Research on Determinants of Rail Transit Ridership

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Chapter 1

Introduction

1.1 Background

■ Current situation

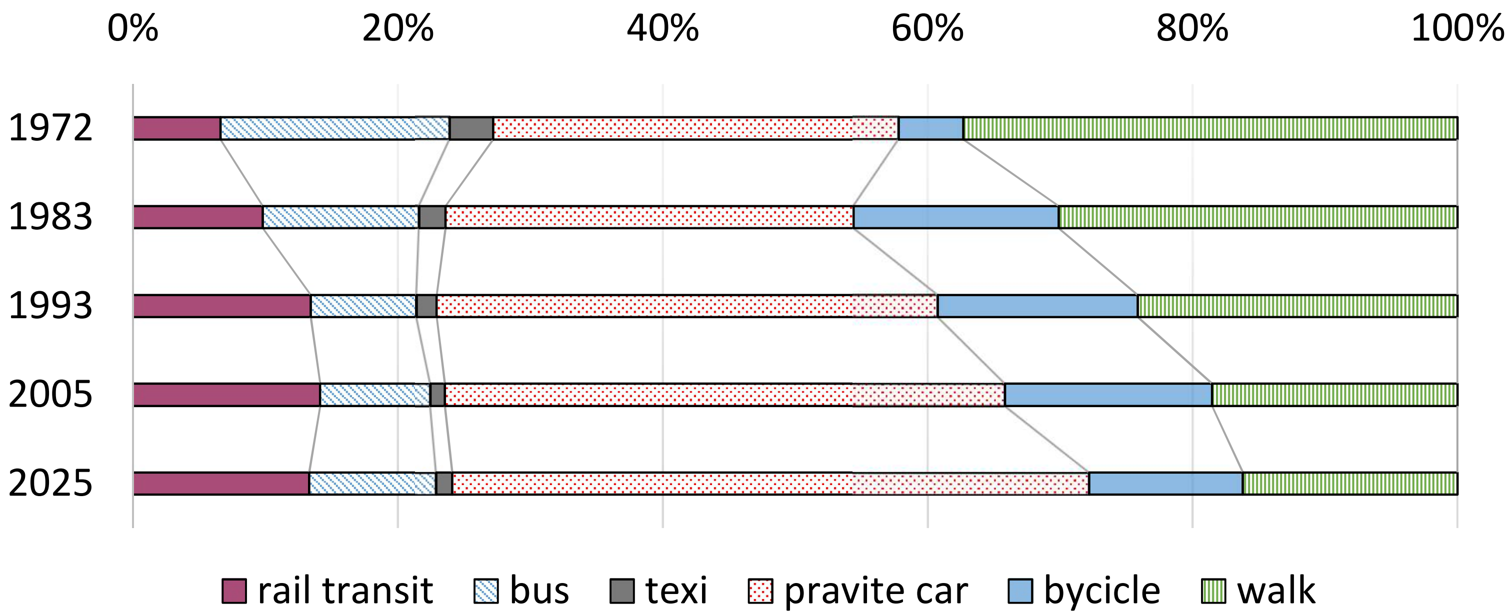
1

Reduction in share rate of public transit

2

Traffic congestion

Traffic mode share rate of Fukuoka



1.1 Background

Current situation

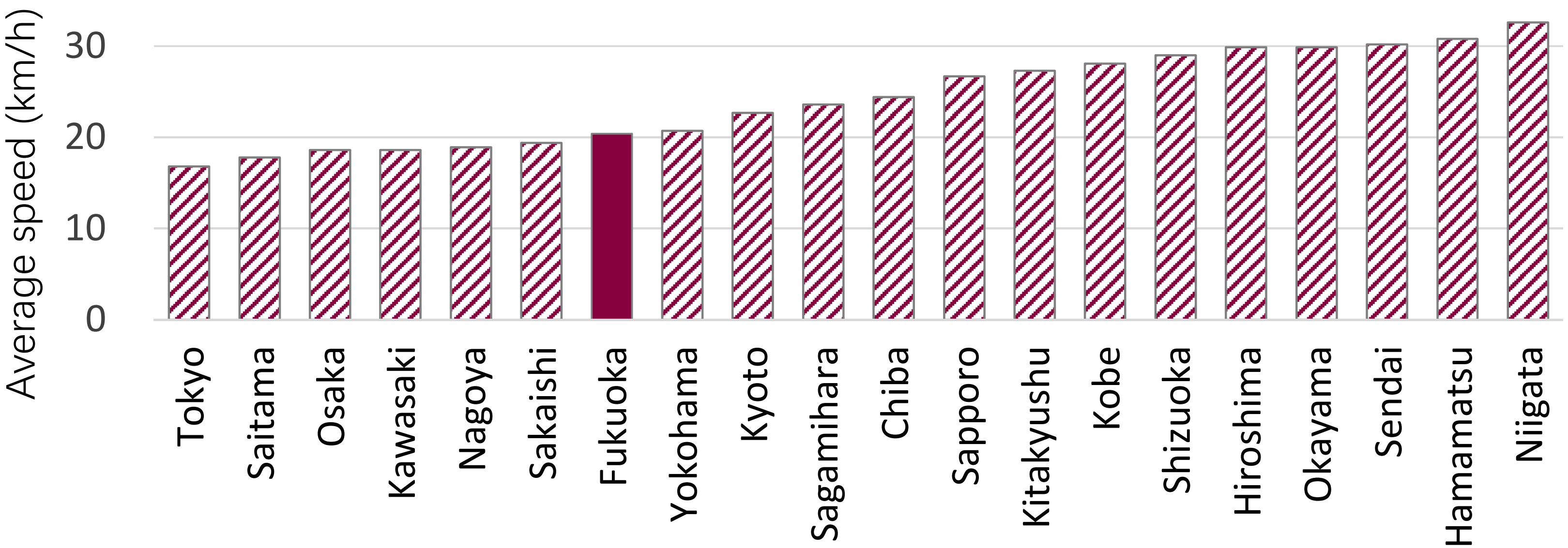
1

Reduction in share rate of public transit

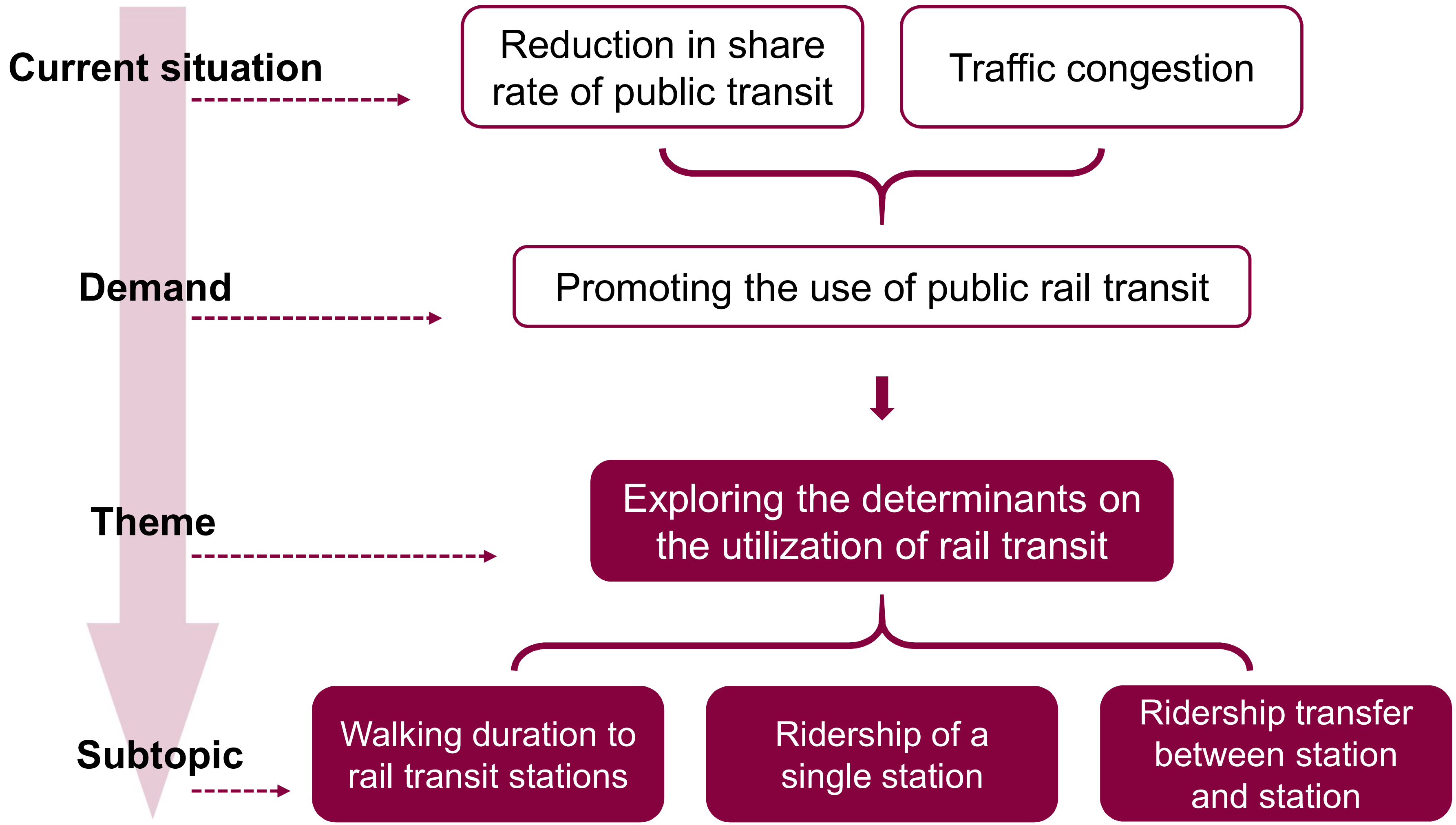
2

Traffic congestion

Average travel speed during crowded time in major cities



1.1 Background



1.1 Background

■ Problems

1. Walking is the most important travel modes in accessing transit stations, also one of the most key determinants on the utilization of rail transit. A quantitative method for describing walking duration preference to rail transit stations is necessary.

2. The rail transit ridership, land use, and population have their own distribution characteristics in space. These characteristics in the case of Fukuoka City need to be further and objectively understood.

3. Rail transit ridership is considered to be mainly affected by the environmental factors surrounding the station. For the rail transit station in Fukuoka City, the influencing factors need to be explored and estimated.

3. The rail transit station is in a network. When the ridership is affected by the environmental factors around the station, it is also influenced by the environmental factors around the other stations in the same network. How to describe and estimate the ridership transfer between station and station is an important issue.

1.2 Purpose

- Main purpose

Exploring the factors influencing rail transit ridership from multiple perspectives and estimating the influence.

- Secondary purposes

Clarifying the characteristics of ridership and land use

Problem 2

Chapter 3

Exploring the factors influencing Walking duration

Problem 1

Chapter 2

Utilization of rail transit

Chapter 5

Problem 4

Exploring the factors influencing the ridership transfer between station and station

Chapter 4

Problem 3

Exploring the factors influencing the ridership at station level

1.2 Organization

Chapter 1 Introduction of the dissertation including background, purpose, literature review.

Chapter 2 Exploring the factors influencing walking duration to transit stations from the perspective of passengers' attributes.

Walking duration

Chapter 3 Clarify the characteristics of transit ridership and land use

Characteristics analysis. Preliminary research for chapter 4, 5

Chapter 4 Exploring the factors influencing transit ridership at station level

Transit ridership at station level

Chapter 5 Exploring the factors influencing transit ridership at station-to-station level

Transit ridership at station-to-station level

Chapter 6 Summarizing the findings achieved in each chapter, and giving the conclusion for this dissertation

Chapter 2

Analyzing Willingness of Walking Duration to Transit Stations Using Socio-Demographic Characteristics

2.1 Introduction

Background

- Walking is the most important travel modes in accessing transit stations.
- Walking duration to transit station is widely accepted to be an important determinants on the utilization of rail transit.
- Walking duration to rail transit stations is mainly obtained by survey statistics, which is limited by the individual and regional characteristics of survey objects that the preference of walking duration cannot be generalized to other cases.

Main purpose

- Exploring the factors influencing walking duration to transit stations from the perspective of passengers' attributes.

2.1 Introduction

Review

	Study	Type 1	Type 2	Type 3	This
Research object	Walking distance	●		●	
	Walking duration		●		●
Method	Statistical description	●			
	Regression		●	●	
	Nonlinear fitting				●
Method	Qualitative	●			
	Quantitative		●	●	●
Result		Survey result description	Some factors were found, but prediction and verification were not given	No relationship found	Having relationship with travel purpose, travel time period, age, and occupation

2.1 Introduction

Research focus

- Problems in previous studies

Problem 1

Most studies use qualitative methods. Few quantitative analysis obtained the significant result on estimating walking duration. The reason of that may be in the data processing, the model constructing, also model estimating.

- Research focus

1 Describe walking duration

Using probability but not the linear relationship to describe the walking duration preference of passengers with different attributes.

2 Identify valid indicators

Using variance analysis to identify the valid influencing factors.

2.1 Introduction

Research focus

- Problems in previous studies
- Research focus

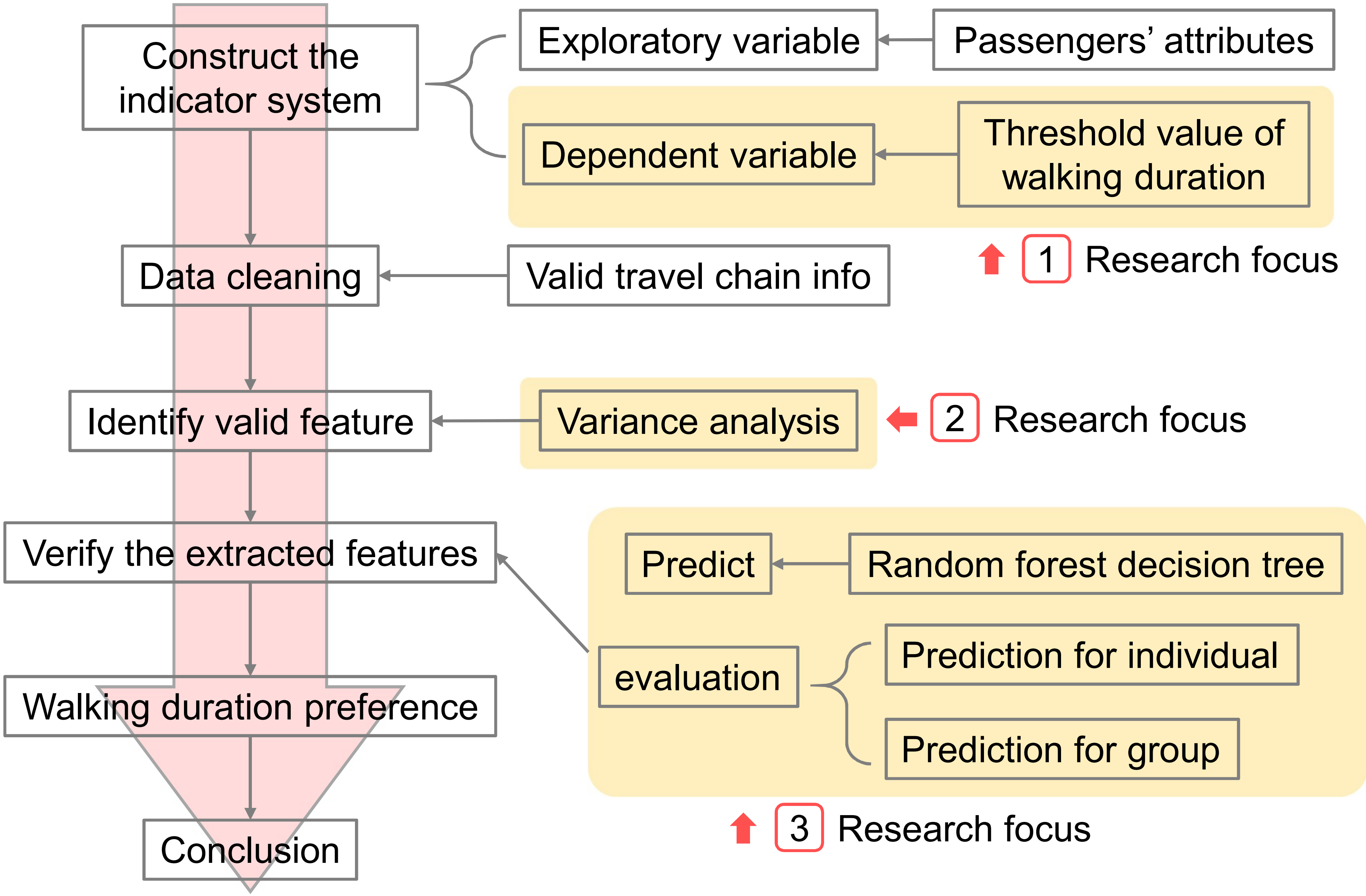
Problem 2

Although many studies have summarized some factors affecting the walking duration through qualitative methods, none of them quantitatively verified the effect of the influencing factors.

3 Predict and evaluate

To estimate and predict the relationship between identified influencing factors and walking duration. Then evaluating the prediction to judge the effectiveness of identified influencing factors.

2.1 Introduction



2.2 Data

Indicators

- Dependent variable

Probability

Walk longer than the given threshold of walking duration

- Explanatory variables

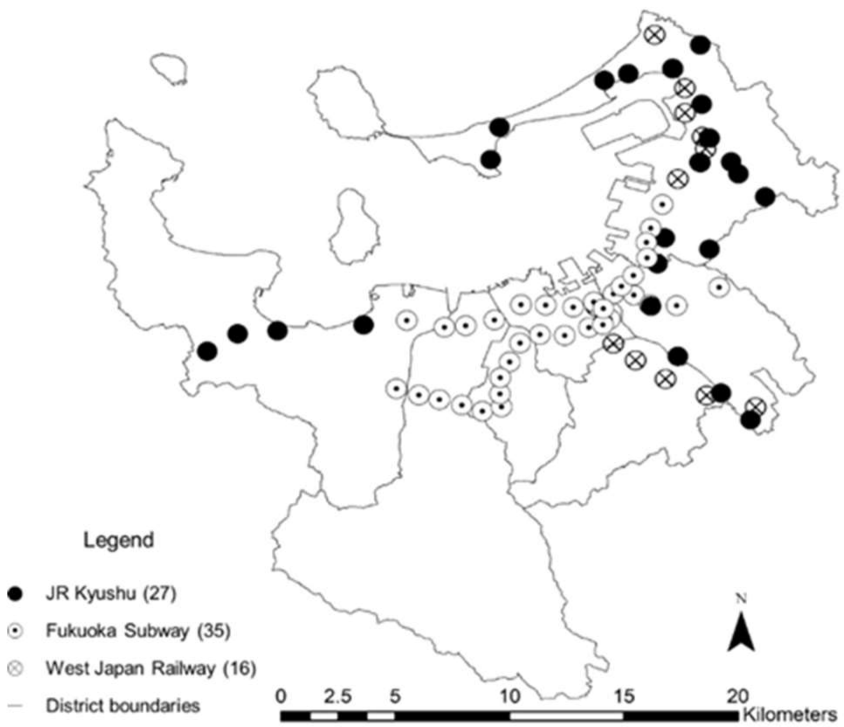
Behavior

Personal socio-demographic characteristics	Other personal attributes	Trip chain info

2.2 Data

Study case: Fukuoka

- Distribution of the transit stations



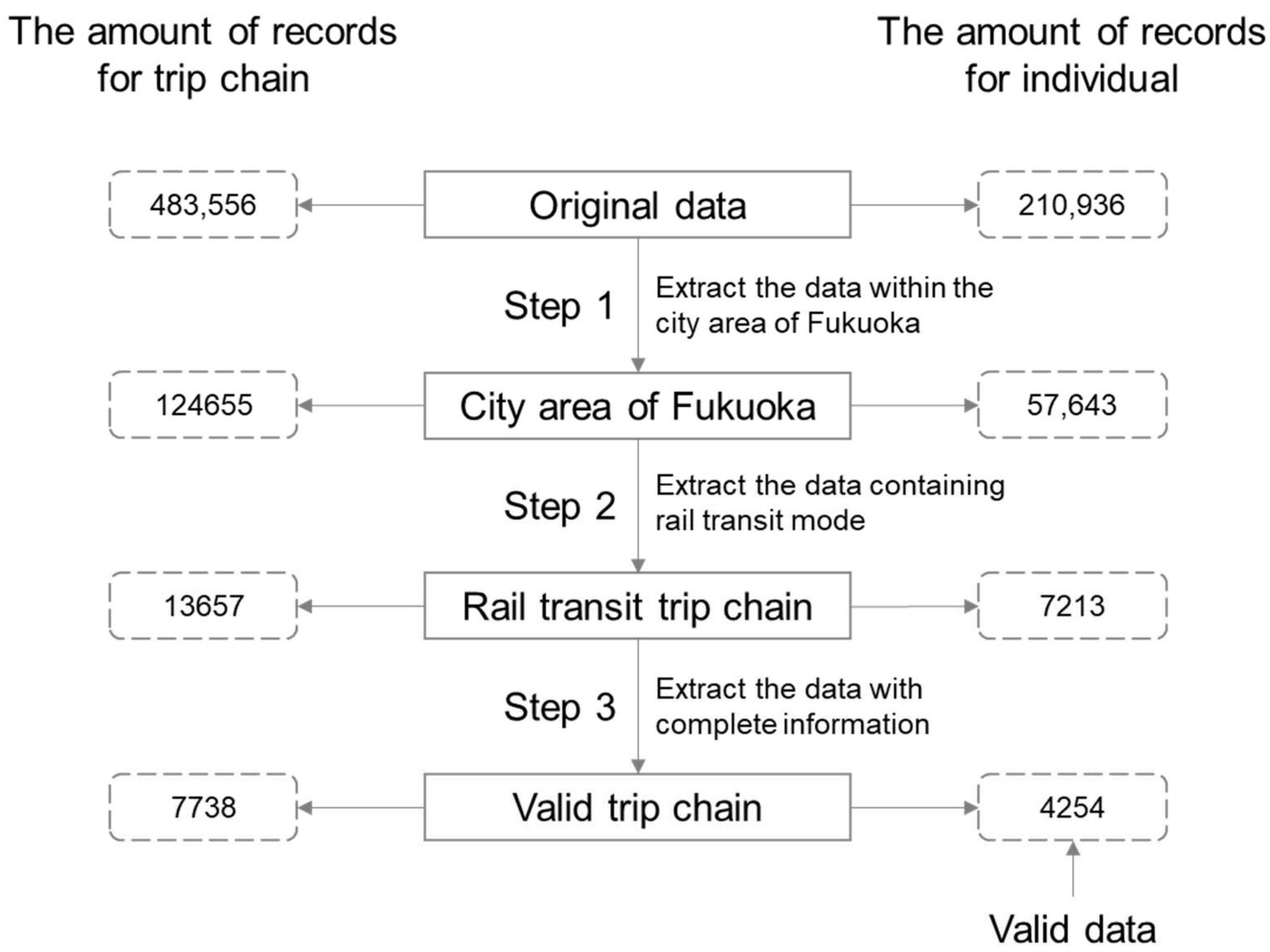
- Data in this study

Category	Feature
Trip chaining behavior	Departure location
	Departure time
	Destination location
	Arrival time
	Transport modes
	Time spent for each mode
	Location of bus stop or rail transit station
Socio-demographic attributes	Age
	Sex
	Occupation
	Trip purpose
	Vehicle/License holding
	Address

2.2 Data

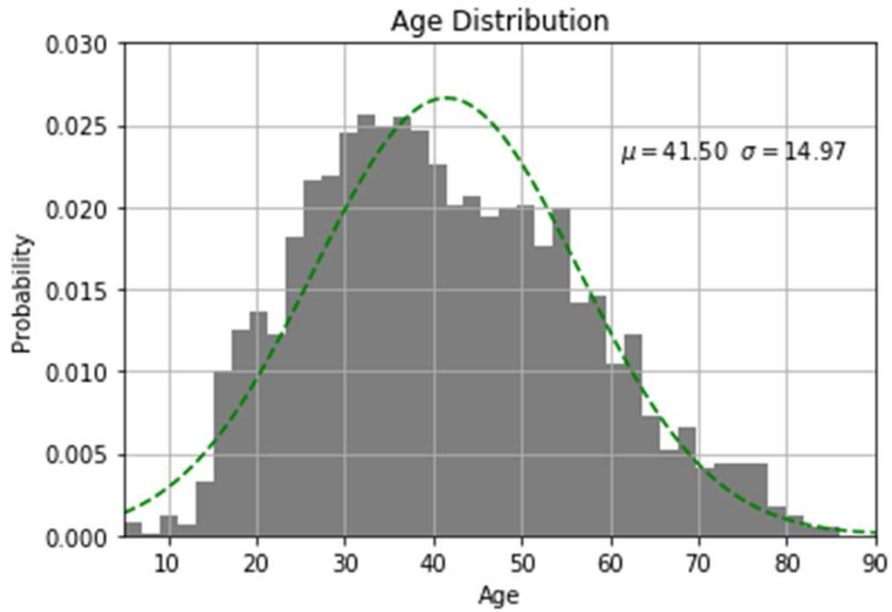
Data processing

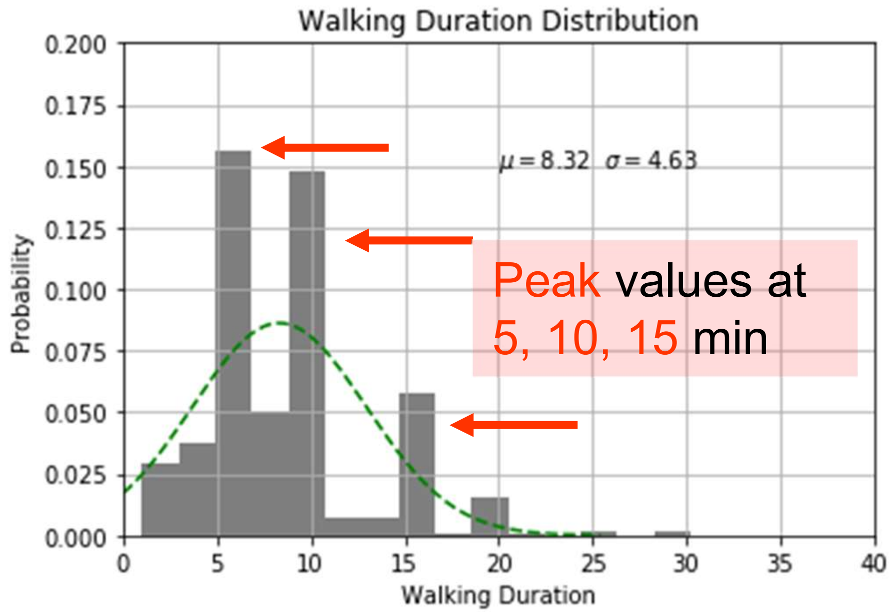
- **Source:** Person Trip Survey



2.2 Data

Distribution verification





- The age distribution of passengers

The passengers aged between 25-55 who are still at production age account for the majority

- Distribution of walking duration

People tend to reply a looser answer when they are being asked some questions about details.

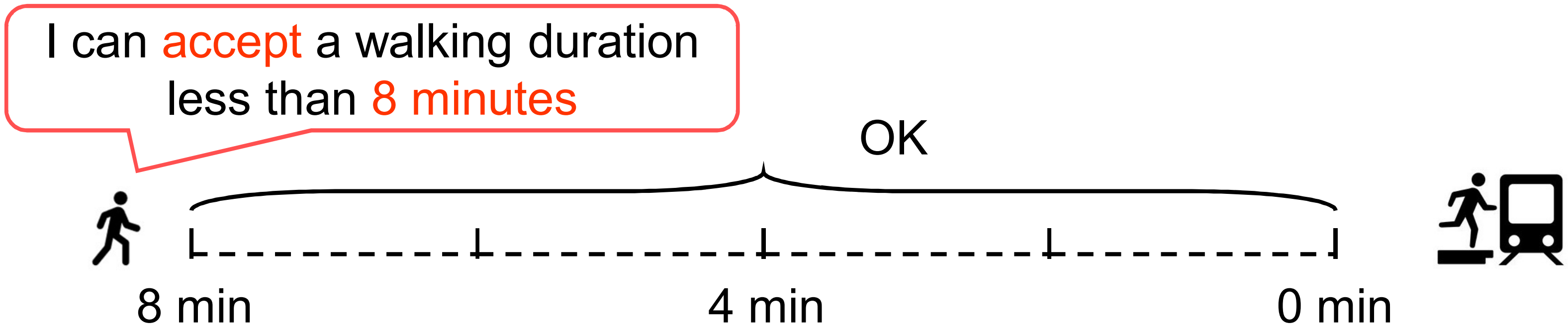
2.3 Methods

Problem description

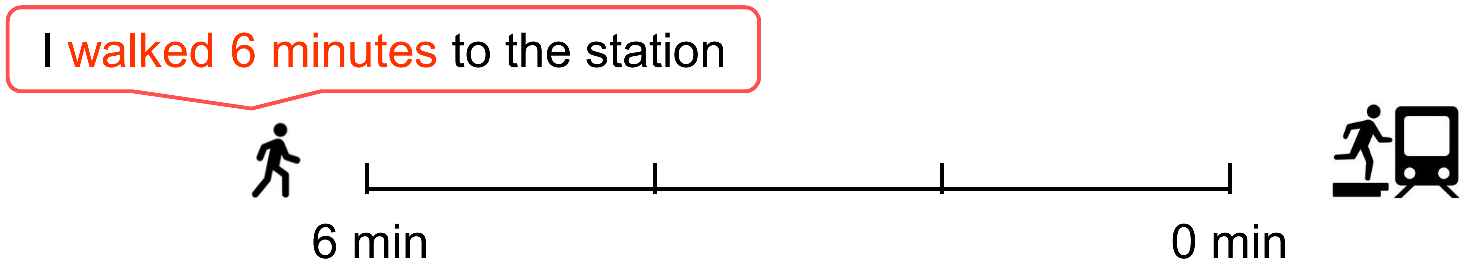
Give an example, for one person who has the attributes:

$$(Male,\ 25\ years\ old,\ student,\ peak\ hour,\ go\ to\ school)$$

- Realistic issue



- Reflected in person trip survey



2.3 Methods

Mathematical description

The general expression can be:

$$Walking\ duration = F(factor_1, factor_2, factor_3, \dots \dots)$$

- Real Walking duration obtained from person trip survey

$$Y_1\ min = F(factor_1, factor_2, factor_3, \dots \dots)$$

Where the Y_1 is the reflection of the walking duration from departures to stations

Real ≠ Acceptable

$Y_1 \sim Y_2$
Deviation is appeared

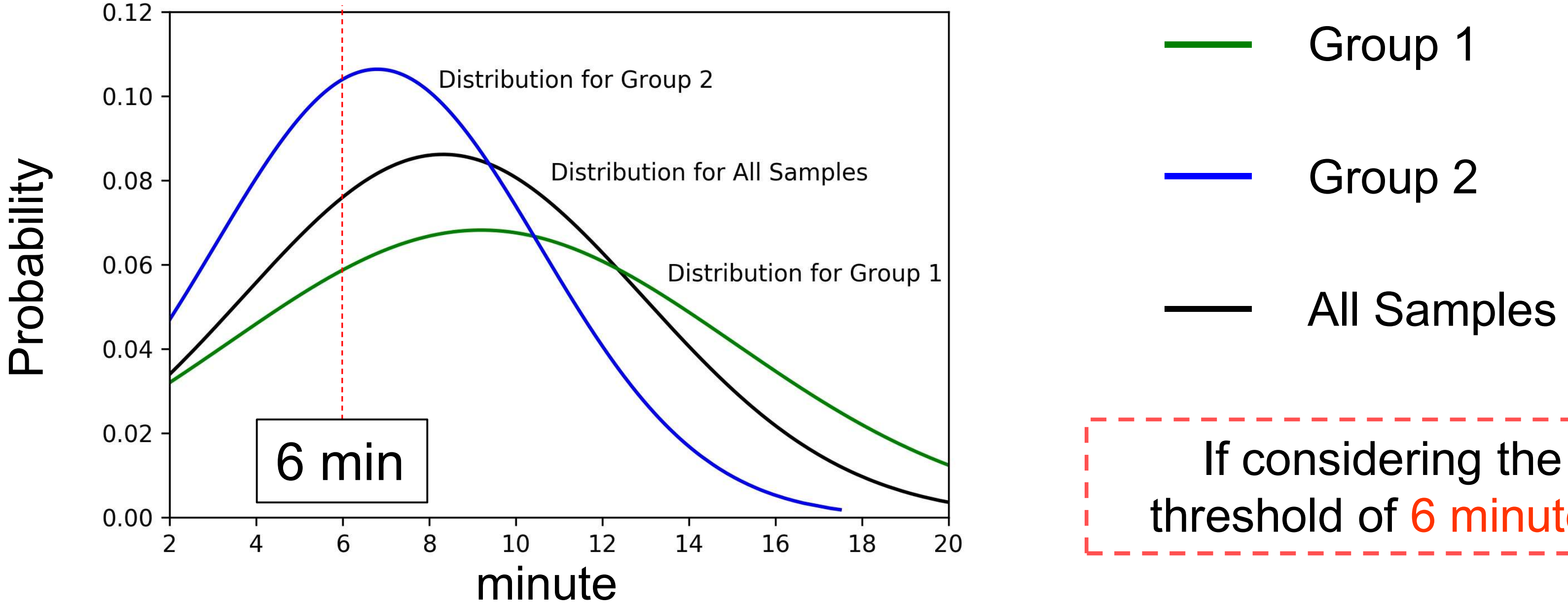
- Acceptable walking duration

$$Y_2\ min = F(factor_1, factor_2, factor_3, \dots \dots)$$

Where the Y_2 is the acceptable walking duration for the people with those factors

2.3 Methods

Important assumption



If considering the threshold of 6 minutes

- Assuming the distribution of walking duration of the passengers with the same attributions subject to the normal distribution.
- If the survey result obtained from the questionnaire showed one group of passengers with specific attributes tend to walk longer, it means this group of passengers can accept a longer walking duration.
- In this graph it can be considered that Group 1 can accept a longer walking duration than Group 2.

2.3 Methods

Model construction

- Abstract form of the model

$$Walking\ duration = F(factor_1, factor_2, factor_3, \ldots \ldots)$$

Continuous value of Walking duration $t_1 \sim t_2$

Threshold of walking duration t_1, t_2, t_3 … …

$$D_{\boxed{y\ min}} = F(\underbrace{factor_1, factor_2, factor_3,}_{\text{Attributes}} \ldots \ldots), \qquad D_{y\ min} \in (0, 1)$$

Where:

y the given threshold of walking duration

$D_{y\ min}$ the probability of accepting or not at the threshold of y minutes.

2.4 Selection of valid features

Selection of thresholds

- According to the existing studies, the acceptable walking duration mainly range from 5 – 13 minutes.
- In this study, the average walking duration is about 8 minutes.

The thresholds selected in this study is 5, 8, 13 minutes.

Analysis of variance

L : tend to spend Less than the threshold
M: tend to spend more than the threshold

5 min threshold		8 min threshold		13 min threshold	
Features	Effect*	Features	Effect*	Features	Effect*
Age over 65	L	Female	M	Age 45-64	M
Peak hour	M	Age 25-44	M	Peak hour	M
O_Null	L	Peak hour	M	P_commuting to work	M
P_commuting to work	M	P_commuting to work	M	P_ private purpose	L
P_official business	L	P_official business	L		
P_private purpose	L	P_ private purpose	L		
P_going home	L	P_ going home	L		

Valid Features at each threshold

2.5 Prediction

Decision tree and forest random

- Reason for choosing decision tree

  Used as an exploratory method for the dataset with unknown feature distribution

- Reason for adding forest random

  Reduce the possibility of over-fitting of data which is easily occurred in the decision tree model.

Flow

2.6 Evaluation

- Predictive power of individual

Object: Individual

Index: Kappa indicator

Range

-1 — Predictive power — 1

Worse | Better

- Predictive power of group trends

Object: Group of 200 individuals

Index: Coefficient of determination

Range

0 — Predictive power — 1

Worse | Better

2.6 Evaluation

5 min threshold		8 min threshold		13 min threshold	
Features	Effect*	Features	Effect*	Features	Effect*
Age over 65	L	Female	M	Age 45-64	M
Peak hour	M	Age 25-44	M	Peak hour	M
O_Null	L	Peak hour	M	P_commuting to work	M
P_commuting to work	M	P_commuting to work	M	P_ private purpose	L
P_official business	L	P_official business	L		
P_private purpose	L	P_ private purpose	L		
P_going home	L	P_ going home	L		

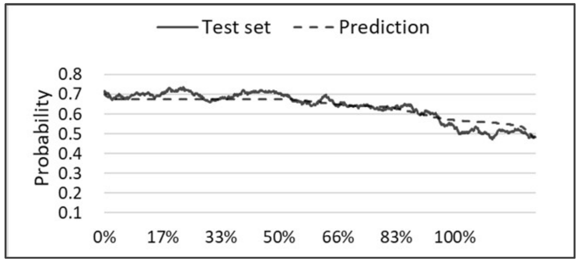
Valid Features at each threshold

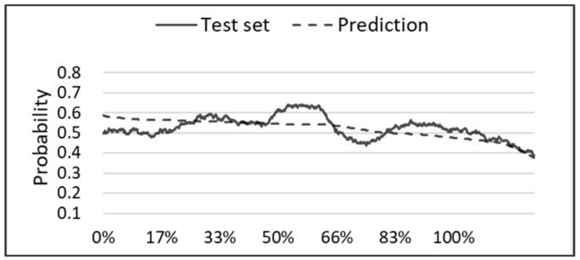
- Kappa index

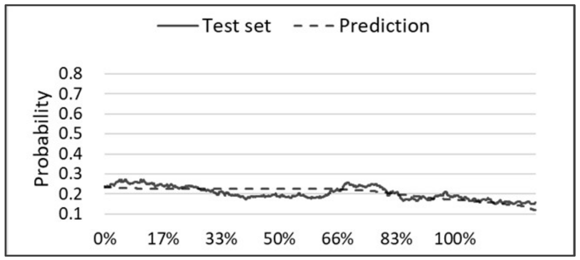
5 min	8 min	13 min
0.284	0.033	0.118

- Coefficient of determination

5 min	8 min	13 min
0.843	0.221	0.426







2.7 Conclusion

Summary

- Problems
- Achievements

1. Little quantitative relationship between walking duration and passengers' attributes was found.
   → Describe passengers' walking duration preferences by examining the probability that passengers with different attributes walk longer than a given threshold.

2. Few of the existing studies quantitative verified the effect of influencing factors
   → The effect of influencing factors is predicted, the results are evaluated from the perspective of both individual and group.

2.7 Conclusion

Findings

	Walk more than the threshold	Walk less than the threshold
● 5 minutes threshold Individual: Slight Group trend: High	➢ Business purpose ➢ Private purpose ➢ Going home purpose ➢ Older than 65 ➢ No occupation	➢ Peak hour ➢ Commuting to work
● 8 minutes threshold Individual: Low Group trend: Low	➢ Business purpose ➢ Private purpose ➢ Going home purpose	➢ Age between 25-44 ➢ Female ➢ Peak hour ➢ Commuting to work
● 13 minutes threshold Individual: Low Group trend: Moderate	➢ Private purpose	➢ Age between 45-64 ➢ Peak hour ➢ Commuting to work

2.7 Conclusion

Recommendations

- Encourage office buildings to move close to stations

  ➡ Results from the factors of business purpose and going home purpose. Office workers tend to access rail transit station in a less time.

- The individual prediction is still not accurate enough for predicting individual behavior.

  ➡ Results from the evaluation of individual prediction

- The group prediction can be used for mastering the overall trend of rail transit utilization in a block.

  ➡ Results from the evaluation of group prediction

Chapter 3

Analysis on the characteristics of transit ridership and land use

3.1 Introduction

Research position

- Preliminary study

  - Characteristics

  Land use ↔ Ridership

  - Relationship

  Chapter 3

- Ridership Estimation

  - Station level → Chapter 4
  - Station-to-station → Chapter 5

Purpose

- To grasp the characteristics of transit stations in terms of both transit ridership and land use in Fukuoka.

3.1 Introduction

- Problems in previous studies

Problem 1

The characteristics of rail transit ridership and land use in Fukuoka needs to be clarified.

- Research focus

➡ 1 Characteristics of transit ridership

Summary the characteristics of rail transit ridership in spatial and temporal distribution

➡ 2 Characteristics of land use

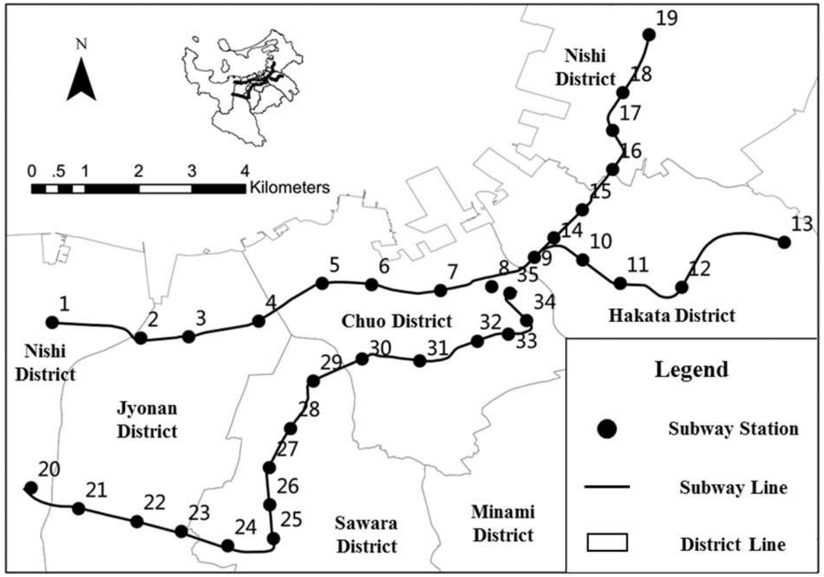
Analyze the characteristics of land use around the subway in terms of the type of land use

➡ 3 Characteristics of land use

Preliminary explore the relationship between rail transit ridership and land use

3.2 Data

Study case



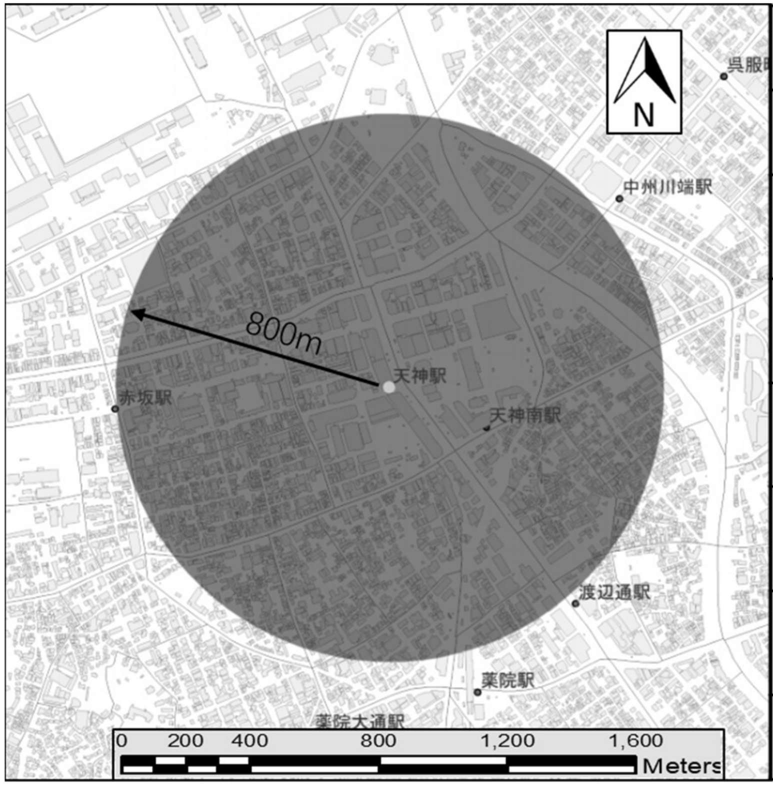
- Fukuoka subway
- 35 subway stations
- 3 operating subway lines
- 29.8 km operating mileage
- 20% share of motorized travel

Data source

Item	Source	Data accuracy	Time point
Subway transit ridership	Fukuoka Traffic Bureau	Station	2005-2014
Population	Resident Basic Account	Town-chome	2005-2014
Land use	Urban Planning Basic Survey	Building	2003, 2008, 2012

3.2 Data

Data extraction



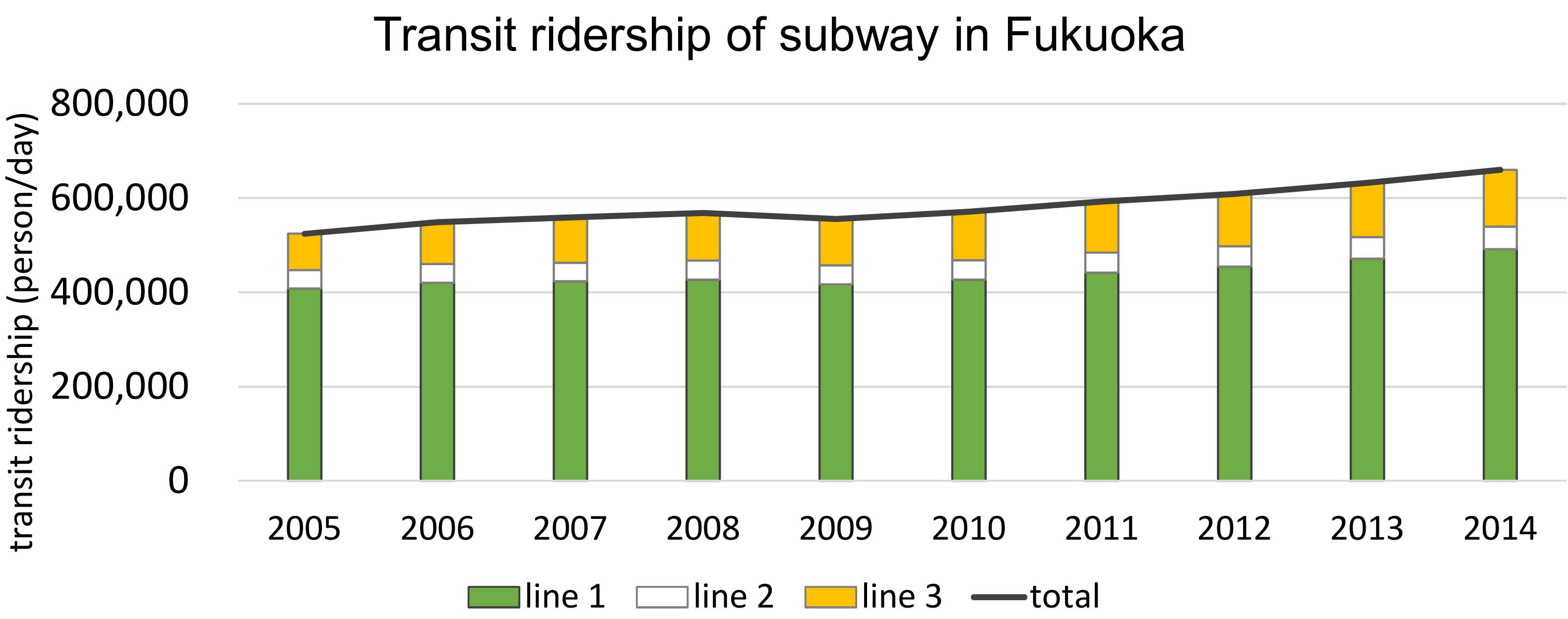
Year	2008
Station No.	11
Transit ridership	108429
Population	28797
Total building area	6854646
Office building area	2100025
Government building area	197787
…	…

1. Matching the region of data.
2. Matching the time points of data.
3. Extracting the data within the catchment area.

3.3 Characteristics of transit ridership and land use

Transit ridership characteristics

- Trends of variation in transit ridership

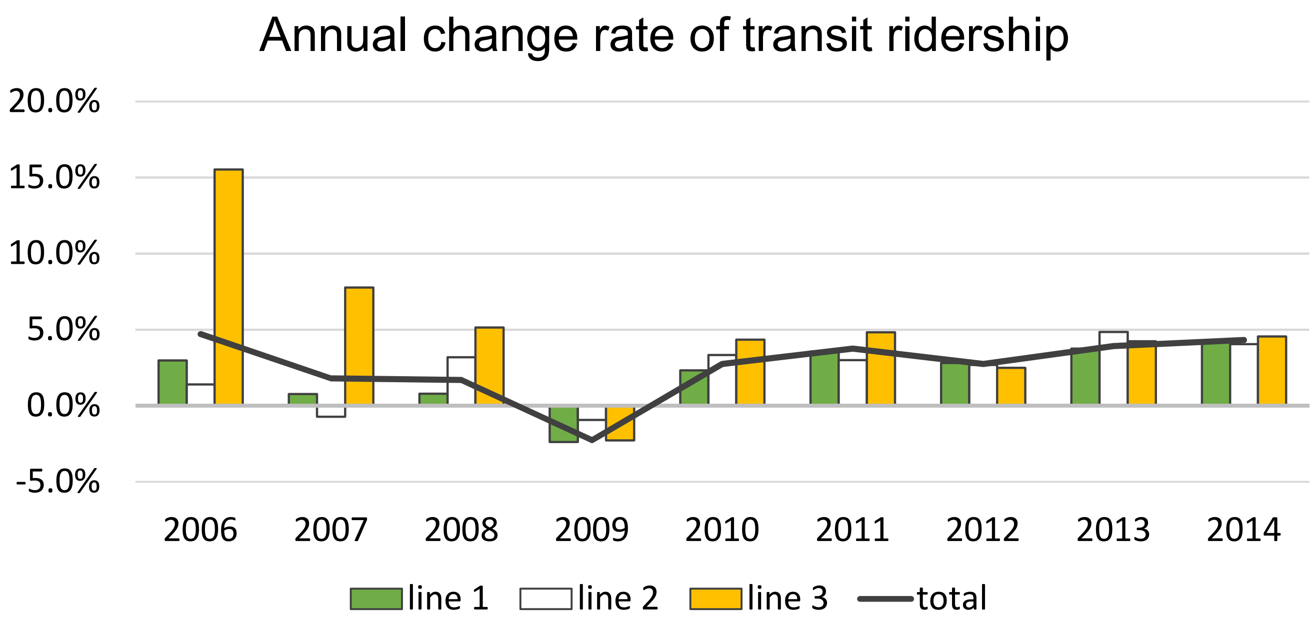


- Growth trend.
- More than 600,000 passengers per day.
- Significant difference in ridership among the three lines.

3.3 Characteristics of transit ridership and land use

Transit ridership characteristics

- Annual growth rate of transit ridership

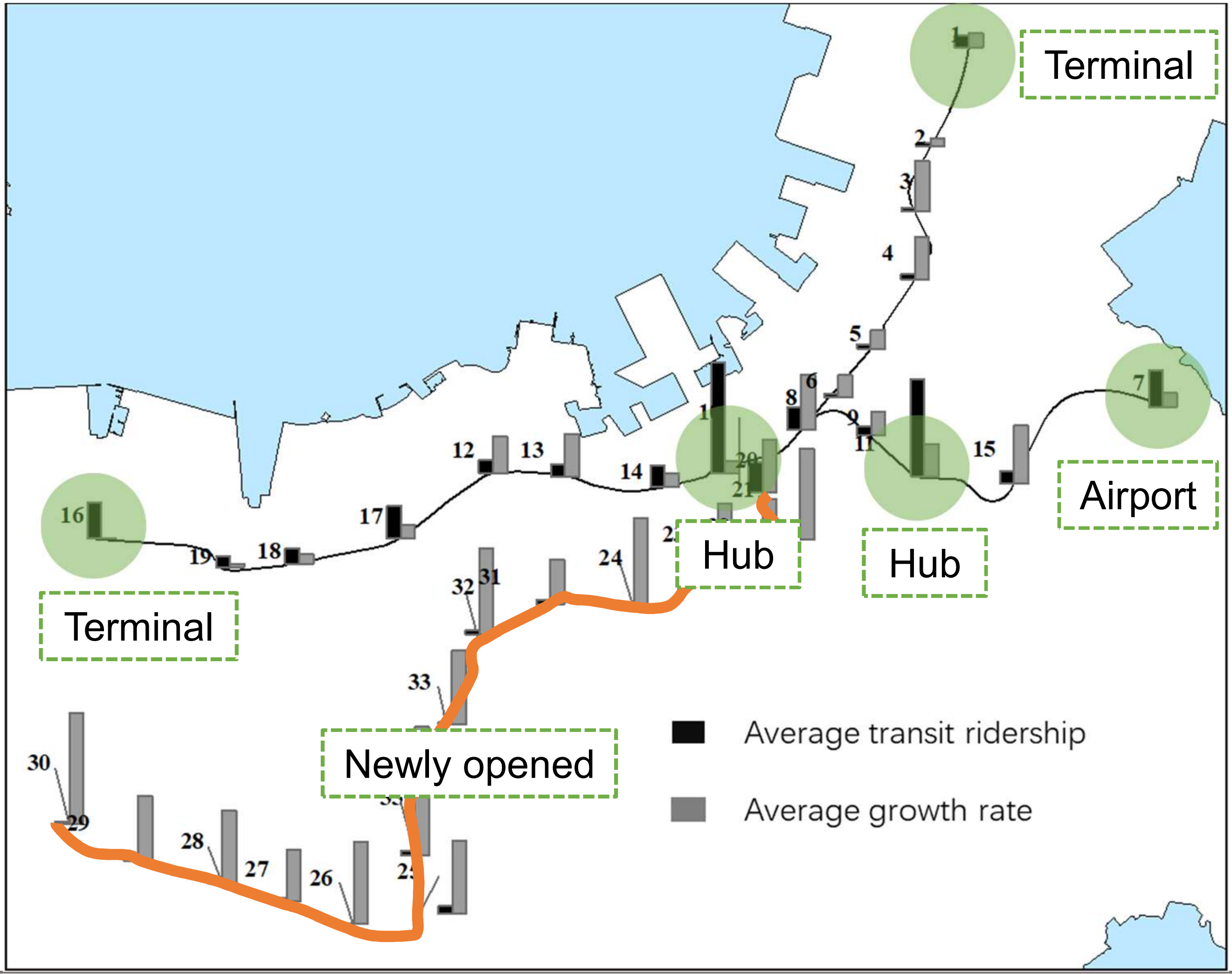


- Line 3 had a much higher growth rate at the first few years of the opening
- The growth rate of three lines tend to be stable after the year of 2009

3.3 Characteristics of transit ridership and land use

■ Transit ridership characteristics

- Spatial distribution of transit ridership



3.3 Characteristics of transit ridership and land use

Transit ridership characteristics

- Classification based on transit ridership

Transit ridership	Total	Line 1	Line 2	Line 3
Hub	2	2	0	0
Large	4	3	0	1
Medium	11	8	1	2
Small	18	0	4	4

Growth rate	Total	Line 1	Line 2	Line 3
0-2.5	12	8	4	0
2.5-4.5	11	5	2	4
4.5-6.0	6	0	0	6
6.0-	6	0	0	6

Line 1

- Large scale
- Low growth rate

Line 2

- Small scale
- Low growth rate

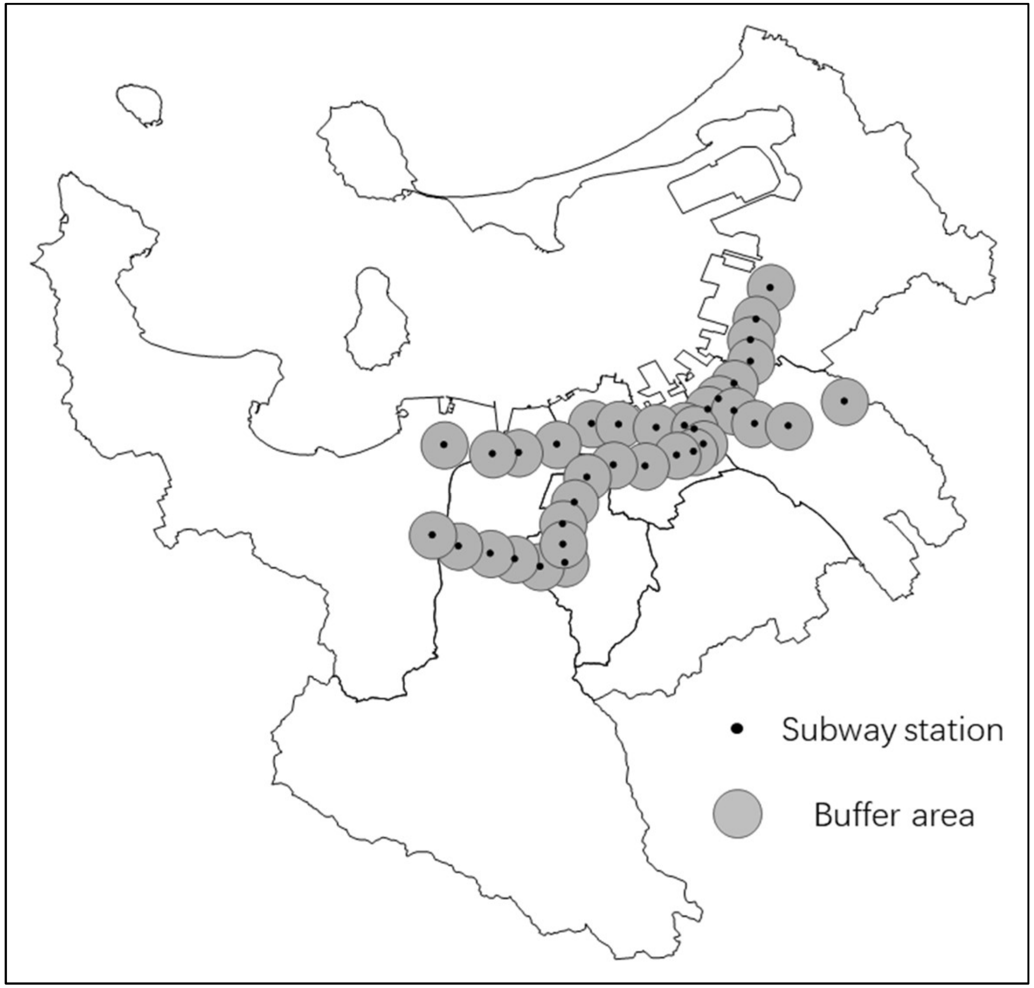
Line 3

- Small scale
- High growth rate

3.3 Characteristics of transit ridership and land use

Land use characteristics

- Data extraction



ArcGIS

- 800m-radius region
- Extracting data

Main land use

- Business
- Commerce
- Hotel
- Entertainment
- Residence
- Apartment house
- Dwelling with shop
- Government
- Education
- Culture

3.3 Characteristics of transit ridership and land use

Land use characteristics

- Correlation analysis for indicators

Indicator	1	2	3	4	5	6	7	8	9	10
1. Business	1.000	0.848	0.987	0.775	-0.385	0.378	0.848	0.615	0.006	0.656
2. Commerce	0.848	1.000	0.828	0.765	-0.293	0.345	0.734	0.645	0.065	0.530
3. Hotel	0.987	0.828	1.000	0.716	-0.361	0.382	0.815	0.585	0.000	0.619
4. Entertainment	0.775	0.765	0.716	1.000	-0.322	0.281	0.663	0.439	-0.018	0.552
5. Residence	-0.385	-0.293	-0.361	-0.322	1.000	0.205	-0.287	-0.164	-0.175	-0.063
6. Apartment house	0.378	0.345	0.382	0.281	0.205	1.000	0.649	0.408	0.087	0.729
7. Dwelling with shop	0.848	0.734	0.815	0.663	-0.287	0.649	1.000	0.641	0.038	0.808
8. Government	0.615	0.645	0.585	0.439	-0.164	0.408	0.641	1.000	0.395	0.549
9. Education	0.006	0.065	0.000	-0.018	-0.175	0.087	0.038	0.395	1.000	-0.012
10. Culture	0.656	0.530	0.619	0.552	-.063	0.729	0.808	0.549	-0.012	1.000

High correlation (>0.7)

3.3 Characteristics of transit ridership and land use

Land use characteristics

- Factor analysis

Purpose
- To deal with the strong collinearity among indicators
- Further explore the internal relationship

- Test for factor analysis

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.756
Bartlett's Test of Sphericity	Chi-Square	346.086
	df	45
	Sig.	0

Suggested value > 0.7

Suggested value < 0.05

PASSED the test

3.3 Characteristics of transit ridership and land use

Land use characteristics

- Factor extraction

Component Matrix

Indicator	Component 1	Component 2	Component 3
Office	0.962	0.122	0.060
Hotel	0.934	0.123	0.050
Commerce	0.878	0.105	0.131
Entertainment	0.850	0.044	-0.030
Dwelling with shop	0.834	0.417	0.125
Apartment house	0.301	0.860	0.134
Residence	-0.521	0.620	-0.234
Education	-0.066	-0.039	0.958
Culture	0.627	0.644	0.057
Government	0.570	0.305	0.582

Factor 1: Office & commerce

- Office
- Hotel
- Commerce
- Entertainment
- Dwelling with shop
- Culture

Factor 2: Residence

- Apartment house
- Residence
- Culture

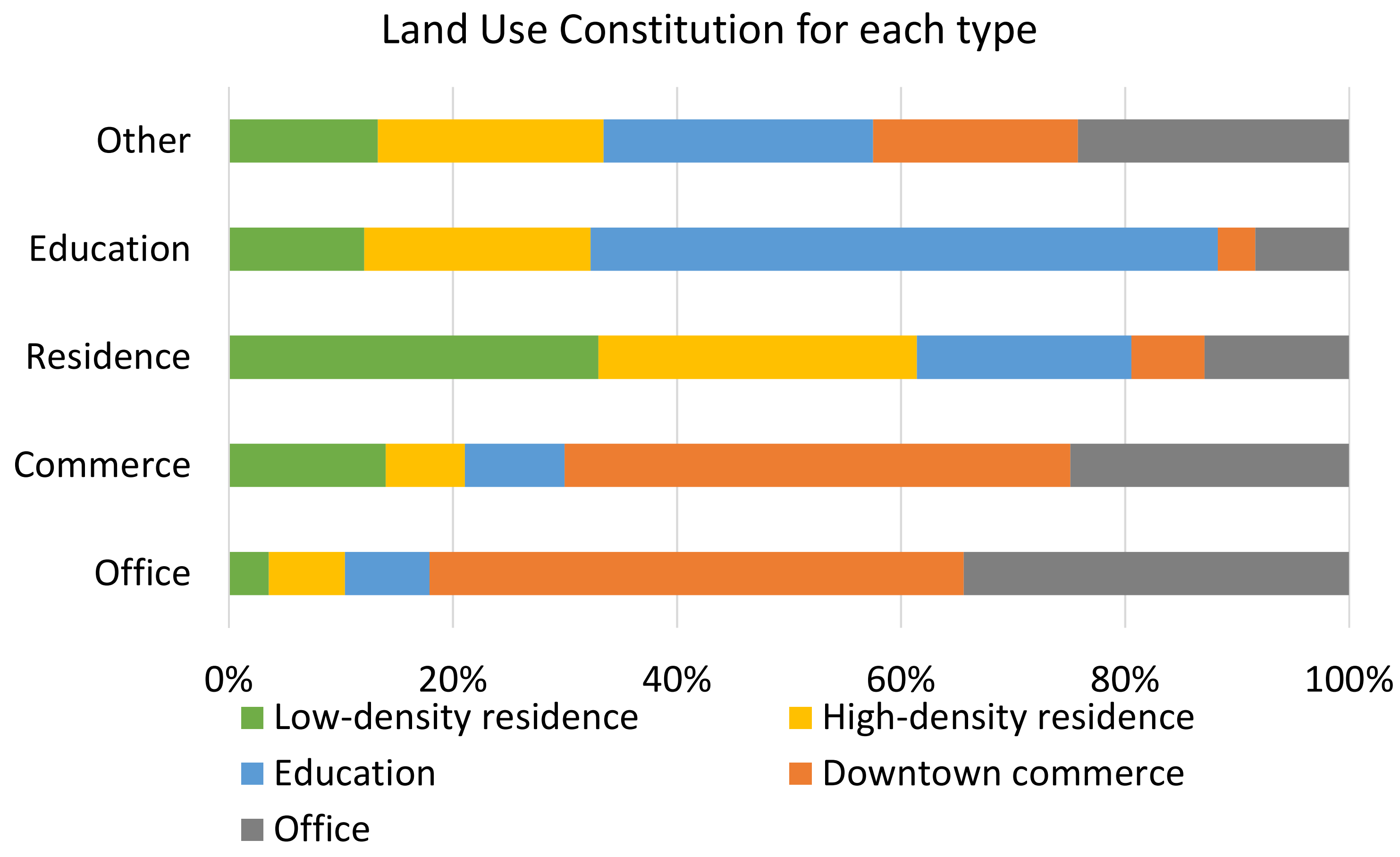
Factor 3: Education

- Education
- Government

3.4 Exploration the influence on transit ridership

Land use characteristics

- Station classification based on land use



3.4 Exploration the influence on transit ridership

General relationship

- Summary for each type of station

Type	Office	Commerce	Residence	Education	Transit ridership
Low-density residence	2.85%	7.99%	69.23%	4.47%	3416
High-density residence	5.43%	4.03%	59.66%	7.47%	15633
Education	6.03%	5.08%	40.22%	20.71%	7391
Downtown commerce	38.08%	25.76%	13.68%	1.24%	52300
Office	27.48%	14.20%	27.09%	3.10%	11038

- Cross table of land use and transit ridership

Type	Hub	Large-scale	Medium-scale	Small-scale
Low-density residence	0	0	0	9
High-density residence	0	2	4	3
Education	0	0	1	5
Downtown commerce	2	1	2	0
Office	0	0	3	2

- Large differences in different types
- Low density = Low ridership
- Commercial center = High ridership

3.4 Exploration the influence on transit ridership

Statistical relationship - quantification method I

- Part 1

Factor category	Category	Number	Score	Range
population density (person/ha)	0-40	3	4644	13004 13.84%
	40-80	13	2283	
	80-120	8	164	
	120-160	8	-2481	
	160-	3	-8360	
Commerce & Office (m^2)	0-100,000	16	-6249	43288 46.07%
	100,000-400,000	9	-6617	
	400,000-1,000,000	5	-4765	
	1,000,000-	5	36671	
Residence (m^2)	0-300,000	4	-1450	16240 17.28%
	300,000-800,000	20	-5575	
	800,000-	11	10664	
Government (m^2)	0-1,000	13	-2957	12267 13.06%
	1,000-10,000	9	-5501	
	10,000-	13	6766	
Education (m^2)	0-10,000	5	4842	9159 9.75%
	10,000-50,000	11	993	
	50,000-100,000	11	-4317	
	100,000-	8	1544	
Independent variable		Sample size		35
Transit ridership		Coefficient of determination		0.513

Dependent variable

- Transit ridership per day

Explanatory variables

- Population density
- Commerce & office
- Residence
- Education

Coefficient of determination

- 0.513

Key factors

- Commerce area
- Office area

3.4 Exploration the influence on transit ridership

Statistical relationship - quantification method I

- Part 2

Factor category	Category	Number	Score	Range
population density (person/ha)	0-40	3	0.0155	0.0265 28.44%
	40-80	13	0.0020	
	80-120	8	-0.0001	
	120-160	8	-0.0110	
	160-	3	0.0056	
Commerce & Office (m^2)	0-100,000	16	-0.0016	0.0097 10.44%
	100,000-400,000	9	0.0006	
	400,000-1,000,000	5	0.0069	
	1,000,000-	5	-0.0028	
Residence (m^2)	0-300,000	4	-0.0183	0.0226 24.31%
	300,000-800,000	20	0.0043	
	800,000-	11	-0.0012	
Government (m^2)	0-1,000	13	0.0111	0.0228 24.54%
	1,000-10,000	9	0.0008	
	10,000-	13	-0.0117	
Education (m^2)	0-10,000	5	-0.0078	0.0114 12.27%
	10,000-50,000	11	-0.0025	
	50,000-100,000	11	0.0034	
	100,000-	8	0.0036	
Independent variable		Sample size		35
Growth rate of transit ridership		Coefficient of determination		0.537

Dependent variable

- Growth rate of transit ridership

Explanatory variables

- Population density
- Commerce & office
- Residence
- Government
- Education

Coefficient of determination

- 0.537

Key factors

- Population density

3.5 Conclusion

- Summary

  - Through the summary and analysis, we got a comprehensive understanding of rail transit utilization and land use status in the case of Fukuoka City.
  - Provided foundation and references for the further exploration on the determinants on transit ridership

- Implications

  - Pedestrian area should be considered.
  - Explanatory variables should be enriched.
  - Model should be improved.
  - The approach of dealing with small sample case should be considered.

Chapter 4

Influencing Factors on Transit Ridership at Station Level

4.1 Introduction

Background

- Rail transit ridership is considered to be mainly affected by the environmental factors surrounding the station.
- The influencing factors are different in cities with different urban form and travel preference. Few studies focus on such a city like Fukuoka with only tens rail transit stations.

Main purpose

- Explore and explain the factors influencing subway ridership at station level using a small sample case

4.1 Introduction

Review

Study type		Type 1	Type 2	Type 3	This
Sample size	Tens				●
	Hundreds	●	●	●	
Method	Linear regression	●	●	●	
	Mixed spatial regression				●
Catchment area	Circle buffer	●	●		
	Walking distance			●	●
Indicators	Land use		●	●	●
	Transit-relation	●	●	●	●
	Demographic-relation	●			●

4.1 Introduction

Research focus

- Problems in previous studies
- Research focus

Problem 1

Index system need to be enriched

➡

1 Improve index system

Propose and reconstruct indicators to improve the index system

Problem 2

Few studies work on the selection of valid indicators using small sample case.

➡

2 Identify valid indicators

Propose effective index screening method for small samples

Problem 3

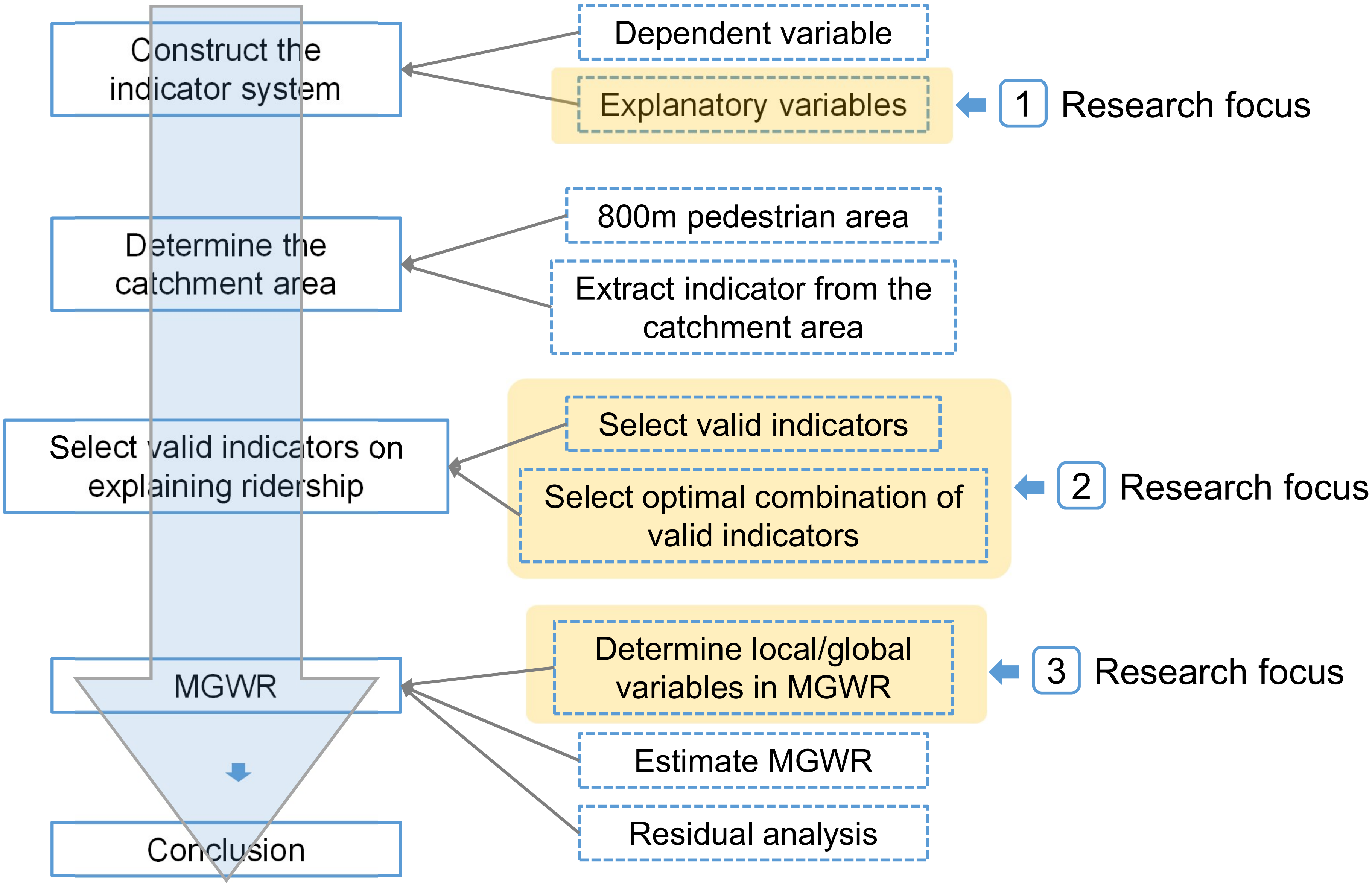
The consideration of spatial correlation among the explanatory variables is inadequate.

➡

3 Improve accuracy in estimation

Consider the different spatial distribution of indicators in the spatial regression model by identifying global/local variables.

4.1 Introduction



4.1 Introduction

Catchment area of stations

- In general
  - Catchment area: walking distance accessing the subway station. (Pedestrian Catchment Area, PCA)
  - Pedestrian area range: 400m ~ 1000m
  - Most adopted: 800m

- In the case of Fukuoka
  - Walking speed: about 4.8km/h
  - Average walking distance: about 600m

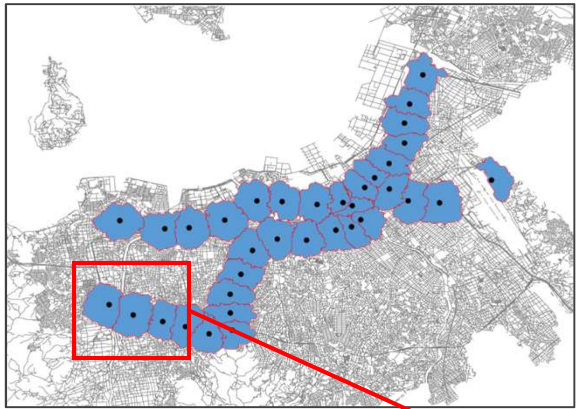
	Walking		Bicycle	
	Proportion	Ave time	Proportion	Ave time
AVG	78%	7.2	9%	9.0
Mid	85%	7.0	8%	9.5
Max	22%	4.8	0%	0.0
Min	100%	9.2	33%	20.0

1. Walking is the main method of accessing transit station.

2. Most walking distances are within 800m

4.1 Introduction

Catchment area of stations



Separated along the river

The walking distances along the real road network are equal from any point on the boundary line to both the station on both sides.

4.2 Indicators system

Variable summary

Category	Variable	Expected sign	Min Value	Max Value	Average	Unit
Built environment	Commerce	+	2,921	811,281	114,353	m^2
	Office	+	2,614	839,956	167,088	m^2
	Residence	+	110,748	1,067,523	528,533	m^2
	Education	+	294	305,559	59,691	m^2
	Government	+	-	128,471	20,878	m^2
	Transportation Facility Area	+	197	132,777	21,204	m^2
	Land use Aggregation	+	0.09	0.75	0.31	-
Transportation Accessibility	Transfer Dummy	+	1	4	1.34	-
	Bicycle Parking	Unknown	64	4,375	778	-
	Bus Capacity	Unknown	3	260	58.48	-
	Bus Accessibility	Unknown	4	455	89.71	-
	Road Density	-	191	479	299	m/ha^2
Demographic and Socioeconomic Environment	Population	+	1,908	19,393	9,813	-
	House Member	-	1.86	2.79	2.18	-
	Population/Job Balance	Unknown	1.27	2.61	1.80	-
	Tenant Proportion	-	0.15	0.65	0.43	%

- Dependent variable: average daily subway ridership

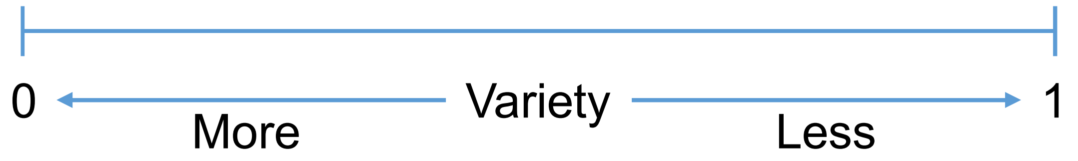
Variable interpretation

- Land-use Aggregation

Describing the variety of land use

$$A = \sqrt{\sum (p_i - P_i)^2}$$

Range



i : the type of land use (respectively government, commercial, residence and education)

p_i: the floor area of land use type i within catchment area of subway station

P_i: the average proportion of i type land use.

Range of PCA	Residence	Office	Commerce	Education	Total
800	55.3%	17.5%	12.0%	6.2%	90.9%

➡ Average P_i

4.2 Indicators system

Variable interpretation

- Indicators of bus system

Supposition

Bus system has both positive and negative effect on rail transit ridership

Share ridership from rail transit

VS

Bring ridership to rail transit

- Bus capacity

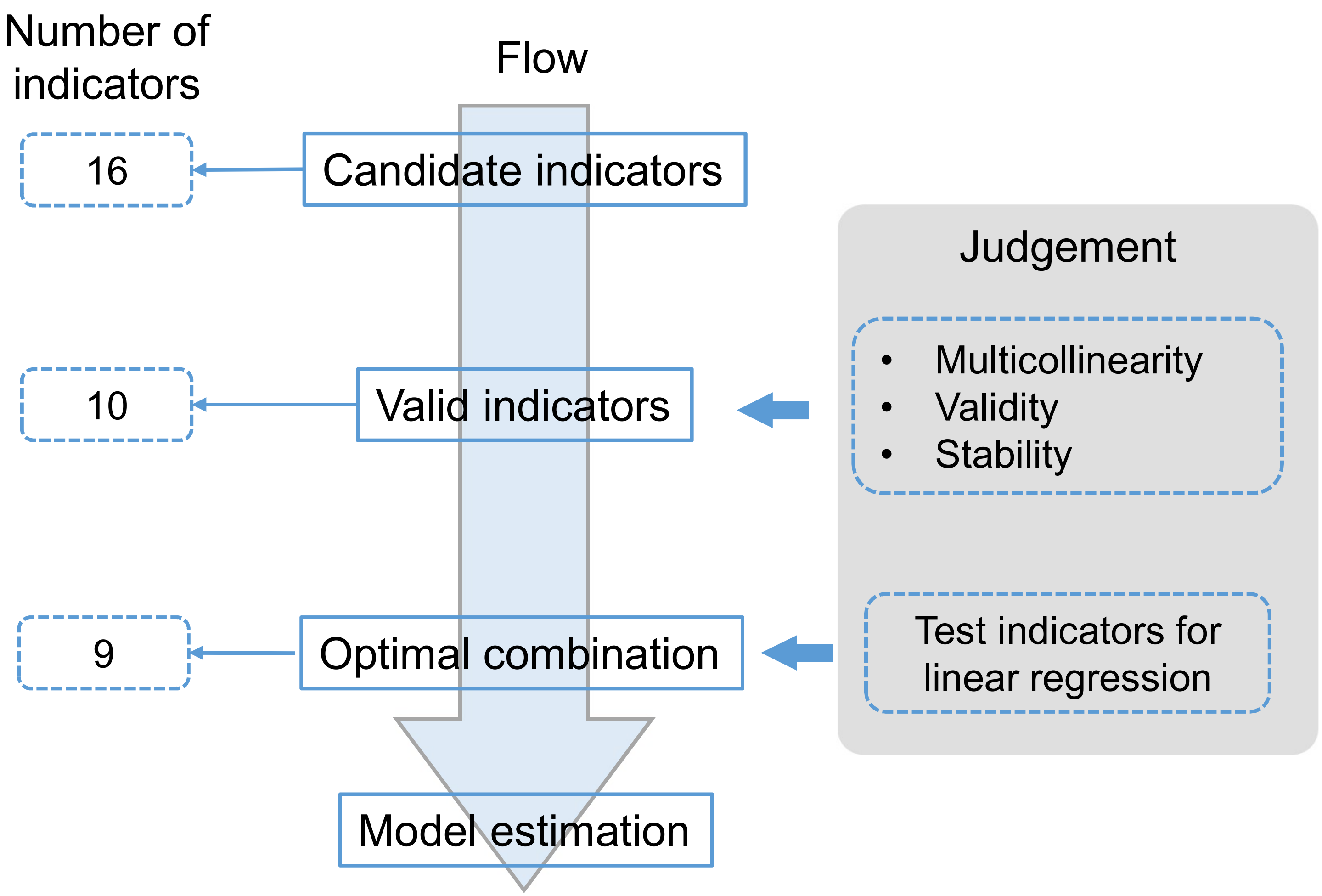
  Share passengers from rail transit. Negative effect on rail transit ridership

- Bus Accessibility

  Bring passengers to rail transit. Positive effect on rail transit ridership

4.3 Identification of valid factors

■ Flowchart of screening valid factors with small sample



4.3 Identification of valid factors

Valid factors

Suggested value
VIF< 7.5; Validity > 10%; Stability >90%

Category	Variable	VIF	Validity	stability	times	+	-
	Total				367	253	114
Built environment	Commerce Area	8.8	32.1%	100.0%	25	25	0
	Office Area	10.4	9.0%	71.4%	7	5	2
	Residence Area	27.5	12.8%	70.0%	10	7	3
	Education Area	1.8	7.7%	100.0%	6	6	0
	Government Area	1.8	42.3%	100.0%	33	33	0
	Transportation Facility	3.0	67.9%	100.0%	53	53	0
	Land use Aggregation	2.5	50.0%	100.0%	39	39	0
Transportation Accessibility	Transfer Dummy	3.0	34.6%	100.0%	27	27	0
	Bicycle Parking	4.5	44.9%	100.0%	35	35	0
	Bus Capacity	6.6	37.2%	96.6%	29	1	28
	Bus Accessibility	6.8	19.2%	100.0%	15	15	0
	Road Density	2.3	1.3%	100.0%	1	1	0
De Socioeconomic Environment	Population	23.9	12.8%	60.0%	10	6	4
	Household Members	3.0	39.7%	100.0%	31	0	31
	Population/Job Balance	3.0	37.2%	100.0%	29	0	29
	Tenant Proportion	2.2	21.8%	100.0%	17	0	17

Valid Variable

- The cell marked with dark color means that it doesn't meet the judgment.

4.3 Identification of valid factors

Optimal combination of factors

Independent variables	Test model		
	Beta	Sig	VIF
Government Area	0.10	0.02	1.36
Transportation Facility Area	0.20	0.00	2.31
Land use Aggregation	0.10	0.03	1.42
Bicycle Parking	0.46	0.00	2.60
Bus Capacity	-0.20	0.01	3.56
Bus Accessibility	0.26	0.00	4.71
Transfer Dummy	0.26	0.00	2.79
Population/Job Balance	-0.10	0.05	1.94
Tenant Proportion	-0.09	0.03	1.32
Household Members	-	-	-
Residual sum of squares	337744990		
Adjusted R^2	0.96		
AICc	694.39		
Jarque-Bera test (Sig)	0.61	No biased standard errors due to heteroscedasticity	
Koenker (BP) test (Sig)	0.85	Not deviating from a normal theoretical distribution	
SA test (Sig)	0.27	Not spatial autocorrelated	

4.4 Model estimation

Identification for global/local variable

Variable	Moran's Index	Z-score	P-value*	Pattern	DIFF of Criterion**	Type
Government Area	0.04	0.66	0.51	Random	-	Global
Transportation Facility	0.29	3.33	0.00	Clustered	-1.95	Local
Land use Aggregation	-0.01	0.20	0.84	Random	-	Global
Transfer Dummy	0.13	1.58	0.12	Random	-	Global
Bicycle Parking	-0.12	-0.92	0.36	Random	-	Global
Bus Capacity	0.70	7.57	0.00	Clustered	0.18	Local
Bus Accessibility	0.45	5.04	0.00	Clustered	0.04	Local
Population/Job Balance	0.77	7.61	0.00	Clustered	-0.17	Local
Tenant Proportion	0.24	2.54	0.01	Clustered	1.02	Local

* Statistical significance means autocorrelation

** More than or equal to 2.00, means the local term is better to be assumed as global

4.4 Model estimation

Estimation of Mix Geographically Weighted Regression

Variable	Type	OLS model			MGWR model		
		B	SE	t	B	SE	t
Government Area	Global	0.05	0.02	2.41	0.05	0.02	2.59
Land Use Aggregation	Global	11,832.53	5323.15	2.22	13,384.34	5,408.81	2.48
Transfer Dummy	Global	6,578.09	1216.82	5.41	5,968.65	1,198.72	4.98
Bicycle Parking	Global	7.51	0.93	8.11	7.72	0.90	8.59
Transport Area	Local	0.11	0.03	3.58	0.10	0.02	-
Bus Capacity	Local	-59.21	20.71	-2.86	-55.14	5.94	-
Bus Accessibility	Local	50.71	14.64	3.46	48.61	2.43	-
Population/Job Balance	Local	-2,762.24	1,079.33	-2.56	-2,411.17	364.44	-
Tenant Proportion	Local	-9,987.81	4,380.30	-2.28	-10,304.66	756.09	-
Best bandwidth					5.7km		
AICc		694.39			690.60		
Residual sum of squares		337,744,989			296,311,499		

4.5 Model estimation

Distribution of residuals

Indicator	OLS	MGWR
Moran's index	0.08	0.03
Expected index	-0.03	-0.03
Variance	0.01	0.01
z-score	1.09	0.61
p-value	0.27	0.54

Closer to the expected value is better

Less is better

- Moran's index in MGWR is closer to the expected index than that in OLS
- Z-score in MGWR is lower than that in OLS

4.6 Conclusion

Summary

- Problems

- Achievements

Problems	Achievements
1 Indicator system need to be enriched	Indicators system are constructed from 3 categories. Redefine the indicators of land use variety. The indicators of bus system are defined into bus capacity and bus accessibility.
2 Selection of effective indicators under small sample	To reduce the possibility of statistical 1,2 errors in small samples, use exploratory regression to screen effective indicators and the most metric combinations.
3 Insufficient consideration of spatial relevance of indicators	Identified global/local indicator in MGWR using the spatial autocorrelation of indicators.

4.6 Conclusion

Findings

- Increasing ridership
  - Government Area
  - Land Use Aggregation
  - Transfer Dummy
  - Bicycle Parking
  - Transport Area
  - Bus Accessibility
- Decreasing ridership
  - Bus Capacity
  - Population/Job Balance
  - Tenant Proportion

4.6 Conclusion

Recommendation

- Increase bicycle parking

  - Results from the indicator of bicycle parking

- From the perspective of bus lines and frequency, reduce the overlap rate between bus lines and rail transit lines, strengthen the transfer function of bus system

  - Results from the indicator of bus accessibility and bus capacity

- Encourage new construction of apartments around the rail transit station

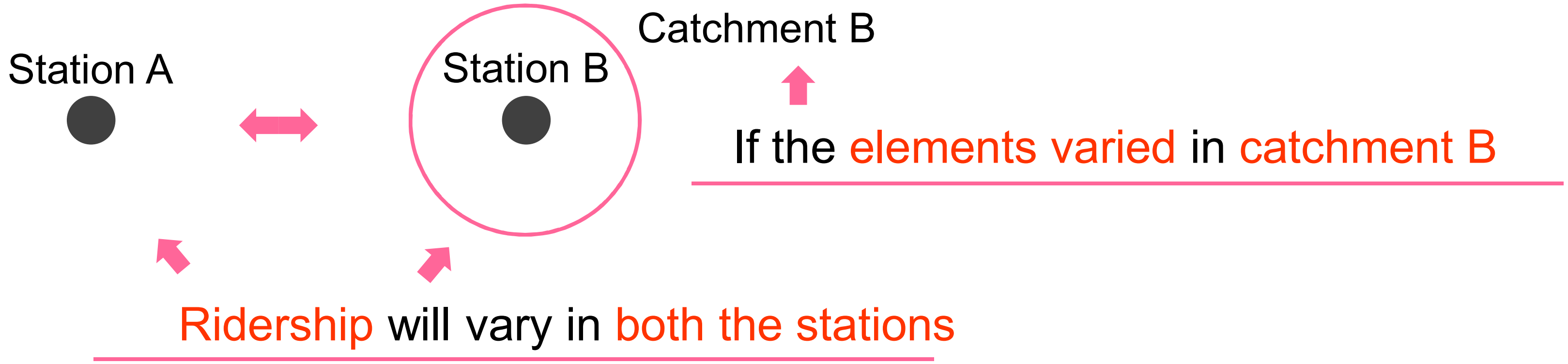
  - Results from the indicator of tenant proportion

Chapter 5

Influencing Factors on Transit Ridership at Station-to-Station Level

5.1 Introduction

Background



- The variation of land use in the catchment B can affect the probability that passengers boarding from station A choose station B as the destination

Main purpose

- Exploring the factors influencing transit ridership at station-to-station level

5.1 Introduction

Review

Previous study		Type 1	Type 2	Type 3	This
Perspective	Station	●			
	Station-to-station		●	●	●
Research object	Dependent variable	Transit ridership	Transit ridership	Transportation Impedance	Destination selection probability
	Explanatory variable	Single station	Both O and D stations	Both O and D stations	Both O and D stations
Method	Linear Regression	●	●		
	Gravity model			●	
	Probability regression				●

5.1 Introduction

Research focus

- Problems in previous studies
- Research focus

Problem 1 ➡ 1 Describe the transfer between station and station

On the research object, the ridership between ODs should be produced by the origin station, and then transferred to the destination station. Direct model for OD transit ridership is lack of this process on estimating the transfer between OD stations.

To find an indicator to describe the passenger transfer between station and station

5.1 Introduction

Research focus

- Problems in previous studies

Problem 2

In terms of method, the issue of analyzing the transfer of ridership between station and station usually adopt the gravity model, however, the gravity model is not used for estimating the influence of indicators.

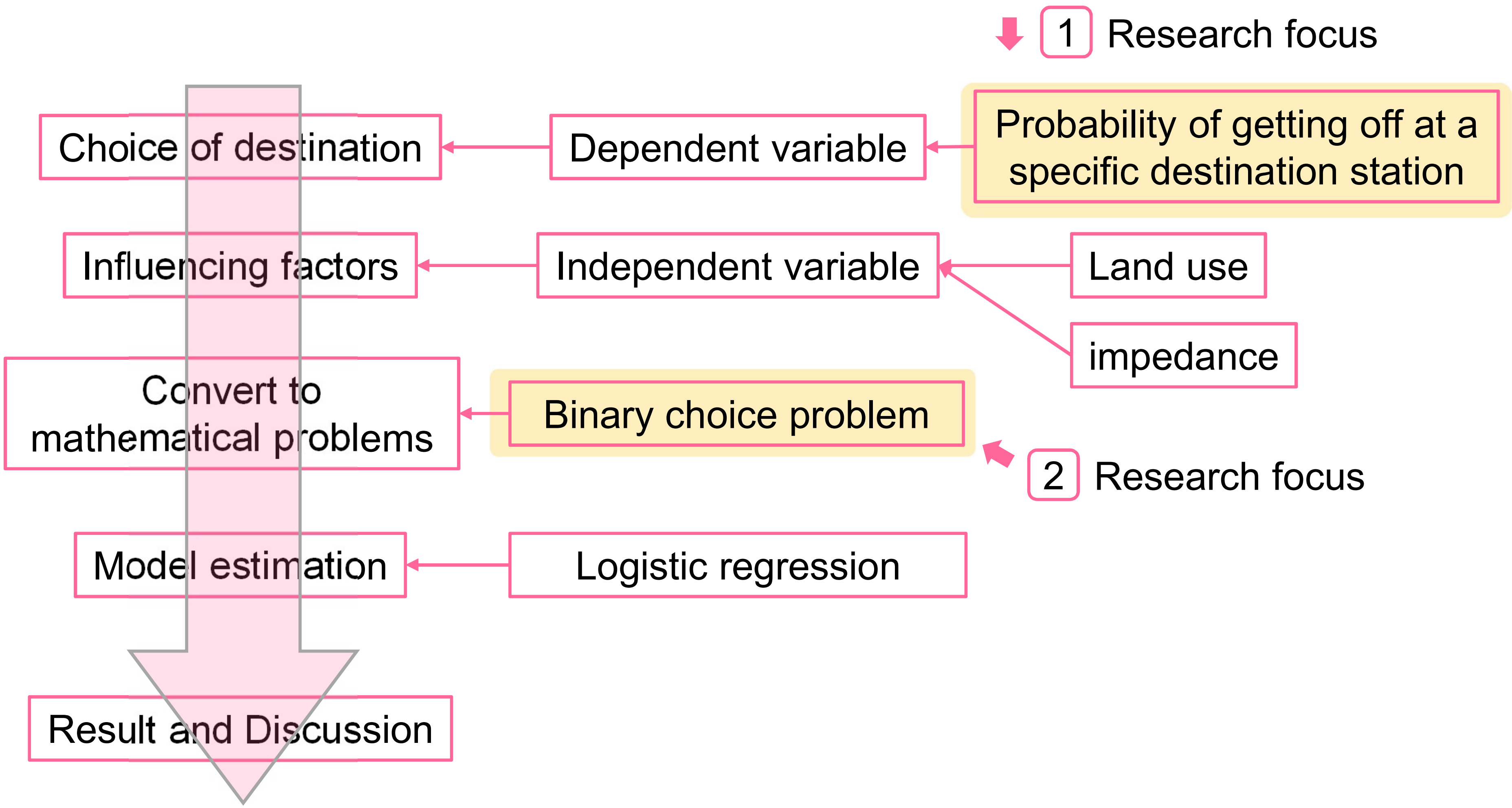
- Research focus

2 Estimate the influencing factors on the transfer of ridership between station and station

Convert this issue into the mathematical problem, then estimate the effect of influencing factors.

5.1 Introduction

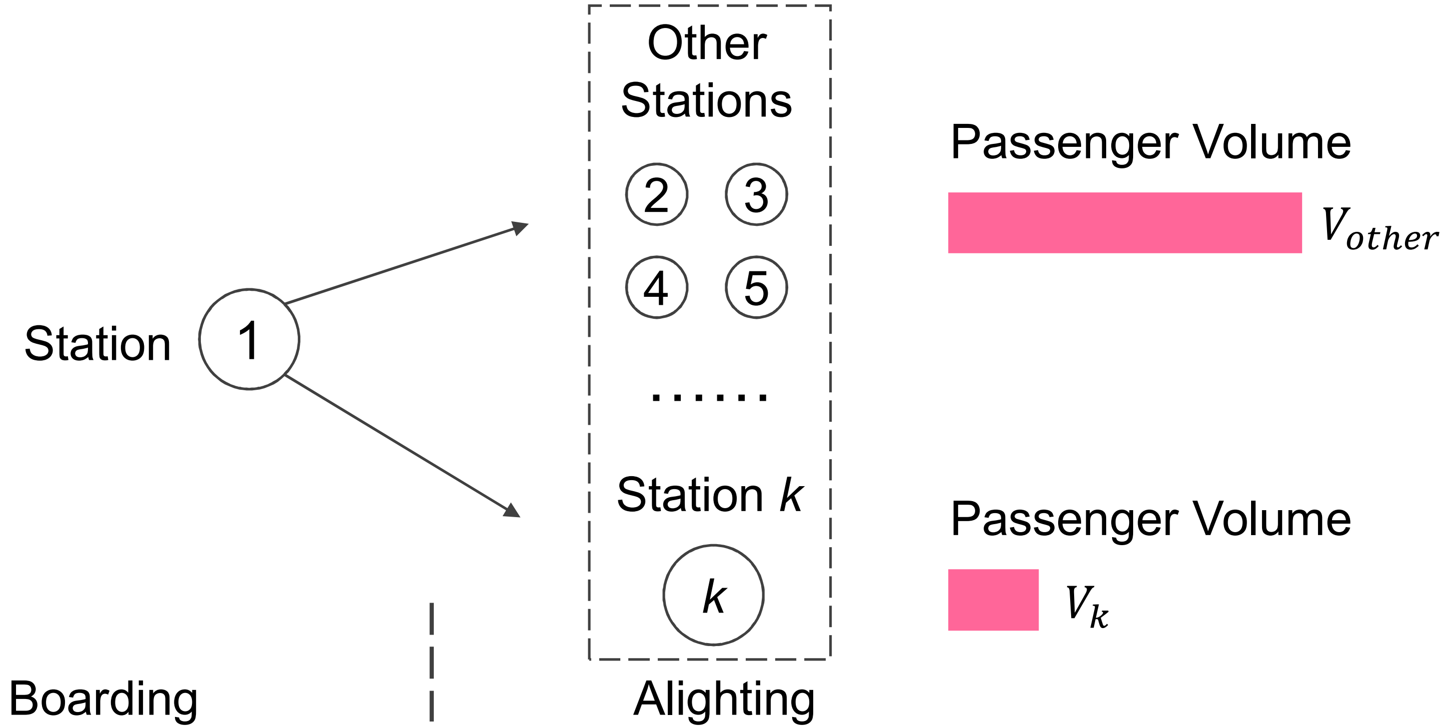
Flowchart



5.2 Research object

Dependent variable

- Probability of choosing the destination



For the passengers boarding from station 1
The probability of getting off at station k

$$P = \frac{V_k}{V_{other} + V_k}$$

5.2 Research object

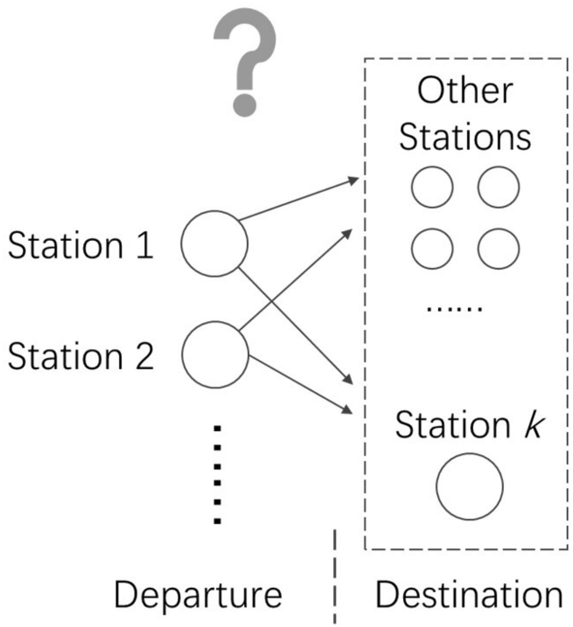
Independent variables

- Land use
  - Residence proportion
  - Office proportion
  - Commerce proportion
  - Education proportion
  - Land-use aggregation
- Impedance
  - Bus capacity
  - Bus accessibility
  - Operation distance of subway

5.3 Method

Mathematical problems

- Conversion



- Binary discrete model

$$\underbrace{P_k}_{\text{Probability of getting off at the investigated station}} = F\underbrace{(x_1, x_2, x_3, \dots\dots)}_{\text{Explanatory variable for making the choice of whether getting off}}$$

- Logistic regression model

5.3 Method

Selecting sample station

Station type	Station name	Population density	Commerce proportion	Office proportion	Residence proportion	Education proportion
Low-density residence	賀茂	98 Person/Ha	4%	3%	83%	4%
High-density residence	藤崎	173 Person/Ha	5%	7%	76%	6%
Education	箱崎九大前	83 Person/Ha	5%	6%	51%	22%
Office	呉服町	135 Person/Ha	8%	31%	49%	3%
Commerce	天神	69 Person/Ha	34%	32%	24%	1%

Note:

The highlighted cells refer to the representative values that having much higher proportion than other land-use types.

5.4 Results and discussion

Result of estimation

Destination Station		Variables in Departure Station							
		Land-use					Impedance		
Station Type	Station Name	C	O	R	E	L-A	D	B-C	B-A
Low-density residence	賀茂	0.95	0.94	0.94	0.93	0.97	1.07	1.01	1.00
High-density residence									1.00
Education									0.00
Office	呉服町	1.02	0.98	1.02	1.06	0.99		1.00	1.00
Commerce									1.00
Airport									1.00

Increase in this type of land use will lead to a decrease in the probability of choosing this station as the destination

Increase in this type of land use will lead to an increase in the probability of choosing this station as the destination

Note

- Meaning of the coefficients

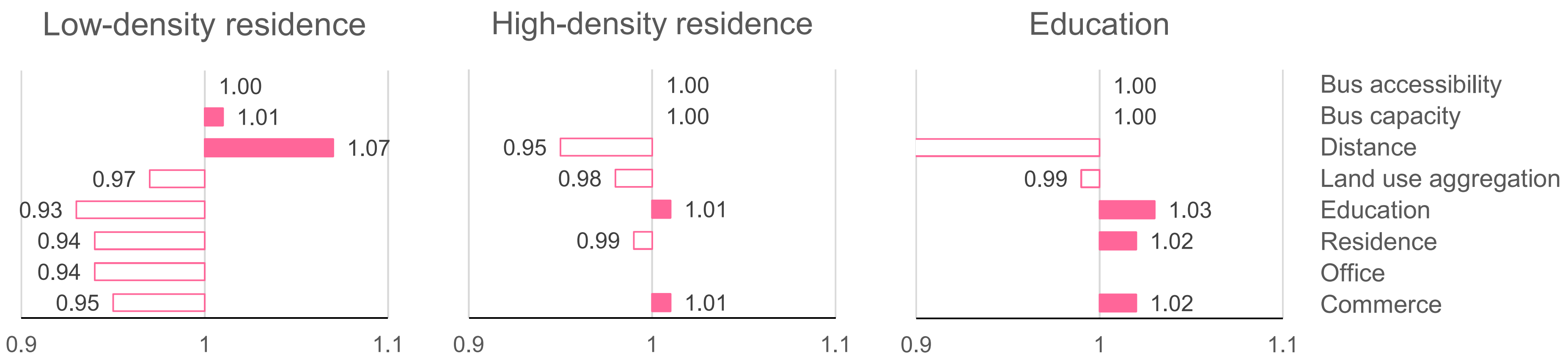
  1% increase in the proportion of land use will lead to a corresponding variation in the probability of getting off at the destination

- Full name of the abbreviation

  C: Commerce R: Residence L-A: Land-use Aggregation B-C: Bus Capacity
  O: Office E: Education D: Distance B-A: Bus Accessibility

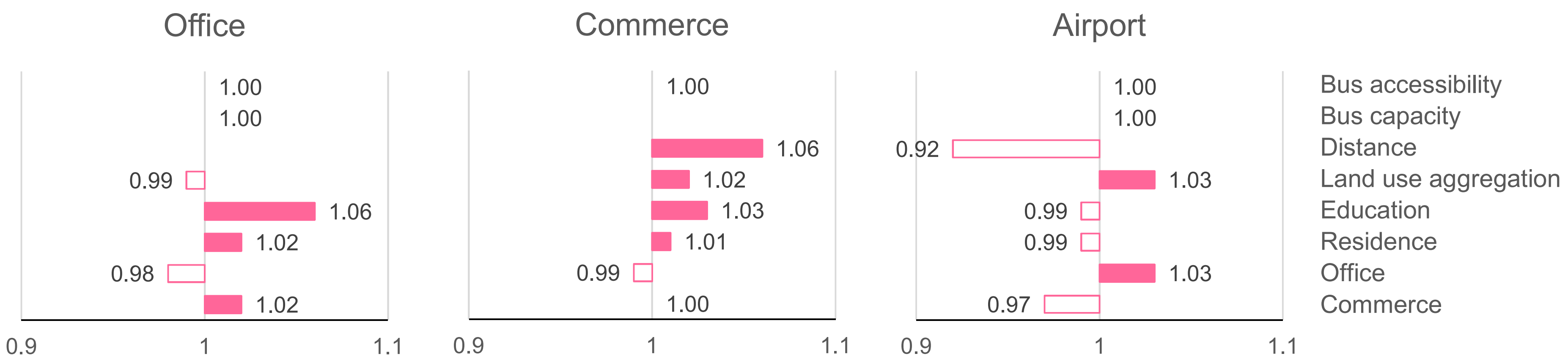
5.4 Results and discussion

Discussion for results



Odd ratio, increase in probability of choosing the destination station

Odd ratio, decrease in probability of choosing the destination station



5.5 Conclusion

Summary

- Problems
- Achievements

1. Description for the process of passenger transfer needs to be clear.

   → Described the passenger transfer using the probability of choosing a specific destination station.

2. The model should be able to reflect the influence extent of the indicators.

   → The problem is converted into a binary choice question. Logistic regression is used to estimate the influence of land use on the probability of passenger destination selection, also taking into account the influence of inter-station impedance.

5.5 Conclusion

Findings

1. The probability of choosing a destination has a trend of decreasing between the same type of land use.

2. The probability of choosing a destination belong to low-density residence type has no tend to raise regarding to the variation of land use in the departure station.

3. Increase in the education land use tends to lead increase in the ridership between station and station.

5.5 Conclusion

Recommendations

- It is recommended to pay more attention to the location of rail transit stations while judging the site selection of a newly planned school.

  - Results from finding 3

- For low-density residence type stations, it is recommended that promoting the utilization of rail transit could start with other measures than land use, such as fare adjustment.

  - Results from finding 2

- Combined with the achievement from chapter 4, a complete forecasting model for rail transit ridership is possible to be established.

  - Results from chapter 4 and chapter 5

Chapter 6

Conclusion

6.1 Conclusion

■ Summary

Based on the theme of exploring the determinants on rail transit utilization in Fukuoka City, this study discussed 4 major issues.

- One

➢ Chapter 2 discussed how the walking duration to rail transit station is affected by passengers' attributes. Centering with this problem, 3 specific research questions are proposed according to the previous studies, then the answers to each question were given.

6.1 Conclusion

Summary

Based on the theme of exploring the determinants on rail transit utilization in Fukuoka City, this study discussed 4 major issues.

- Two

- Chapter 3 summarized the characteristics of rail transit ridership and land use in the case of Fukuoka, which helped to make a comprehensive understanding of the research object in this dissertation. This chapter also gave some important reference and implication for the next research.

6.1 Conclusion

Summary

Based on the theme of exploring the determinants on rail transit utilization in Fukuoka City, this study discussed 4 major issues.

- Three

- Chapter 4 explored and estimated the influencing factors on rail transit ridership at the station level. With the focus on the case of Fukuoka with small sample size, this chapter proposed improved approach from indicator system, valid indicator selection, and model estimation three aspects, and the results are proved effective and improved.

6.1 Conclusion

■ Summary

Based on the theme of exploring the determinants on rail transit utilization in Fukuoka City, this study discussed 4 major issues.

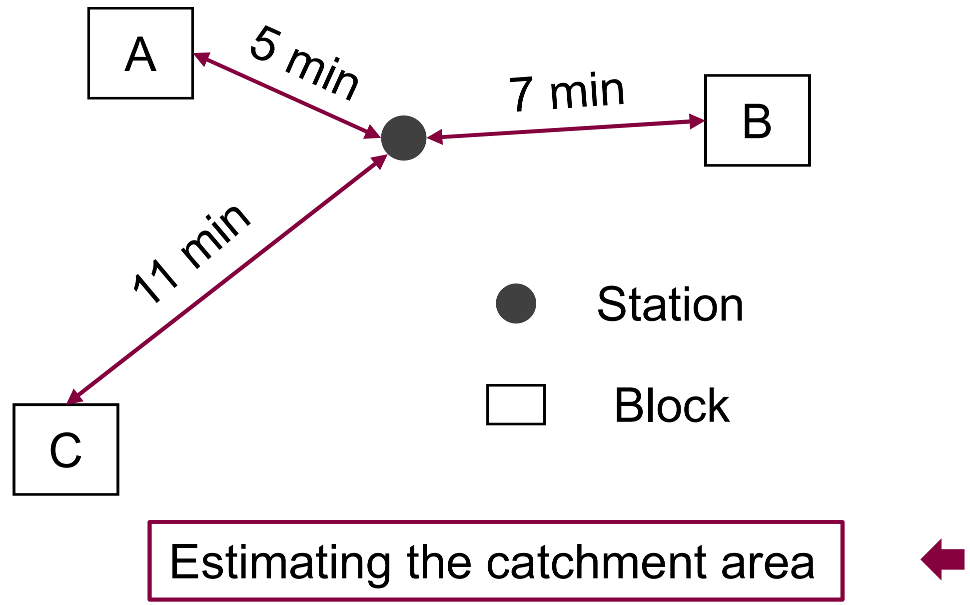
- Four

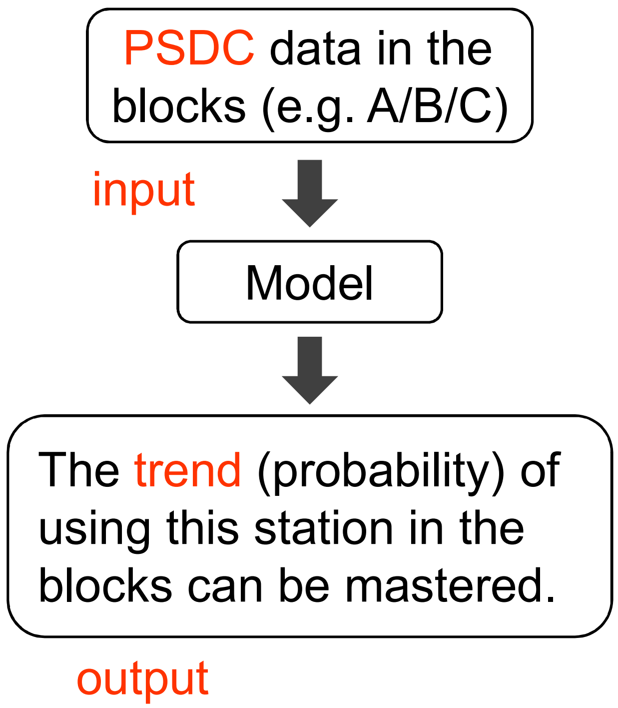
➢ Chapter 5 gave a description for the transfer of ridership between station and station that use the land use type around a station to explain the probability of choosing that station as the destination station. Then ran logistic regression to estimate the influence of land use on the probability of getting off at the destination station. The influence of land use on the transfer of ridership between station and station is confirmed in this chapter.

6.2 Recommendations

Application of the achievements

- Achievement from Chapter 2





- Combination with the achievements
  - Using the estimated catchment area to make prediction of transit ridership
  - Using the results of ridership transfer between station and station to correct the prediction of ridership at single station