Meanwhile, the intensive concentration of offices would increase the vacancy in the center and outskirt areas.

For other amenities, we found the clinic, parking, public transportation, and educational facilities had a medium effect on the vacancy. Remarkably, some facilities had an inverse influence over areas, such as clinics and attached car parking, and some facilities had an effect only in specific areas, for example, educational institutions. This disparity would represent the variation in housing dynamics across the city. Thus, the policies should be flexible in implementation in a specific area.

APPENDIXES

Appendix A. Summary of cluster data sets

Variable	Hot-spot				Cold-spot				Random			
	Min	Median	Mean	Max	Min	Median	Mean	Max	Min	Median	Mean	Max
Dependent variable												
zenVCrooms	0.00	379.00	407.70	1457.00	0.00	5.00	15.41	231.00	0.00	61.00	89.41	678.00
Explanatory variables												
Dependent variable												
Neighborhood characteristics												
Geographic conditions												
ElevAv	6.14	21.54	24.36	75.73	2.30	45.08	67.65	375.51	2.37	14.71	29.15	217.14
SlopeAv	0.01	0.50	0.66	10.39	0.00	1.90	3.28	27.54	0.00	0.55	1.37	19.74
FloodArea	0.00	0.00	11.98	559.04	0.00	0.00	49.92	625.06	0.00	0.00	40.25	625.06
Public facilities in 500m radius area												
R5ParkingA	9.08	31.22	31.76	73.00	0.00	4.92	7.47	51.40	0.00	18.72	19.58	62.58
R5Hosp	0.00	1.00	1.14	6.00	0.00	0.00	0.20	4.00	0.00	0.00	0.61	4.00
R5Clinic	2.00	15.00	17.15	116.00	0.00	2.00	2.59	16.00	0.00	5.00	6.96	182.00
R5Welf	0.00	4.00	4.52	16.00	0.00	1.00	1.78	11.00	0.00	3.00	3.40	16.00
R5Cult	0.00	2.00	2.39	13.00	0.00	0.00	0.89	11.00	0.00	1.00	1.48	10.00
R5RailS	0.00	1.00	0.95	11.00	0.00	0.00	0.03	1.00	0.00	0.00	0.25	13.00
R5BusS	0.00	5.00	5.76	34.00	0.00	3.00	3.51	10.00	0.00	5.00	4.73	37.00
R5Fuel	0.00	1.00	1.27	6.00	0.00	0.00	0.35	3.00	0.00	1.00	0.74	6.00
R5Univ	0.00	0.00	0.20	11.00	0.00	0.00	0.02	2.00	0.00	0.00	0.07	3.00
R5HighS	0.00	0.00	0.25	3.00	0.00	0.00	0.12	2.00	0.00	0.00	0.10	2.00
R5Junior	0.00	0.00	0.39	3.00	0.00	0.00	0.26	3.00	0.00	0.00	0.27	2.00
R5Ele	0.00	1.00	0.71	3.00	0.00	0.00	0.44	2.00	0.00	1.00	0.60	3.00
R5Kind	0.00	1.00	0.62	3.00	0.00	0.00	0.26	2.00	0.00	0.00	0.42	3.00
Nearest facilities distance												
HubPark	0.07	1.61	1.90	7.69	0.06	1.38	1.60	10.06	0.02	1.43	1.57	6.58
HubCultura	0.16	3.33	3.41	8.77	0.15	5.07	5.65	20.29	0.11	3.96	4.26	16.18
HubHospita	0.10	3.94	4.17	12.64	0.17	9.07	9.70	35.96	0.07	5.57	6.28	36.11
HubClinic	0.01	1.25	1.35	3.81	0.06	3.28	3.75	17.04	0.03	2.02	2.24	14.05

Variable	Hot-spot				Cold-spot				Random			
	Min	Median	Mean	Max	Min	Median	Mean	Max	Min	Median	Mean	Max
HubWelfare	0.08	2.08	2.31	6.90	0.08	3.87	4.32	16.69	0.00	2.58	2.80	11.76
HubRailS	0.34	4.13	4.26	10.00	0.62	22.51	29.26	167.32	0.25	9.47	12.09	57.46
HubBusS	0.11	1.67	1.84	6.79	0.02	2.06	2.31	10.23	0.06	1.82	1.95	7.21
HubPking	0.02	0.50	0.56	2.54	0.05	1.49	1.83	8.97	0.01	0.80	1.00	6.64
HubFuelS	0.14	3.64	4.06	13.42	0.17	7.29	8.53	42.93	0.31	4.91	5.33	20.26
HubUniv	0.60	13.40	14.70	45.35	1.17	28.47	31.30	136.02	0.36	22.80	23.53	59.92
HubHighs	0.24	8.53	9.34	25.86	0.50	11.41	13.55	103.82	0.27	12.55	13.12	33.82
HubJunior	0.28	5.90	6.08	14.79	0.46	7.58	8.02	23.53	0.10	7.21	7.37	22.40
HubEle	0.14	4.33	4.33	9.46	0.19	5.60	6.14	20.72	0.14	4.81	5.01	16.19
HubKind	0.21	4.79	4.99	14.01	0.15	7.48	9.64	88.34	0.31	6.03	6.26	35.51
Infrastructure index												
RoadDen	0.86	24.76	24.71	46.27	0.00	22.48	21.16	43.47	0.00	23.54	22.20	44.51
BusDen	0.00	5.67	20.25	276.85	0.00	3.04	8.95	152.73	0.00	6.21	15.83	377.75
RailDen	0.00	0.00	1.03	9.75	0.00	0.00	0.08	5.11	0.00	0.00	0.43	16.68
Building characteristics												
ParkingA	0.00	23.38	31.87	557.59	0.00	3.96	5.06	269.61	0.00	7.19	11.31	1276.94
woodA	0.00	12.41	13.00	68.10	0.00	10.86	10.69	27.91	0.00	11.98	12.00	44.47
semifireA	0.00	2.27	2.80	21.72	0.00	0.56	0.95	21.35	0.00	1.04	1.52	23.29
fireproofA	0.00	28.36	37.11	339.60	0.00	0.00	1.89	276.62	0.00	3.07	10.59	391.03
AgeFloorAv	1.82	24.33	24.18	57.27	1.96	27.13	26.04	62.07	1.06	27.00	26.61	90.00
zenPriRoom	0.00	169.00	175.60	758.00	0.00	101.00	101.70	460.00	0.00	133.00	130.60	652.00
zenOffRoom	0.00	18.00	29.07	404.00	0.00	3.00	4.17	47.00	0.00	6.00	8.71	544.00
Demographic characteristics												
Children	0.92	74.11	76.40	267.49	0.00	34.57	37.52	215.59	0.00	51.20	53.35	208.71
Elderly	2.69	188.72	191.67	679.88	0.00	79.47	83.98	410.81	0.21	130.46	127.17	389.72
HHowner	0.44	141.52	151.45	528.31	0.00	87.88	85.28	331.23	0.00	102.98	102.85	522.99
HHsingle	5.09	256.63	290.96	1363.40	0.00	18.24	20.71	96.57	0.00	53.23	64.58	529.58

Appendix B. Variable Influence on Projection and Coefficient values of the four models

No	Variable	Overall		Hotspot		Cold-spot		Random	
		VIP	Coef	VIP	Coef	VIP	Coef	VIP	Coef
1	ElevAv	0.81	1.83	0.40	3.02	0.92	0.42	0.47	0.77
2	SlopeAv	0.85	-2.03	0.60	4.39	0.87	-0.43	0.61	-0.10
3	FloodArea	0.38	0.88	0.23	-3.94	0.30	0.56	0.38	1.19
4	R5ParkingA	1.53	3.84	0.74	4.26	1.44	1.50	1.17	1.18
5	R5Hosp	1.17	-1.00	0.82	8.51	0.54	-0.44	0.79	0.76
6	R5Clinic	1.43	-6.10	1.14	-9.74	1.06	0.54	0.93	-1.61
7	R5Welf	0.86	2.16	0.33	4.92	0.71	0.76	0.51	-1.28
8	R5Cult	0.59	1.29	0.52	3.39	0.40	-1.42	0.51	-0.83
9	R5RailS	1.24	10.71	0.79	10.42	0.49	0.47	0.86	1.04
10	R5BusS	1.07	3.38	0.82	5.16	0.85	0.41	0.92	-0.10
11	R5Fuel	0.86	1.23	0.42	-0.65	0.83	-0.86	0.55	1.82
12	R5Univ	0.43	-0.51	0.39	-2.55	0.25	0.22	0.47	-1.44
13	R5HighS	0.42	2.92	0.27	1.29	0.54	-0.37	0.30	-0.45
14	R5Junior	0.38	-0.36	0.21	-2.68	0.34	0.54	0.50	-0.85
15	R5Ele	0.53	3.95	0.31	6.83	0.65	0.76	0.70	-1.29
16	R5Kind	0.66	0.24	0.39	3.61	0.67	1.21	0.55	-2.89
17	HubPark	0.74	-1.00	0.63	-3.22	0.84	-0.08	0.75	-1.98
18	HubCultura	0.65	3.37	0.60	0.45	0.53	0.95	0.64	-3.30

No	Variable	Overall		Hotspot		Cold-spot		Random	
		VIP	Coef	VIP	Coef	VIP	Coef	VIP	Coef
19	HubHospita	0.92	-1.04	0.66	7.91	0.53	-0.76	0.87	-1.73
20	HubClinic	1.02	0.51	1.06	0.49	1.09	-0.54	1.05	0.02
21	HubWelfare	0.77	1.76	0.58	11.38	0.82	-0.41	0.61	-1.50
22	HubRailS	0.92	-2.93	1.18	-11.18	1.01	-1.57	1.02	-2.47
23	HubBusS	0.75	0.68	0.62	-1.60	0.78	-1.30	0.48	-0.71
24	HubPking	0.87	-0.89	1.11	-3.73	1.24	-0.95	1.03	-2.42
25	HubFuelS	0.76	-1.59	0.52	-0.58	0.81	-0.72	0.73	3.03
26	HubUniv	0.82	2.08	0.40	3.41	0.90	-0.51	0.56	0.22
27	HubHighs	0.64	1.52	0.27	0.15	0.98	-1.62	0.42	0.06
28	HubJunior	0.53	-0.72	0.29	-2.79	0.52	-0.61	0.72	3.03
29	HubEle	0.69	3.75	0.33	1.95	0.79	0.70	0.81	0.56
30	HubKind	0.72	-4.18	0.32	1.24	0.97	-0.18	0.82	-3.19
31	ParkingA	1.32	-6.13	1.00	-12.68	1.40	0.13	1.00	-9.29
32	woodA	0.80	30.73	1.16	45.50	1.31	1.03	1.07	12.51
33	semifireA	1.44	12.74	1.87	19.38	0.83	2.26	1.01	8.54
34	fireproofA	1.54	30.40	1.44	46.08	1.72	4.11	1.64	27.88
35	AgeFloorAv	0.27	-1.77	0.55	-1.79	0.58	-1.82	0.58	3.43
36	zenPriRoom	1.12	-52.79	1.44	-58.99	1.24	-0.41	1.47	-26.87
37	zenOffRoom	1.22	2.09	1.24	13.05	1.11	2.16	0.71	3.44
38	RoadDen	0.83	-13.98	0.80	-5.21	1.38	-4.01	1.22	-9.24
39	BusDen	0.75	-1.53	0.60	-4.64	0.40	1.06	0.42	0.08
40	RailDen	0.78	-3.49	0.56	-7.05	0.19	-0.34	0.48	-1.91
41	Children	1.06	17.19	1.27	26.15	1.02	3.71	1.71	23.44
42	Elderly	1.33	20.86	1.61	14.42	1.25	-0.18	1.53	-4.00
43	HHowner	1.13	-3.57	1.29	-0.28	1.61	-8.92	1.49	-2.19
44	HHsingle	2.61	177.66	3.61	171.87	2.62	15.24	3.17	69.57

Appendix C: Dwelling, population, and commuting indexes of Sapporo's districts

Index	Atsubetsu	Chuo	Higashi	Kita	Kiyota	Minami	Nishi	Shiroishi	Teine	Toyohira
Real estate market										
Average rental price 2018 (1000 JPY/house)	42.37	55.51	46.50	47.51	50.63	45.37	52.03	47.39	47.15	48.20
Average land price 2018 (10,000 JPY/m2)	63.70	141.00	65.80	56.50	48.00	38.00	77.10	67.40	42.00	89.80
Dwelling indexes										
# dwellings 2018 (1000 units)	59.81	157.26	140.42	150.04	48.19	68.29	108.9	120.13	63.65	129.46
# occupied dwellings 2018 (1000 units)	55.63	128.35	125.12	134.54	45.58	58.95	97.34	105.98	58.62	110.79
# vacant dwellings 2018 (1000 units)	4.18	28.91	15.3	15.5	2.61	9.34	11.56	14.15	5.03	18.67
Dwelling vacancy rate 2018 (%)	6.99	18.38	10.9	10.33	5.42	13.68	10.62	11.78	7.90	14.42
Owned dwellings rate 2018 (%)	53.1	40.77	42.32	52.79	72.59	67.72	58.04	37.09	69.29	42.03
Rental vacant dwelling rate 2018 (%)	80.62	50.78	75.95	67.48	52.49	43.90	71.97	82.47	37.38	46.01
Change in dwelling 2008-2013 (dwellings)	-720	13,260	3,900	-60	1,130	**-1,530**	4,960	1,090	-2,040	4,220
Change in dwelling 2013-2018 (dwellings)	1,120	8,340	6,590	11,470	3,150	**-1,270**	3,300	-1,680	5,950	4,840
Change in vacant dwelling 2008-2013 (dwellings)	60	7,410	-460	-510	-990	**1,150**	3,060	-4,490	-70	-710

Index	Atsubetsu	Chuo	Higashi	Kita	Kiyota	Minami	Nishi	Shiroishi	Teine	Toyohira
Change in vacant dwelling 2013-2018 (dwellings)	-1,720	-3,520	-2,590	-1,470	-220	**-320**	-2,400	-5,410	-340	-90
Demographic										
# Households with elderly (1000 households)	25.60	35.28	**40.72**	**47.79**	20.30	28.72	37.50	31.70	24.26	34.42
Proportion of households with elderly (%)	**45.85**	27.41	32.47	35.43	**44.27**	**48.47**	38.34	29.83	**41.16**	31.01
# Low-income households (1000 households)	22.59	**52.45**	48.72	57.40	15.79	23.86	36.90	42.34	21.70	47.31
Proportion of low-income households (%)	40.61	40.86	38.94	42.66	34.64	40.47	37.91	39.95	37.02	42.70
# High-income households (1000 households)	8.80	22.95	12.98	15.87	7.92	7.32	13.25	9.07	8.31	12.29
Proportion of high-income households (%)	15.82	17.88	10.37	11.80	17.38	12.42	13.61	8.56	14.18	11.09
# High-income single/couple household (1000 households)	3.02	**12.53**	4.64	6.24	2.43	2.92	4.55	3.95	2.71	5.16
Proportion of high-income single/couple household (%)	5.43	9.76	3.71	4.64	5.33	4.95	4.67	3.73	4.62	4.66
Population 2020 (1000 persons)	124.39	250.01	265.1	289.4	111.63	135.05	217.09	211.37	142.71	225.85
Change in population 2010-2020 (1000 persons)	-4.17	29.52	9.13	10.39	-5.05	-11.19	5.90	7.05	2.88	13.57
Change in population 2015-2020 (1000 persons)	-3.30	12.00	2.97	3.71	-4.05	-6.09	3.68	1.90	1.64	6.99
Elderly proportion 2020 (%)	32.90	23.02	25.76	26.7	30.52	35.54	27.62	25.15	31.52	25.26
Change in elderly population 2015-2020 (%)	14.59	13.87	11.12	12.06	16.42	7.00	9.29	11.03	16.66	10.88
Commuting time										
Proportion of household's earner commuting time less than 30 minutes (%)	69.11	58.65	63.8	63.75	56.71	59.6	59.79	51.03	52.62	54.69
Proportion of household's earner commuting time less than 45 minutes (%)	89.92	83.76	85.85	88.28	78.00	85.18	77.87	74.80	83.10	73.88

REFERENCES

Abramsson, M., & Andersson, E. (2016). Changing preferences with ageing – housing choices and housing plans of older people. Housing, Theory and Society, 33(2), 217–241. https://doi.org/10.1080/14036096.2015.1104385

Accordino, J., & Johnson, G. T. (2000). Addressing the vacant and abandoned property problem. Journal of Urban Affairs, 22(3), 301–315. https://doi.org/10.1111/0735-2166.00058

Alonso, W. (1964). Location and Land Use. Harvard University Press. https://doi.org/10.4159/harvard.9780674730854

Andersson, E. K., Abramsson, M., & Malmberg, B. O. (2019). Patterns of changing residential preferences during late adulthood. Ageing and Society, 39(8), 1752–1781. https://doi.org/10.1017/S0144686X18000259

Andrade, K., Nakano, H., Sugiki, N., & Tamura, T. (2017). Influencing Factors on the Increase of Child-rearing Households. Procedia Engineering, 198(September 2016), 490–495. https://doi.org/10.1016/j.proeng.2017.07.103

Angelini, V., & Laferrère, A. (2012). Residential mobility of the European elderly. CESifo Economic Studies, 58(3), 544–569. https://doi.org/10.1093/cesifo/ifr017

Appel, S. U., Botti, D., Jamison, J., Plant, L., Shyr, J. Y., & Varshney, L. R. (2014). Predictive analytics can facilitate proactive property vacancy policies for cities. Technological Forecasting and Social Change, 89, 161–173. https://doi.org/10.1016/j.techfore.2013.08.028

Arimura, M., Vinh Ha, T., Kimura, N., & Asada, T. (2020). Evacuation awareness and behavior in the event of a tsunami in an aging society: An experience from the 2018 Hokkaido Eastern Iburi earthquake. Safety Science, 131(July), 104906. https://doi.org/10.1016/j.ssci.2020.104906

Baba, H., & Asami, Y. (2017). Regional Differences in the Socio-economic and Built-environment Factors of Vacant House Ratio as a Key Indicator for Spatial Urban Shrinkage. Urban and Regional Planning Review, 4(0), 251–267. https://doi.org/10.14398/urpr.4.251

Baba, H., & Hino, K. (2019). Factors and tendencies of housing abandonment: An analysis of a survey of vacant houses in Kawaguchi City, Saitama. Japan Architectural Review, 2(3), 367–375. https://doi.org/10.1002/2475-8876.12088

Berg, L. van den, Drewett, R., Klaassen, L. H., Rossi, A., & Vijverberg, C. H. T. (1982). Urban Europe a study of growth and decline (First Edit). Pergamon Press.

Boulesteix, A.-L., & Strimmer, K. (2006). Partial least squares: a versatile tool for the analysis of high-dimensional genomic data. Briefings in Bioinformatics, 8(1), 32–44. https://doi.org/10.1093/bib/bbl016

City of Sapporo. (2020). Sapporo City General Transportation Plan Revised Edition - Part I: Basic Approach. Sapporo City General Transportation Plan.

Cohen, J. R. (2001). Abandoned housing: Exploring lessons from Baltimore. Housing Policy Debate, 12(3), 415–448. https://doi.org/10.1080/10511482.2001.9521413

Couch, C., & Cocks, M. (2013). Housing Vacancy and the Shrinking City: Trends and Policies in the UK and the City of Liverpool. Housing Studies, 28(3), 499–519. https://doi.org/10.1080/02673037.2013.760029

Deng, C., & Ma, J. (2015). Viewing urban decay from the sky: A multi-scale analysis of residential vacancy in a shrinking U.S. city. Landscape and Urban Planning, 141, 88–99. https://doi.org/10.1016/j.landurbplan.2015.05.002

Druta, O., & Ronald, R. (2018). Young adults' pathways into homeownership in Tokyo: Shifting practices and meanings. Environment and Planning A, 50(5), 1092–1108. https://doi.org/10.1177/0308518X18763372

Duan, L., Xie, H., Li, Z., Yuan, H., Guo, Y., Xiao, X., & Zhou, Q. (2020). Use of partial least squares regression to identify factors controlling rice yield in Southern China. Agronomy Journal, 112(3), 1502–1516. https://doi.org/10.1002/agj2.20161

Farrés, M., Platikanov, S., Tsakovski, S., & Tauler, R. (2015). Comparison of the variable importance in projection (VIP) and of the selectivity ratio (SR) methods for variable selection and interpretation. Journal of Chemometrics, 29(10), 528–536.

https://doi.org/10.1002/cem.2736

FEANTSA and the Abbé Pierre Foundation. (2021). Sixth overview of housing exclusion in Europe.

FEANTSA and the Foundation Abbé Pierre. (2016). Filling Vacancies - Vacant Real Estate: Seizing the Opportunity To Find Affordable Housing Solutions in Europe.

Fernandez, R., Hofman, A., & Aalbers, M. B. (2016). London and New York as a safe deposit box for the transnational wealth elite. Environment and Planning A, 48(12), 2443–2461. https://doi.org/10.1177/0308518X16659479

Filipovič Hrast, M., Sendi, R., Hlebec, V., & Kerbler, B. (2019). Moving House and Housing Preferences in Older Age in Slovenia. Housing, Theory and Society, 36(1), 76–91. https://doi.org/10.1080/14036096.2018.1510854

Gentili, M., & Hoekstra, J. (2019). Houses without people and people without houses: a cultural and institutional exploration of an Italian paradox. Housing Studies, 34(3), 425–447. https://doi.org/10.1080/02673037.2018.1447093

Getis, A., & Ord, J. K. (1992). The Analysis of Spatial Association by Use of Distance Statistics. Geographical Analysis, 24(3), 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Glaeser, E. L., & Gyourko, J. (2005). Urban decline and durable housing. Journal of Political Economy, 30.

Glock, B., & Häussermann, H. (2004). New trends in urban development and public policy in eastern Germany: Dealing with the vacant housing problem at the local level. International Journal of Urban and Regional Research, 28(4), 919–929. https://doi.org/10.1111/j.0309-1317.2004.00560.x

Gu, D., Newman, G., Kim, J. H., Park, Y., & Lee, J. (2019). Neighborhood decline and mixed land uses: Mitigating housing abandonment in shrinking cities. Land Use Policy, 83(February), 505–511. https://doi.org/10.1016/j.landusepol.2019.02.033

Haase, A., Bernt, M., Großmann, K., Mykhnenko, V., & Rink, D. (2016). Varieties of shrinkage in European cities. European Urban and Regional Studies, 23(1), 86–102. https://doi.org/10.1177/0969776413481985

Haase, A., Rink, D., Grossmann, K., Bernt, M., & Mykhnenko, V. (2014). Conceptualizing urban shrinkage. Environment and Planning A, 46(7), 1519–1534. https://doi.org/10.1068/a46269

Han, H. S. (2014). The Impact of Abandoned Properties on Nearby Property Values. Housing Policy Debate, 24(2), 311–334. https://doi.org/10.1080/10511482.2013.832350

Han, H. S. (2019). Exploring Threshold Effects in the Impact of Housing Abandonment on Nearby Property Values. Urban Affairs Review, 55(3), 772–799. https://doi.org/10.1177/1078087417720303

Hattori, K., Kaido, K., & Matsuyuki, M. (2017). The development of urban shrinkage discourse and policy response in Japan. Cities, 69, 124–132. https://doi.org/10.1016/j.cities.2017.02.011

Hirayama, Y. (2010). The role of home ownership in Japan's aged society. Journal of Housing and the Built Environment, 25(2), 175–191. https://doi.org/10.1007/s10901-010-9183-8

Hoekstra, J., & Vakili-zad, C. (2011). High vacancy rates and rising house prices: The spanish paradox. Tijdschrift Voor Economische En Sociale Geografie, 102(1), 55–71. https://doi.org/10.1111/j.1467-9663.2009.00582.x

Hsueh, L., Tseng, H., & Hsieh, C. (2007). Relationship Between the Housing Vacancy Rate, Housing Price, and the Moving Rate at the Township Level in Taiwan, in 1990 and 2000. International Real Estate Review, 10(1), 119–150.

Hulland, J. (1999). Use of partial least squares (PLS) in strategic management research: a review of four recent studies. Strategic Management Journal, 20(2), 195–204. https://doi.org/10.1002/(SICI)1097-0266(199902)20:2<195::AID-SMJ13>3.0.CO;2-7

Huuhka, S. (2015). Vacant residential buildings as potential reserves: a geographical and statistical study. Building Research and Information, 44(8), 816–839. https://doi.org/10.1080/09613218.2016.1107316

Immergluck, D. (2015). Examining Changes in Long-Term Neighborhood Housing Vacancy During the 2011 To 2014 U.S. National Recovery. Journal of Urban Affairs, 38(5), 607–622. https://doi.org/10.1111/juaf.12267

Ishikawa, M., Matsuhashi, K., Ariga, T., Kanamori, Y., & Kurishima, H. (2016). Estimation of current and future distribution of vacant dwellings within municipalities - With a focus on the difference between the numbers of dwellings and households. Journal of the City Planning Institute of Japan, 51(3), 833–838.

Ishikawa, M., Matsuhashi, K., Kanamori, Y., & Ariga, T. (2017). Method of grasping detailed regional distribution of vacant dwelling based on the number of dwellings and households. Journal of the City Planning Institute of Japan, 52(3), 689–695.

JAMA. (2020). The Motor Industry of Japan. Japan Automobile Manufacturers Association, Inc.

Jancz, A., & Trojanek, R. (2020). Housing Preferences of Seniors and Pre-Senior Citizens in Poland—A Case Study. Sustainability, 12(11), 4599. https://doi.org/10.3390/su12114599

Jensen, J. O. (2016). Vacant Houses in Denmark: Problems, Localization and Initiatives. ENHR Conference 2017 Tirana, Tirana, Albania, 1–13.

Jeon, Y., & Kim, S. (2020). Housing abandonment in shrinking cities of East Asia: Case study in Incheon, South Korea. Urban Studies, 57(8), 1749–1767. https://doi.org/10.1177/0042098019852024

JMA. (2021). Tables of Monthly Climate Statistics. Japan Meteorological Agency.

Kanayama, Y., & Sadayuki, T. (2021). What types of houses remain vacant? Evidence from a municipality in Tokyo, Japan. Journal of the Japanese and International Economies, 62(August), 101167. https://doi.org/10.1016/j.jjie.2021.101167

Keenan, P., Lowe, S., & Spencer, S. (1999). Housing abandonment in inner cities-the politics of low demand for housing. Housing Studies, 14(5), 703–716. https://doi.org/10.1080/02673039982687

Khan, D., Rossen, L. M., Hamilton, B. E., He, Y., Wei, R., & Dienes, E. (2017). Hot spots, cluster detection and spatial outlier analysis of teen birth rates in the U.S., 2003–2012. Spatial and Spatio-Temporal Epidemiology, 21, 67–75. https://doi.org/10.1016/j.sste.2017.03.002

Kobayashi, M. (2015). Housing and demographics: Experiences in Japan. Housing Finance International, Winter, 32–38.

Kobayashi, M. (2016). The Housing Market and Housing Policies in Japan. In SSRN Electronic Journal (Issue 558). https://doi.org/10.2139/ssrn.2752868

Kubo, T. (2020a). Homeownership by Single Women in Central Tokyo. In Divided Tokyo (pp. 67–85). Springer Nature Singapore Pte Ltd. https://doi.org/10.1007/978-981-15-4202-2_4

Kubo, T. (2020b). Shrinking suburbs in Tokyo. In Divided Tokyo (pp. 111–125). http://doi.org/10.1007/978-981-15-4202-2_6

Kubo, T., & Mashita, M. (2020). Why the Rise in Urban Housing Vacancies Occurred and Matters in Japan. In The Rise in Vacant Housing in Post-growth Japan (pp. 3–22). https://doi.org/10.1007/978-981-13-7920-8_1

Kubo, T., & Yui, Y. (2011). Transformation of the Housing Market in Tokyo since the Late 1990s: Housing Purchases by Single-person Households. Asian Studies, 3(3), 3–21. https://doi.org/10.4312/as.2011.15.3.3-21

Kuroda, Y. (2018). The effect of school quality on housing rents: Evidence from Matsue city in Japan. Journal of the Japanese and International Economies, 50(January), 16–25. https://doi.org/10.1016/j.jjie.2018.05.002

Kvalheim, O. M. (2020). Variable importance: Comparison of selectivity ratio and significance multivariate correlation for interpretation of latent-variable regression models. Journal of Chemometrics, 34(4), 1–10. https://doi.org/10.1002/cem.3211

Martinez-Fernandez, C., Audirac, I., Fol, S., & Cunningham-Sabot, E. (2012). Shrinking Cities: Urban Challenges of Globalization. International Journal of Urban and Regional Research, 36(2), 213–225. https://doi.org/10.1111/j.1468-2427.2011.01092.x

Mayumi, K. T. (2020). Aging Population, Vacant Dwellings and the Compatibility Problem Between Human and Exosomatic Populations. In Sustainable Energy and Economics in an Aging Population Lessons from Japan (pp. 123–141). https://doi.org/10.1007/978-3-030-43225-6_6

McDonald, J. (2000). Rent, Vacancy and Equilibrium in Real Estate Markets. Journal of Real Estate Practice and Education, 3(1), 55–69. https://doi.org/10.1080/10835547.2000.12091569

Mehmood, T., Liland, K. H., Snipen, L., & Sæbø, S. (2012). A review of variable selection methods in Partial Least Squares Regression. Chemometrics and Intelligent Laboratory Systems, 118, 62–69. https://doi.org/10.1016/j.chemolab.2012.07.010

Mills, E. S. (1972). Studies in the structure of the urban economy. The Johns Hopkins Press.

Miyazawa, H. (2020). Distribution of vacant homes in Tama city in the Tokyo metropolitan area: Estimation using GIS and small area statastics. In The Rise in Vacant Housing in Post-growth Japan (pp. 87–109). https://doi.org/http://doi.org/10.1007/978-981-13-7920-8_6

Mondal, S. (2020). Modeling the spatial pattern of household quality of living in West Bengal: an approach of hotspot and cluster analysis. Modeling Earth Systems and Environment, 6(2), 833–851. https://doi.org/10.1007/s40808-020-00711-2

Morckel, V. (2014). Predicting abandoned housing: does the operational definition of abandonment matter? Community Development, 45(2), 121–133. https://doi.org/10.1080/15575330.2014.892019

Morckel, V. C. (2014). Spatial characteristics of housing abandonment. Applied Geography, 48, 8–16. https://doi.org/10.1016/j.apgeog.2014.01.001

Mukherjee, R., Sengupta, D., & Sikdar, S. K. (2015). Selection of Sustainable Processes Using Sustainability Footprint Method: A Case Study of Methanol Production from Carbon Dioxide. In Computer Aided Chemical Engineering (Vol. 36). Elsevier. https://doi.org/10.1016/B978-0-444-63472-6.00012-4

Mulliner, E., Riley, M., & Maliene, V. (2020). Older people's preferences for housing and environment characteristics. Sustainability (Switzerland), 12(14), 1–25. https://doi.org/10.3390/su12145723

Muramatsu, N., & Akiyama, H. (2011). Japan: Super-aging society preparing for the future. Gerontologist, 51(4), 425–432. https://doi.org/10.1093/geront/gnr067

Muth, R. F. (1969). Cities and Housing: the Spatial Pattern of Urban Residential Land Use. University of Chicago Press.

Nadalin, V. G. (2014). Residential Vacancy in City Center: The Case of São Paulo. Discussion Paper - Institute for Applied Economic Research, 1987a, 1–26.

Nam, J., Han, J., & Lee, C. (2016). Factors contributing to residential vacancy and some approaches to management in Gyeonggi Province, Korea. Sustainability (Switzerland), 8(4). https://doi.org/10.3390/su8040367

Nash, M. S., & Chaloud, D. J. (2011). Partial Least Square Analyses of Landscape and Surface Water Biota Associations in the Savannah River Basin. ISRN Ecology, 2011, 1–11. https://doi.org/10.5402/2011/571749

Newman, G., Gu, D., Kim, J. H., Bowman, A. O. M., & Li, W. (2016). Elasticity and urban vacancy: A longitudinal comparison of U.S. cities. Cities, 58, 143–151. https://doi.org/10.1016/j.cities.2016.05.018

Newman, G., Lee, R. J., Gu, D., Park, Y., Saginor, J., Van Zandt, S., & Li, W. (2019). Evaluating drivers of housing vacancy: a longitudinal analysis of large U.S. cities from 1960 to 2010. Journal of Housing and the Built Environment, 34(3), 807–827. https://doi.org/10.1007/s10901-019-09684-w

Nishiyama, H. (2020). A Problem of Vacant Housing in Local Cities: Utsunomiya City, Tochigi Prefecture Case Study. In The Rise in Vacant Housing in Post-growth Japan (pp. 123–146). Springer Nature Singapore Pte Ltd. https://doi.org/http://doi.org/10.1007/978-981-13-7920-8_8

OECD. (2018). Housing market. OECD Housing Project.

OECD. (2021a). HC3.1 Homeless population [estimates]. OECD Affordable Housing Database, 1–12.

OECD. (2021b). Unemployment rate.

Ohba, T., Nakazono, M., Ushijima, A., & Mishima, S. (2020). Detached housing utilized as shared houses: establishment process and living style – case study in Yamaguchi Prefecture. JAPAN ARCHITECTURAL REVIEW, 3(4), 564–578. https://doi.org/10.1002/2475-8876.12172

Onderka, M., Wrede, S., Rodný, M., Pfister, L., Hoffmann, L., & Krein, A. (2012). Hydrogeologic and landscape controls of dissolved inorganic nitrogen (DIN) and dissolved silica (DSi) fluxes in heterogeneous catchments. Journal of Hydrology, 450–451, 36–47. https://doi.org/10.1016/j.jhydrol.2012.05.035

Ord, J. K., & Getis, A. (1995). Local Spatial Autocorrelation Statistics: Distributional Issues and an Application. Geographical Analysis, 27(4), 286–306. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x

Oversight, S., & Reform, G. (2012). Vacant properties: Growing number increases communities' costs and challenges. In No One Home: Challenges and Costs of Vacant Properties (Issue November).

Pan, Y., Zeng, W., Guan, Q., Yao, Y., Liang, X., Yue, H., Zhai, Y., & Wang, J. (2020). Spatiotemporal dynamics and the contributing factors of residential vacancy at a fine scale: A perspective from municipal water consumption. Cities, 103(March), 102745. https://doi.org/10.1016/j.cities.2020.102745

Park, J. Il. (2019). A multilevel model approach for assessing the effects of house and neighborhood characteristics on housing vacancy: A case of Daegu, South Korea. Sustainability (Switzerland), 11(9), 9–12. https://doi.org/10.3390/su11092515

Park, Y., Newman, G. D., Lee, J. E., & Lee, S. (2021). Identifying and comparing vacant housing determinants across South Korean cities. Applied Geography, 136(August), 102566. https://doi.org/10.1016/j.apgeog.2021.102566

Peeters, A., Zude, M., Käthner, J., Ünlü, M., Kanber, R., Hetzroni, A., Gebbers, R., & Ben-Gal, A. (2015). Getis-Ord's hot- and cold-spot statistics as a basis for multivariate spatial clustering of orchard tree data. Computers and Electronics in Agriculture, 111, 140–150. https://doi.org/10.1016/j.compag.2014.12.011

Philip McCann. (2013). Modern Urban and Regional Economics (2nd ed.). Oxford University Press. https://doi.org/10.4324/9781315014814

Radzimski, A. (2016). Changing policy responses to shrinkage: The case of dealing with housing vacancies in Eastern Germany. Cities, 50, 197–205. https://doi.org/10.1016/j.cities.2015.10.005

Rajalahti, T., Arneberg, R., Berven, F. S., Myhr, K. M., Ulvik, R. J., & Kvalheim, O. M. (2009). Biomarker discovery in mass spectral profiles by means of selectivity ratio plot. Chemometrics and Intelligent Laboratory Systems, 95(1), 35–48. https://doi.org/10.1016/j.chemolab.2008.08.004

Rossi, F., & Becker, G. (2019). Creating forest management units with Hot Spot Analysis (Getis-Ord Gi*) over a forest affected by mixed-severity fires. Australian Forestry, 82(4), 166–175. https://doi.org/10.1080/00049158.2019.1678714

RVD. (2019). Hong Kong Property Review 2019. Rating and Valuation Department. https://www.rvd.gov.hk/doc/en/PR_fullbook/PR2019.pdf

Sapporo City (b). (n.d.). Basic Resident Register Population. http://www.city.sapporo.jp/toukei/jinko/juuki/juuki.html#ku

Sapporo city (d). (2021). Sapporo City Statistics. Town Development Bereau City Planning Department City Planning Divison (in Japanese).

Segú, M. (2020). The impact of taxing vacancy on housing markets: Evidence from France. Journal of Public Economics, 185, 104079. https://doi.org/10.1016/j.jpubeco.2019.104079

Seirin-Lee, S., Nomata, M., & Mukunoki, M. (2020). Mathematical modeling and regionality-based optimal policy to reduce empty houses, Akiya, in Japan. Japan Journal of Industrial and Applied Mathematics, 37(2), 365–382. https://doi.org/10.1007/s13160-019-00400-3

Sophie, B. (2010). From shrinking cities to toshi no shukusho: Identifying patterns of urban shrinkage in the Osaka Metropolitan Area. In Berkeley Planning Journal (Vol. 23, Issue 1, pp. 132–155).

Statistics Bureau of Japan. (2020). Statistical Handbook of Japan 2020. Ministry of Internal Affairs and Communications.

Statistics of Japan. (2018). Housing and Land Survey. Statistics Bureau, & Ministry of Internal Affairs and Communications.

Suzuki, T., & Muromachi, Y. (2010). Empirical Analysis on the Railroad Development Impact on Local Population Density in Japan. Journal of the Eastern Asia Society for Transportation Studies, 8(2006), 1039–1052.

Thalmann, P. (2012). Housing market equilibrium (almost) without vacancies. Urban Studies, 49(8), 1643–1658. https://doi.org/10.1177/0042098011417902

The U.S. Census Bureau. (2020). Quarterly Residential Vacancies And Homeownership, First Quarter 2020.

Tran, T. N., Afanador, N. L., Buydens, L. M. C., & Blanchet, L. (2014). Interpretation of variable importance in Partial Least Squares with Significance Multivariate Correlation (sMC). Chemometrics and Intelligent Laboratory Systems, 138, 153–160. https://doi.org/10.1016/j.chemolab.2014.08.005

Vinzi, V. E., Chin, W. W., Henseler, J., & Wang, H. (2010). Handbook of Partial Least Squares. In V. Esposito Vinzi, W. W. Chin, J. Henseler, & H. Wang (Eds.), Springer Handbooks of Computational Statistics. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-32827-8

Wang, K., & Immergluck, D. (2018). Housing vacancy and urban growth: explaining changes in long-term vacancy after the US foreclosure crisis. Journal of Housing and the Built Environment, 34(2), 511–532. https://doi.org/10.1007/s10901-018-9636-z

Wang, Y., Potoglou, D., Orford, S., & Gong, Y. (2015). Bus stop, property price and land value tax: A multilevel hedonic analysis with quantile calibration. Land Use Policy, 42, 381–391. https://doi.org/10.1016/j.landusepol.2014.07.017

Weaver, R., Bagchi-Sen, S., Knight, J., & Frazier, A. E. (2016). Shrinking Cities. In Shrinking Cities: Understanding Urban Decline in the United States. Routledge. https://doi.org/10.4324/9781315757582

Wegmann, J. (2020). Residences without residents: Assessing the geography of ghost dwellings in big U.S. cities. Journal of Urban Affairs, 42(8), 1103–1124. https://doi.org/10.1080/07352166.2019.1657020

Wheaton, W. C. (1990). Vacancy, Search, and Prices in a Housing Market Matching Model. Journal of Political Economy, 98(6), 1270–1292. https://doi.org/10.1086/261734

Wilhelmsson, M., Andersson, R., & Klingborg, K. (2011). Rent control and vacancies in Sweden. International Journal of Housing Markets and Analysis, 4(2), 105–129. https://doi.org/10.1108/17538271111137903

Wilson, W., Cromarty, H., & Barton, C. (2018). Empty Housing (England). 3012, 34. file:///C:/Users/user/Downloads/SN03012.pdf

Wold, S., Johansson, E., & Cocchi, M. (1993). PLS: Partial Least Squares Projections to Latent Structures. 3D QSAR in Drug Design: Theory, Methods and Applications., 523–550.

Wold, S., Sjöström, M., & Eriksson, L. (2001). PLS-regression: A basic tool of chemometrics. Chemometrics and Intelligent Laboratory Systems, 58(2), 109–130. https://doi.org/10.1016/S0169-7439(01)00155-1

Wuyts, W., Sedlitzky, R., Morita, M., & Tanikawa, H. (2020). Understanding and managing vacant houses in support of a material stock-type society-The case of Kitakyushu, Japan. Sustainability (Switzerland), 12(13). https://doi.org/10.3390/su12135363

Xie, Y., Gong, H., Lan, H., & Zeng, S. (2018). Examining shrinking city of Detroit in the context of socio-spatial inequalities. Landscape and Urban Planning, 177(May 2017), 350–361. https://doi.org/10.1016/j.landurbplan.2018.03.002

Xu, H., & Zhou, Y. (2019). Public housing provision and housing vacancies in Japan. Journal of the Japanese and International Economies, 53(January). https://doi.org/10.1016/j.jjie.2019.101038

Yamada, H., & Uosaki, K. (2007). National Report of Japan. Third United Nations Conference on Housing and Sustainable Urban Development, July, 1–15. http://habitat3.org/wp-content/uploads/Habitat-III-National-Report-Japan-final.pdf

Yamashita, S., & Morimoto, A. (2015). Study on Occurrence Pattern of the Vacant Houses in the Local Hub City. Journal of the City Planning Institute of Japan, 50(3), 932–937.

Yang, Y., Zhao, T., Wang, Y., & Shi, Z. (2015). Research on impacts of population-related factors on carbon emissions in Beijing from 1984 to 2012. Environmental Impact Assessment Review, 55, 45–53. https://doi.org/10.1016/j.eiar.2015.06.007

Yoo, H., & Kwon, Y. (2019). Different Factors Affecting Vacant Housing According to Regional Characteristics in South Korea. Sustainability, 11(24), 6913. https://doi.org/10.3390/su11246913

Zhang, B. (2020). Why is japan's housing vacancy rate so high a history of postwar housing policy. Social Science Japan Journal, 23(1), 65–77. https://doi.org/10.1093/ssjj/jyz041

CHAPTER 3

Assessing the transportation system efficiency in the relationship to the utilization of urban housing

ABSTRACT

Urban housing and transportation are strongly related systems. The balance between them has an important role in urban development. In the context of urban shrinkage, many urban areas face a dramatic decrease in population. This leads to a fall in passenger demand and under-capacity operations. Furthermore, excess investment in transportation systems puts intense pressure on local governments' budgets, especially in shrinking urban areas. To evaluate the spatial efficiency of the transportation systems in the relationship with urban housing, in this chapter, the data envelopment analysis is proposed. The findings highlight that two-thirds of the areas were operating below capacity, and among them, car parking sites and areas were excessive at 27.81% and 15.86%, respectively. Meanwhile, bus stops, road density, and train station service areas exceeded the demand by about 12% to 16%. Moreover, the results also indicate that the shortfall in the housing filling rate was high, at 3.82%. Finally, based on the analysis, some suggestions for city policymakers are introduced to improve overall efficiency.

Keywords: *Transportation resources, data envelopment analysis, DEA, urban housing, efficiency.*

3.1. INTRODUCTION

As mentioned in the previous chapters, the proportion of vacant houses in developed countries has increased dramatically in recent decades. When housing vacancy in urban areas becomes a crisis, it causes many socioeconomic problems, including the decline in the value of nearby properties, rising crime, and poor sanitation (Gu et al., 2019; Han, 2014, 2019; Immergluck, 2016; Keenan et al., 1999; Martinez-Fernandez et al., 2016). For an urban transportation system, an increase in vacancy rates in an area subsequently decreases the number of passengers using the area's which then runs under capacity. While the local revenue is reduced by increased vacant houses, maintaining normal operations of the transport system in many low-density areas can put many pressures on the governments. In this context, assessing the efficiency of the transportation system in its relationship with the urban housing is necessary. Although this problem is attracting attention in the literature, its severity has not yet been evaluated thoroughly.

According to Alahmadi et al. (2016), Biljecki et al. (2016), and Talent (2017), residential housing is a proxy for the population; therefore, it can be used to estimate the resident density in urban areas. In fact, there is an interaction between the number of residential houses and the transportation system. On the one hand, high-density housing increases the road network density and public transport use (Cervero, 1994; Hawbaker et al., 2005). On the other hand, the high capacity and accessibility of the transportation system promotes housing development. For example, high-rise buildings and high-density dwellings are more likely to be constructed close to metro stations (Guan, 2019; Lin et al., 2020; Wang et al., 2019; Yang et al., 2020). Furthermore, the capacity of the road network can be used to estimate the optimal and maximum housing floor area ratio (HFAR) and office and industry floor areas (Iravani, 2011; Li et al., 2020; Morimoto et al., 2000). Apart from this interaction, the transportation system also influences the urban form and housing market. For instance, the road network is a reliable variable for detecting land-use changes and the speed of urban expansion (Kamarajugedda & Lo, 2019; Q. Zhang et al., 2002; Zhao et al., 2017). Wang et al. (2015) showed that bus stop locations and the walking distance to the bus stop were associated with property prices. Meanwhile, access to rail transit and bus rapid transit (BRT) was found to increase the value of residential housing in the US, Asia, and Europe (Brandt & Maennig, 2012; He, 2020; Ma et al., 2014; Martínez & Viegas, 2009; Pan, 2013). The literature shows that transportation and housing have a mutual relationship. Notably, no studies have mentioned the under-capacity of the transportation system when housing use is low, which may cause the system to run inefficiently. Investment in transportation infrastructure is costly; therefore, a quantitative investigation to fill this knowledge gap is necessary.

In benchmarking, data envelopment analysis (DEA) is a superior tool for estimating the efficiency of a decision-making unit (DMU), which is any organization, system, or entity that uses resources as inputs to its deliberations. Farrell (1957) introduced DEA as a nonparametric method in 1957. Two decades later, Charnes et al. (1978) developed DEA using the linear programming solution that established the production frontier. DEA has since been applied widely in socioeconomic fields and is a favourable method in five: i.e., banking, health care, agriculture and farming, transportation, and education (Liu et al., 2013). In transportation, Mahmoudi et al. (2020) declared that DEA is one of the most effective techniques in evaluating not only the transportation system, but its related issues, such as the environment, sustainability, and eco-design. Fancello et al. (2020) used the basic DEA model to compare the capability of different urban road networks. In addition, DEA is popular in measuring road safety on a national scale or within urban areas (Seyedalizadeh Ganji & Rassafi, 2019; Shen et al., 2012, 2015). Regarding public transportation systems, DEA can be used to estimate the efficiency of mass rapid transit projects, urban railways, and bus systems (Fitzová & Matulová, 2020; Georgiadis et al., 2014; Graham, 2008; Jain et al., 2008; Li et al., 2013; Min et al., 2015). Other researchers have used DEA to benchmark the efficiency of individual transportation organizations. For instance, Nguyen et al. (2016) measured the performance of seaports in Vietnam, while Lin and Tseng (2007) examined their scale in the Asia–Pacific region. Moreover, Rashidi and Cullinane (2019) found DEA to be a reliable method for assessing the sustainability of national logistics performance. These studies suggest that DEA is a promising solution for our problem.

Researchers prefer DEA to other methods for two reasons. First, besides measuring the DMU's efficiency, DEA estimates the surplus of inputs and shortfall of outputs quantitatively. Second, DEA can remedy the drawbacks of statistical methods, of which, the constraint of one dependent variable is a weakness. As a nonparametric approach, DEA manages multiple inputs and outputs in just one model. These advantages assure the utility of DEA to examine the relationship between transportation features and housing indexes. Nevertheless, to the best of my knowledge, there are only two studies (Dewita et al., 2018, 2019) related to this subject. Both studies focused on the influence of housing and transport expenditure on household net income. No association was found between those works and the present study.

To fill the knowledge gap described above, this study aims to measure the efficiency of the transportation system regarding housing patterns in urban areas and answer the following three research questions. First, which areas outperform others in using the transportation system to boost their residential and commercial properties and control the housing filling rate? Second, how is inefficiency related to a surplus of transportation resources and a shortfall in the volume of properties? Third, what is the optimal scale in both transportation and housing systems that the areas should achieve? To address these questions, in this study, the efficiency of an area is defined as follows. A zone that uses fewer resources without affecting the quality of service has a higher efficiency score. Here, the transportation system and housing indexes represent the resources and service quality, respectively.

3.2. MATERIAL AND METHODOLOGY

3.2.1. Research area

In this study, Sapporo is still chosen as a case study. Located in the centre of Hokkaido, the biggest prefecture of Japan, Sapporo is facing a vacant housing crisis. As mentioned in the previous chapter, the vacancy rate in the city increased from 4.66% in 1973 to 11.93% in 2018

(Statistics of Japan, 2018). This value is much larger than the natural vacancy rate at 5%, which has a role in stabilizing the housing market (Gentili & Hoekstra, 2019). Besides, the city's population is expected to decrease in the future with an aging demographic. According to the City of Sapporo (2020), the ratio of elderly (≥65 years old) will increase from 28% in 2020 to 32% in 2030. Likewise, the total passenger volume of the city decreased in all public transportation sectors by 2.5% in 2019 compared with 2018 (City of Sapporo, 2019). The subway lost about 1.7%, while the declines in bus, tram, and train use were 4.2%, 8%, and 0.9%, respectively. This fall in demand causes the transportation system to run under its capacity. As a result, the city is experiencing financial pressure. Specifically, the city must balance its resources to maintain the quality of service. Thus, the present study would be meaningful to the target city.

3.2.2. Material

Regarding the material, this research gathered the data from two main resources. Firstly, the public transportation system (including the national railway, subway, tram, and bus systems) is collected on the website of the National Land Information Division (NLID, 2020). These data were validated by cross-checking with the information distributed by the Sapporo City Planning Policy Bureau (TDP, 2020). Similarly, the road network and the location and size of car parking areas were extracted from the city planning survey data and the Sapporo Industry Promotion Foundation (SIPF, 2020). Secondly, the information related to buildings is provided by ZENRIN, including the total floor area of residential and commercial buildings and occupied housing. Here, the term "commercial" refers to office, business, and commercial use.

To analyse the DEA model, the quality and quantity of the DMU dataset are key factors that influence the model's performance. First, a DMU should have the characteristics of inputs and outputs. This condition ensures the ranking estimation. In addition, the number of DMUs should not be too small or large. This affects the computation cost and the interpretation of results. At present, Sapporo city has three geographic administrative levels, including 10 wards (or Ku in Japanese), 70 sub-wards, and 5.454 city districts (or Chome in Japanese). To use a ward as the DMU, the DMUs dataset is not large enough to meet the model constraints, which are explained later. Moreover, the city district is not suitable for DMU because of its enormous size. The first condition may be violated when some transportation services do not exist in a small city district, e.g., train or subway lines. Thus, the analysis used the sub-ward zones as DMUs to investigate the system.

3.2.2.1. Transportation facilities index.

For transportation facilities index, this study strived to integrate all transportation elements into the benchmarking model. First, public transport includes the bus, tram, and rail systems. Other transportation infrastructure includes car parking areas and road networks. Bus and rail lines were not considered because they do not represent travel accessibility, except for bus stops and rail stations. These components are measured in density and ratio indexes. The former represents the bus stops, car parking locations, bus routes, and road network. The latter represents the car parking areas and rail stations derived as the ratio of the service area to the total area of the zone and multiplied by 100 (using percentages). As the spacing of rail stations is relatively high, this work used the term “service area” instead. This index was determined as being equal to a circular area with a radius of 800 m and the station at the centre. The radius is equivalent to about 10 minutes’ walk, which is a reasonable walking pace at a comfortable speed of 1.2–1.4 m/s for commuters (Mohler et al., 2007; Wu et al., 2019).

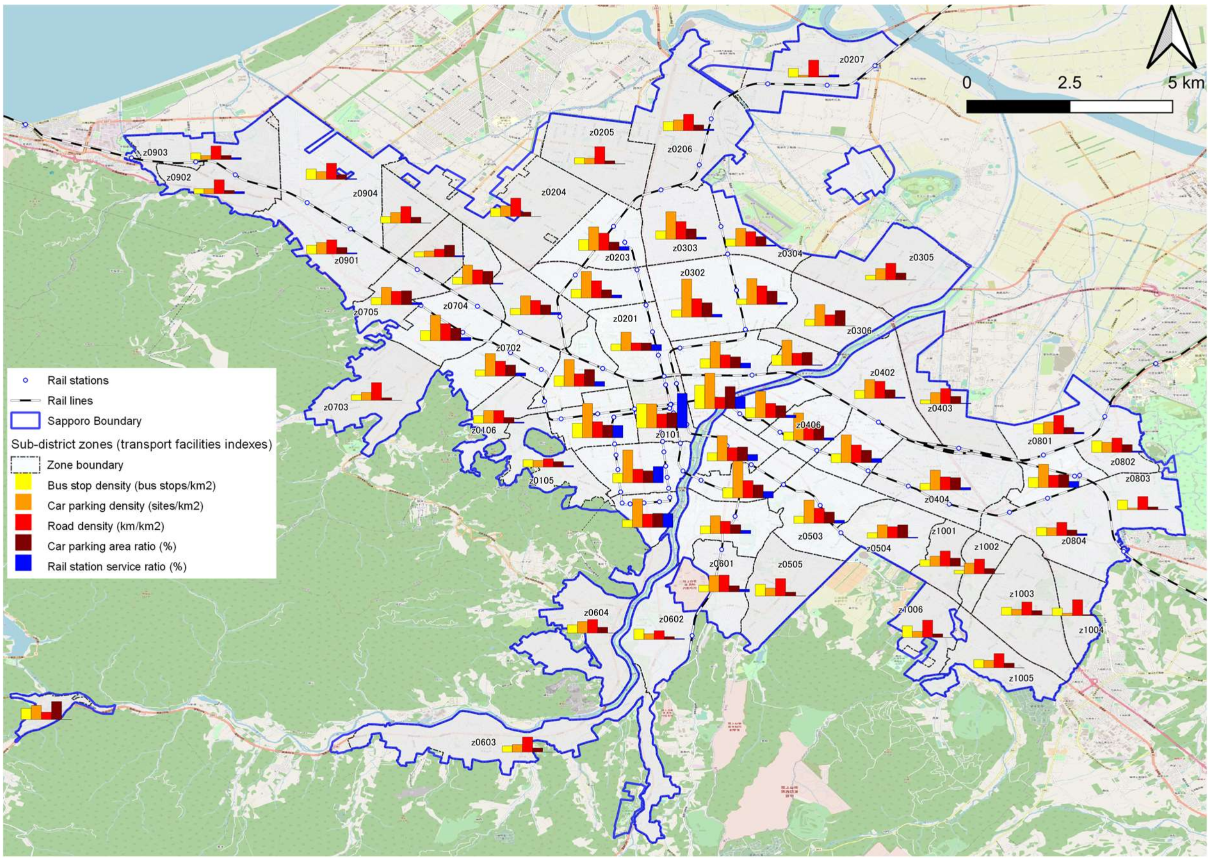


Figure 3.1. *Transportation facility indexes by sub-district zones*

Figure 3.1 shows the spatial distribution of transportation resources. As the figure shows, the indexes near the city’s centre are higher than for surrounding areas. For example, z0101, which is the central business district (CBD), has a high number of bus stops and rail station service areas. Zones near the CBD, e.g., z0102, z0103, and z0108, have even higher car parking indexes than z0101. Notably, car parking indexes are relatively high in most areas. This reflects that the car is the most popular means of transportation in the city. In addition, the road network density does not vary much across the city and rail services do not exist in some areas.

3.2.2.2. Housing and its spatial distribution in Sapporo city

In terms of outputs, three variables were used in this study. The first two are the commercial floor area ratio (CFAR) and HFAR. These two outputs are the components of the total floor area ratio (FAR), which is usually used as a restriction on the buildings' form in specific areas. To determine the values of CFAR and HFAR, this study modified the Japanese definition of FAR as in the study by Gao et al. (2006), where the CFAR value is derived from the commercial floor area divided by the total land area and multiplied by 100. Likewise, HFAR is calculated by replacing the commercial floor area with the housing floor area. HFAR can represent the limited population load, but not the actual value; therefore, this study used the filling rate as the third output, which is the ratio of total occupied floor area divided by total floor area and multiplied by 100. The ZENRIN data was used to create a distribution map of outputs (Fig 3.2).

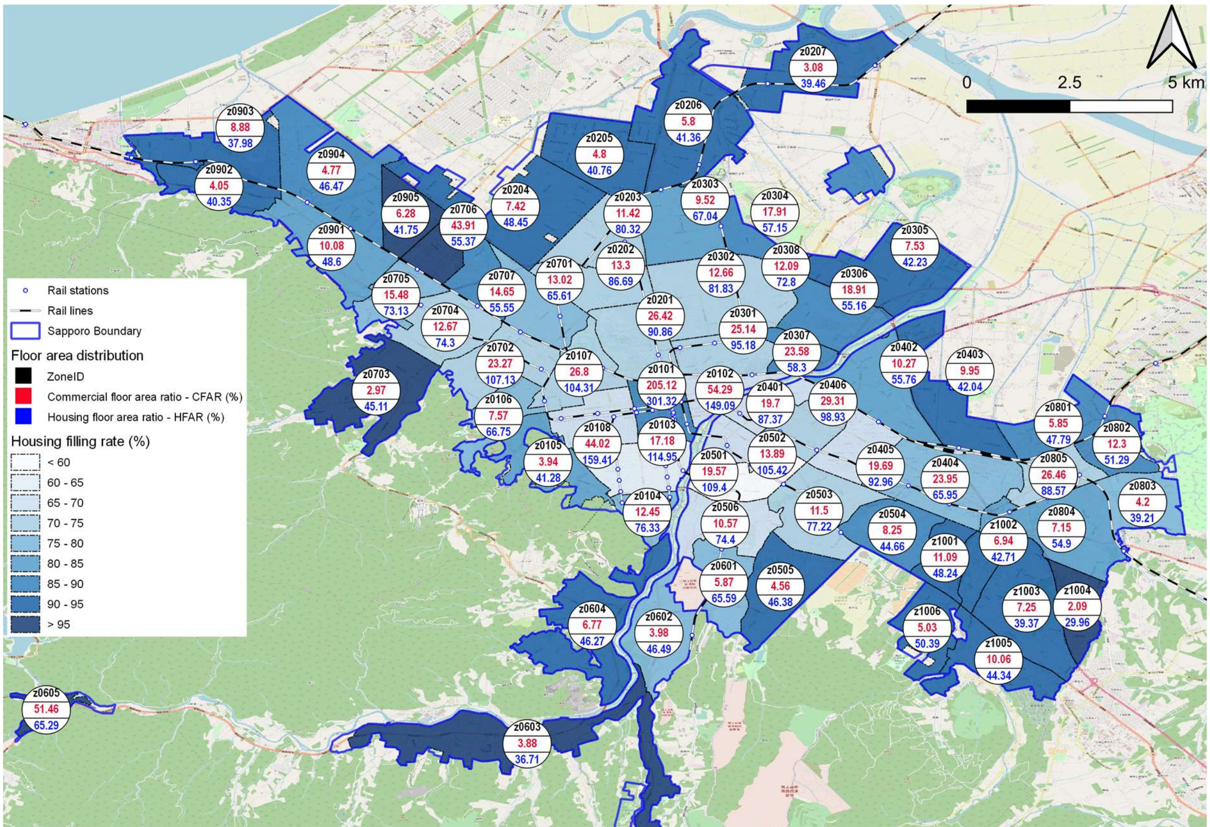


Figure 3.2. *CFAR, HFAR, and housing filling rate distribution*

As illustrated in Figure 3.2, the CBD (z0101) had the highest CFAR and HFAR values at 205.12% and 301.32%, respectively. Remarkably, the filling rate was not high in the city centre. The CBD had an 88.24% filling rate, while the nearby zones were even lower, e.g., z0103 and z0502 with 64.03% and 58.06%, respectively. The outskirt areas with low CFAR and HFAR values had a better filling rate with a value of over 90%.

Table 3.1 summarises the data set, including both input and output variables. The small zones were removed to ensure the homogeneity of the data set. The final number of DMUs was 63. As shown in Table 3.1, most of the variables seemed to have a normal distribution except for rail stations, CFAR, and HFAR. The distributions of these three variables were more likely to skew to the left, indicating the high frequency of the observation value less than the mean. For example, rail station services are not available in a variety of zones and the spatial distribution of rail stations is unequal. The common spacing between tram stations in z0103 and z0104 is about 360 m, while the same value for rail and subway stations is 1.2 km. By converting the density to the average distance, this study found that the average space between the bus stops is about 400 m. The value for car parking sites is 140 m. Likewise, the average road density implies that the average distance between roads is about 180 m. Remarkably, the sum of CFAR and HFAR varied from 32.05% (in z1004) to 506.44% (in z0101). These values are much lower than the constraints of 80% (in a residential area) and 800% (in a commercial area) (Sapporo City Development Policy Planning Bureau, 2019).

Table 3.1. *Data statistics summary*

No	Variable	Explanation	Unit	Min	Median	Mean	Max
			Input				
1	BusS	Bus stop density	Stops/km^2	2.74	6.19	6.61	18.66
2	CarPs	Car parking site density	Sites/km^2	5.35	50.29	51.72	117.09
3	Road	Road density	km/km^2	11.34	22.27	22.34	28.67
4	CapPa	Car parking area ratio	%	0.34	2.58	2.78	6.81
5	RailS	800 m rail station service area ratio	%	0.00	54.54	97.07	1,065.67
			Output				
1	CFAR	Commercial floor area ratio	%	2.09	11.09	17.18	205.12
2	HFAR	Housing floor area ratio	%	29.96	55.76	69.21	301.32
3	Fill_rate	Housing filling rate	%	58.06	83.23	82.25	98.76

3.2.3. DEA models

As mentioned in the previous chapter, the principal goal of this study is to identify surplus resources. This process matches the input orientation in the DEA approach. Thus, the two basic DEA models were applied, CCR and BCC, which refer to Charnes–Cooper–Rhodes (Charnes et al., 1978) and Banker–Charnes–Cooper (Banker et al., 1984), respectively. The concept of input orientation using DEA models is based on the ratio of virtual output and virtual input, which can be presented as in the graph in Figure 3.3.

In Figure 3.3, this study illustrated a set of DMUs (A, B, C, D, E, F) and two frontiers of the CCR model (the dash line) and BCC model (bold convex segment). The DMUs B and C are said to be overall or global efficient when they lay on the CCR frontier, while A, D, and E are pure or local efficient when they are on the BCC frontier. As F is under the two frontiers, it becomes inefficient. Basically, in the input orientation model, the CCR score of F is identified by the fraction of XF2/XF and the BCC score is XF1/XF. Meanwhile, the output orientation scores are YF/YF4 and YF/YF3 for CCR and BCC efficiency, respectively. Here, F1 and F3 are the projections of F to the BCC frontier, likewise, F2 and F4 are the projections of F to the CCR frontier. Of the four projections, F1 and F2 represent the input orientation, while F3 and F4 stand for the output orientation. Also, we have two pairs of points A and B, and D and E are the reference sets of F in the BCC model corresponding to the input and output orientation, respectively.

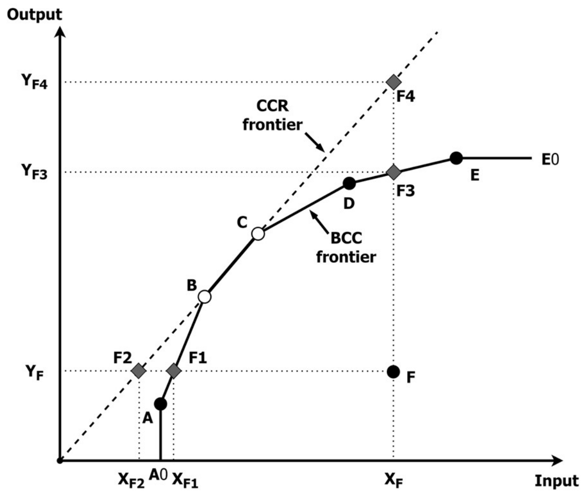


Figure 3.3. *CCR and BCC frontier visualization (produced by the authors)*

In the interpretation above, the noting point is that the CCR score is not larger than the BCC score. The fraction of CCR and BCC efficiency is called scale efficiency (SE). This value indicates the situation of a DMU, whether it is operating on an optimal scale. In another word, this score relates to the term of return to scale (RTS), though it does not reveal the status of increasing or decreasing return to scale (IRS and DRS). For example, in Figure 3, A0-A-B segments represent the IRS, which implies the enlargement of a DMU under this area will improve its efficiency. Whereas C-D-E-E0 is the DRS where the DMU's scale reduction will create an efficiency improvement and vice versa. By default, if the SE value is equal to 1, the DMU is on CRS. With SE score less than 1, then the DMU may fall onto the IRS or DRS status. Thus, the RTS identification is worth understanding the trend of scale adjustment to reach a better benefit. Note that the status of RTS may change regarding the orientation of the model. For the given DMU F, it operates on the IRS area in the input orientation model but DRS area in the output orientation model (Figure 3.3).

The mathematical form of the DEA models can be presented as follows (Cooper et al., 2007):

$$\min \quad \theta_o^* = \theta_o - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+) \tag{1}$$

Subject to

$$\theta_o x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \quad i = 1, \dots, m \tag{2}$$

$$y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \quad r = 1, \dots, s \tag{3}$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \; \forall \; i, j, r \tag{4}$$

$$\sum \lambda_j = 1 \quad (for\ BCC\ model) \tag{5}$$

where,

θ_o^* : technical efficiency score of DMU o,

ε : a small positive real number,

s_i^- : a slack input (surplus input),

s_r^+ : a slack output (output shortfall),

x_{io}, y_{ro} : the amount of input *i* and output *r* of DMU o,

λ_j : a semi-positive weight,

n, m, s : number of DMUs, inputs, and outputs, respectively.

With a set of *n* DMUs, the program solves *n* time to identify the optimal value of θ_o^* for DMU o. Then, DMU o is qualified to be efficient when it satisfies the two conditions: $\theta_o^* = 1$ and $s_i^- = s_r^+ = 0$, otherwise, it is inefficient. Any DMU that meets conditions (2) and (3) is in the reference set. The high frequency of a DMU in the reference set shows the high performance for other emulating DMUs. The low frequency of a DMU in the reference set indicates marginal efficiency, which implies that this DMU may lose efficiency if inputs increase, or outputs decrease even slightly. Notably, if an efficient DMU is not present in any reference set, then it is considered "efficient by default." Here, the DMU is operating with little input or producing an enormous output. Thus, it lies on the frontier by default and not by model measurement.

One meaningful outcome of the DEA model is the return-to-scale (RTS) status, which shows whether the DMU is operating optimally. When a DMU achieves CCR efficiency (the global efficiency), it has a constant RTS. Meanwhile, other DMUs are inefficient or local efficiency. They are operating at a decreasing RTS (DRS) or increasing RTS (IRS). Here, the efficiency can be improved by enlarging or reducing the DMU scale regarding IRS and DRS, respectively. In DEA models, the sum of lambda ($\sum \lambda_j$) in the CCR model determines the RTS status of a DMU. The DMU is under the IRS, CRS, or DRS when $\sum \lambda_j < 1, \sum \lambda_j = 1$, and $\sum \lambda_j > 1$, respectively.

When a DMU is inefficient, there are two ways to improve its performance. The first is to adjust the DMU scale based on its RTS status. Removing the input slack or supplementing the output slack are good alternatives for this adjustment. These processes represent the target or projection of the DMU using the theta parameter (θ^*). The following equations illustrate the projections of an inefficient DMU.

$$\hat{x}_{io} = \theta_o^* x_{io} - s_i^{-*} \quad (6)$$

$$\hat{y}_{ro} = y_{ro} + s_r^{+*} \quad (7)$$

Derived from equations (6) and (7), this study can estimate the gross amount of input reduction and output increment using equations (8) and (9):

$$\Delta x_{io} = x_{io} - (\theta_o^* x_{io} - s_i^{-*}) = (1 - \theta_o^*) x_{io} + s_i^{-*} \quad (8)$$

$$\Delta y_{ro} = (y_{ro} + s_r^{+*}) - y_{ro} = s_r^{+*} \quad (9)$$

Another important aspect of DEA is that the number of DMUs (*n*) must be large enough to ensure the model's reliability. Commonly, the observation size depends on the number of inputs (m) and outputs (s). Cooper et al. (2007) claimed that the value of *n* should be several times larger than the sum of *m* and *s*, but they did not mention any specific ratio. Meanwhile, Sarkis (2015) summarised how to determine the value of *n*. Based on this introduction, the minimum number of DMUs should equal ($m*s$), (m + s)*2, ($m + s$)*3, or ($m*s$)*2.

To summarise, the present study has three steps. First, the data was manipulated and removed the outliers. Then used multilinear regression models to determine the relevant variables with the outputs as the dependent variables and the transportation indexes as explanatory variables. The results of the regression model verify the significant factors in the DEA. Finally, this study applied the two basic DEA models, CCR and BCC, to clarify the research questions.

3.3. RESULTS

3.3.1. Selection of variables

The results of multilinear regression models are illustrated in Table 3.2. Remarkably, all input variables were significant in at least one model. For example, bus stops and rail stations were significant in the CFAR and FAR models, while car parking indexes were significant in commercial floor area and filling rate models. Meanwhile, road density showed a significant correlation only with the housing filling rate. The adjusted R-Squared values of the models were high. These figures accounted for 0.807, 0.895, and 0.725 in commercial, total FAR, and housing filling rate models, respectively. The result also highlighted that the variance inflation factor (VIF) values for all inputs were lower than 5, which indicates there was no non-collinearity problem among the variables. Hence, this study used these five features as inputs in the DEA.

Table 3.2. *Results of the linear regression models*

Term	CFAR model			HFAR model			Housing filling rate model		
	Coefficient	Std Error	VIF	Coefficient	Std Error	VIF	Coefficient	Std Error	VIF
(Intercept)	−17.918	11.795		11.404	13.131		76.082	5.580***	
BusS	1.711	0.790*	1.878	2.686	0.880**	1.878	−0.052	0.374	1.878
CarPs	−0.536	0.113***	4.703	0.194	0.126	4.703	−0.475	0.054***	4.703
Road	0.425	0.463	1.606	0.198	0.515	1.606	0.821	0.219***	1.606
CapPa	10.807	2.335***	4.591	3.478	2.600	4.591	4.460	1.105***	4.591
RailS	0.123	0.014***	2.238	0.164	0.016***	2.238	0.003	0.007	2.238
R-squared	0.807			0.895			0.725		
Adj R-squared	0.790			0.886			0.701		
RMSE	11.602			12.916			5.489		
F ratio	47.692			97.211			30.015		
P value	3.85E-19			1.31E-26			8.28E-15		

*, **, *** represent significance levels of <0.05, <0.01, and <0.001, respectively.

3.3.2. Data envelopment analysis

3.3.2.1. Efficient zones

By summarizing the values shown in Appendix A, Table 3.3 shows the overall efficiency of DMUs. The results show that 20 and 22 zones were efficient, which accounts for about 31.75% and 34.92% of the zones in the CCR and BCC models, respectively. The average efficiency score for the BCC model (0.890) was higher than that for the CCR model (0.877), which suggests that about 11% to 13% of resources were surplus. About 54% of the zones had an efficiency value higher than the average, where the CCR and BCC models showed 34 and 36 zones, respectively, which indicates that their efficiency is generally quite low.

Table 3.3. *Summary of efficiency analysis*

Term	CCR model		BCC model		Total
	$\boldsymbol{\theta_{CCR}}$	$\mathbf{1}\text{-}\boldsymbol{\theta_{CCR}}$	$\boldsymbol{\theta_{BCC}}$	$1-\boldsymbol{\theta_{BCC}}$	
Average	0.877	0.123	0.890	0.110	
Min	0.652	0.348	0.665	0.335	
Max	1	0	1	0	
Efficient zones	20		22		
Scores over average	34		36		
RTS*					
CRS	1		1		20
DRS	0.839		0.862		16
IRS	0.809		0.826		27

Min/Max – minimum and maximum value; RTS – Return to scale; IRS – increasing RTS; DRS – decreasing RTS; CRS – constant RTS; *Average efficiency score

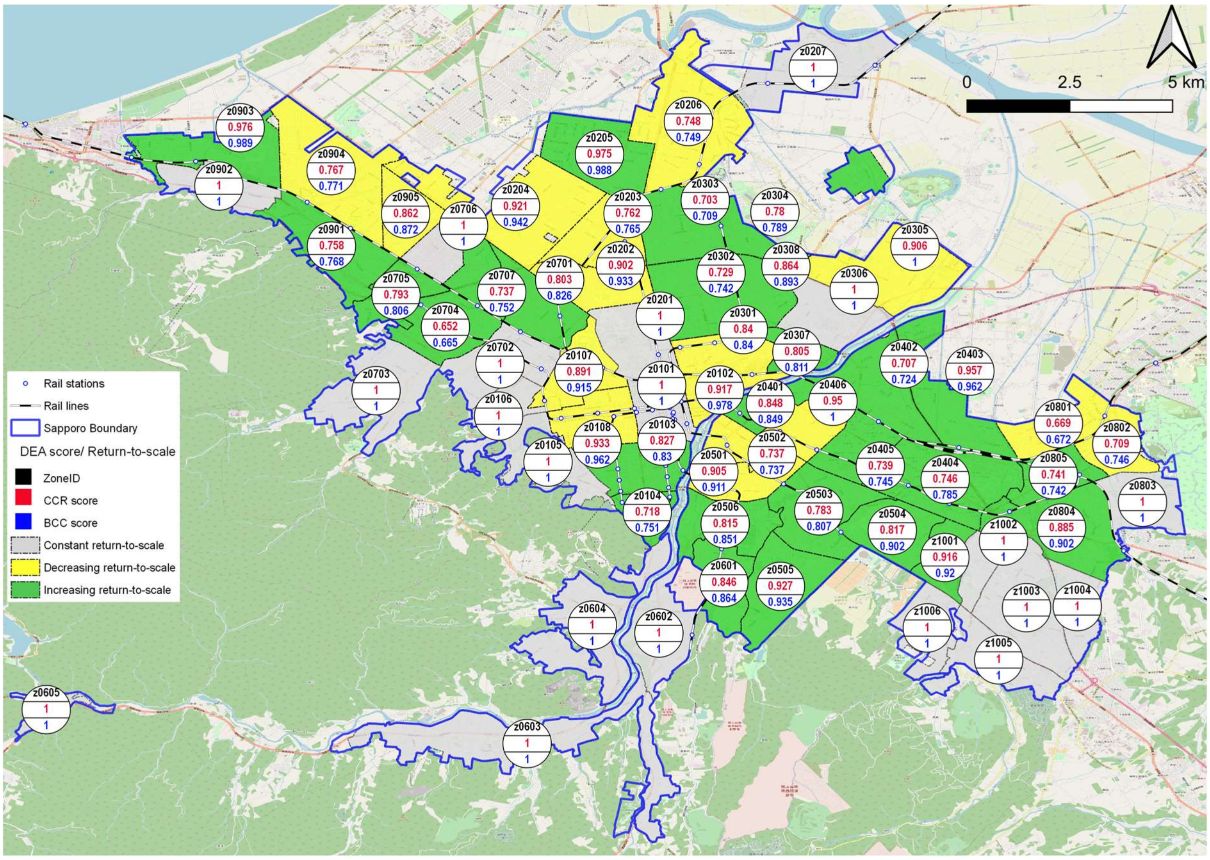


Figure 3.4. *Efficient score and return-to-scale status by zone*

Figure 3.4 illustrates the efficiency score of each zone, including the BCC and CCR scores. Almost efficient BCC zones reached global efficiency, CCR efficiency, except z0305 and z0406. Notably, the city centre had only two efficient zones: z0101 (the CBD) and z0201 (Hokkaido University). The other efficient zones were mostly near the city border. On the northeast side, three zones were efficient (i.e., z0207, z0305, and z0306). Only two zones in the northwest were efficient (i.e., z0706 and z0902). Meanwhile, the south and the west each had four efficient zones. Three efficient zones on the west side were near the city's centre (i.e., z0105, z0106, and z0702). The southeast had six efficient zones, which was the highest (i.e., z1002 to z1006, and z0803).

Regarding the inefficient areas, the results showed that the zones surrounding the CBD were inefficient. Nonetheless, these zones had high efficiency scores of about 0.9. The low-efficiency zones were mainly in three locations. The north had five zones (i.e., z0203, z0206, z0302, and z0303), each with a score under 0.8. Likewise, a group of five zones, including the least efficient zone, z0704, was in the northwest, and the largest group of inefficient zones-seven-were in the east.

Besides showing the efficiency scores, Figure 3.4 illustrates the RTS status of each zone. As the results show, a large proportion of zones operated under CRS and IRS conditions. The proportions of CRS and IRS zones accounted for about 31.7% and 42.9% of the zones, respectively. Meanwhile, the DRS zones comprised just 25.4% of the zones (16 zones). Eight of the DRS zones were near the city's centre, and of them only one zone (z0502) had an efficiency score lower than 0.8. The other low-efficiency DRS zones were in the north (z0203, z0206, and z0904) and the east of the city (z0801 and z0802). Note that among the DRS zones, two zones showed local efficiency (z0406 and z0305).

In contrast to the DRS zones, the IRS zones occurred equally on both sides of the Toyohira River, which flows through the city. Of the 27 IRS zones, 14 were on the north side and 13 were on the south side of the river. Although the two sides had a similar number of zones, the south side outperformed the north side. The south had seven low-efficiency zones compared with 10 zones in the north. Remarkably, the DRS zones had higher efficiency scores than the IRS zones. The average BCC scores for the DRS and IRS zones were 0.862 and 0.826, respectively.

3.3.2.2. Projection and improvement

Using the results shown in Appendix B, my study illustrates the input and output slacks in Figure 3.5. In terms of input slack, the number of car parking sites appeared to be the most popular surplus transportation resource. Car parking sites were found in 36 zones, including seven zones that had parking site slack of over 20 sites/km^2. The highest surplus was in z0102 with a value of 47.63 sites/km^2 following by z0302 with 35.25 sites/km^2. As shown in Figure 3.5, the greatest surplus was on the north side of the Toyohira River. Remarkably, while the number of car parking sites showed a surplus in numerous zones, a car parking area surplus occurred in only 10 zones. The highest surpluses of car parking areas were in z0102, z0104, and z0308, each with a value of more than 1.0%.

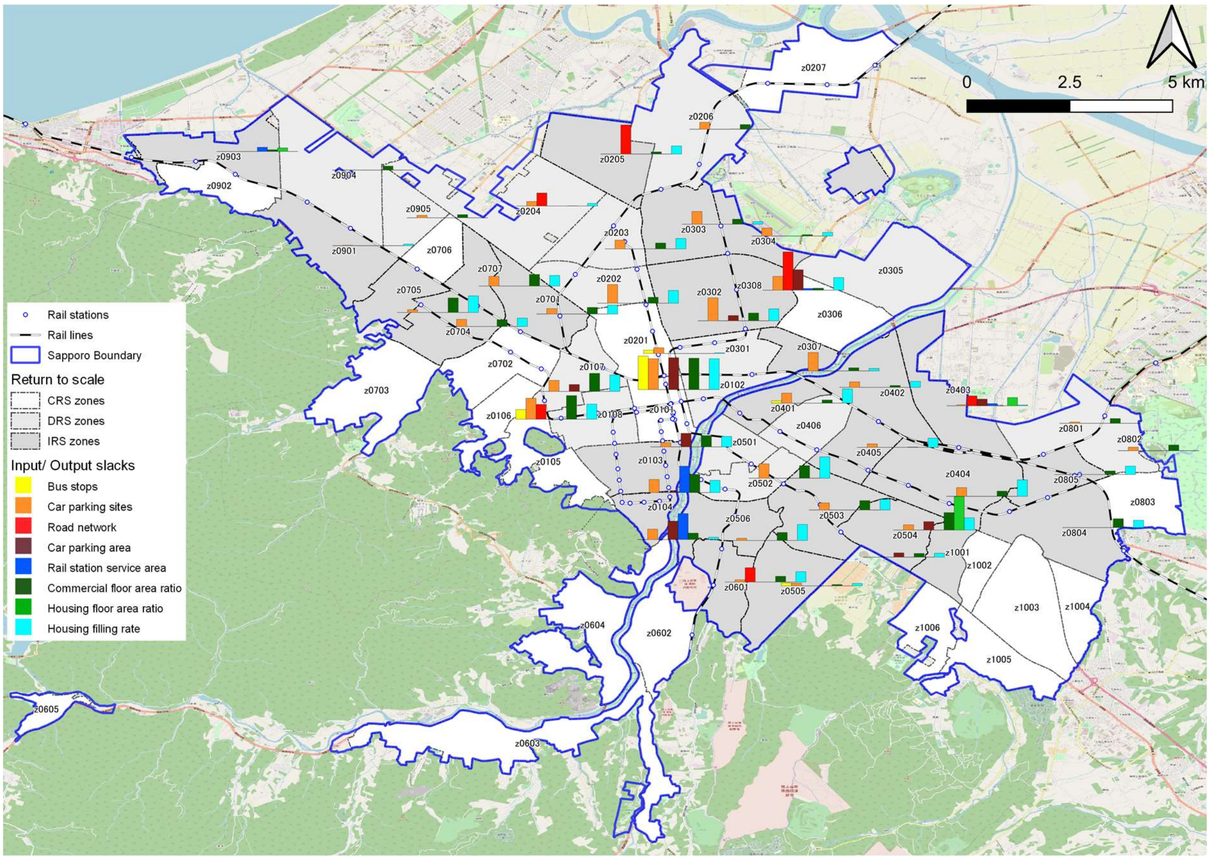


Figure 3.5. *Distribution of input excess and output shortfall*

After car parking areas, the surplus was highest in the rail station service area and road density. Of 63 zones, six had a surplus of rail station service area and road density. Nevertheless, the slack of the rail stations was extremely high in z0103 and z0104 at a value of over 190%. Meanwhile, the average slack of road density in six zones was just 1.40 km/km^2. Bus stop density appeared to be a useful resource because it showed slack in only five zones. Similar to road density, the surplus in the bus stop variable was quite low. The average slack value of bus stop density in five zones was 1.77 stops/km^2. z0102 had the highest slack in bus stop density, with a value of 6.89 stops/km^2.

In terms of output slack, the results indicated a substantial difference between the three outputs. Slack in HFAR occurred in just three zones, i.e., about 4.8% of zones. Whereas slack of CFAR and floor-filling rate appeared in 60.3% and 55.6% of the zones, respectively. As Figure 3.5 shows, the HFAR slack zones were z0403, z0504, and z0903. Likewise, shortfalls in CFAR and the filling rate were mainly in the zones surrounding the city center. Remarkably, three zones had a high shortfall of both CFAR and filling rate (i.e., z0102, z0107, and z0108).

Using equations (8) and (9), this study computed the total amount of input and output improvement for each zone. Then the outcomes were converted into the actual units as expressed in Table 3.4. Regarding the improvement of inputs, car parking sites had the highest surplus in transportation services with 3,309 surplus sites or 27.81% of the sites. Next was the rail station service area, with a surplus of about 18.19% (equal to 3,839.91 thousand square meters). Meanwhile, the surplus of the car parking area was 15.86% (equal to 99.30 thousand square meters). Compared to car parking sites, the number of surplus bus stops was 207 at about 12.94%. The road network was found to have 690.67 km of surplus, equal to 10.30% of the current value.

Table 3.4. *Summary of input reduction and output improvement*

Input/Output	Bus stops (stops)	Car parking sites (sites)	Road network (km)	Cap parking area (10,000m^2)	Rail station service (10,000m^2)	CFAR(*) (%)	HFAR(*) (%)	Housing filling rate(*) (%)
Actual value	1,596	11,897	5,722.85	625.92	20,015.16	17.18	69.21	82.25
Improvement	207	3,309	690.67	99.30	3,839.91	5.62	0.15	3.82
Change (%)	12.94	27.81	12.07	15.86	19.19	32.71	0.21	4.64
Num. zone	41	41	41	41	39	38	3	35

(*) Average value

In terms of output improvement, the results suggest that the CFAR was presumed to increase 5.62%, about 32.71 percentage points, over the current value. Meanwhile, HFAR was expected to increase 0.15%, about 0.21 percentage points over the current amount. Interestingly, the housing filling rate of the city was supposed to increase by about 3.82 percentage points. This means the average proportion of occupied houses should rise to 86.07%.

3.3.2.3. Zones reference sets

Table 3.5 summarizes the reference frequency of the efficient zones, including their self-references. In the reference sets, we categorized the efficient zones into four classes: high performance (class A), medium performance (class B), marginal performance (class C), and default performance (class D). The first group comprises the zones that have a high frequency (presented more than 14 times in the reference set, i.e., z0106, z0201, z0602, z0702, z0706, and z1002). Of the six zones, z0706 outperformed the others with a frequency of 27 and provided the best practice for inefficient areas to imitate.

Table 3.5. *Frequency of references*

No.	Ref. zones	Total	Class	No.	Ref. zones	Total	Class	No.	Ref. zones	Total	Class
1	z0101	14	B	9	z0602	17	A	16	z0803	3	C
2	z0105	4	C	10	z0603	2	C	17	z0902	6	C
3	z0106	15	A	11	z0604	1	D	18	z1002	22	A
4	z0201	23	A	12	z0605	13	B	19	z1003	1	D
5	z0207	1	D	13	z0702	26	A	20	z1004	9	B
6	z0305	1	D	14	z0703	12	B	21	z1005	2	C
7	z0306	2	C	15	z0706	27	A	22	z1006	8	B
8	z0406	1	D								

The medium performance group contained five zones that had a reference frequency between 7 and 14 (i.e., z0101, z0605, z0703, z1004, and z1006). The marginal group or class C encompassed areas that had references between 2 and 7 (i.e., z0105, z0306, z0603, z0803, z0902, and z1005). As mentioned in Section 2, these sub-districts are sensitive to changes in inputs and outputs. Any increase in transportation resources or decrease in outputs may eliminate these areas from the frontier. The fourth group includes the zones that appeared as the reference for themselves only. They had the status of "efficient by default," as explained in subsection 2.2.

3.4. DISCUSSIONS

3.4.1. Achieving efficiency

Based on their BBC efficiency scores, the zones were divided into three categories. The BCC score of the first category was equal to 1, while the second was from 0.9 to less than 1, and the third was lower than 0.9 as shown in Table 3.6. Note that in this table, the reference value should be the median to eliminate outliers except rail stations, which are discussed later. Based on these outcomes, this research recommend that the city emulate the first category's indexes. When these optimal indexes cannot be achieved, the second category is acceptable. Any area in the third category should be improved. The improvement process involves many factors; therefore, the following discussions focus on the approaches to deal with problems of inputs and outputs.

The results suggest that the optimal and acceptable values of parking site density are 23.92 and 34.52 sites/km^2, respectively. Likewise, the optimal value for the parking area ratio is 1.68%, while the acceptable value is 2.51%. Even though this value is lower than that of some cities in Australia and the US (Kimpton et al., 2020; Scharnhorst, 2018), it reflects Japanese commuting habits. A large proportion of commuters use a private vehicle for traveling. Car ownership in Japan is 105 units per 100 households (JAMA, 2020). Though parking is an essential transportation service, it promotes the use of private vehicles rather than non-motorized mobility. For instance, free parking sites stimulate automobile commuting and vice versa. Therefore, restricting car parking at both destinations and home has a great impact on reducing car use, especially in compact cities (Christiansen et al., 2017). Christiansen et al. (2017) and Guo (2013) argued that the parking supply has a significant effect on the rate of private vehicle use, with an even stronger effect than household income and demographic factors. Conversely, an increase in the cost of parking significantly reduces travel demand and car ownership (Nourinejad & Roorda, 2017; Seya et al., 2016).

Table 3.6. *Summary of transportation and housing indexes by efficiency rank*

BCC score	Number of zones	Index	Bus stop density (stops/km^2)	Car parking density (sites/km^2)	Road density (km/km^2)	Cap parking area ratio (%)	Rail station area ratio (%)	CFAR (%)	HFAR (%)	Filling rate (%)
1	22	mean	6.32	33.37	20.31	2.15	78.87	21.72	64.76	87.92
		median	5.84	23.92	21.58	1.68	4.47	7.09	45.69	91.53
0.9–1	13	mean	7.22	51.92	22.79	2.93	105.47	16.93	74.79	82.20
		median	6.33	34.52	23.47	2.51	60.75	9.95	48.45	86.09
<0.9	28	mean	6.55	66.04	23.73	3.21	107.47	13.74	70.11	77.82
		median	6.64	66.28	22.84	3.47	76.70	12.55	69.92	76.45

To reduce the parking scale, the efficient approach is to reduce the demand for car parking by improving the quality of public transportation or shifting the parking standard. For example, De Gruyter et al. (2020) declared that a 10% increase in public transport services can reduce 1.0% of the car parking demand. Meanwhile, Li and Guo (2014) found that changing the parking standard from minimum to maximum decreased 49% of the parking provision in London (equal to 0.76 parking spaces per dwelling). Note that the analysis data include only open-space parking areas. The actual area for car parking is even larger because many buildings have integrated parking lots. To promote sustainable development, car parking restrictions have a long-term benefit for the city.

Regarding public transportation, the results recommend a bus stop density between 5.84 and 6.33 stops/km^2, which suggests that the average distance between bus stops should be between 400 and 420 m. Bus stop spacing has a significant impact on both operation and accessibility. Longer distances increase vehicle speeds and thus reduce in-vehicle travel time. However, increasing the distance between bus stops also increases the customers' walking time. Thus, finding the optimal spacing of stops plays an important role in providing bus services. This value is normally found in bus design guidelines. For example, the usual distance between stops in the CBD is 300 m. In residential areas of the UK and Brazil, a distance between 300 m and 500 m is advised (Tirachini, 2014). In contrast, the U.S. manuals suggest that bus stop spacing should be 90 to 300 m in the CBD, 150 to 365 m in urban areas, 180 to 760 m in suburban areas, and 200 to 800 m in rural areas (Chen et al., 2016). However, the real-world values differ in practice from the guidelines. Tirachini (2014) reported that the common spacing between stops in European cities is between 300 m and 450 m. Meanwhile, Pandey et al. (2021) found that the average bus stop spacing in 43 US cities was 316 m in the city core and 407 m in the outskirts.

Li and Bertini (2008) estimated the optimal spacing between bus stops using cost functions and found that the value is 930 ft (about 305 m). According to Tirachini (2014), for the highest demand of 340,000 people per day, the best bus stop spacing for a single route is roughly 600 m in the suburbs and 400 m in the CBD if segregated busways and automated fare collection are applied. In high-volume urban corridors, Furth and Rahbee (2000) recommended a bus stop spacing between 320 m and 400 m. Note that the bus stop density in the present study relates to geographic distribution. The other studies estimated spacing between bus stops on a single route or bus network. Therefore, the bus stop spacing in Sapporo city may be dense in some areas but less dense in others. Changing the locations of bus stops will greatly affect operations; therefore, this study suggests that dedicated studies should examine the bus stop distribution in the city. Based on those results, the city can rearrange the system to achieve better performance.

In terms of the rail stations, the service area ratio is a proxy for rail station density. Therefore, it is also a proxy for rail station spacing. As expressed in Section 2, the spacing between the train and subway stations in Sapporo city is still far lower than the density in US cities at 2.17 km, including train, subway, and light rail transit (LRT) systems (Scharnhorst, 2018). Comparing the spacing of tram stations to the LRT system, this research found that the tram station spacing in Sapporo was shorter than that in North America (841 m) and in Europe (722 m), but longer than that in Australia (279 m) (Chen et al., 2016). In contrast to the bus stops, train station spacing mainly depends on operating speed and targeted objectives. Lutin and Benz (1992) suggested that a suitable spacing between stops in a CBD with bus service is

400 m and 1600 m for the suburbs to attract commuters away from freeways. As rail systems are costly and have permanent characteristics, rearranging or removing them is impractical. The present research argues that this phenomenon implies the inefficiency of using the system capacity. Thus, the study's results lead to two proposals. For Sapporo city, the administrators should set up a program to reduce the shortfalls in outputs, such as the housing filling rate. This improvement will fill the gaps in the capacity of services. As for other municipalities, when a railway system is available, the station service area should refer to a value of 60.75%. In the long term, to adapt to the change of demographics, the operation of new services, such as demand–responsive transport (DRT) and mobility-as-a-service (MaaS), is necessary.

For road networks, my study suggests that the road density should be between 21.58 and 23.47 km/km^2. These values are close to the median value of 22.34 km/km^2 of the city. Compared with other cities, the road network in Sapporo is like that of Toronto (22.24 km/km^2) but with higher density than in Kuala Lumpur (17.8 km/km^2) or Bangkok (17.24 km/km^2) (Kamarajugedda & Lo, 2019; Law et al., 2015; Maleki et al., 2012). Nevertheless, it is still lower than several densely urbanized areas, such as New York, London, and Chicago, at about 36–64 km/km^2 (Zhao et al., 2017). When the surplus amount of road is acceptable, removal is unnecessary. This study recommends treating these areas with the approaches introduced in the discussion of the rail system above.

The results show that the transportation system in Sapporo city operated under its capacity in many areas. To improve the efficiency of these services should not simply be to reduce the inputs because the outputs should also be increased. The present study argues that transportation policies should prioritize optimizing the CFAR and HFAR, and especially the housing filling rate. First, apart from areas like the CBD, commercial areas should be well organized across the city. This element plays an important role in serving the daily necessities of the residences and it reduces the pressure on the CBD. Based on the values in Table 3.6, this research suggests that the ratio of commercial floor area in residential zones should not be below 10%. Likewise, HFAR, which is an important component of FAR, has two roles. First, HFAR maintains the balance between population load and infrastructure. Second, it assures the quality of the living environment, e.g., providing natural light and ventilation, and avoiding heat island issues. Thus, besides the upper limit of FAR, we suggest the lower limit for HFAR should be 48.45%.

Finally, the housing filling rate is a big problem in the city. Consistent with the statistical data, the present study shows a low filling rate and its slack occurred in many locations. Among the reasons that cause houses to be vacant, depopulation and housing policies are the primary determinants. Concerning policies, Hattori et al. (2017) and Kobayashi (2015) claimed that population decline, an aging society, and low fertility are strongly associated with high vacancy rates. Meanwhile, the imbalance in tax rates on empty land and land with property makes it more likely that houses will be abandoned (Kobayashi, 2016; Xu & Zhou, 2019a). Furthermore, a low ownership rate also increases the vacancy ratio. My research argues that the city should have a plan to remedy these issues, which may include improving the property tax system, subsidizing young people to become owners of their own private house, or establishing projects to renovate the current living environment.

3.4.2. Productivity scale implications

Table 3.7 summarizes the variables' index in groups represented by CRS, DRS, and IRS. The CRS zones stand for the CCR efficiency; thus, their scale is like the first group in Table 3.6. Meanwhile, DRS zones use the highest resources and IRS zones have medium levels of both inputs and outputs. Regarding the implications for RTS, to improve efficiency, decision makers have three options. The first is to expand the scale of the IRS zone, while the second is to shrink the scale of the DRS zone and the third is to operate simultaneously in both orientations.

Table 3.7. *Summary of transportation and housing indexes by efficiency RTS status*

RTS	Number of zones	Index	Bus stop density (stop/km^2)	Car parking density (site/km^2)	Road density (km/km^2)	Cap parking area ratio (%)	Rail station area ratio (%)	CFAR (%)	HFAR (%)	Filling rate (%)
CRS	20	Mean	6.45	30.77	19.93	2.04	82.89	22.04	64.18	88.46
		Median	5.84	23.28	21.18	1.55	4.47	6.86	45.69	91.53
DRS	16	Mean	7.92	64.66	24.11	3.14	120.44	17.98	81.76	78.84
		Median	7.49	75.02	25.16	2.55	85.73	12.80	83.51	73.12
IRS	27	Mean	5.94	59.57	23.09	3.12	93.73	13.11	65.50	79.68
		Median	5.54	58.36	22.27	3.46	68.27	12.09	65.61	78.92

In Sapporo city, which has an aging society with a proportion of elderly at about 24.9% (Statistics Bureau of Japan, 2020), a policy of increasing only the productivity scale may be inappropriate. Therefore, my research suggests that the city should focus on managing the current infrastructure rather than investing in new areas. This approach is the same as the concept of active demand management (Martin et al., 2016). And this considers more like the first stage of recovering the city core because many zones in the city centre are operating under the DRS status. Likewise, the second stage is to expand the scale of the IRS zones. A suitable method is to improve cost-efficient transportation services, such as the bus system. Moreover, shifting transportation resources from DRS to IRS zones might be worth considering. This transformation will improve the zone's efficiency without affecting the total amount of resources.

Eventually, considering the term "efficient by default," the analysis identified five efficient zones that did not appear in any reference set. Consistent with the DEA theory, these zones have unique characteristics of using the least inputs and producing high outputs. For example, z0305, z0604, and z1003 do not have rail stations, but the filling rate is above 90.0%. Similarly, in z0207, the car parking indexes were extremely low (5.8 sites/km^2 and 0.37%), but the filling rate reached 93.0%. By contrast, z0406 has a high car parking index, but it has high values for CFAR and HFAR, accounting for 83.35% and 98.93%, respectively. The DEA model does not judge these zones' efficiency; hence, my research suggests that there are other influential characteristics, such as socioeconomic considerations. However, these zones do not provide the best practices to emulate.

3.5. CONCLUSIONS

This research applied the DEA model to measure the efficiency of the transportation system as it relates to urban housing conditions. The results show that the CBD and the outskirts outperform other areas. In addition, the study estimated the surplus quantity of transportation services, which should be adjusted to optimize the operation of infrastructure and control maintenance costs. The present study suggested some useful policy implications for policymakers. First, the development strategy should balance the transportation and urban housing systems. The transportation surplus affects the local budget and sustainability; therefore, the priority is to improve the outputs, especially the housing filling rate. Second, the urban plan must examine the development orientation for each area carefully. Based on the RTS status, some areas should enlarge the transportation scale, while others remain the same or reduce access to transportation. Third, when an aging society is growing, conventional transportation services become less attractive. Thus, the city should operate new services such as DRT or MaaS. Finally, concerning the urban housing issue, my research suggests the commercial and HFAR in residential areas should be higher at 10% and 48.45%, respectively. Likewise, the housing filling rate should be higher than 91%.

APPENDIXES

Appendix A. DEA efficiency scores and RTS status

Zones	CCR score	CCR rank	BCC score	BCC rank	SE	Σλ	RTS
z0101	1	1	1	1	1	1	CRS
z0102	0.917	28	0.978	25	0.937	1.146	DRS
z0103	0.827	40	0.830	42	0.996	0.863	IRS
z0104	0.718	58	0.751	53	0.957	0.922	IRS
z0105	1	1	1	1	1	1	CRS
z0106	1	1	1	1	1	1	CRS
z0107	0.891	33	0.915	32	0.974	1.196	DRS
z0108	0.933	25	0.962	27	0.970	1.518	DRS
z0201	1	1	1	1	1	1	CRS
z0202	0.902	32	0.933	30	0.967	1.074	DRS
z0203	0.762	49	0.765	51	0.996	1.008	DRS
z0204	0.921	27	0.942	28	0.978	1.032	DRS
z0205	0.975	22	0.988	24	0.987	0.959	IRS
z0206	0.748	51	0.749	54	1.000	1.004	DRS
z0207	1	1	1	1	1	1	CRS
z0301	0.840	39	0.840	41	0.999	1.042	DRS
z0302	0.729	57	0.742	58	0.982	0.930	IRS
z0303	0.703	61	0.709	61	0.992	0.983	IRS
z0304	0.780	47	0.789	47	0.988	0.977	IRS
z0305	0.906	30	1	1	0.906	1.025	DRS
z0306	1	1	1	1	1	1	CRS
z0307	0.805	43	0.811	44	0.993	0.984	IRS
z0308	0.864	35	0.893	36	0.968	0.914	IRS
z0401	0.848	37	0.849	40	1.000	0.943	IRS
z0402	0.707	60	0.724	60	0.977	0.959	IRS
z0403	0.957	23	0.962	26	0.994	0.994	IRS
z0404	0.746	52	0.785	48	0.950	0.893	IRS
z0405	0.739	54	0.745	56	0.992	0.973	IRS
z0406	0.950	24	1	1	0.950	1.070	DRS
z0501	0.905	31	0.911	33	0.993	1.057	DRS
z0502	0.737	55	0.737	59	1.000	1.108	DRS
z0503	0.783	46	0.807	45	0.970	0.930	IRS
z0504	0.817	41	0.902	34	0.906	0.903	IRS
z0505	0.927	26	0.935	29	0.992	0.983	IRS
z0506	0.815	42	0.851	39	0.957	0.895	IRS
z0601	0.846	38	0.864	38	0.979	0.910	IRS
z0602	1	1	1	1	1	1	CRS
z0603	1	1	1	1	1	1	CRS
z0604	1	1	1	1	1	1	CRS
z0605	1	1	1	1	1	1	CRS
z0701	0.803	44	0.826	43	0.972	0.941	IRS
z0702	1	1	1	1	1	1	CRS
z0703	1	1	1	1	1	1	CRS
z0704	0.652	63	0.665	63	0.980	0.946	IRS
z0705	0.793	45	0.806	46	0.985	0.919	IRS
z0706	1	1	1	1	1	1	CRS
z0707	0.737	56	0.752	52	0.980	0.934	IRS
z0801	0.669	62	0.672	62	0.996	1.042	DRS
z0802	0.709	59	0.746	55	0.951	1.055	DRS
z0803	1	1	1	1	1	1	CRS
z0804	0.885	34	0.902	35	0.981	0.944	IRS
z0805	0.741	53	0.742	57	0.999	0.943	IRS
z0901	0.758	50	0.768	50	0.988	0.983	IRS
z0902	1	1	1	1	1	1	CRS
z0903	0.976	21	0.989	23	0.987	0.985	IRS

Zones	CCR score	CCR rank	BCC score	BCC rank	SE	Σλ	RTS
z0904	0.767	48	0.771	49	0.994	1.007	DRS
z0905	0.862	36	0.872	37	0.988	1.024	DRS
z1001	0.916	29	0.920	31	0.995	0.985	IRS
z1002	1	1	1	1	1	1	CRS
z1003	1	1	1	1	1	1	CRS
z1004	1	1	1	1	1	1	CRS
z1005	1	1	1	1	1	1	CRS
z1006	1	1	1	1	1	1	CRS

SE - Scale efficiency; Σλ - Sum lambda; RTS – Return to scale; IRS – Increasing RTS; DRS – Decreasing RTS; CRS – Constant RTS

Appendix B. Input/output slack and target

DMU	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
z0101	0	0	0	0	0	0	0	0	18.66	73.94	21.52	4.71	1065.67	205.12	301.32	88.24
z0102	6.89	47.63	0	1.87	0	38.71	0	21.78	10.82	59.14	17.28	4.79	357.77	93.00	149.09	88.93
z0103	0	20.19	0	0.05	195.33	22.40	0	8.62	6.05	63.66	17.47	3.01	222.27	39.58	114.95	72.65
z0104	0	16.04	0	1.08	192.08	7.91	0	1.59	4.35	49.73	15.44	2.15	128.87	20.36	76.33	76.98
z0105	0	0	0	0	0	0	0	0	5.73	20.64	12.92	1.70	49.27	3.94	41.28	81.48
z0106	0	0	0	0	0	0	0	0	5.77	39.21	19.63	1.77	36.17	7.57	66.75	78.60
z0107	0	17.10	0	0.41	0	22.28	0	11.73	7.41	58.63	17.69	4.36	137.44	49.07	104.31	84.01
z0108	1.99	32.33	1.04	0	0	29.09	0	10.70	8.72	69.38	22.72	3.73	365.48	73.12	159.41	77.07
z0201	0	0	0	0	0	0	0	0	5.08	56.88	11.88	2.35	188.55	26.42	90.86	70.59
z0202	0	28.81	0	0	0	7.35	0	9.00	6.21	47.44	24.72	2.35	87.64	20.65	86.69	82.72
z0203	0	13.52	0	0	0	7.22	0	7.32	6.43	41.79	20.34	1.97	91.94	18.64	80.32	79.63
z0204	0	7	1	0	0	0	0	2	6.05	24.15	25.75	1.28	0.09	7.64	48.45	95.04
z0205	0	0	2	0	0	3	0	6	4.78	17.49	24.33	0.98	7.54	7.45	40.76	96.66
z0206	0	10.62	0	0	1	6	0.00	0	5.23	14.24	18.99	1.34	35.97	11.54	41.36	92.45
z0207	0	0	0	0	0	0	0	0	6.66	5.80	26.17	0.37	70.17	3.08	39.46	93.00
z0301	0.68	8.86	0	0	0	0.00	0	0.44	5.29	59.84	17.19	2.92	131.72	25.14	95.18	72.95
z0302	0	35.25	0	0.31	0	9.59	0	8.43	4.11	51.62	21.11	2.99	66.51	22.25	81.83	81.11
z0303	0	19.54	0	0	0	6.21	0	1.85	4.59	40.71	19.40	2.27	48.41	15.73	67.04	82.65
z0304	0	12.34	0	0	0	2	0	2.51	4.36	31.08	17.78	2.35	32.24	19.60	57.15	87.96
z0305	0	0	0	0	0	0	0	0	3.57	34.82	25.69	2.14	0	7.53	42.23	94.38
z0306	0	0	0	0	0	0	0	0	5.15	65.71	17.17	4.77	0.09	18.91	55.16	89.28
z0307	0	28.26	0	0	0	4	0	1.78	6.55	34.85	15.28	3.26	14.89	27.40	58.30	89.87
z0308	0	21.31	2.70	1.20	13.05	2.48	0	8.91	3.69	49.97	22.91	2.49	47.29	14.57	72.80	82.28
z0401	0.49	15.43	0	0	0	3.92	0	10.05	6.04	54.06	18.90	3.18	71.71	23.62	87.37	77.22
z0402	0	8.38	0	0	0	2	0	4.22	4.48	33.54	19.03	1.92	30.40	12.60	55.76	85.41
z0403	0	1	1	0	16	0	2	1	2.84	31.73	21.89	1.81	3.53	9.95	43.74	91.78
z0404	0	13	0	0	0	6	0	12	4.03	34.75	15.95	3.00	63.28	30.33	65.95	88.37
z0405	0	5.37	0	0	0	0.42	0	6.53	5.11	58.30	20.23	2.85	95.25	20.10	92.96	74.04
z0406	0	0	0	0	0	0	0	0	6.33	84.03	22.49	4.43	77.49	29.31	98.93	70.72
z0501	0	6.49	0	0.80	0	13.97	0	7.38	5.60	64.35	18.43	3.10	180.02	33.54	109.40	72.60
z0502	0	22.27	0	0	0	15.49	0	15.08	5.81	61.22	19.87	2.99	149.20	29.38	105.42	73.14
z0503	0	10.94	0	0	0	11.61	0	7.52	4.39	46.55	18.68	2.79	74.96	23.11	77.22	81.53
z0504	0	8.11	0	0.49	0	21.54	6.89	8.62	3.73	28.44	15.83	3.18	25.11	29.79	51.55	94.71
z0505	0.60	4.13	0	0	0	2	0	1.72	7.83	18.56	25.02	1.11	0.04	6.14	46.38	93.80
z0506	0	3.39	0	0	0	9.85	0	11.31	5.03	43.52	16.32	2.36	89.70	20.42	74.40	79.15
z0601	0	3.46	1.01	0	0	7.10	0	7.33	4.43	40.02	21.34	1.63	71.52	12.97	65.59	84.67
z0602	0	0	0	0	0	0	0	0	7.99	17.43	13.43	0.84	24.20	3.98	46.49	77.62
z0603	0	0	0	0	0	0	0	0	4.79	23.58	23.18	1.26	0	3.88	36.71	97.08
z0604	0	0	0	0	0	0	0	0	6.33	35.47	20.83	1.79	0	6.77	46.27	90.30
z0605	0	0	0	0	0	0	0	0	8.53	43.52	11.34	5.54	0	51.46	65.29	98.18
z0701	0	8.40	0	0	0	8.15	0	6.30	3.97	39.82	18.28	2.50	60.18	21.17	65.61	85.22
z0702	0	0	0	0	0	0	0	0	4.77	69.42	23.06	3.44	101.25	23.27	107.13	72.04
z0703	0	0	0	0	0	0	0	0	4.29	24.26	27.29	0.79	0	2.97	45.11	95.42

DMU	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
z0704	0	11.03	0	0	0	8.41	0	5.91	5.18	41.65	17.40	2.56	68.05	21.08	74.30	80.61
z0705	0	4.20	0	0	0	17.90	0	11.68	4.43	38.96	16.79	3.46	57.62	33.38	73.13	87.82
z0706	0	0	0	0	0	0	0	0	3.95	18.28	11.95	3.63	43.37	43.91	55.37	97.64
z0707	0	15.06	0	0	0	14.29	0	7.48	4.03	29.26	16.60	3.00	28.59	28.94	55.55	93.02
z0801	0	2.05	0	0	0	5.85	0	0	5.29	22.98	19.22	1.35	36.64	11.70	47.79	89.39
z0802	0	5.47	0	0	0	7.12	0	0	6.68	17.61	16.57	1.80	35.54	19.42	51.29	89.39
z0803	0	0	0	0	0	0	0	0	7.43	5.35	20.34	0.87	8.85	4.20	39.21	79.34
z0804	0	0	0	0	0	10.94	0	5.18	5.71	22.10	18.52	1.60	54.78	18.09	54.90	89.25
z0805	0	0	0	0	0	4.37	0	5.91	5.72	53.22	14.10	2.97	141.26	30.83	88.57	76.51
z0901	0	0.69	0	0	0	0	0	1.18	5.23	26.50	16.80	1.56	31.23	10.08	48.60	84.41
z0902	0	0	0	0	0	0	0	0	3.95	15.82	21.63	1.03	70.15	4.05	40.35	91.80
z0903	0	0	0	0	31	2	1	0	5.09	12.09	20.72	1.25	29.66	11.00	38.72	94.82
z0904	0	0	0	0	0	5	0	0	6.21	18.50	19.24	1.16	20.68	9.72	46.47	88.82
z0905	0	3.81	0	0	0	3.91	0	0	4.43	24.67	22.37	1.59	3.13	10.19	41.75	95.40
z1001	0	0	0	0.25	0	4.57	0	2.74	4.55	28.55	21.70	2.06	4.59	15.65	48.24	94.18
z1002	0	0	0	0	0	0	0	0	2.74	32.92	22.77	1.65	0	6.94	42.71	91.26
z1003	0	0	0	0	0	0	0	0	6.15	18.16	20.34	1.43	0	7.25	39.37	92.43
z1004	0	0	0	0	0	0	0	0	5.90	7.47	24.65	0.34	0	2.09	29.96	98.76
z1005	0	0	0	0	0	0	0	0	6.31	22.98	21.89	1.44	0	10.06	44.34	92.62
z1006	0	0	0	0	0	0	0	0	8.91	18.51	26.61	1.10	0	5.03	50.39	93.49
Aver	0.17	7.50	0.13	0.11	7.14	5.62	0.15	3.82	5.71	37.12	19.60	2.32	78.38	22.80	69.35	86.07
Oav	5	23	6	9	5	24	3	25	28	29	31	30	16	21	23	34
S/T	6	37	6	10	7	39	4	35	63	63	63	63	53	63	63	63

S-prefix: slack; T-prefix: target; Aver – average; Oav – over average zones; S/T – number of slack and target zones
(1) Bus stop density; (2) Car parking site density; (3) Road density; (4) Car parking area ratio; (5) Rail station service area ratio; (6) CFAR; (7) HFAR; (8) Housing filling rate.

REFERENCES

Alahmadi, M., Atkinson, P. M., & Martin, D. (2016). A Comparison of Small-Area Population Estimation Techniques Using Built-Area and Height Data, Riyadh, Saudi Arabia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *9*(5), 1959–1969. https://doi.org/10.1109/JSTARS.2014.2374175

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, *30*(9), 1078–1092. https://doi.org/10.1287/mnsc.30.9.1078

Biljecki, F., Ohori, K. A., Ledoux, H., Peters, R., & Stoter, J. (2016). Population estimation using a 3D City Model: A multi-scale country-wide study in the Netherlands. *PLoS ONE*, *11*(6), 1–22. https://doi.org/10.1371/journal.pone.0156808

Brandt, S., & Maennig, W. (2012). The impact of rail access on condominium prices in Hamburg. *Transportation*, *39*(5), 997–1017. https://doi.org/10.1007/s11116-011-9379-0

Cervero, R. (1994). Transit-based housing in California: evidence on ridership impacts. *Transport Policy*, *1*(3), 174–183. https://doi.org/10.1016/0967-070X(94)90013-2

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chen, J., Currie, G., Wang, W., Liu, Z., & Li, Z. (2016). Should Optimal Stop Spacing Vary by Land Use Type?: New Methodology. *Transportation Research Record: Journal of the Transportation Research Board*, *2543*(1), 34–44. https://doi.org/10.3141/2543-04

Christiansen, P., Engebretsen, Ø., Fearnley, N., & Usterud Hanssen, J. (2017). Parking facilities and the built environment: Impacts on travel behaviour. *Transportation Research Part A: Policy and Practice*, *95*, 198–206. https://doi.org/10.1016/j.tra.2016.10.025

City of Sapporo. (2019). *Urban Transportation Annual in Sapporo*.

City of Sapporo. (2020). *Sapporo City General Transportation Plan Revised Edition - Part I: Basic Approach*. Sapporo City General Transportation Plan.

Cooper, W. W., Seiford, L. M., Tone, K., Cooper, W. W., Seiford, L. M., & Tone, K. (2007). Data Envelopment Analysis A Comprehensive Text with Models, Applications, References and DEA-Solver Software. In *Springer, ISBN* (Vol. 387452818).

De Gruyter, C., Truong, L. T., & Taylor, E. J. (2020). Can high quality public transport support reduced car parking requirements for new residential apartments? *Journal of Transport Geography*, *82*(October 2019), 102627. https://doi.org/10.1016/j.jtrangeo.2019.102627

Dewita, Y., Burke, M., & Yen, B. T. H. (2019). The relationship between transport, housing and urban form: Affordability of transport and housing in Indonesia. *Case Studies on Transport Policy*. https://doi.org/10.1016/j.cstp.2019.01.004

Dewita, Y., Yen, B. T. H., & Burke, M. (2018). The effect of transport cost on housing affordability: Experiences from the Bandung Metropolitan Area, Indonesia. *Land Use Policy*, *79*(October 2017), 507–519. https://doi.org/10.1016/j.landusepol.2018.08.043

Fancello, G., Carta, M., & Serra, P. (2020). Data Envelopment Analysis for the assessment of road safety in urban road networks: A comparative study using CCR and BCC models. *Case Studies on Transport Policy*, *November 2019*, 1–9. https://doi.org/10.1016/j.cstp.2020.07.007

Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General)*, *120*(3), 253. https://doi.org/10.2307/2343100

Feantsa, & Foundation Abbé Pierre. (2016). *Filling Vacancies - Vacant Real Estate: Seizing the Opportunity To Find Affordable Housing Solutions in Europe*. https://ec.europa.eu/futurium/sites/futurium/files/long_version_en.pdf.pdf

Fitzová, H., & Matulová, M. (2020). Comparison of urban public transport systems in the Czech Republic and Slovakia: Factors underpinning efficiency. *Research in Transportation Economics*, *81*(November 2019). https://doi.org/10.1016/j.retrec.2020.100824

Furth, P. G., & Rahbee, A. B. (2000). Optimal Bus Stop Spacing Through Dynamic Programming and Geographic Modeling. *Transportation Research Record: Journal of the Transportation Research Board*, *1731*(1), 15–22. https://doi.org/10.3141/1731-03

Gao, X., Asami, Y., & Katsumata, W. (2006). Evaluating land-use restrictions concerning the floor area ratio of lots. *Environment and Planning C: Government and Policy*, *24*(4), 515–532. https://doi.org/10.1068/c0531

Gentili, M., & Hoekstra, J. (2019). Houses without people and people without houses: a cultural and institutional exploration of an Italian paradox. *Housing Studies*, *34*(3), 425–447. https://doi.org/10.1080/02673037.2018.1447093

Georgiadis, G., Politis, I., & Papaioannou, P. (2014). Measuring and improving the efficiency and effectiveness of bus public transport systems. *Research in Transportation Economics*, *48*, 84–91. https://doi.org/10.1016/j.retrec.2014.09.035

Graham, D. J. (2008). Productivity and efficiency in urban railways: Parametric and non-parametric estimates. *Transportation Research Part E: Logistics and Transportation Review*, *44*(1), 84–99. https://doi.org/10.1016/j.tre.2006.04.001

Gu, D., Newman, G., Kim, J. H., Park, Y., & Lee, J. (2019). Neighborhood decline and mixed land uses: Mitigating housing abandonment in shrinking cities. *Land Use Policy*, *83*(February), 505–511. https://doi.org/10.1016/j.landusepol.2019.02.033

Guan, C. H. (2019). Spatial distribution of high-rise buildings and its relationship to public transit development in Shanghai. *Transport Policy*, *81*(September 2018), 371–380. https://doi.org/10.1016/j.tranpol.2018.09.004

Guo, Z. (2013). Does residential parking supply affect household car ownership? The case of New York City. *Journal of Transport Geography*, *26*, 18–28. https://doi.org/10.1016/j.jtrangeo.2012.08.006

Han, H. S. (2014). The Impact of Abandoned Properties on Nearby Property Values. *Housing Policy Debate*, *24*(2), 311–334. https://doi.org/10.1080/10511482.2013.832350

Han, H. S. (2019). Exploring Threshold Effects in the Impact of Housing Abandonment on Nearby Property Values. *Urban Affairs Review*, *55*(3), 772–799. https://doi.org/10.1177/1078087417720303

Hattori, K., Kaido, K., & Matsuyuki, M. (2017). The development of urban shrinkage discourse and policy response in Japan. *Cities*, *69*, 124–132. https://doi.org/10.1016/j.cities.2017.02.011

Hawbaker, T. J., Radeloff, V. C., Hammer, R. B., & Clayton, M. K. (2005). Road density and landscape pattern in relation to housing density, and ownership, land cover, and soils. *Landscape Ecology*, *20*(5), 609–625. https://doi.org/10.1007/s10980-004-5647-0

He, S. Y. (2020). Regional impact of rail network accessibility on residential property price: Modelling spatial heterogeneous capitalisation effects in Hong Kong. *Transportation Research Part A: Policy and Practice*, *135*(March), 244–263. https://doi.org/10.1016/j.tra.2020.01.025

Hsueh, L., Tseng, H., & Hsieh, C. (2007). Relationship Between the Housing Vacancy Rate, Housing Price, and the Moving Rate at the Township Level in Taiwan, in 1990 and 2000. *International Real Estate Review*, *10*(1), 119–150.

Huuhka, S. (2015). Vacant residential buildings as potential reserves: a geographical and statistical study. *Building Research and Information*, *44*(8), 816–839. https://doi.org/10.1080/09613218.2016.1107316

Immergluck, D. (2015). Examining Changes in Long-Term Neighborhood Housing Vacancy During the 2011 To 2014 U.S. National Recovery. *Journal of Urban Affairs*, *38*(5), 607–622. https://doi.org/10.1111/juaf.12267

Iravani, H. (2011). Defining land use intensity based on roadway level-of-service targets. *Development*, *4*(1), 59–69. https://doi.org/10.5198/jtlu.v4i1.168

Jain, P., Cullinane, S., & Cullinane, K. (2008). The impact of governance development models on urban rail efficiency. *Transportation Research Part A: Policy and Practice*, *42*(9), 1238–1250. https://doi.org/10.1016/j.tra.2008.03.012

JAMA. (2020). *The Motor Industry of Japan*. Japan Automobile Manufacturers Association, Inc.

Jeon, Y., & Kim, S. (2020). Housing abandonment in shrinking cities of East Asia: Case study in Incheon, South Korea. *Urban Studies*, *57*(8), 1749–1767. https://doi.org/10.1177/0042098019852024

Kamarajugedda, S. A., & Lo, E. Y. M. (2019). Modelling urban growth for Bangkok and assessing linkages with road density and socio- economic indicators. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(4/W19), 255–262. https://doi.org/10.5194/isprs-archives-XLII-4-W19-255-2019

Keenan, P., Lowe, S., & Spencer, S. (1999). Housing abandonment in inner cities-the politics of low demand for housing. *Housing Studies*, *14*(5), 703–716. https://doi.org/10.1080/02673039982687

Kimpton, A., Pojani, D., Ryan, C., Ouyang, L., Sipe, N., & Corcoran, J. (2020). Contemporary parking policy, practice, and outcomes in three large Australian cities. *Progress in Planning*, *May*, 100506. https://doi.org/10.1016/j.progress.2020.100506

Kobayashi, M. (2015). Housing and demographics: Experiences in Japan. *Housing Finance International*, *Winter*, 32–38.

Kobayashi, M. (2016). The Housing Market and Housing Policies in Japan. In *SSRN Electronic Journal* (Issue 558). https://doi.org/10.2139/ssrn.2752868

Law, J., Quick, M., & Chan, P. (2015). Open area and road density as land use indicators of young offender residential locations at the small-area level: A case study in Ontario, Canada. *Urban Studies*, *53*(8), 1710–1726. https://doi.org/10.1177/0042098015576316

Li, F., & Guo, Z. (2014). Do parking standards matter? Evaluating the London parking reform with a matched-pair approach. *Transportation Research Part A: Policy and Practice*, *67*, 352–365. https://doi.org/10.1016/j.tra.2014.08.001

Li, H., & Bertini, R. L. (2008). Optimal Bus Stop Spacing for Minimizing Transit Operation Cost. *Traffic and Transportation Studies*, *2008*, 553–564. https://doi.org/10.1061/40995(322)51

Li, J., Chen, X., Li, X., & Guo, X. (2013). Evaluation of Public Transportation Operation based on Data Envelopment Analysis. *Procedia - Social and Behavioral Sciences*, *96*(Cictp), 148–155. https://doi.org/10.1016/j.sbspro.2013.08.020

Li, M., Ran, J., Niu, X., & Shi, B. (2020). Estimating the Floor Area Ratio of the Vehicular Infrastructure Network Based on Road Grid Cell. *Mobile Networks and Applications*, *25*(2), 650–659. https://doi.org/10.1007/s11036-019-01226-6

Lin, J., Wan, H., & Cui, Y. (2020). Analyzing the spatial factors related to the distributions of building heights in urban areas: A comparative case study in Guangzhou and Shenzhen. *Sustainable Cities and Society*, *52*(May 2019), 101854. https://doi.org/10.1016/j.scs.2019.101854

Lin, L. C., & Tseng, C. C. (2007). Operational performance evaluation of major container ports in the Asia-Pacific region. *Maritime Policy and Management*, *34*(6), 535–551. https://doi.org/10.1080/03088830701695248

Liu, J. S., Lu, L. Y. Y., Lu, W. M., & Lin, B. J. Y. (2013). A survey of DEA applications. *Omega (United Kingdom)*, *41*(5), 893–902. https://doi.org/10.1016/j.omega.2012.11.004

Lutin, J. M., & Benz, G. P. (1992). Key Issues in Light Rail Transit Station Planning and Design. *Transportation Research Record*, 117–124.

Ma, L., Ye, R., & Titheridge, H. (2014). Capitalization effects of rail transit and bus rapid transit on residential property values in a booming economy: Evidence from Beijing. *Transportation Research Record*, *2451*, 139–148. https://doi.org/10.3141/2451-16

Mahmoudi, R., Emrouznejad, A., Shetab-Boushehri, S. N., & Hejazi, S. R. (2020). The origins, development and future directions of data envelopment analysis approach in transportation systems. *Socio-Economic Planning Sciences*, *69*(December 2018), 100672. https://doi.org/10.1016/j.seps.2018.11.009

Maleki, M. Z., Zain, M. F. M., & Ismail, A. (2012). Variables communalities and dependence to factors of street system, density, and mixed land use in sustainable site design. *Sustainable Cities and Society*, *3*(1), 46–53. https://doi.org/10.1016/j.scs.2012.01.005

Martin, E., Shaheen, S., Zohdy, I., Chan, N., Bansal, A., Bhattacharyya, A., Tawfik, A., Yelchuru, B., Finson, R., & Wah, C. Y. Y. (2016). Understanding Travel Behavior: Research Scan. *U.S. Department of Transportation. Federal Highway Administration*.

Martinez-Fernandez, C., Weyman, T., Fol, S., Audirac, I., Cunningham-Sabot, E., Wiechmann, T., & Yahagi, H. (2016). Shrinking cities in Australia, Japan, Europe and the USA: From a global process to local policy responses. In *Progress in Planning* (Vol. 105). https://doi.org/10.1016/j.progress.2014.10.001

Martínez, L. M., & Viegas, J. M. (2009). Effects of transportation accessibility on residential property values: Hedonic price model in the Lisbon, Portugal, metropolitan area. *Transportation Research Record*, *2115*, 127–137. https://doi.org/10.3141/2115-16

Min, H., Ahn, Y. H., & Lambert, T. E. (2015). Evaluating the comparative efficiency of urban mass transit systems: a longitudinal analysis of the Ohio case. *International Journal of Logistics Research and Applications*, *18*(6), 518–534. https://doi.org/10.1080/13675567.2014.992304

Mohler, B. J., Thompson, W. B., Creem-Regehr, S. H., Pick, H. L., & Warren, W. H. (2007). Visual flow influences gait transition speed and preferred walking speed. *Experimental Brain Research*, *181*(2), 221–228. https://doi.org/10.1007/s00221-007-0917-0

Morimoto, A., Koike, H., Suzuki, K., & Seki, T. (2000). Transportation impact assessment on urban development using NETSIM. *Proceedings of the 8th International Conference on Computing in Civil and Building Engineering*, *279*(2000), 1519–1526. https://doi.org/10.1061/40513(279)198

Nguyen, H. O., Nguyen, H. Van, Chang, Y. T., Chin, A. T. H., & Tongzon, J. (2016). Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports. *Maritime Policy and Management*, *43*(5), 644–659. https://doi.org/10.1080/03088839.2015.1107922

NLID. (2020). *National Land Numerical Information Download Site*. National Land Information Division, National Spatial Planning and Regional Policy Bureau, MLIT of Japan.

Nourinejad, M., & Roorda, M. J. (2017). Impact of hourly parking pricing on travel demand. *Transportation Research Part A: Policy and Practice*, *98*, 28–45. https://doi.org/10.1016/j.tra.2017.01.023

Pan, Q. (2013). The impacts of an urban light rail system on residential property values: A case study of the Houston METRORail transit line. *Transportation Planning and Technology*, *36*(2), 145–169. https://doi.org/10.1080/03081060.2012.739311

Pandey, A., Lehe, L., & Monzer, D. (2021). Distributions of Bus Stop Spacings in the United

States. *Findings*. https://doi.org/10.32866/001c.27373

Rashidi, K., & Cullinane, K. (2019). Evaluating the sustainability of national logistics performance using Data Envelopment Analysis. *Transport Policy*, *74*(March 2018), 35–46. https://doi.org/10.1016/j.tranpol.2018.11.014

Sapporo City Development Policy Planning Bureau. (2019). *Regional District Designation Standard*.

Sarkis, J. (2015). Preparing Your Data for DEA –Information Technology. In N. K. Avkiran (Ed.), *Productivity Analysis in the Service Sector with Data Envelopment Analysis* (pp. 115–125). N K Avkiran. https://doi.org/10.2139/ssrn.2627576

Scharnhorst, E. (2018). Quantified parking: Comprehensive parking inventories for five U.S. cities. In *Research Institute for Housing America Special Reports*.

Seya, H., Nakamichi, K., & Yamagata, Y. (2016). The residential parking rent price elasticity of car ownership in Japan. *Transportation Research Part A: Policy and Practice*, *85*, 123–134. https://doi.org/10.1016/j.tra.2016.01.005

Seyedalizadeh Ganji, S. R., & Rassafi, A. A. (2019). Measuring the road safety performance of Iranian provinces: a double-frontier DEA model and evidential reasoning approach. *International Journal of Injury Control and Safety Promotion*, *26*(2), 156–169. https://doi.org/10.1080/17457300.2018.1535510

Shen, Y., Hermans, E., Bao, Q., Brijs, T., & Wets, G. (2015). Serious Injuries: An Additional Indicator to Fatalities for Road Safety Benchmarking. *Traffic Injury Prevention*, *16*(3), 246–253. https://doi.org/10.1080/15389588.2014.930831

Shen, Y., Hermans, E., Brijs, T., Wets, G., & Vanhoof, K. (2012). Road safety risk evaluation and target setting using data envelopment analysis and its extensions. *Accident Analysis and Prevention*, *48*, 430–441. https://doi.org/10.1016/j.aap.2012.02.020

SIPF. (2020). *DATA-SMART CITY SAPPORO*. Sapporo Industrial Promotion Foundation.

Statistics Bureau of Japan. (2020). *Statistics Dashboard*. Statistics Dashboard, Statistics Bureau, Ministry of Internal Affairs and Communications.

Statistics of Japan. (2018). *Housing and Land Survey*. Statistics Bureau, & Ministry of Internal Affairs and Communications.

Suzuki, T., & Muromachi, Y. (2010). Empirical Analysis on the Railroad Development Impact on Local Population Density in Japan. *Journal of the Eastern Asia Society for Transportation Studies*, *8*(2006), 1039–1052.

Talent, M. (2017). Improving estimates of occupancy rate and population density in different dwelling types. *Environment and Planning B: Urban Analytics and City Science*, *44*(5), 802–818. https://doi.org/10.1177/0265813516649596

TDP. (2020). *Transportation data in Sapporo*. Transportation Planning Division, General Transportation Planning Department, Sapporo City Planning Policy Bureau.

Tirachini, A. (2014). The economics and engineering of bus stops: Spacing, design and congestion. *Transportation Research Part A: Policy and Practice*, *59*, 37–57. https://doi.org/10.1016/j.tra.2013.10.010

Wang, X., Tong, D., Gao, J., & Chen, Y. (2019). The reshaping of land development density through rail transit: The stories of central areas vs. suburbs in Shenzhen, China. *Cities*, *89*(June 2018), 35–45. https://doi.org/10.1016/j.cities.2019.01.013

Wang, Y., Potoglou, D., Orford, S., & Gong, Y. (2015). Bus stop, property price and land value tax: A multilevel hedonic analysis with quantile calibration. *Land Use Policy*, *42*, 381–391. https://doi.org/10.1016/j.landusepol.2014.07.017

Wu, A. R., Simpson, C. S., van Asseldonk, E. H. F., van der Kooij, H., & Ijspeert, A. J. (2019). Mechanics of very slow human walking. *Scientific Reports*, *9*(1), 1–10. https://doi.org/10.1038/s41598-019-54271-2

Xu, H., & Zhou, Y. (2019a). Public housing provision and housing vacancies in Japan. *Journal of the Japanese and International Economies*, *53*(January). https://doi.org/10.1016/j.jjie.2019.101038

Yang, J., Su, P., & Cao, J. (2020). On the importance of Shenzhen metro transit to land development and threshold effect. *Transport Policy*, *99*(August), 1–11. https://doi.org/10.1016/j.tranpol.2020.08.014

Zhang, Q., Wang, J., Peng, X., Gong, P., & Shi, P. (2002). Urban built-up land change detection with road density and spectral information from multi-temporal Landsat TM data. *International Journal of Remote Sensing*, *23*(15), 3057–3078. https://doi.org/10.1080/01431160110104728

Zhao, G., Zheng, X., Yuan, Z., & Zhang, L. (2017). Spatial and temporal characteristics of road networks and urban expansion. *Land*, *6*(2). https://doi.org/10.3390/land6020030

CHAPTER 4

Conclusions

4.1. SUMMARISE OF THE DISSERTATION FINDINGS

The vacant houses crisis can be seen as an expression of unsustainable urban development. With the sharp increase in the number of units as well as its negative impacts, it is a challenge for local and national governments, especially in developed countries. The necessity of controlling the vacant houses becomes urgent.

To identify the determinants of vacant dwellings in Japan, this dissertation chose Sapporo city as a case study. For the city of Sapporo, the spatial distribution trend of vacant dwellings was examined along with the determinants of each cluster. In addition, based on the available transportation system data, the present study performed an analysis to evaluate the efficiency of the city's transportation system in the relationship to housing utilization. Through the spatial autocorrelation analysis, partial least squares regression, and the DEA analysis, the study stated some main findings as follows:

- Areas with a high vacancy density (Hot-spot clusters) would likely concentrate in the city core. Although it only accounts for 17.5% of the total grid cells, it has the highest average value of vacant homes per grid, equivalent to 407.7. While this figure is 89.41 and 15.41 units per grid in the Random and Cold-spot clusters.
- The demographic characteristics have the highest affected the occurrence of vacant dwellings across the city, especially the level of single households. Coupled with the elderly population, the number of children factor has contributed to the increase of vacant houses, and it has the highest influence in the Random cluster. Meanwhile, the high ratio of housing ownership can reduce the vacancy rate.
- In terms of building characteristics, the housing structure plays an important role in the rise of vacant dwellings. Compared with other structures, the fireproof floor area has a stronger relationship with the high vacancy rate across the city, particularly in Hot-spot clusters. Meanwhile, the number of office rooms stimulates the increase of vacant dwellings, the number of private rooms and integrated car parking area had the inverse effect direction. Contrary to some previous studies, there is not any relationship between the building's age and vacant houses.
- Regarding the transportation system efficiency, about 30% of areas of the city were efficient. In which, the efficient zones of the CCR and BCC models are 20 and 22, respectively. Besides, about 54% of zones had an efficiency value higher than the

average (0.9). This indicates the under-capacity that the transportation system is operating.

- For the returning to scale of the areas, the number of zones in the IRS, CRS, and DRS is 27 (42,9%), 20 (31,7%), and 16 (25,4%), respectively. This suggests the policies applied for each area should be adjusted to fit their characteristics.
- In terms of the input slack, the most popular surplus is car parking sites with 36 zones, including seven zones that had parking site slack of over 20 sites/km^2. The greatest surplus was on the north side of the Toyohira River. While a car parking area surplus occurred in only 10 zones. Besides, the lower surplus was found in the rail station area (6zones), road density (6 zones), and bus stop density (5 zones).
- Regarding the output slack, the slack in HFAR occurred in just three zones with about 4.8% of the zones. Whereas slack of CFAR and floor-filling rate appeared by 60.3% and 55.6% of the zones, respectively.

4.2. LIMITATIONS

Though the present study has addressed various issues, there are limitations remain that need to be further investigated.

First, there is a lack of important explanatory variables, e.g., income level and state preference, to clarify the determinants of people's behaviour in choosing or purchasing accommodation. This supplement could solidify the findings and support the decision-making more sufficiently.

Second, the present study combined the vacant dwelling types (temporary and permanent vacancy) as one response variable. Though this can reveal the vacant houses in the market from a more holistic perspective, we argue that splitting these two terms in the analysis would be meaningful for determining a solution for each vacant type.

Third, we used the stationary data for the model, which can only express the situation of the issue at a specific time. In the long term, all the factors and their influence may change. Thus, the analysis with time-series data would be worthy of discovering the variation of the vacancy determinants.

Fourth, the efficiency score presents the DMU's performance. However, it is inconstant with the variation in inputs and outputs over time. Further studies using the DEA advanced model (such as the Malmquist DEA model) is necessary to understand the progress of changing performance across regions and help create the right policies.

Fifth, the study focused on addressing the problem using the alternative variables, i.e., the housing indexes. However, these indexes partly represent the travel demand in the city, but do not illustrate the demographic structure or socioeconomic factors. Therefore, future studies should remedy this shortcoming.

Finally, the efficiency score implies that the area has a better organized transportation system compared with the others. However, it is not necessarily a shortage of services. This would seem more likely true for the city that has developed a comprehensive transportation system with high capacity. With Sapporo, the city has been experiencing a decline in travel demand in recent years (refer to Section 2.1). In the future, the decrease in travel demand is expected to become significant because of depopulation and the aging society. This downturn will cause a surplus of transportation supplies in various areas. Thus, on the one hand, the implications of the present study are only good references for areas with similar conditions. On the other hand, for new or developing areas, a dedicated investigation should be conducted to identify their specific conditions.

4.3. FUTURE WORKS

Besides addressing the limitations stated in the previous section, the prospective researches can be worth noting for further conducting.

First, investigating the vacant housing problem in the other cities in Japan and in foreign countries. Since the social-economical, demographical, and geographical characteristics may vary from area to area, their effect on the housing market and housing vacancy may different. Thus, finding the changes in determinants over various scenarios and at a larger scale would be necessary. The outcomes may support the decision-making to create a more efficient and flexible policy.

Second, finding solutions for the transportation system that can remedy the under-capacity operation of the current system. As the results from the case study show, most of the transportation services in the city are operating under their capacity. This issue would likely continue in the future when the population is predicted to decline and become aging. Thus, in the long term, the transportation services should transform to adapt to the new demand and costumer's characteristics. The prospective approaches may include the application of information technology and modern transportation services such as MaaS.

Third, investigating the efficiency of the promotion programs for the housing market. Currently, many administrations are introducing plans or programs in order to recover the housing market. These acts may include financial support, renovative programs, or developing projects. Nevertheless, the efficiency of these programs is still obscure. Thus, it is necessary to quantitively identify the strengths and weaknesses of the policy. The outcomes, on the one hand, can help to address the limitation of the current approach. And, on the other hand, they support the local governments to establish a more attractive program that can improve the problem.