BALANCING MASS TRANSIT RIDERSHIP THROUGH LAND USE DEVELOPMENT

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การสร้างสมดุลของปริมาณผู้โดยสารเป็นปัจจัยสนับสนุนให้เกิดอรรถประโยชน์สูงสุดต่อระบบขนส่ง ซึ่งไม่เพียงจะเพิ่มผลประโยชน์จากการดำเนินงาน แต่ยังเพิ่มประสิทธิภาพของระบบโดยรวมอีกด้วย การพัฒนาพื้นที่รอบสถานีขนส่งมวลชนเป็นการบูรณาการระหว่างการใช้ประโยชน์ที่ดินและระบบขนส่งเข้าด้วยกัน โดยมุ่งเน้นพื้นที่บริเวณสถานี ซึ่งลักษณะการใช้ประโยชน์ที่ดินเป็นปัจจัยสำคัญที่มีผลต่อการเกิดการเดินทาง การใช้ประโยชน์ที่ดินบางประเภทก่อให้เกิดการเดินทางในช่วงเวลาเร่งด่วน ในขณะที่บางประเภทก่อให้เกิดการเดินทางในช่วงนอกเวลาเร่งด่วน

งานวิจัยนี้มุ่งเน้นศึกษาการสร้างสมดุลของปริมาณผู้โดยสารระบบขนส่งมวลชนผ่านการใช้ประโยชน์ที่ดิน ซึ่งเป็นแนวทางการพัฒนาที่ยั่งยืน โดยได้ศึกษาแบบจำลองการกระจายการเดินทาง ได้แก่ The Gravity Model และ The modified Fluid Analogy Method (FAM) ซึ่งพบว่า แบบจำลอง The modified FAM สอดคล้องกับลักษณะพฤติกรรมการเดินทางของผู้โดยสารระบบขนส่งมวลชน และเหมาะสมสำหรับการนำไปประยุกต์ใช้ต่อไป โดยแบบจำลองนี้ได้ถูกประยุกต์กับการลักษณะการใช้ประโยชน์ที่ดิน พบว่า การจัดสรรที่ดินที่สนับสนุนให้เกิดความสมดุลของผู้โดยสาร คือ ที่อยู่อาศัยตั้งอยู่ปลายทั้งสองด้านและช่วงกลางของเส้นทางระบบขนส่งมวลชน พื้นที่เชิงพาณิชย์กระจายตามแนวสายทาง และพื้นที่ธุรกิจหนาแน่นในช่วงกลาง นอกจากนี้ แบบจำลองได้ถูกนำไปวิเคราะห์กับรถไฟฟ้าสายสีน้ำเงินเป็นกรณีศึกษา โดยได้กำหนดสถานการณ์การพัฒนาที่ดิน เพื่อเป็นแนวทางการพัฒนาในขั้นต้น รวมถึงวิเคราะห์ผลกระทบของตำแหน่งที่ตั้งโครงการต่อความสมดุลของผู้โดยสาร พบว่า หากโครงการตั้งอยู่ในตำแหน่งที่เหมาะสมจะสามารถเพิ่มความสมดุลได้ งานวิจัยนี้จะเป็นรากฐานของการบูรณาการระหว่างระบบขนส่งมวลชนและการใช้ที่ดิน เพื่อการพัฒนาที่ยั่งยืนตามหลักการพัฒนาพื้นที่รอบสถานีขนส่งมวลชนต่อไป

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The utmost utility of the transit system can be supported by the balance of ridership. It is not only gaining more operational benefits but also enhancing the efficiency of the system as a whole. Transit Oriented Development (TOD) is defined as an integration between land use and transportation, which focuses on the station areas. Land use characteristics are the essential factors that affect trip generation and trip attraction. Some types of land use generate trips mainly during peak hours. Meanwhile, some other types generate trips during off-peak hours.

This dissertation therefore focuses on the balancing mass transit ridership through land use development which is regarded as a great solution for the sustainable development. The trip distribution models; the Gravity Model and the modified Fluid Analogy Method (FAM), are proposed. The results achieved by the modified FAM prove more robust and will be more reliable when put into practice. The model is further adapted to deal with land use consideration. The results of optimal land use allocation indicate that the residential area should be accumulated at both ends and the center of the transit line, the retail area should be consistently spreading along the whole line, whereas business area should be concentrated in the Central Business District (CBD). The modified FAM is also utilized in practical use with a case study in Thailand, The MRT Blue Line. The scenarios of mixed-use development are initiated to figure out the development guideline of some specific types of land use. The analysis of the effect of mixed-use projects location along the corridor suggests that if the projects are located around well-chosen location, they would substantially enhance the balance of ridership. The contributions from this dissertation are to serve as a foundation of the integration between mass transit and land use to build upon in sustainable development, incorporating TOD.

Field of Study: Civil Engineering		Student's Signature ....
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Achara Limmonthol

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

Chapter 1
INTRODUCTION

1.1 CONTEXT AND BACKGROUND

Each transportation sector has its own purposes regarding service provision. They include system utilization, high profit margin, market share, commercial development, etc. All transportation sectors also have different pathways to achieve their purposes. One of the pathways that lead to the success is the efficiency of system utilization, which should be fully adopted by transit system providers as a fundamental principle. Such method can be implemented by balancing ridership distribution.

The balance of ridership distribution can be examined both on the macro and micro level, from transit network to corridor level. For a better understanding, the transit route analysis on the micro level would be the definite answer as to how to reach the highest efficiency of the whole transit route. This research therefore focuses on the corridor level balance, which is concerned with the aspects of mass transit agencies.

The utmost utility of the transit system can be supported by the even balance of ridership along the transit route, which is regarded as a significant characteristic. Imbalanced ridership problems, which often overwhelm many transit agencies, always occur in various transportation modes. As a result, the non-optimality of Origin-Destination (O-D) distribution leads to the waste of available capacity and inefficient usability.

From a transportation perspective, the problems of inefficient O-D distribution and the corresponding imbalance of ridership distribution can be witnessed through several aspects, which reflect ridership characteristics. They are as follows:

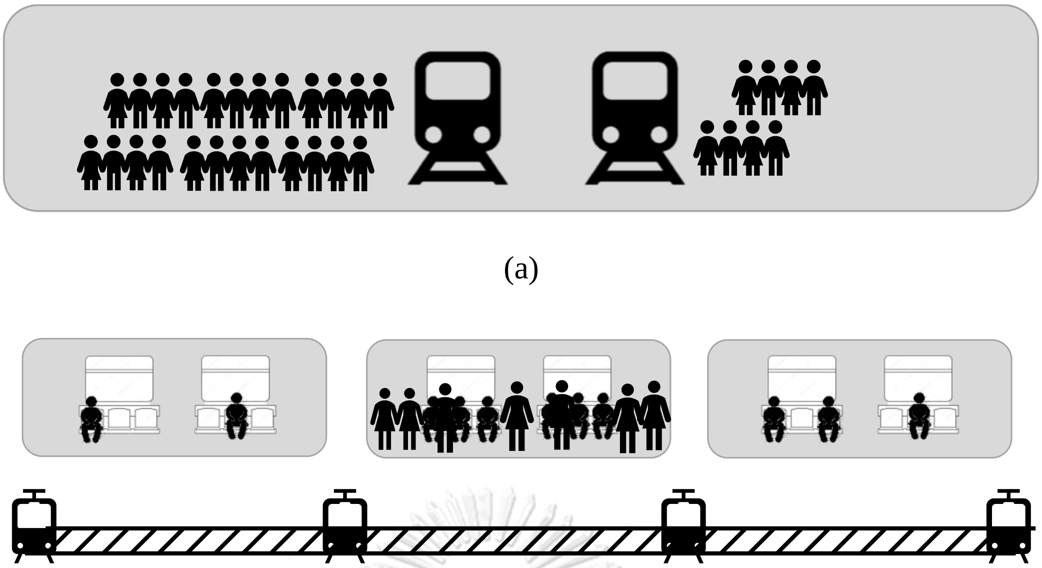


Figure 1-1 labels (a) and (b):

(a)

(b)

Figure 1-1 The characteristics of imbalanced ridership: (a) the imbalance between two directions, (b) the imbalance between any adjoining stations.

(1) The imbalance between inbound and outbound directions: one direction of the transit system is densely-packed with passengers, whereas numerous seats in the other direction are left vacant, as shown in Figure 1-1(a).

(2) The imbalance of the numbers of onboard passengers between any adjoining stations: the crowds of passengers can only be seen in some particular sections of the route, as shown in Figure 1-1(b).

Evidently, balancing a mass transit ridership distribution not only makes a transit agency gain more operational benefits but also enhances the efficiency of the transit system as a whole by reducing losses from an unoccupied capacity of the system. In addition, passengers can enjoy more punctuality, comfortable services as they can board the train they are waiting for without having to wait for the next one because of the excess of capacity, which causes longer travel time.

Transit Oriented Development (TOD) is defined as a land use and transport integrated urban planning strategy. It is highly notable for promoting sustainable city development, which focuses on the development of station areas that link a transit corridor. TOD is a mixed-use community within walking distance of a transit stop. Many countries might have many guidelines, definitions and concepts of TOD, according to their own development standards. However, it is generally accepted that it can encourage public transport ridership (Calthorpe, 1993; Cervero, 2007).

Mixed-use attributes are also a significant aspect of TOD. Some types of land use for residential and business areas, which generate trips mainly during peak hours, often lead to overcrowded trains. Meanwhile, some other types of land use that generate trips during off-peak hours can promote the efficiency of rail services. These types of land use involve entertainment complexes, retail shops and restaurants. TODs typically have a diverse range of land uses. They require good transit service frequency both during peak and off-peak periods to support both work and non-work trips.

One significant benefit of TOD is that it helps to balance directional split. When TOD is perfectly and functionally applied, it would result in trip distribution being evenly spread. It thus produces efficient bi-directional flows. The result of TOD in trip distribution in Stockholm, Copenhagen, Curitiba and Brazil shows that the directional split of mixed-use development is 45:55. At the same time, the imbalance of ridership distribution is greater in America, where trains are overcrowded in one direction and largely unoccupied in the other. These actual situations are a good indication of how mixed and balanced land use supports mixed and balanced passenger flows. In other words, land use form and transport system balance out and support each other (Cervero 2007).

Several studies claim that land use characteristics are among the essential factors that affect trip generation and trip attraction, both of which can be interpreted as fundamental behaviors of O-D distribution. They therefore have considerable impacts on transit ridership, depending on different generated activities (Pushkarev and Zupan, 1977; Hendrickson, 1986; Crane, 2000; Taylor and Fink, 2003; Wang and Hofe, 2008; Generation, 2008).

As a result, the adjustment of land use development with the application of the TOD concept, which influences the O-D distribution, could be a possible solution. It can be implemented to improve the current pattern of O-D distribution and counteract the imbalance of transit ridership accordingly.

1.2 PROBLEM STATEMENT

In this research, the integration of trip distribution and land use development, together with the TOD principle, is the focused solution to the imbalanced ridership problems. Nonetheless, there are 2 main critical problems that should be tackled. They are as follows:

(1) There are many trip distribution models for the estimation of O-D passengers. Each model has different strengths and drawbacks, depending on the conditions of employment. Nevertheless, the appropriate trip distribution model for a mass transit system, which is not the immediate mode of transportation between origin and destination, does not exist. A precise distribution model, which performs the behavior of mass transit ridership distribution, is necessary for solving imbalanced ridership problems. The trip distribution model for mass transit system should therefore be formulated in order that the fundamentals of the research can originate in a proper way.

(2) Academic studies about the relationship between the pattern of O-D distribution and the balance of transit ridership are insufficient. There have also been no researches that integrate O-D distribution and land use variables together. The integration of these two features would be the fundamental of transit route planning and land use regulations in order to make them supplement each other for sustainable transportation and land use.

In Thailand, the imbalance of ridership is obviously seen in the Metropolitan Rapid Transit Chaloem Ratchamongkhon Line (The MRT Blue Line), the first subway of the MRT system in Bangkok's downtown area. The situation of imbalanced ridership appears to be both the imbalance between directions and the imbalance of onboard passengers between adjoining stations. It is realized that the aforementioned problems can be solved by planning the transit system, together with systematic land use, for the long-term unity growth.

1.3 RESEARCH OBJECTIVES

The most principal objective of this dissertation is to balance mass transit ridership through the development of land use. To achieve the purpose, other important objectives of this research have to be specified. They are as follows:

(1) To develop a theoretical model that can explain optimal O-D distribution in order to balance mass transit ridership.

(2) To theorize a relationship model between land use and O-D distribution and conduct numerical simulation.

(3) To verify the model by actual land use and mass transit ridership data.

1.4 SCOPE OF RESEARCH

Balancing mass transit ridership can be managed in many ways, depending on each sector's aspects. This research focuses on the integration between the trip distribution and development of land use, which is regarded as a solution to imbalanced ridership problems. As trip distribution models cover a wide range of research areas, the models have thus been developed and modified for many different contexts. Furthermore, the development of land use can be performed in many different contexts as well. The research will therefore be scoped in the following ways:

(1) This research focuses on balancing mass transit ridership in the viewpoints of transit agencies to reduce losses from the unoccupied space of mass transit system and utilize a mass transit system for approaching the maximum efficiency.

(2) The development of land use is assigned to be the solution for O-D distribution adjustment. Other factors, including pricing strategy, fare policy, flexible working hours policy on work employment and level of service, are not examined in this study.

(3) The structure of a mass transit line is scoped for the linear system, which is a single and stand-alone rail line. It can be implied that there is no connection with any other lines.

(4) The effective area to balance mass transit ridership is scoped within the radius of approximately 550 meters around a mass transit station in accordance with the principle of TOD potential coverage area.

(5) The allocation of land use is captured in terms of the station level and the corridor level to balance ridership, whereas the allocation for the network level is not examined in this research.

1.5 OUTLINE OF DISSERTATION

This dissertation is organized into six chapters, which are as follows:

Chapter 1 Introduction: as described in this chapter.

Chapter 2 Literature review: This chapter reviews the transportation demand management. Factors that affect transit demand, including impacts of land use characteristics on transit ridership, TOD's background and concept for urban planning and the application of TOD in other countries, are taken into account. It also reviews trip generation and trip attraction rates, as well as various trip distribution models with the advantages and limitations.

Chapter 3 Methodology: This chapter delves into the structure of trip distribution models, formulates the model for the balance of ridership and compares the model performances in mass transit behavior reflection.

Chapter 4 Balancing mass transit ridership through land use development: This chapter presents the application of the chosen model to cope with land use consideration and assumes the development scenarios to verify the effects of the development of land use on the balance of ridership.

Chapter 5 The case study in Thailand: This chapter provides the background of MRT blue line, optimizes the land use allocation with the existing total proportion and analyzes the effects of the mixed-use project location at stations.

Chapter 6 Conclusions and recommendations: This chapter summarizes the findings and contributions of this research and demonstrates the model validation for switching the application between the morning and evening peak hours. The recommendations for the future works are also provided.

Chapter 2
LITERATURE REVIEW

This chapter provides an overview of the previous research about the TOD background and concept, concerning a land use and transport integration for urban planning, and the application of TOD in other countries. The factors that affect the transit ridership are concerned with the impacts from land use characteristics. The O-D estimation models for a variety of situations with the advantages and limitations are also reviewed in this study. Trip generation and trip attraction rates in other countries are referred to as guidelines on the trip distribution models with the application of land use to balance ridership.

2.1 THE TRANSPORTATION DEMAND MANAGEMENT

The transportation demand can be managed in many methods. Transportation Demand Management (TDM) has become a popular issue in recent years. It focuses on how people make their decisions on travel modes. Also, it refers to various strategies that affect travel behavior as they increase the efficiency of transport in alignment with objectives of planning.

There are many factors that affect people's transport-related decisions and justify mobility management, such as infrastructure supply, vehicle supply, transportation diversity, institutional capacity, traffic safety, comfort level of mode choice, environment in urban areas and economic development including land use. These factors are influenced by TDM strategies, which attempt to encourage more efficient travel patterns. In any case, the guidelines may be different, depending on the factors that influence transit demand. This part reviews those factors that affect the transportation demand and how they induce or discourage transit passengers.

2.1.1 Factors Influencing the Transit Demand

The factors that influence transit demand can be divided into 2 types, namely internal factors and external factors, as shown in Table 2-1. The difference between these two types is that the internal factors can be controlled by transit agencies, whereas the external factors are beyond their control.

'The external factors' that affect transit ridership can be subdivided into 3 categories. The first one is ***the socio-economic factors***, such as population, employment level, income level and automobile ownership. These socio-economic factors are investigated in several aspects. Each study might focus on different factors. However, the results reveal that these socio-economic factors have effects on transit ridership. (Hendrickson 1986) analyzed the impacts of socio-economic factors on the transit demand in terms of *regional population*, whereas (Chung 1997) focused on the effects of passenger's *income level* as the socio-economic factors affecting transit demand.

Table 2-1 Factors Influencing the Transit Ridership.

EXTERNAL	INTERNAL
Socio-Economic	**Pricing Policy** (Sale 1976); (Kain and Liu 1995)
• Population (Hendrickson 1986) • Employment (Liu 1993); (Gomez-Ibanez 1996) • Income (Chung 1997) • GDP (Taylor, Haas et al. 2002) • Car ownership (Kitamura 1989)	• Fare • Marketing
Spatial	**Level of Service** (Taylor and Fink 2003)
• Land Use and urban form (Pushkarev and Zupan 1977); (Corporation, Planners Collaborative et al. 2007)	• Frequency • Accessibility
General Public Policy	**Service quality (Taylor and Fink 2003)**
• Car ownership taxes / Transit campaign /Road pricing. • Flexible working hours • Parking cost	• Facilities. • Technologies employment • Transit operation efficiency

Gomez-Ibanez (1996) analyzed the effects of pricing system and found that the *employment and income level* has more influences on ridership than the level of service or fare. (Liu 1993) applied the sensitivity analysis to compare the influence of each factor on the transit ridership. They concluded that *employment* had a greater impact on the transit ridership than other relevant socio-economic factors. Furthermore, they also argued that some factors had a correlation between one another. They include car ownership, car use and transit use. Likewise, Kitamura (1989) specified that changes in *car ownership* affect the frequency of car use, which leads to the shifts in transit ridership demand. Economic factors concerning *Gross Domestic Product* (GDP) were also scrutinized as they have effects on the transit ridership (Taylor and Fink 2003).

The second category is ***the spatial factors***, which are comprised of *land use* and *urban form*, transportation system and travel behavior. Various land use configurations have wide-ranging impacts on other city components, including the transportation system. The characteristics of land use and urban form that influence transit ridership would be examined in terms of compact, density, mixed-use development, level of automobile access, pedestrian network, residential density, size of downtown, multi-family housing and distance from stations to downtown (Pushkarev and Zupan 1977).

The last category of external factors is ***the general public policy factors***, which are the plan on the level of transit funding, subsidy in transit service, car ownership taxes, road pricing, parking cost, flexible working hours and transit campaign.

On the other hand, ***'the internal factors'*** that affect transit ridership could be regulated by transit agencies. They can also be subdivided into 3 categories, namely pricing policy, level of service, and service quality.

The pricing policy factors involve fare level. It is found that they have great impacts on transit ridership in many cities, such as Eugene, Madison, Minneapolis-St. Paul, Portland, Salt Lake City, San Diego and Vancouver (Kain and Liu 1995) (Liu 1993).

Taylor and Fink (2003) defined that the factors that promote transit use can be grouped into the second category of internal factors, ***the level of service factors,*** as number of available transit service, service coverage area, service frequency. Meanwhile, other factors that affect transit use can be grouped into the third category of internal factors, ***the service quality factor*s**. They are defined as safety, signage information, on-street service, customer service, cleanliness, reliability and punctuality (Kain and Liu 1995).

Nonetheless, each factor or the combination of both internal and external factors, such as fare, employment, average fare, revenue, vehicle, mile of service, fuel price and auto ownership level, would affect ridership demand

2.1.2 Impacts of Land Use Characteristics on Transit Ridership

Focusing on the factors that affect transit ridership, the second category of external factors, *the spatial factors*, with regard to land use and urban development, is supposed to be the most sustainable solution for the balance of ridership. The impacts of land use characteristics on transit will be reviewed further in detail.

The impacts of urban form on travel demand have been analyzed in many studies to verify how they facilitate the design of urban development strategies in travel demand management and determine how new urban planning paradigms affect the transit efficiency.

The urban form factors related to the land use management can be indicated by main characteristics. The most significant components of urban dynamics are land use, transport network, movement, employment, workplace, population and housing (Pushkarev and Zupan 1977). The urban form factors are summarized in the following points:

(1) *The density of urban form* such, as residential density, building density, employment density and increasing density of land use surrounding the transit station will trigger trip generation rate and reduce private-mode choice.

(2) *The diversity of urban form*, such as mix type, housing-job, housing-retail and retail-job is expressed by land use entropy index.

(3) *The design of urban form*, such as level of automobile access, pedestrian network, size of downtown, multi-family housing, and the distance from stations to downtown areas. Community design is one of the factors that have influences on travel patterns. It is assumed that the great integration between transit and land use is the benefit of transportation that can widen a range of alternative modes of travel.

Mostly, these urban form characteristics are executed by the government's land use regulations in terms of limitations of land use density, specified principal activities of a development and minimum lot size requirement. They all have impacts on transit system demand both in positive and negative ways. Both land use and transportation are part of a dynamic system as the retroactions, whereby one component changes its influence on others. The changes will also influence the initial component later, either positively or negatively.

The effects of land use configurations on transit system were analyzed in many studies. The results might be different, depending on particular study areas or countries. The issue, however, should be determined carefully and legitimately as land use classifications are different due to the land use implementation plan of each country.

Hu, Legara et al. (2016) investigated the relationship between public transit ridership and land use information. The amenities of a locality were used to add more granularity to its land use features, retrieved from Open Street Map. The amenities were grouped as follows - sustenance, education, transportation, healthcare, entertainment, finance and commerce. The study supports the idea that strategizing and planning land-use configurations, the amenity resource distribution in particular, influences and shapes the demand for public transportation. The land use amenities are indeed the influential feature variables on public transit ridership.

Bordoloi, Mote et al. (2013) categorized the land use characteristics, according to the usability, into five categories, which are as follows: 1) Residence - dwelling, home, condominium. 2) Commercial - retail shop, shopping complex, building with retail shop and office. 3) Educational - school, college. 4) Service - building as an office only. 5) Others - social welfare center, temple, recreation center, cinema hall and community hall.

They verified how the changes in land use mix influence the travel patterns by the elasticity analysis. The results showed that a slight change in the land use mix significantly affects trip-related parameters. They also demonstrated that mixed land use is one of the major factors that affect non-motorized and public transport trips specifically for work purposes.

A study of the relationship between land use and transit ridership in Fukuoka, Japan was conducted by Zhuang and Zhao (2014). They examined the effects of land and building use on the population, land prices, and passengers in station areas, using multiple regression algorithms, the target area scopes were classified into two groups with different distances; a radius of 0 – 400 meter from railway stations as 1st area and 400 – 800 meters from subway stations as 2nd area. There are 68 stations and 8 lines in total. The land use categories and building usage factors are as follows:

- Land use: commerce, house, government, industry, transportation and warehouse, park and green land, used space, unused space, agriculture, forest, water and road.
- Building usage: business and hotel, entertainment, detached house, condominium, government, transportation and industry.

The explanatory variables of each station in every 5-year period; 1985, 1993, 1998, 2003, and 2008 are included to examine land use developing trends, with regard to the multiple regression analyses in terms of the average size and area percentage of each explanatory variable. In conclusion, the adjusted R^2 for 1st area tended to be higher than 2nd area. The 1st area is affected by transportation and warehouse, whereas the 2nd area is affected by commercial land.

Galelo, Ribeiro et al. (2014) evaluated TOD level of suburban train line stations connecting Azambuja and Lisbon in Portugal. The service area was buffered within the radius of 400 meters and 800 meters around the station by using GIS, covering a total of 14 stations along the TOD characterizations. The TOD level was analyzed in terms of population, building, dwelling, and transportation availability. The data were collected in 2001 and 2011 for considering the variation tendency. The correlation analysis was applied to examine the association between train connection and each variable.

The results show that more train connections tend to have bigger values of the population, building density and employment.

Sung, Choi et al. (2014) investigated the impacts of land use, rail service coverage and rail station accessibility on rail transit ridership in the city of Seoul and Seoul Metropolitan Region (SMR). There are 304 and 473 stations, respectively. They employed the regression analysis with buffered service coverage area within the radius of 250 meters, 500 meters, 750 meters, 1 kilometers and 1.5 kilometers from each rail station to analyze the impacts of land use on rail transit ridership, which can be differentiated by service coverage area.

The daily ridership of each station is converted into the logarithm function to approach a normal distribution. The first explanatory variable is *density factors* concerning residential building, neighborhood living, commercial hub, public space and office, measured by the total area of each type per coverage area. The second explanatory variable is *diversity factor* between each land use type concerning mixed index. The last explanatory variable is *accessibility factor* concerning number of station entrances/exits, number of bus routes at the station, distance from the nearest station, transfer station and railway type (intra/inter urban railway).

For the density variables, most are positively related to rail transit ridership within the radius of 250 meters, 500 meters and 750 meters. Especially, the residential land use is statistically significant regarding the positive relation to rail transit ridership within the radius of 1 kilometers and 1.5 kilometers for the city of Seoul and SMR respectively. According to the result, it can be concluded that the residential land use density is a highly important factor for increasing ridership beyond the walking distance of 500 meters.

For the diversity variables, only the diversity between residence and small-scale neighborhood living use within 250 meters boundary is statistically significant for rail transit ridership in positive ways. All other variables, however, have no significant impacts in any coverage areas. It can be implied that the association between land use mix and rail transit ridership is unclear.

For the accessibility variables, the number of station entrances/exits and bus routes tend to be statistically significant for rail transit ridership in positive ways. The result suggests that improved bus-rail transfer systems can increase demand for railway service, whereas the distance variables present their negative significance within the radius of 750 meters, 1 kilometers, 1.5 kilometers for Seoul, and 750 meters, 1 kilometers for SMR. This means that the distance between rail stations is more effective in attracting ridership if stations are located in walkable distances of each other. In addition, transferring to other transportation modes has no impacts on ridership for all coverage areas.

Deng and Xu (2015) collected the ridership data from IC card in every half an hour and got the total 48 times per day regarding both boarding and alighting in morning and evening peak hours. The data are categorized by a cluster analysis method.

Each category investigates surrounding land use, population and employment to determine significant factors of the relationship between ridership characteristics and surrounding land use. The time distribution analysis results show that the category I - III, which has a greater amount of residential land uses, tends to generate more commuters during morning peak hours, leading to larger boarding ridership. The category IV - VI, which has more employment land use, tends to generate more commuters during morning peak hours, leading to larger alighting ridership. The category VII with more commercial lands attracts a large amount of non-regular commuters during non-peak hours. The category VIII, which is located near the urban external transportation hub, the scale of ridership depends on flows of passengers in the traffic hub. Lastly, the category IX, which has many mixed land uses, leads to unobvious peak time periods and larger ridership in non-peak time periods, as shown in Figure 2-1.

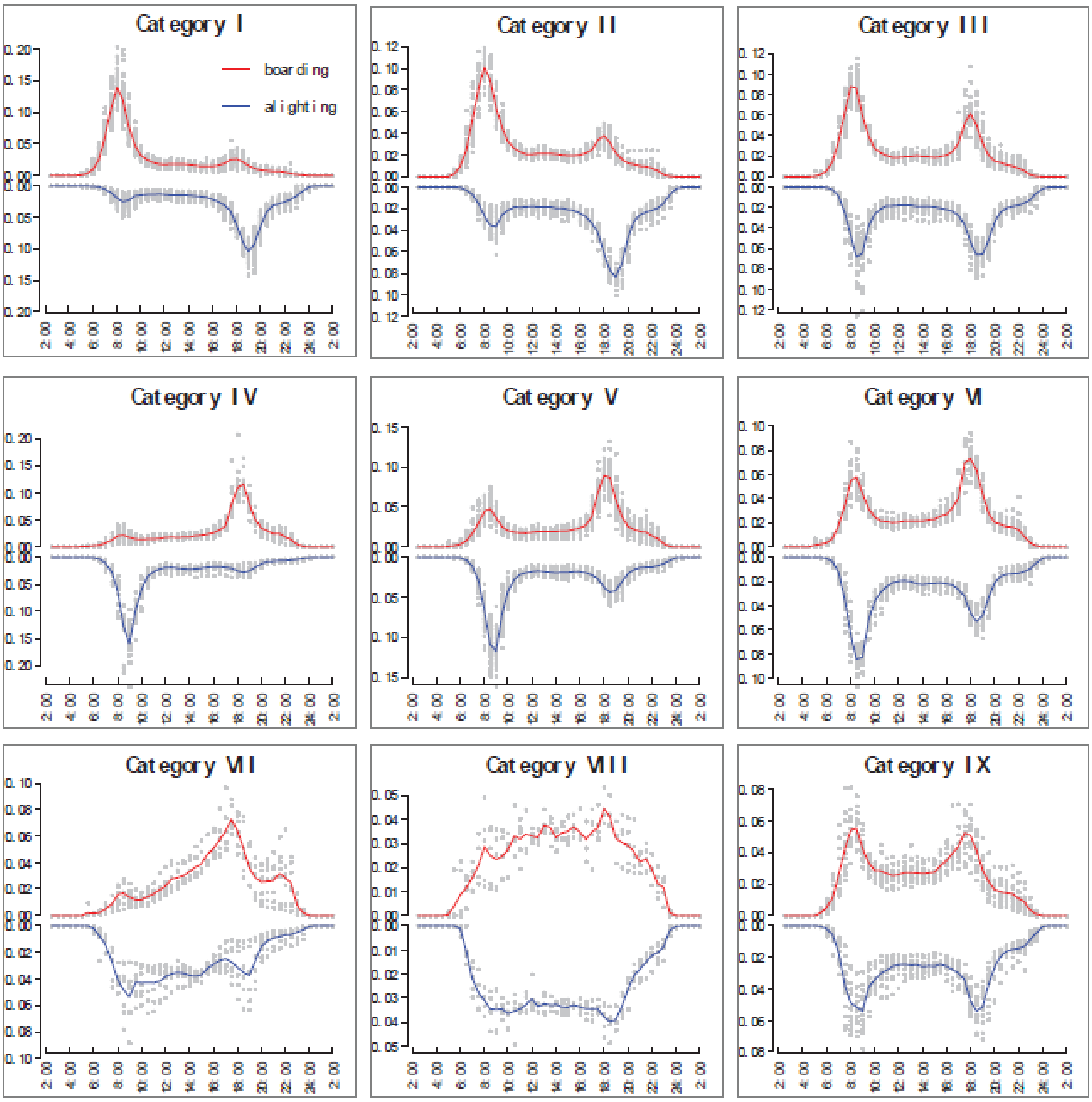


Figure 2-1 Time distribution curve analysis.

It can be assumed from the results of time distribution curve analysis that the differences of land use around stations tend to make different patterns of boarding and alighting distribution characteristics.

2.2 TRANSIT ORIENTED DEVELOPMENT IN THE CONTEXT OF DEVELOPING COUNTRY

TOD is a land-use and transport integrated urban planning strategy, which is widely known for promoting sustainable city development. The TOD concept focuses on station area development. It integrates transit with land use to enhance urban communities and transit use along with sustainable transportation. TOD is typically defined as a highly dense and mixed-use development around transit stations. The 3-D principle, Density, Diversity and Design, is adopted to support transit use through the regulations of land use development.

The fundamental objective of TOD is to reduce automobile dependency and promote the use of mass transit and other sustainable modes. The benefits achieved through the implementation of the successful TOD are all about reducing traffic congestion, creating livable communities, achieving sustainable transport and increasing the use of transit and non-motorized transport (NMT). TOD can make the greater connectivity between each transit mode, together with the increasing urban living demand and pedestrian safety. It is assumed that the proximity of densely-populated areas to rail lines is instrumental in improving the qualities of urban life as public transport helps reduce travel time.

There are several literatures that provide a number of definitions of TOD. Nonetheless, they are all alike in sharing the same idea of the relationship and connection between public transportation and urban land development around transit stations, both of which are expected to be developed together.

Calthorpe (1993) defined TOD as a mixed-use community in a walkable environment, such as residence, retail, office and open space. Such area is highly convenient for residents who can travel by many different modes of transport, including public transit, bicycle, walking and car. Recommendations for the land use proportion of urban and neighborhood TOD sites are given in Table 2-2 In case TOD is applied on a regional scale, it can provide a network of mix-use proximity that balances the inner-city development with suburban development by creating nodal and compact growth around the transit system.

Table 2-2 Recommendations for land use proportion of urban and neighborhood TOD.

Use	Neighborhood TOD	Urban TOD
Public	10% minimum	10% minimum
Core	10-15%	10-30%
Housing	40-80%	20-60%
Office	0-40%	20-60%

Cervero (2007) mentioned that TOD is a concentrated mix of moderately dense and pedestrian-friendly development and transit stations as it promotes the use of public transport, walking, cycling, as well as providing other alternatives to automobile dependency.

TOD is also described as a specified geographical area development within a specified radius from transit stations with the integration of a variety of types land uses and the cooperation of a multiplicity of landowners. Still (2002) explained that TOD is a mixed-use community that induces people to live near transit services and discourages car use. It is essentially an approach that aims to encourage the mixed-use and compact development, increase numbers of passengers using public transport and create more livable communities (Arrington and Cervero 2008). TOD is also regarded as a planning technique to reduce automobile dependency and a promotion of the public transit within walking distance of residential areas (Sung and Oh 2011).

At present, TOD is getting attention from many countries and increasingly becoming a crucial means to develop land use around transit stations. It supports the interface between public transport and land use features around stations. Each country is likely to partially adopt guidelines and standards for its planning schemes and implementation. The basic elements to make practical use of TOD are reviewed afterward.

2.2.1 The Potential TOD Coverage Area

Generally, the TOD concept specifies strategies to promote sustainable transport through the development of areas around mass transit stations. Such approach helps to advance and improve mixed land use, which supports a vigorous community life. The extents of these areas, which have the potential to be developed along the TOD principle, should be determined by the types of mobility modes serving first or last-mile connectivity and area characteristics. The potential area that influences the transit use is often described as the use of access distance and/or access time to the transit system.

Calthorpe (1993) explained that the extent of TOD is an area within an average walking distance, approximately 2,000 feet (600 meters) from a transit stop and core commercial areas. Each development is a cluster of residence and public spaces within a radius of 2,000 feet from the transit stop, which is expected to be densely developed. Meanwhile, coastal and other environmentally sensitive areas are conserved as secondary areas outside central urban hubs. They are considered to be low-density areas specifically suitable for agriculture. The Calthorpe's TOD illustration is shown in Figure 2-2(a). Furthermore, the regional development that ties a central city to its surrounding urban areas is developed. TODs are linked together and also connected with urban centers by bus or rail transit, as shown in Figure 2-2(b).

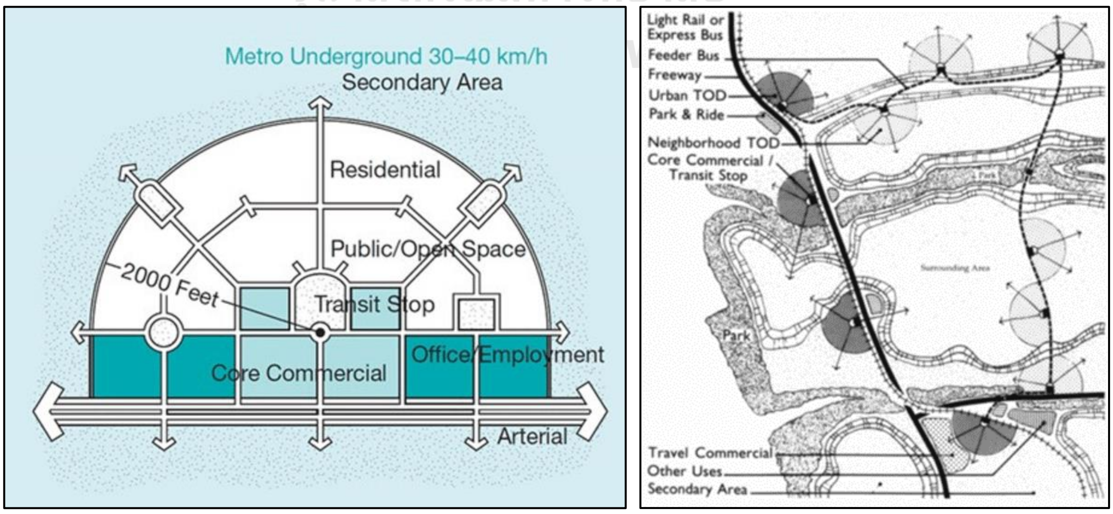


Figure 2-2 Calthorpe's TOD concept. Source: Peter Calthorpe, The Next Metropolis (1993)
(a) Illustration of TOD based on Calthorpe. (b) Regional development.

As to the TOD guideline, there is a broad range of walking-distance uses. Several literatures define the boundary of TOD based on the walking distance within a half-mile radius (800 meters) around each stop used by commuters to access transit stations (Cervero 2007).

Cervero (2007) mentioned the extent of the TOD projects in California within the radius of 400, 550 and 800 meters (1/4, 1/3, and 1/2 miles respectively). For the TOD adoption, numerous cities have practically implemented TOD with different boundaries. For example, Portland and San Diego have applied a 400-meter radius (1/4-miles) and 600-meter radius (2000 feet) respectively, whereas Washington County in Oregon has applied 800 meters (1/2 miles). The average distance applied by the chosen cities in the study are approximately 550 meters. Some influence or catchment areas of TOD are reported as a distance range. The radius of influence area in the United States varies between 400 and 800 meters (1/4 - 1/2 miles).

Besides, the TOD coverage areas have also been expressed in terms of time, suggesting the areas where people can access the transit stations within a specified time. Calthorpe (1993) mentioned that the coverage area within a 10-minute walk is equivalent to a 800-meter distance (1/2 miles).

Cervero (2007) defined the TOD coverage area as a ‘donut’, represented in Figure 2-3, and determined the share of trips via transit in California among those residing in the donut. The results showed that the number of rail passengers living within a radius 0.5 mile of a rail stop is around four times greater than the number of those living within a distance between 0.5 and 3 miles from the station. The study also found that 52 percent of the travelers, who live far away from the transit, switch from driving to the transit service upon the walking distance within 0.5 miles of a rail station.

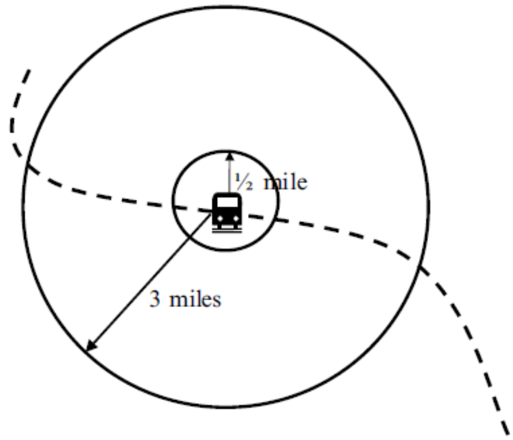


Figure 2-3 Cervero's schematic of TOD residency and donut.

Source: Robert Cervero, Transit-oriented development's ridership bonus: a product of self-selection and public policies (2007).

Some studies verified the TOD coverage area by empirical analyses. The walking time were used as a decay function with one-way analysis of variance to determine the willingness of people to access the public transit by walking in Queensland, Australia. They found that two major drops are 268 meters (4 minutes) and 670 meters (10 minutes).

Zhao, Chow et al. (2003) employed the regression analysis and the distance decay method to determine the catchment areas in Florida, USA, by using GIS to calculate the walking distances. They found that drops are noticed at 550 meters and 820 meters and no noticeable increase in accessibility is observed after 800 meters approximately. They surveyed the catchment area, focusing on cycling to the transit mode by means of questionnaires. The distance with the average of 4,500 meters (2.8 miles) are summarized for Philadelphia and 8,700 meters (4.5 miles) for San Francisco.

Chullabodhi and Chalermpong (2014) identified the walking distance by using the rank at the 85th percentile of walking distance. The data are analyzed from the 6,668 commuters, with 21 stations of BTS and MRT stations in Thailand. It is found that the rank of 85th percentile is the walking distance within an approximately 700-meter radius from the station, affected by commuters as well as land use characteristics around the station.

2.2.2 The Transit Oriented Development in Other Countries

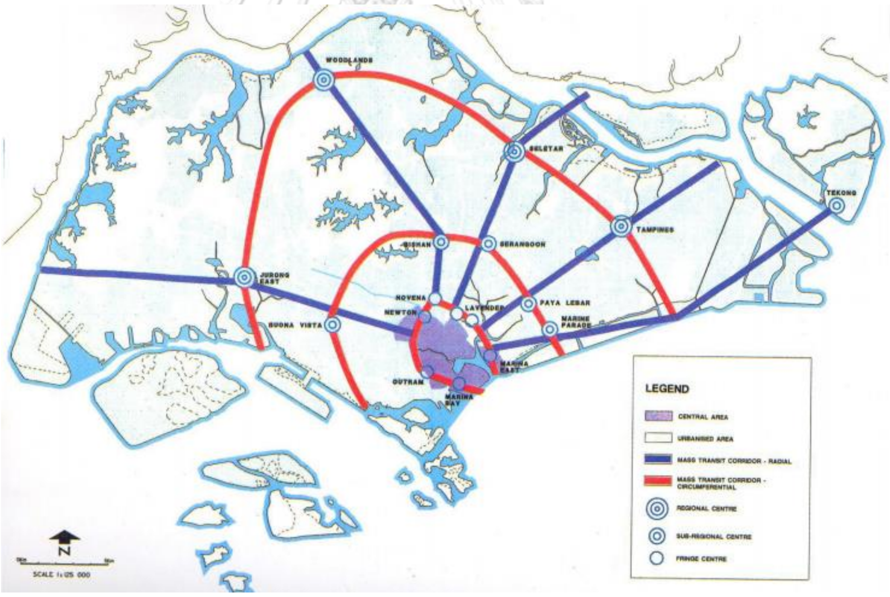
Various cities in the developed world have adopted their own standards for TOD implementation (Ann, Yamamoto et al. 2019). The guidelines for development should be carefully examined based on planned strategies. In this part, the model of successful TOD in other countries are illustrated as follows:

Singapore – Singapore is listed as one of the representative sustainable transit capitals. Nowadays, the compact and ecological urban environment of Singapore is inseparable from its integrated land use and transport planning. The first TOD concept plan was proposed in 1971 by Urban Redevelopment Authority (URA), which is the foundation of entire spatial structure of the country today. It outlines a pattern of connecting new towns with Mass Rapid Transit (MRT), a belt-shaped urban form with the downtown and natural reserves at the center. Housing is located in new towns, together with living service facilities, retails, education and parks, as shown in Figure 2-4(a).

In 1983, the construction of MRT lines connecting the North-South and East-West began. However, it was not until 1991 when the plan was revised and released. It outlined the urban form of constellation shaping on the basis of the ring form and five radial corridors. Commercial centers were distributed along the rail transit to achieve a balance of occupation and residence. The objective was to reduce congestion in the city center, as shown in Figure 2-4(b).

Currently, Singapore deliberately integrates the rail transit development into new town planning and designs. The new towns are developed along the MRT corridor, exhibiting the typical characteristics of TOD pattern. The compact residential areas are located in new towns, connected by MRT. It is strikingly similar to the TOD model proposed by Cervero.

(a)



(b)

Figure 2-4 The concept plan of Singapore: (a) Year 1971, (b) Year 1991

(Source: Urban Redevelopment Singapore)

Germany – A new development was planned from the outset to create a sustainable neighborhood in Vauban, Freiburg District. The development is a great example of an ambitious TOD scheme as it was built on a brownfield site.

The area prioritizes walking and cycling with low-speed limits. Pedestrians are given the first priority. The area is served by a tram. All households are within 400 meters of a tram stop. There are many local facilities and housing, using a brownfield site and delivering 2,000 houses and 600 jobs at completion in 2010. The development plan can discourage car use as 40% of households do not own private cars. Likewise, the plan can also encourage public transport use as 57% of residents of non-car owing households leave the car when they move to Vauban.

As a result, car trips in Vauban only account for 16% of all. It is significantly lower than Freiburg District, where car makes up a 30-percent mode share. This testify to the fact that TOD can lead to more sustainable transport (Urban Transport Group, 2019).

California, United State of America (USA) – BAY AREA RAPID TRANSIT (BART) has provided the rapid transit connections across the San Francisco Bay Area and is involved in a number of TOD schemes. Since 2000, there has been ridership growth in BART. The public transit has made up trips, walking and cycling has also increased over this period of time. The Contra Costa Centre is developed on the BART network. The TOD scheme is defined by a mixed-use, multi-phase program. There are a broad range of offers available to residents of Contra Costa so as to motivate sustainable transport options, including discounts on public transport tickets for cycling or walking to work.

BART investigated the value capture mechanism to finance transit improvements on the successful TOD implementation and found that the properties within half a mile from stations had approximately 15-18% value premium attributed to their proximity to the station. At present, the BART TOD program discusses the lease revenue and benefit fees from developments to capture value over time. This in turn helps to support the maintenance and service improvements of BART. The evidence also reveals that BART TOD schemes result in increased ridership as the completed and projects under construction generated a million extra trips a year, supporting long-term sustainability of BART in 2017.

Hong Kong – the Mass Transit Rail (MTR) Corporation was established in 1975 as a government-owned enterprise to build, operate and maintain a mass transit railway system for public transport. The MTR line construction in the 1970s and 1980s was capital intensive and required substantial funding. The government attempted to cover and cut the costs of the project without raising fares. The government land subsidies were arranged for rail and property development by implementing the Rail + Property (R+P) program. It is relevant to railway companies and cities in developing lands around rail stations. The R+P program enabled MTR Corporation to capture real estate income to finance parts of the capital and the running costs of new railway lines, as well as enlarging the transit system by facilitating the high-quality creation, and dense and walkable catchment areas around stations.

The R+P program is carefully determined on a line-by-line basis. The Transport and Housing Bureau issues and updates a railway development strategy with the practical advice of the MTR Corporation who grants development rights to partners as developers. However, the MTR remains in full control of the land and sales/leases of all completed units.

When the MTR proceeded the proposal of the preliminary planning and design, the detailed scope of the transit line and the identification of sites are reserved for development. The proposed program is agreed by all parties. MTR would select a developer who is given some flexibility to recommend and negotiate site modifications of the R+P proposals. The property development contributed enormously to expansions of the rail lines. The R+P program is the supporting case study relevant to railway companies and cities looking to generate cash flow by developing lands around rail stations.

South Korea – South Korea initiated a new city to moderate the excessive concentration of public and private facilities in the Seoul Metropolitan Area (SMA) by the planned and balanced territorial development in Sejong City as the second capital city of South Korea with decentralized urban structure characteristics.

The master plan for Sejong City was formulated in 2005 through a project initiated by the Korean government. A mass transit system is planned for the whole city in accordance with the ring-shaped urban structure along the center of the urban area. The transit stations are located along pedestrian pathways, cycling routes, community retail facilities and public facilities.

Even the structure of decentralization could cause some practical urban problems as it has increased the movement time and the uncertainty of urban strengthening. Nonetheless, a mass transit system is planned through the central axis along the ring-shaped development area. It may sufficiently address concerns over the decentralized urban structure. This decentralized urban structure characteristics and the composition of urban space are clearly the development that corresponds to TOD (Kwon 2015).

Tokyo, Japan – Tokyo has one of the highest rates of transit usage in the world, with the railway station areas based on the TOD concept. Automobile dependence is hardly essential in metropolitan areas, since all daily activities can be conducted by public transit, which is of high quality and has a high level of frequency of service. In the mid-1960s, Tokyo's dense rail network and its station area communities were already well established. The private railways innovated and diversified a wide variety of related businesses, most notably real estates along the rail lines.

The Rail Integrated Community (RIC) has been adopted to describe the developments around highly dense, mixed-use and pedestrian-friendly railway stations as community junctions served by rail rapid transit. The community junctions can be accessible primarily by foot, bicycle and public transit. A well-functioning RIC requires not only attention to the station and surrounding neighborhoods form but also the support of the transit service agencies to succeed over the long-term growth through funding sources other than the farebox. The high-quality rail service, together with mixed-use and pedestrian-friendly developments, has supported Tokyo to achieve the enviable rates of public transit usage.

The urban development surrounding the stations provides commuters with the transit systems, which could be considered destinations themselves. These areas are always mixed-use, complete with stores, education, government offices, housing and restaurants within walking distance from the stations (Calimente 2012).

2.3 TRIP GENERATION AND TRIP ATTRACTION RATES

As stated earlier, when one component changes, it influences others. Each type of land use affects transit demand with different levels and behaviors. At the same time, some types of land use might generate a great deal of transit demands while attracting only few transit demands, the behavior might be reversed in another time. Each type would generate/attract with the unequal level, according to the activity operation. In this part, effects of trip generation and attraction rate on transit demand are shown as follows:

Rodrigue (2016) described that the communities would depend on their transportation systems for sustaining the activities ranging from tourism, commuting, shipping, and commercial activities. The land use pattern is influenced by the existing urban form and spatial structure. The activities affected by the land use pattern are divided into three major groups, which are as follows:

(1) Routine activities, which occur regularly and predictably, such as working (travel from a residence to an industrial, commercial or government office) and shopping (travel from a residence to a retail store), etc. Land use is a rather stable pattern, whereas the activities were zonal and links between inter-areas.

(2) Institutional activities, which are linked to an urban environment. The links would depend on lifestyles or special needs (students, sports, leisure, health, etc.).

(3) Production activities, whose land use pattern might be linked to an external region, nation or the world.

Cervero (1998) described that the transportation characteristics were affected by a variety of activities which was the important factors that led to land use patterns. The three major classes of cities classified by their transit systems are shown in Figure 2-5.

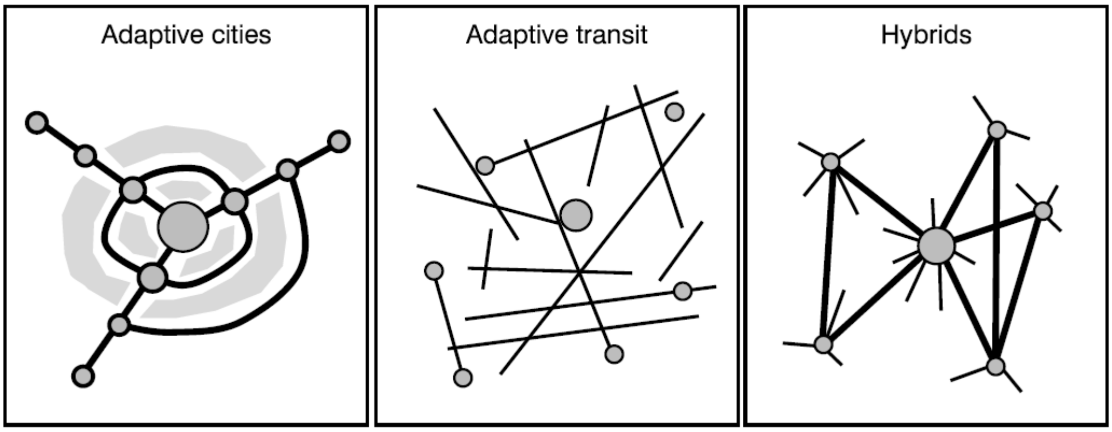


Figure 2-5 Transit and urban form.

(Source: Cervero, R. (1998) The Transit Metropolis.

(1) Adaptive cities, where urban land use developments are coordinated with transit developments. The central areas are adequately served by a pedestrian-friendly metro system, whereas the peripheral areas are oriented along the transit rail lines.

(2) Adaptive transit, where the automobile accounts for the greatest share of transportation modes. The urban form is decentralized and low-density.

(3) Hybrids, which show the balance between transit development and automobile dependency. The central areas have an adequate level of service, whereas peripheral areas are automobile-oriented.

Trip Generation Handbook, which is a new guidance on proper techniques for estimating person and vehicular trip generation rates, is provided by the Institute of Transportation Engineers, a community of transportation professionals. It is the guidance for the evaluation of mixed-use developments and the establishment of local trip generation rates, which expand pass-by trip and truck trip generation data.

Each type of land use has different trip generation and attraction levels. The trip generation and attraction rates are typically derived from the observed data through the regression analysis. The trip generation rates for different types of land use are estimated through collecting data on vehicle trip rates and focusing on single-use, vehicle-oriented trip rates in suburban sites of the United States (PTOE 2017).

The Trip Generation Manual published by ITE presents the time-of-day distribution for a wide range of land uses. The vehicle trip rates entering and exiting for each time period of each type of land use are collected. However, it could be a guideline for transit trip rates tendency, according to the land usability.

Moreover, the report is updated periodically with the new land use descriptions, trip generation rates, equations, and data plots. The number of trips generated from/attracted to a particular site or area according to the inventory of land uses, is estimated as trip generation and attraction rates. It can also be calculated as daily trips or peak-hour trips for a particular site, depending on the type of land use, and expressed as vehicle trips or person trips, such as the amount of trips per employee and the amount of trips per unit land area (Wang and Hofe 2008).

Manual (2003) surveyed the information of vehicular traffic generated by different land uses the data were collected as a trip generation manual. The trip generation rates, including the percentage of AM and PM peak-hour trips and the proportion of trips entering and exiting during the peak hours, were summarized as the trip generation manual, which provided a cooperation from the City of San Diego, the San Diego Association of Governments (SANDAG), and ITE.

The process of a trip generation study started with sites selection, which could be categorized as the same land use. The data was then collected regarding various characteristics, such as location, lot size, structure size and number of employees, etc. The counters were placed at every entrance and exit point to count the number of trips. The surveyed data were later compiled to determine daily and peak-hour trip generation rates for the subject use. Additional data, including the proportion of trips made in the morning and afternoon peak periods and the proportion of peak trips that entered and exited, were collected at the sites.

The partial example of The City of San Diego trip manual is shown in Table 2-3. The trip generation manual could be a confirmation that the ridership pattern would be different in accordance with the activities from each type of land use.

Table 2-3 Trip Generation Rate on weekday, The City of San Diego Manual. (Source: Trip Generation Manual, revised May 2003).

LAND USE	DRIVEWAY (1) (2) VEHICLE TRIP RATE	CUMULATIVE (8) VEHICLE TRIP RATE	PEAK HOUR AND IN/OUT RATIO AM (IN:OUT)	PM IN:OUT)
AGRICULTURE (OPEN SPACE) (3)	2 trips/acre	2 trips/acre	- -	- -
AIRPORT (3)				
Commercial	100 trips/flight; 60 trips/acre	100 trips/flight; 60 trips/acre	6% (6:4)	7% (5:5)
General Aviation	2 trips/flight; 6 trips/acre	2 trips/flight; 6 trips/acre	- -	- -
CEMETERY	5 trips/acre	5 trips/acre	- -	- -
COMMERCIAL-RETAIL (4) (5)				
Automobile Services:				
Car Dealer	50 trips/1,000 sq. ft.; 300 trips/acre	45 trips/1,000 sq. ft.; 297 trips/acre	5% (7:3)	8% (4:6)
Carwash:				
Full service	900 trips/site; 600 trips/acre	450 trips/site; 300 trips/acre	4% (5:5)	9% (5:5)
Self service	100 trips/wash stall	50 trips/wash stall	4% (5:5)	8% (5:5)
Gasoline Stations:	130 trips/vehicle fueling space; 750 trips/station	26 trips/vehicle fueling space; 150 trips/station	7% (5:5)	11% (5:5)
With food mart	150 trips/vehicle fueling space	30 trips/vehicle fueling space	8% (5:5)	8% (5:5)
With fully automated carwash	135 trips/vehicle fueling space	27 trips/vehicle fueling space	- -	- -
With food mart & fully automated carwash	155 trips/vehicle fueling space	31 trips/vehicle fueling space	8% (5:5)	9% (5:5)
Parts Sale	62 trips/1,000 sq. ft.	56 trips/1,000 sq. ft.	4% (5:5)	10% (5:5)
Repair Shop	20 trips/1,000 sq. ft.; 20 trips/service stall; 400 trips acre	18 trips/1,000 sq. ft.; 19 trips/service stall	8% (7:3)	11% (4:6)
Tire Store	25 trips/1,000 sq. ft.; 30 trips/service stall	23 trips/1,000 sq. ft.; 27 trips/service stall	7% (6:4)	11% (5:5)
Convenience Market Chain:				
Open Up to 16 Hours Per Day	500 trips/1,000 sq. ft.	250 trips/1,000 sq. ft.	8% (5:5)	8% (5:5)
Open 24 Hours	700 trips/1,000 sq. ft.	350 trips/1,000 sq. ft.	9% (5:5)	7% (5:5)
Discount Store/Discount Club	70 trips/1,000 sq. ft.	49 trips/1,000 sq. ft.	2% (6:4)	10% (5:5)
Drugstore	90 trips/1,000 sq. ft.	40 trips/1,000 sq. ft.	4% (6:4)	10% (5:5)
Furniture Store	6 trips/1,000 sq. ft.; 100 trips/acre	5.4 trips/1,000 sq. ft.	4% (7:3)	9% (5:5)
Lumber/Home Improvement Store	30 trips/1,000 sq. ft.; 150 trips/acre	27 trips/1,000 sq. ft.; 135 trips/acre	7% (6:4)	9% (5:5)
Nursery	40 trips/1,000 sq. ft.; 90 trips/acre	36 trips/1,000 sq. ft.; 81 trips/acre	3% (6:4)	10% (5:5)
Restaurant:				
Quality	100 trips/1,000 sq. ft.; 3 trips/seat; 500 trips/acre	90 trips/1,000 sq. ft.; 2.7 trips/seat; 450 trips/acre	1% (6:4)	8% (7:3)
High Turnover (sit-down)	130 trips/1,000 sq. ft.; 7 trips/seat; 1,200 trips/acre	104 trips/1,000 sq. ft.; 5.6 trips/seat; 460 trips/acre	8% (5:5)	8% (6:4)
Fast Food (with or without drive-through)	700 trips/1,000 sq. ft.; 22 trips/seat; 3,000 trips/acre	420 trips/1,000 sq. ft.; 13.2 trips/seat; 1,800 trips/acre	4% (6:4)	8% (5:5)
Shopping Center:				
Neighborhood (30,000 sq. ft. or more GLA on 4 or more acres)	120 trips/1,000 sq. ft. GLA; 1,200 trips/acre	72 trips/1,000 sq. ft.; 720 trips/acre	4% (6:4)	11% (5:5)
Community (100,000 sq. ft. or more GLA on 10 or more acres)	70 trips/1,000 sq. ft. GLA; 700 trips/acre	49 trips/1,000 sq. ft.; 490 trips/acre	3% (6:4)	10% (5:5)
Regional (300,000 sq. ft. or more GLA) (6)	Ln(T) = 0.756 Ln(x) + 5.25 *	0.8 [Ln (T) = 0.756 Ln (x) + 5.25] *	2% (7:3)	9% (5:5)
Specialty Retail Center/Strip Commercial	40 trips/1,000 sq. ft.; 400 trips/acre	36 trips/1,000 sq. ft.; 360 trips/acre	3% (6:4)	9% (5:5)
Supermarket	150 trips/1,000 sq. ft.; 2,000 trips/acre	90 trips/1,000 sq. ft.; 2,000 trips/acre	4% (7:3)	10% (5:5)

2.4 ORIGIN – DESTINATION (O-D) DEMAND ESTIMATION

The demand forecasting models are used to predict the travel patterns and the utilization of transportation system. Travel demand modelling is a highly challenging process. It is important for transportation planning and evaluation. The four-step model is a sequence for determining transportation demand, which is comprised of the following attributes: Trip Generation, Trip Distribution, Mode Split, and Trip Assignment. Trip distribution is the second component, which determines trip interchanges between each zonal pair beyond estimates of the magnitude of activity in each analysis zone. The model employs the effects of impedance or accessibility on destination choice.

A distribution model estimates the number of trips in each of the matrix cells from the available information. The various distribution models have thus been proposed according to the different situations and conditions (de Dios Ortúzar and Willumsen 2011). Therefore, the general models for trip distribution estimation, including the advantages and limitations of each model are reviewed as follows:

2.4.1 The Gravity Model

The *Gravity Model* has the assumption that all trips starting from a given zone are attracted by various traffic generators in other zones. The Gravity Model has been developed to forecast future trips when the important factors influenced by external factors in the network have changed. Those factors include total trip ends and distance travelled. The number of trip attractions is directly proportional to the size of these generators and inversely proportional to the spatial separation between the zones. The gravity model is also one of the methods used to distribute trips among the destinations (Mathew and Rao 2006). In addition, it is further modified by embracing the principle of a trip distribution model to ensure the conservation law of trip production and trip attraction (Bressan and Nguyen 2015).

The gravity model is practically extended in social sciences and economic coefficients, such as gross salary and employment in a municipality (Drobne, Bogataj et al. 2012). It can also be considered the estimation of the commuting flows. The distance constitutes an impediment to commuting, whereas the developed economic parameters pull in commuters (Stefanouli and Polyzos 2017).

The deterrence factor is the generalized function of travel costs with the parameters for calibration, described as an impedance to the interaction among two points in space and directly influences the trip distribution as it represents the disincentive to travel. Finding a way to introduce the impact of deterrence factors into the gravity model has been a common area of academic research in recent years. This factor is known as the generalized cost in the literatures. It can also be regarded as distance, time, travel cost or any combination of the aforementioned ones (Mathew and Rao 2006).

The deterrence function of the gravity model has been proposed in various functional forms, such as exponential function, power function, gamma function and piecewise function (de Dios Ortúzar and Willumsen 2011).

There are many researches that estimate trip distribution by employing the gravity model with different functions of deterrence factors, each one of which takes advantage of its function with the situation of model application. Samanta and Mazumder (2006) employed the gravity model with the cost deterrence described by the power function for estimating a trip distribution matrix. Moreover, the gravity model with an exponential deterrence function proves that the deterrence function is particularly useful for exhibiting the probabilistic trip behavior, it is also consistent with the cost-efficiency principle. In some researches, however, the inverse power function is more reliable than the negative exponential function when representing the behavior of deterrence factors (Chen and Xu 2013). The negative exponential function is also proposed to alleviate the limitation of the travel impedance or cost measurement as the traditional gravity model formulation would approach infinity when the distance between locations decrease sharply.

2.4.2 The Growth Factor Method

The *Growth Factor Method* is a model used to re-examine the pattern of trip distribution with the application of an existing O-D matrix, the data from previous study or the estimated data from the survey. The expected growth rate in the future years is used to estimate the number of trips originating and attracted between each zone in the future.

The growth factor method is simple to employ. It can also make direct use of observed trip matrices. Consequently, it can preserve the primary observation trip. However, this advantage is also the limitation, since it is employed for long-term planning horizons or when some characteristics have changed a great deal.

The fundamental of the growth factor method is Uniform Growth Factor, which uses the general growth rate to apply to each cell in the matrix. The more advanced types of Growth Factor Method are *Singly Constrained Growth-Factor* and *Doubly Constrained Growth Factors.* The difference of each factor is the expected growth data available at that time. The most efficient growth factor technique is the *Fratar Method* introduced by Thomas J. Fratar in 1954. The future trip generation proportions are estimated as a function of the current trips between zones based on the basic premise of the Fratar procedure, assuming that the distribution of trips from one zone is proportional to the present movements out of that zone modified by the growth factor of another zone to which the trips are attracted However, the Fratar procedure do not differentiate trips by purpose (Fratar 1954).

2.4.3 The Intervening Opportunities Model

The *Intervening Opportunities Model* has the basic hypothesis given by Stouffer (1940)0. The concept is that the number of trips between zones is directly proportional to the number of opportunities at the destination zone and inversely proportional to the number of intervening opportunities. The trip making is not explicitly related to distance but to the relative accessibility of opportunities for satisfying the trip objective.

The Intervening Opportunities Model utilizes a probability hypothesis and assumes that a trip length should be as short as possible. A trip is lengthened only when it fails to find an acceptable destination at a shorter distance. All trip opportunities are treated as the function of a travel time. The spatial separation for the intervening opportunities model is surveyed in terms of the number of intervening opportunities determined by arranging all available destinations with the corresponding travel time from the zone of origin.

In the application of the model, the first examined opportunity is the one closest to the origin and has the stated area probability of acceptance. The next opportunity has the same fundamental probability of acceptance. Nevertheless, the actual probability is decreased by the fact that the distributed trip has an opportunity of already having accepted the first opportunity. The method continues with each consecutive opportunity having, in effect, a decreased probability of being accepted.

As the intervening opportunities model uses distance as an ordinal variable, it obviously determines the opportunities to satisfy a trip purpose at increasing distance. However, the idea of matrices with destinations ranked by distance from origin is much difficult. The intervening opportunities model is thus not widely employed in practice accordingly.

Gibson (1975) demonstrated that the original intervening opportunities model can clearly predict the inverse relationship between total opportunities and total migration. Nonetheless, for the contrary prediction, it is incredibility for the original intervening opportunities hypothesis.

2.4.4 The Fluid Analogy Method

The Fluid Analogy Method (FAM) is a method for integrating a route – the level trip distribution developed by Tsygalnitzky (1977) for the O-D estimation of transit passengers along transit routes with the concept of fluid pipe flow. This method has been used by London Transport. The model shows that this method fits well with the data from Toulouse in France.

According to the difficulty in the trip data survey, previous researches attempted to estimate O-D flows with the incomplete of historical O-D matrices. The model is formulated based on the concept of fluid pipe flow, with the main assumption that every passenger has the equal probability to alight from the train at the specific stop if the distance between origin and destination is a certain minimum distance. It is also implied that the passengers are equally likely to alight from the vehicle after they have traveled for at least a minimum distance.

The model is applied for estimating bus passenger O-D trips by Tsygalnitzky. The bus is compared as a container travelling along a route. The passengers are considered fluid added to the bus at each boarding station. The fluid is blended between stations and then poured out of the container at each alighting station. Nonetheless, the modification problems of the bus-passenger version as a static model with space-dimension are only realized subsequently (Tsygalnitzky 1977).

The accuracy of this method was proven by Simon and Furth (1985) by applying the FAM to estimate an O-D matrix of a bus line, using the data from the Southern California Rapid Transit district (SCRTD). They summarized that the FAM is statistically important for the linear transit routes and for linear routes containing some branching. The performance is proved to function proficiently for simple transit routes. The FAM verifies the precision on any situation by comparing with the doubly constrained gravity model, using the ticket data from an intercity coach route in Indonesia. The result shows that the trip distributions generated by FAM are more accurate than the doubly constrained gravity model. However, FAM remains the major limitation as it cannot be used to estimate the trip distribution of complex networks or non – linear route (Herijanto and Thorpe 2005).

To overcome the limitation of FAM, however, Herijanto and Thorpe (2005) had enhanced the accuracy of the FAM by incorporating it into the singly constrained gravity model, which has a limitation in the quality and quantity of input data to estimate trip distribution. The incorporated model can be applied to forecast the ridership of bus system after a change in the efficiency of service characteristics.

Liao and Lin (2012) revised the FAM with explicit time-dimension parameters, using the structure of multi-layer matrices. The extended research verifies the model performance by empirical data on freeway ramps using flow counts. The estimation results show acceptable deviations and estimation efficiency.

2.4.5 The data-driven method

The *data-driven method* estimates trip distribution flow by the available data sources. It is a bottom-up procedure as the innovation in transportation knowledge can be divided into two primary approaches, which are technology-oriented and methodology-oriented approaches.

The technology-oriented method is a developed technique for estimating the trip distribution pattern using technology, such as the sensor, telecommunications, detection, connected vehicles data, etc.

The methodology-oriented method is the method that emphasizes the reformed analytics of the big data collected from the transportation system.

The data-driven approach refers to the algorithms, which are driven by data instead of the model-driven method. It sorts out a solution in an algorithm driven by data, whereas the primary methods depend on human experiences and historical data. On the contrary, the traditional top-down methods, such as gravity model, destination choice model, would be approached by the city socio-economic data and land use characteristics. However, the data are not utilized to calibrate model parameters. There is a limitation of traditional model when detailed data are absent and the fitness of model to complicated reality is insufficient as the traditional models would be employed based on the assumptions. As a result, the data-driven method has the advantages on the reliable historical traffic data and multi-dimensional city statistical data. The method can estimate trip distribution without behavior assumptions.

With the increasing quantity and variety of data collected from Intelligent Transportation Systems (ITS) and other technologies, many researches rely on a new generation of tools to analyze the O-D pattern. Li, Wang et al. (2018) proposed the data-driven method based on Poisson distribution theory to estimate intercity trip distribution, using sensor data and various city features.

2.5 THE CITY COMPREHENSIVE GUIDELINE

Land use development must follow the guidelines, which enforce and regulate the direction of development and the area that should be developed or reserved. The type or activity of developed land use must conform to the regulated criteria. This part reviews the land use development guidelines of Thailand and other countries, as well as describing how land use regulations are integrated with the transportation network planning.

2.5.1 The Bangkok Comprehensive Plan 2013

One of the regulations for land use development in Bangkok is the Bangkok Comprehensive Plan provided by The Department of City Planning and Urban Development, which is an authority under the Bangkok Metropolitan Administration (BMA). It is a guideline for area development, proper land use activities specification in urban and rural areas of Bangkok Metropolitan Region (BMR).

The Bangkok Comprehensive Plan is enforced for the new developments. It divides the BMR areas into color zones, both of which have their own development standards. The regulations are concerned with the density. Open spaces are regulated for controlling the height of building structures and making an equilibrium between the buildings and land use activities. The regulations on the height of buildings are controlled by Floor Area Ratio (FAR), which is the ratio of the total built space on its land area, as shown in Equation (2-1), and Open Space Ratio (OSR), as shown in Equation(2-2). For developers and landowners who conduct public beneficent projects, they would obtain special privileges in the development. This plan would motivate the developers and the landowners to achieve the plan objectives.

$$FAR = \frac{total\ floor\ area\ of\ the\ buildings}{land\ area} \tag{2-1}$$

$$OSR(\%) = \frac{total\ open\ space\ without\ any\ coverage}{total\ floor\ area\ of\ the\ buildings} \times 100 \tag{2-2}$$

The latest Bangkok Comprehensive Plan was issued in 2013, as shown in Figure 2-6. The plan covers a total area of 1,568.73 square kilometers. One of the plan visions is that Bangkok would be a metropolis of convenience with comprehensive transportation networks. The plan objectives concerning the land use development and the mass transit system are as follows:

(1) To promote BMR as a business, commercial and service center of the country by providing appropriate facilities that support the growth development.

(2) To promote a comfortable, convenient, rapid and secure modes of travel by developing an integrated mass transit system and comprehensive transportation networks efficiently.

The land use control specified in the Bangkok Comprehensive Plan 2013 is divided into 3 categories as follows:

(1) Permitted Uses: a list of the land use allowance within a zoning district for both principle uses and additional uses.

(2) Prohibited Uses: a list of prohibited activities within a particular area.

(3) Conditional Uses: it defines permitted or prohibited uses and the conditions for the proper site.

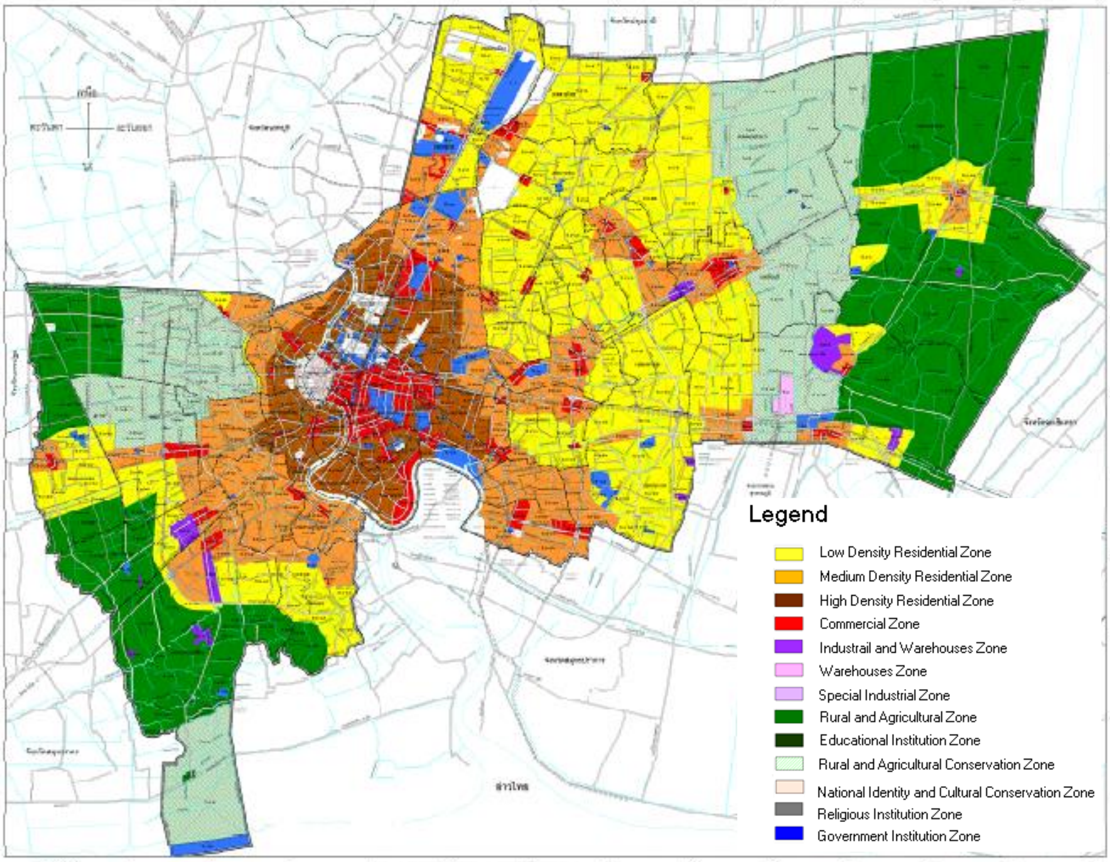


Figure 2-6 The Bangkok Comprehensive Plan B.E. 2556.

Source: www.cpdbangkok.go.th.

Even though the Bangkok Comprehensive Plan has defined the guideline for land development, the land use regulations and the transit system planning are developed individually. The Ministry of Transport (MOT) has the authority to control transportation agencies, while the BMA has the authority of urban planning in BMR. Both government agencies have no control over each other, however. This lack of integration would result in the unproductive urban development and transportation planning conformance. The integrated transportation and land use planning will thus be quite difficult (Chalermpong 2019).

2.5.2 City Planning Guideline in Other Country

The Metropolitan Atlanta Rapid Transit Authority (MARTA) issued the guideline for land use development from the basic principles of TOD with the strategic goals in order to generate greater transit ridership and promote the sustainable and affordable system of the Atlanta metro, including a return on transit investment by enhanced fare revenues.

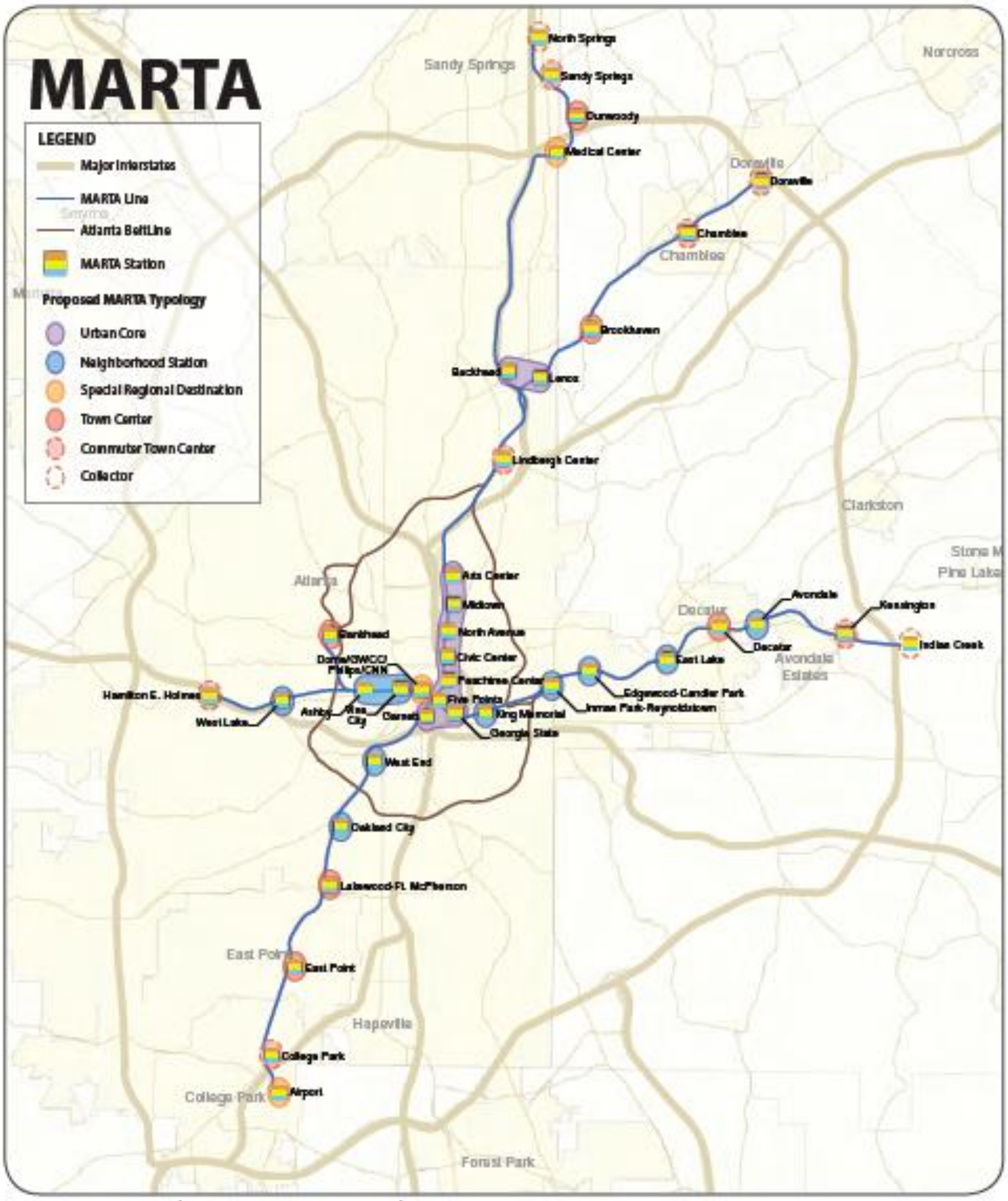


Figure 2-7 Stations map with the station typology (Source: MARTA TOD guidelines)

Table 2-4 TOD station typology of The Metropolitan Atlanta Rapid Transit Authority. (Source: MARTA TOD guidelines).

Station Typology Matrix						
Station Type	**Ideal Land Use Mix and Scale of Development**	**Transit Mode and Function**	**Public Realm**	**Keys to Success**	**Local Examples**	**National Examples**
Urban Core	- Downtown-scale mix of employment (office), institutional, hotel and civic uses. Return of multi-family residential is a growing trend. - Retail and restaurant sector gaining. - High-rise towers common; new buildings at least mid-rise.	- Heavy rail/ multi-modal. - High-volume transfers between corridors; modes - No park-and-ride. - A regional transit destination at or near system core.	- Stations usually grade-separated and closely spaced for walking. - Station is part of the core pedestrian network. - Buses stop at sidewalk.	- Attract a 24/7 mix (i.e., more residential, retail, dining, cultural). - Ensure station-area safety during non-9-5 hours.	- Downtown (Five Points, Peachtree, Civic Center, Garnett) - Midtown (North Avenue, Midtown, Arts Center)	- South Boston Waterfront (Boston, MA) - Market Street, San Francisco
Town Center	- Balanced mix of multi-family residential development with office, retail, entertainment, and civic uses. Vertical mixed-use is common. - May be pre-existing or new town center. Transition to lower-density outside the quarter-mile mile radius. - Mid-rise buildings dominate; some high-and low-rise.	- Multi-modal rail or BRT station with regional and local bus service. - Park-and-ride, if any, is secondary. - A transit origin *and* destination.	- Stations grade-separated (heavy rail) or at-grade. - Traditional town center pedestrian network with station at focal point. - Curb-side parking desirable; no off-street parking in front of buildings; garages wrapped.	- Get market to accept reduced residential and commercial parking. - Optimize street level relationships among transit, public realm, development.	- Decatur (e.g. of historic town center) - Brookhaven (e.g. of new town center based on LCI study)	- Rockville Town Center (Rockville, MD) - Mockingbird Station (Dallas, TX)
Commuter Town Center	- Balanced mix of multi-family residential development with office, retail, entertainment, and civic uses. Vertical mixed-use is common. - Likely to be a new town center at or near a regional highway exit. Transition to lower-density outside the quarter-mile mile radius. - Mid-rise buildings dominate; some high- and low-rise.	- Multi-modal rail or BRT station with regional and local bus service. - A primary park-and-ride capture point with at least 1,000 spaces. - A transit origin and destination environment.	- See town center description above. - Park-and-ride is in structure and ideally feeds retail environment.	- Town Center attributes, plus: - Optimize park-and-ride count, operation, and management. - Locate park-and-ride to minimize conflict with TOD.	- Lindbergh City Center (existing) - Doraville (future)	- Pleasant Hill (Contra Costa, CA) - White Flint (Bethesda, MD)
Neighborhood	- Multi-family residential and/or neighborhood-scale mixed-use with retail, restaurant, and service-oriented offices. Transition to lower-density single- or multi-family away from the "main street". - Low to mid-rise buildings.	- Can be a rail, streetcar, or local bus stop. - A transit origin and walk-in line station. - Park-and-ride avoided or minimized.	- Heavy rail stations grade-separated; light rail stations off-street; bus or streetcar stops on-street. - Pedestrian network leading to (or encompassing) station is critical.	- Design bus or streetcar stops as integral part of high-quality streetscape. - Attract feasible, mixed-use, mixed-income development.	- Ashby and Vine City (rail) - Future BeltLine stations (streetcar) - Ponce de Leon Corridor (bus)	- Bland Street Station (Charlotte, NC, rail) - Washington Street Silver Line (Boston, on-street rapid bus)

Table 2-4 (Continued) TOD station typology of The Metropolitan Atlanta Rapid Transit Authority. (Source: MARTA TOD guidelines).

Station Typology Matrix (continued)						
Station Type	**Ideal Land Use Mix and Scale of Development**	**Transit Mode and Function**	**Public Realm**	**Keys to Success**	**Local Examples**	**National Examples**
Arterial Corridor	- Multi-family residential and/or mixed-use, replacing auto-oriented, commercial strip pattern on a major arterial. Transition to lower-density development between stations. - Scale varies; mixed-rise typical, but some high- and low-rise.	- Arterial BRT or light rail, on a corridor that may be radial or cross-regional. - May be a transit origin and destination. - Stations may have park-and-ride.	- Enhanced stations are at-grade, either on sidewalk or in dedicated median. - Pedestrian environment is critical.	- Create a transformative pedestrian environment from scratch. - Market the TOD/BRT concept.	- Memorial Drive - Buford Highway	- VIVA BRT System (York, Ontario) - South Corridor BRT (Grand Rapids, MI)
Special Regional Destination	- A regionally-significant public venue (sports or entertainment), campus (educational or medical), commercial or industrial complex, or airport. Usually *not* a mixed-use setting. - Scale varies with type of use; generally less dense and compact than typical TOD settings.	- Usually heavy rail plus bus routes. - A region-level transit destination; may have pulse pattern. - Usually no park-and-ride, but use pattern may allow it.	- Large surface parking lots typical. - Safe, well-defined connections are key, but area-wide TOD streetscape may not be applicable.	- Distribute passengers to venues; may need shuttles, foot bridges. - Encourage ancillary uses (e.g. retail, offices related to main use).	- Georgia Dome/ GWCC/Arena - Medical Center	- Pepsi Center and INVESCO Stations (Denver, CO) - Centro Médico (San Juan, PR)
Collector	- Park-and-ride is the primary use. Nearby development should be as accessible to transit station as possible, but may be more automobile-oriented than normal TOD. - Building scale, if any, depends on type of nearby use.	- Commuter rail, heavy rail, free way bus; light rail in some settings. - A transit origin; a primary park-and-ride capture point with at least 1,000 spaces.	- Primarily serves park-and-ride, which may be at-grade. - High-quality links to nearby buildings, important, but no area-wide TOD streetscape.	- Optimize intermodal transfers from feeder modes. - Provide nearby uses with good pedestrian connections.	- Indian Creek - North Springs (substantial residential use nearby)	- Fallowfield Station (Ottawa, ON) - Anderson Center (Woburn, MA)

Focusing on the objective to generate the transit ridership, the clustering mixed-use development around stations and along corridors is indeed the solution. The MARTA has classified a station typology into seven categories. The typology indicates not only location, land use and density around that type but also the transit system operations. The MARTA's existing rail station map with the station typology is shown in Figure 2-7, the station typology is shown in Table 2-4. The MARTA guideline describes the characteristics of each MARTA station and other transit systems in metropolises of the United States. The typology is forward-looking to the rail extension in the future with taking TOD principle as a foundation.

According to the guideline, it defines the land use development with dissimilar characteristics: density, transit availability and location according to the classified categories of transit stations. The guideline also provides the specific standards of density and use for development in terms of FAR, number of floors, and residential units per acre for the development.

This chapter covers an overview of the transportation demand management, TOD concept and application, trip generation and trip attraction rate, the O-D demand estimation and the city comprehensive guideline. The literature reviews from this chapter are the initial information and assumption for further unitization and analyses in this research.

In conclusion, TOD strategies can encourage more efficient travel patterns, such as mode shift and O-D shift, including the shift from peak to off-peak periods. The reciprocal relationship between land use and transportation made TDM affects land use patterns, whereas land use can in turn affect transportation activities. As a result, transportation decisions have influences on land use development patterns.

In addition, comparing the city planning guidelines of Thailand and Atlanta, the explicit difference is that the MARTA's guideline examines land use development and transportation planning simultaneously, whereas the Bangkok comprehensive guideline examines them separately.

Following the mentioned reasons, the transit system implementation and the urban planning in Thailand should be worked on simultaneously. This might present a problem of imbalanced ridership in Thailand as it lacks integrated planning.

In this Chapter, the literatures have clearly revealed that land use development is a significant factor that affects transportation demand. This inspires the idea of balancing the mass transit ridership thorough land use development by employing the precise trip distribution model for mass transit system. It is highly regarded as a great solution for the sustainable transportation development.

Chapter 3
METHODOLOGY

This chapter provides the methods for balancing ridership. The trip distribution models are formulated and compared to determine which one is a more appropriate model for reflecting mass transit ridership characteristics. The organization of this chapter begins with the assumption of ridership balancing in this study and the explanation of trip distribution models' structure. The models are later formulated to deal with the balance of ridership. The comparisons of the model performances are also made afterward to figure out which one gets along well with mass transit attributes.

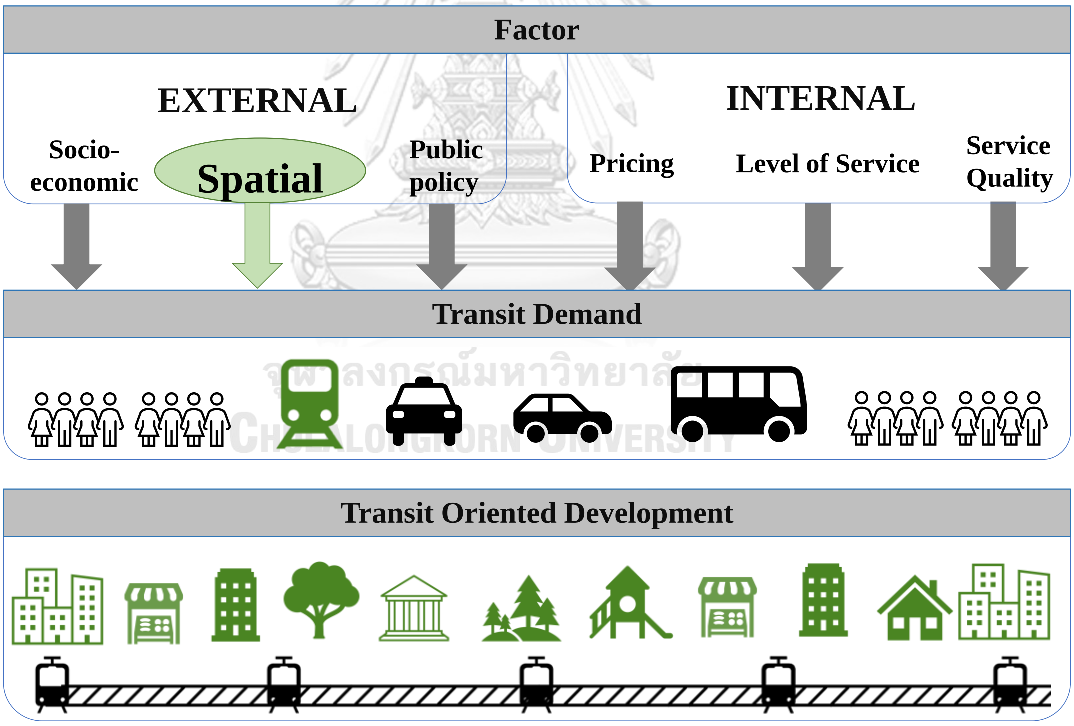


Figure 3-1 Balancing mass transit ridership through land use development.

According to the information and knowledge from previous studies in a particular subject of transit ridership, the diagram can be concluded in Figure 3-1. Considering the factors that affect transit demand, it can be observed that spatial factors are among the factors that affect transit ridership. They can generate, attract and shape ridership patterns based on activity creation. Moreover, spatial factors regarding land use and urban development would be the most sustainable solution to the balance of ridership with the application of the TOD principle.

Before focusing on balancing ridership through land use development, the appropriate trip distribution model, which can give a precise estimation of the mass transit ridership, must be investigated properly. It can convey the mass transit ridership behavior through the estimation. First of all, the assumption of model formulation would be made prior to the model formulation.

3.1 THE ASSUMPTION OF MASS TRANSIT RIDERSHIP BALANCING

The balance of ridership can be measured in many ways. The meaning of the balance of ridership must be specified in order to give a general understanding. The assumptions of the balance of ridership and the structure of railway alignment must be described to specify the scope of the study. They are as follows:

(1) The structure of railway is a single, stand-alone transit line. This means that there are no connections with any other lines.

(2) The alignment of railway is a linear train route along the urban areas. The balance of ridership is examined in terms of the railway alignment corridor.

(3) The spatial interaction with land use along the rail line has the same characteristic. The extraordinary attractiveness of CBD, for example, will not be taken into account.

(4) The model formulation in this study is for employing morning peak hours when most passengers are traveling into the central business district (CBD) for work and study.

(5) The number of passengers boarding the train at a mass transit station is the only endogenous variable, which is the decision variable for this optimization problem.

(6) The demand in case of special events and the transferred ridership, which makes other incentive factors other than distance, will not be considered.

(7) The balance of ridership is assumed to be indicated by the variations of onboard passengers between any adjoining mass transit stations. The more balance of ridership, the fewer variations of onboard passengers.

3.2 THE TRIP DISTRIBUTION MODEL FOR BALANCING RIDERSHIP

From the trip distribution models as reviewed in the previous chapter, it can be observed that the models can be classified into two categories, according to the characteristics of input data — the theoretical model and the empirical model.

In this part, this study prefers ***'the Gravity Model'*** and ***'the FAM'*** as the basis for the further formulation of ridership balancing scheme. The supporting reasons for the model selection are explained as follows:

(1) Both *the Gravity Model and the FAM* are the theoretical models, which can be employed in the mathematic problem setting. Both models require no primary O-D data of existing ridership. Only the numbers of boarding/alighting passengers are used for the model application. Moreover, the numbers of boarding and alighting passengers are related at each station.

In addition, when both models are further modified to incorporate the land use, they can diminish the deviation from the recorded trip generation and trip attraction data.

(2) *The gravity model* is the most fundamental model for trip distribution estimation. It is the extensively used functional form for any modes of travel to predict the O-D passengers.

(3) *The FAM* is another appropriate model as it is originated for integrating a route – level trip distribution. The accuracy of the model approach has been proven statistically for the linear routes. The model performance is able to function proficiently for the simple transit routes. This attribute is compatible with the railway structure characteristic in this study.

The structures of chosen models; *the Gravity Model, the FAM*, are described in detail as follows:

3.2.1 The Gravity Model Structure

The original transportation gravity model is consequently developed from the gravity model generated, according to the Newton's gravitational law. The structure of the transportation gravity model is proposed to estimate the traffic or passenger distributes between zonal pairs as a simple function of population and deterrence factors. The general structure of the model is shown in Equation (3-1).

$$\tau_{ij} = \frac{\phi_{ij} G_i A_j}{\delta_{ij}^{\lambda}} \tag{3-1}$$

where,

i is an origin of the trip.

j is a destination of the trip.

τ_{ij} is the number of trips generated at the origin i and attracted to the destination j.

G_i is the total number of trips generated at the origin i.

A_j is the total number of trips attracted to the destination j.

ϕ_{ij} is the adjustment factor taking into account the effect on travel patterns of defined socio-economic linkages for specific zone-to-zone.
In the absence of special information, this optional adjustment factor is recommended to be 1 (Navick and Furth 1994).

δ_{ij} is the deterrence factor representing the disincentive in trip demand between zones i and j, for example, distance, travel time or travel cost.
The deterrence factor must be positive number.

λ is the degree of deterrence, the value is specified as 2, according to the Newton's gravitational law. However, it can be specified as arbitrary value for applying in more universal purposes. The higher degree of deterrence signifies the case that any passengers have a lower probability to travel a long-distance trip than a short-distance one.

The deterrence factor is defined as 'the power/exponential function', expressing distance-deterrence factors for accurately setting up a transport model and incorporating the impacts of factors on human travel behavior. The power/exponential function is the most straightforward form extensively used in the trip distribution model without a calibration process.

Despite the diversity of deterrence factors, the main deterrence of a travel demand in this study focuses principally on *'distance'*. The main reason is the theoretical nature of problem settings in this study. It is quite difficult to quantify the impact of other factors in terms of travel time and travel cost.

As a matter of fact, distance is the main component directly influencing the trip distribution for a mass transit trip as the fare rate structure of a mass transit system is set from standardization in which the fare rate varies depending on distance. In addition, it can also interpret the 'distance' in a broad sense as 'the degree of deterrence' that increases by distance, time, travel cost, and so on.

3.2.2 The Fluid Analogy Method Structure

The structure of FAM was proposed with the concept of fluid pipe flow by Tsygalnitzky to estimate the trip distribution matrices along public transport routes, using boarding and alighting passenger data.

The transit system is compared as a pipe laid along an alignment. The passengers are considered as fluid filled in the transit system at each boarding stop. The fluid is blended between stations and then poured out of a pipe at each alighting station. The formulation of the original FAM is described as follows:

i is the boarding transit stop and j is the alighting transit stop, where $j \geq i$.

v_{ij} is the number of passengers traveling from the stop i to the stop j.

e_{ij} is the number of passengers boarding at the stop i and qualified to alight at the stop j.

Assume that $v_{ij} = e_{ij} = 0$ for $j = i$, and $v_{ij} = e_{ij}$ for $j - i = 1$.

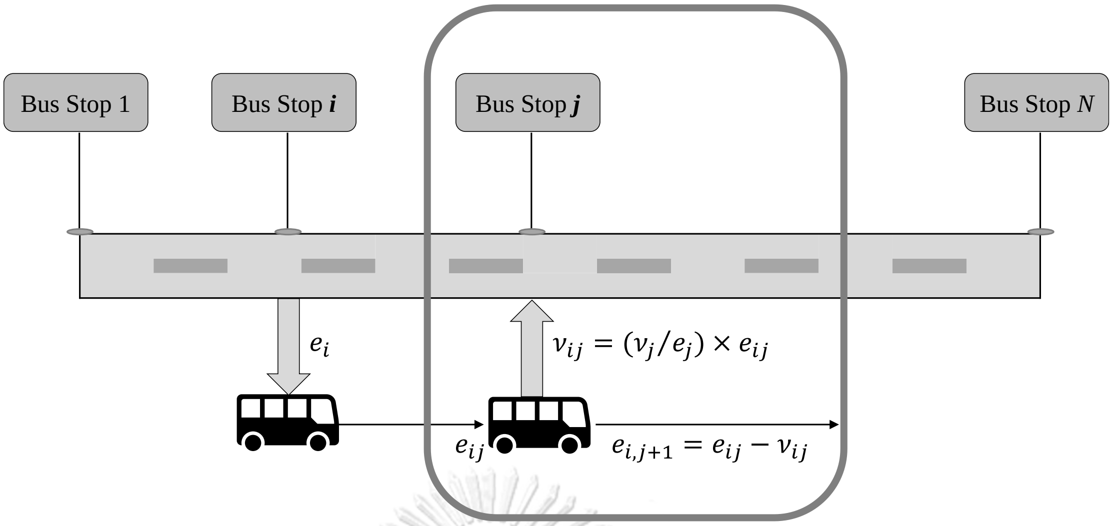


Figure 3-2 Trip distribution along the bus route.

The calculation is then proceeded from the alighting stop $j = i+1$ to $j = n$.

The diagram of FAM along the bus route is shown in Figure 3-2.

At the alighting stop j, the passengers qualified to alight are e_j, and the actual alighting passengers are ν_j. Therefore, the terms of fraction; $f_j = \nu_j / e_j$, explain the ratio of actually alighting passengers to the passengers qualified to alight at stop j.

This fraction is applied to each boarding stop i with the qualified passengers to alight. The number of passengers traveling from the stop i to the stop j is shown in Equation (3-2).

$$\nu_{ij} = f_j e_{ij}, \forall i < j \tag{3-2}$$

Therefore, the number of passengers traveling and eligible to alight at the next alighting stop $j = j+1$ would remain, as shown in Equation (3-3).

$$e_{i,j+1} = e_{ij} - \nu_{ij} \tag{3-3}$$

3.3 THE TRIP DISTRIBUTION MODEL FORMULATION

This part provides the model formulation, which is in accordance with ridership balancing problems. The transit trip distribution models are specifically formulated for a mass transit system to achieve the objective of the research. To simplify the model, the structure of railway alignment is assumed to be the linear system, which is a single and stand-alone train line. This means that the railway has no connections with any other lines along the route. The structure of railway alignment is shown in Figure 3-3.

As mentioned above, the imbalanced ridership problem is reflected through mass transit ridership characteristics. The problem is that the line is only overcrowded in one direction, whereas it is largely unoccupied in the opposite direction. The crowds of passengers can only be seen in some particular sections of the route. The objective of balancing mass transit ridership in this study is therefore to distribute passengers from the origin to the destination with the minimum variation of onboard passengers along the whole route.

In other words, it can be implied that overcrowded passengers will not be seen in only some particular sections of the route but the number of passengers will disperse evenly throughout the whole route when the objective of ridership balancing is achieved.

The objective function is formulated so as to minimize the variations of onboard passengers between any adjoining stations i and j, where $j = i+1$ for an outbound direction and $j = i-1$ for an inbound direction, along a single rail line during the morning peak hours when most passengers travel to the Central Business District (CBD) for work and study. The objective function is shown in Equation (3-4).

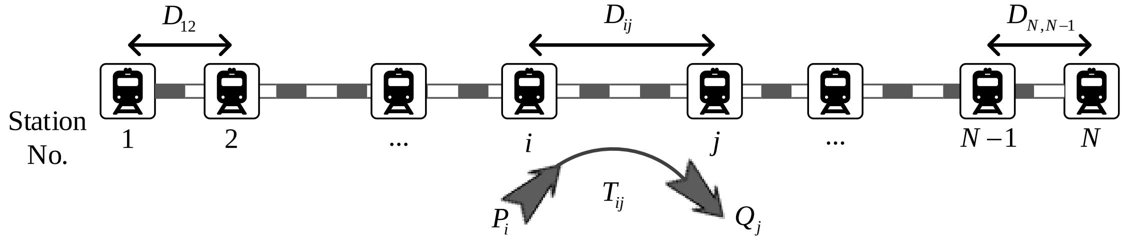


Figure 3-3 Structure of railway alignment.

$$\min \quad Var\ (R_{12},...,R_{i,i+1},...,R_{N-1,N},R_{N,N-1},...,R_{i,i-1},...,R_{21})$$

$$\text{or} \tag{3-4}$$

$$\min \quad Var\ (R_{ij}), \quad \forall |i-j|=1; \quad i,j \in \{1,2,...,N\}$$

where,

R_{ij} is the number of onboard passengers between the stations i and j, representing the ridership between each pair of stations (unit: person).

N is the total number of stations within the whole transit route (unit: station).

The other variables used in the model are defined as follows.

P_i is the number of passengers boarding at the station i (unit: person).

Q_j is the number of passengers alighting at the station j (unit: person).

T_{ij} is the number of passengers boarding at the station i and alighting at the station j (unit: person).

D_{ij} is the distance between the stations i and j (unit: kilometer).

$\bar{T}$ is the total number of passengers within the transit system (unit: person),

$\bar{C}$ is the maximum capacity of the train (unit: person).

Given the explanation of the variables and the objective function as stated above, the next step is to formulate the boarding and alighting behavior of passengers for the mass transit system.

Firstly, the gravity model is revised to explain the O-D distribution of the overall population, using the transit route in consideration. The proposed mass transit trip distribution model based on a fluid-flow analogy method is subsequently formulated. The assumptions and constraints of each model will be identified afterward.

3.3.1 The Gravity Model Formulation for Balancing Ridership

Being employed for the traffic flow estimation, the gravity model assumes that the number of trips produced at an origin and attracted by a destination is directly proportional to the distance between this pair of origin and destination.

To explain the deterrence variables,

D is the distances between any adjoining stations.

$D_{\max,i}$ is the maximum distance that any passengers could plausibly travel from the station i within the individual transit line.

Consequently, the possibility that any passengers who board the train at the station i will alight from the train at the station j is proportionally decreasing by the distance between the stations i and j. It can be further explained in Equations (3-5) and (3-6).

$$T_{ij} = \left(\frac{\left(\frac{D_{\max,i}}{|i-j|D} \right)^{\lambda}}{\sum_{j=1}^{N} \left(\frac{D_{\max,i}}{|i-j|D} \right)^{\lambda}} \right) \times P_i \tag{3-5}$$

$$D_{\max,i} = \max\{N-i, i-1\} \times D \tag{3-6}$$

The term $\frac{D_{\max,i}}{|i-j|D}$ is the reciprocal of the relative distance between the stations i and j to the maximum distance from the station i. This number will be smaller as the destination station j is getting farther from the origin station i and will be equal to 1 for the remotest station.

The degree of deterrence, λ, is applied in a behavioral function. It expresses the acceleration of the decrease in the possibility of traveling a farther distance. In other words, the possibility of going a farther distance is then smoothly decreasing as passengers move away from the origin.

Finally, the number of passengers boarding between the stations i and j, the so-called *'ridership'*, can be determined by Equations (3-7) and (3-8) for the outbound direction and the inbound direction respectively.

$$R_{i,i+1} = \sum_{k=1}^{i} \sum_{j=i+1}^{N} T_{kj}, \forall i \in \{1, 2, \ldots, N-1\} \tag{3-7}$$

$$R_{i,i-1} = \sum_{k=i}^{N} \sum_{j=1}^{i-1} T_{kj}, \forall i \in \{2, \ldots, N\} \tag{3-8}$$

Two more necessary constraints are given below.

The passenger flow conservation constraint; the fundamental of balancing ridership for a trip distribution is the equivalence of the number of trips originating from all origin zones, the number of trips attracted by all destination zones and the total population within the mass transit route. The passenger flow conservation constraint describing the equivalence is shown in Equation (3-9).

The total population for a given route is assumed to be fixed under the short-run nature of the optimization problem. However, the allocation of boarding passengers among all train stations, or P_i ,can be flexibly adjusted.

The capacity of the train constraint; the ridership between any adjoining stations i and j must not exceed the capacity of the train, as shown in Equation (3-10).

$$\sum_i \sum_j T_{ij} = \sum_i P_i = \sum_j Q_j = 100 \tag{3-9}$$

$$R_{ij} \leq \bar{C} \tag{3-10}$$

Considering the objective function in Equation (3-4) and all the Constraints (3-5) – (3-10), it can be readily verified that the only endogenous variable for this optimization problem is the number of passengers boarding at station i, P_i.

Given the pre-specified value of exogenous variables, the optimal solution can be found by solving this system of non-linear equation, the results will be discussed later.

3.3.2 The Modified FAM Formulation for Balancing Ridership

In this part, the modified FAM is proposed by assuming that the O-D distribution pattern is described by the behavior of a fluid flowing through a cone-shaped pipeline, whose diameter varies by distance.

The variation of diameter is introduced to represent the decrease in the possibility of going a farther distance from the origin and to deal with the limitation of the original FAM, which can be applied only for the case that a bidirectional O-D data is available. This means that the input data must be the directional boarding/alighting counts (Kikuchi and Perincherry 1992).

The movement of passengers through a mass transit system is analogous to the fluid flowing in a pipeline. Each station is comparable to a hole through which the fluid can drain away. Figure 3-5 shows the concept of applying the modified FAM to a mass transit trip distribution. When considering any station i, the diameter of the pipeline is set equal to 1 at the farthest station. The diameter is then increasing relative to the distance from the farthest station when approaching the particular station i in consideration. If the specific station i is the in-between station, the diameter of the pipeline will be decreasing again when passing through the station i.

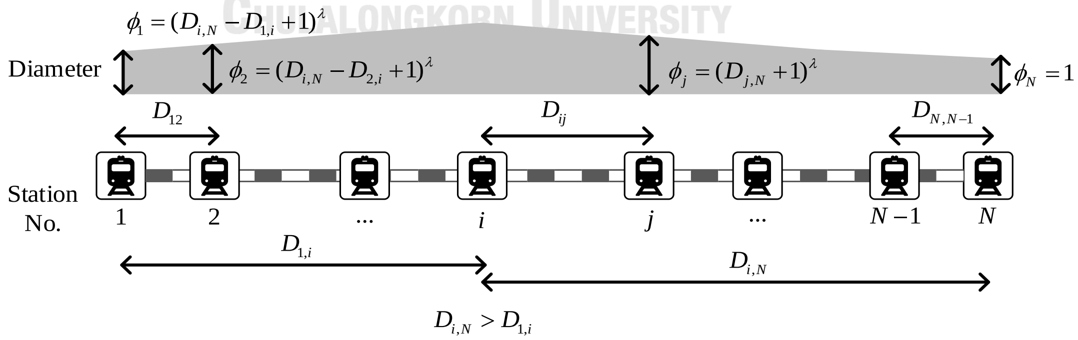


Figure 3-4 Cone-shaped pipeline with the modified FAM.

For any passengers boarding at the station i, the possibility that the passengers will alight from the train at the station j is proportionally increasing by the size of the diameter of the pipeline as explained earlier. It is similar to the 'volume flow rate' of fluid flowing through the pipeline.

Therefore, the proportion of passengers who board the train at the station i and alight from the train at the station j can be determined, as shown in Equation (3-11).

$$T_{ij} = \left(\frac{(D_{\max,i} - |i-j| + 1)^{\lambda}}{\sum_j (D_{\max,i} - |i-j| + 1)^{\lambda}} \right) \times P_i \qquad (3\text{-}11)$$

Again, the distances between all stations are set equal to D. The degree of deterrence, λ, explains the acceleration rate, by which the size of the diameter increases relative to a distance from the most remote station.

The term $D_{\max,i} - |i-j| + 1$ defines the size of the diameter at the station j when considering the passengers boarding the train at the station i.

The maximum distance, $D_{\max,i}$, that any passengers can plausibly travel from the station i within the same transit route is calculated by Equation (3-6). Other constraints are all the same with those explained in the gravity model, as shown in Equations (3-7) – (3-10).

Therefore, the system of non-linear equations for the modified FAM is defined by the objective Equation (3-4) and the Constraints (3-6) - (3-11) is used to solve the optimal number of passengers boarding the train at the station i, P_i, under a given set of exogenous variables.

3.4 RIDERSHIP BALANCING SCHEME FROM TWO BEHAVIORAL MODELS

To illustrate the results from two systems of non-linear equations; the gravity model and the modified FAM, the value of exogenous variables is specified as follows:

Firstly, the total number of stations in the whole transit route, N, is classified into 5 cases — 6, 9, 12, 15, 18 stations — ranging from a relatively short to a practically long transit line with both odd and even station numbers.

The total number of stations is set the maximum at 18 stations for supporting further application with the MRT Blue Line, which has 18 stations. Meanwhile, other cases are formulated in descending order by each 3 stations.

Secondly, the total number of passengers within the transit system, T_{ij}, is set to be 100 passengers. This setting is convenient for the interpretation of the results as the whole number of passengers will be automatically translated into the 'percentage' of the whole population.

Lastly, the distance between the adjoining stations, D, is assumed to distribute evenly at one kilometer for the simplicity of calculation, even though it can have any values and does not have any effects on the results. This 'one-kilometer' also reflects the coverage area, the walkable distance, and the average distance between adjoining stations of a mass transit system as mentioned in the previous chapter.

The attribute of two behavioral models in terms of relative distance between each pair of origin and destination are shown in Table 3-1(a) and Table 3-1(b) respectively. The probability of alighting from the train, which can explain the attribute of the gravity model and the modified FAM, are shown in T(a) and T(b) respectively.

Table 3-1 The relative distance between the stations i and j to the maximum travelling distance from station i.

(a) For the gravity model; $\dfrac{D_{\max,i}}{|i-j|D}$.

O/D	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
ST01		289	72	32	18	12	8	6	5	4	3	2	2	2	1	1	1	1
ST02	256		256	64	28	16	10	7	5	4	3	3	2	2	2	1	1	1
ST03	56	225		225	56	25	14	9	6	5	4	3	2	2	2	1	1	1
ST04	22	49	196		196	49	22	12	8	5	4	3	2	2	2	1	1	1
ST05	11	19	42	169		169	42	19	11	7	5	3	3	2	2	1	1	1
ST06	6	9	16	36	144		144	36	16	9	6	4	3	2	2	1	1	1
ST07	3	5	8	13	30	121		121	30	13	8	5	3	2	2	1	1	1
ST08	2	3	4	6	11	25	100		100	25	11	6	4	3	2	2	1	1
ST09	1	2	2	3	5	9	20	81		81	20	9	5	3	2	2	1	1
ST10	1	1	2	2	3	5	9	20	81		81	20	9	5	3	2	2	1
ST11	1	1	2	2	3	4	6	11	25	100		100	25	11	6	4	3	2
ST12	1	1	1	2	2	3	5	8	13	30	121		121	30	13	8	5	3
ST13	1	1	1	2	2	3	4	6	9	16	36	144		144	36	16	9	6
ST14	1	1	1	2	2	3	3	5	7	11	19	42	169		169	42	19	11
ST15	1	1	1	2	2	2	3	4	5	8	12	22	49	196		196	49	22
ST16	1	1	1	2	2	2	3	4	5	6	9	14	25	56	225		225	56
ST17	1	1	1	2	2	2	3	3	4	5	7	10	16	28	64	256		256
ST18	1	1	1	1	2	2	2	3	4	5	6	8	12	18	32	72	289	

TTable 3-1 The relative distance between the stations i and j to the maximum travelling distance from station i.

(b) For the modified FAM; $D_{\max,i} - |i-j| + 1$.

O/D	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
ST01		289	256	225	196	169	144	121	100	81	64	49	36	25	16	9	4	1
ST02	256		256	225	196	169	144	121	100	81	64	49	36	25	16	9	4	1
ST03	196	225		225	196	169	144	121	100	81	64	49	36	25	16	9	4	1
ST04	144	169	196		196	169	144	121	100	81	64	49	36	25	16	9	4	1
ST05	100	121	144	169		169	144	121	100	81	64	49	36	25	16	9	4	1
ST06	64	81	100	121	144		144	121	100	81	64	49	36	25	16	9	4	1
ST07	36	49	64	81	100	121		121	100	81	64	49	36	25	16	9	4	1
ST08	16	25	36	49	64	81	100		100	81	64	49	36	25	16	9	4	1
ST09	4	9	16	25	36	49	64	81		81	64	49	36	25	16	9	4	1
ST10	1	4	9	16	25	36	49	64	81		81	64	49	36	25	16	9	4
ST11	1	4	9	16	25	36	49	64	81	100		100	81	64	49	36	25	16
ST12	1	4	9	16	25	36	49	64	81	100	121		121	100	81	64	49	36
ST13	1	4	9	16	25	36	49	64	81	100	121	144		144	121	100	81	64
ST14	1	4	9	16	25	36	49	64	81	100	121	144	169		169	144	121	100
ST15	1	4	9	16	25	36	49	64	81	100	121	144	169	196		196	169	144
ST16	1	4	9	16	25	36	49	64	81	100	121	144	169	196	225		225	196
ST17	1	4	9	16	25	36	49	64	81	100	121	144	169	196	225	256		256
ST18	1	4	9	16	25	36	49	64	81	100	121	144	169	196	225	256	289	

Table 3-2 The probability of alighting from the train with degree of deterrence of 2; (a) For the gravity model; $\left(\dfrac{\left(\dfrac{D_{\max,i}}{|i-j|D}\right)^{\lambda}}{\sum_{j=1}^{N}\left(\dfrac{D_{\max,i}}{|i-j|D}\right)^{\lambda}} \right)$

.

O/D	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
ST01		0.630	0.157	0.070	0.039	0.025	0.017	0.013	0.010	0.008	0.006	0.005	0.004	0.004	0.003	0.003	0.002	0.002
ST02	0.387		0.387	0.097	0.043	0.024	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.003	0.002	0.002	0.002	0.002
ST03	0.088	0.353		0.353	0.088	0.039	0.022	0.014	0.010	0.007	0.006	0.004	0.004	0.003	0.002	0.002	0.002	0.002
ST04	0.038	0.085	0.340		0.340	0.085	0.038	0.021	0.014	0.009	0.007	0.005	0.004	0.003	0.003	0.002	0.002	0.002
ST05	0.021	0.037	0.083	0.334		0.334	0.083	0.037	0.021	0.013	0.009	0.007	0.005	0.004	0.003	0.003	0.002	0.002
ST06	0.013	0.021	0.037	0.083	0.330		0.330	0.083	0.037	0.021	0.013	0.009	0.007	0.005	0.004	0.003	0.003	0.002
ST07	0.009	0.013	0.020	0.036	0.082	0.328		0.328	0.082	0.036	0.020	0.013	0.009	0.007	0.005	0.004	0.003	0.003
ST08	0.007	0.009	0.013	0.020	0.036	0.082	0.327		0.327	0.082	0.036	0.020	0.013	0.009	0.007	0.005	0.004	0.003
ST09	0.005	0.007	0.009	0.013	0.020	0.036	0.082	0.326		0.326	0.082	0.036	0.020	0.013	0.009	0.007	0.005	0.004
ST10	0.004	0.005	0.007	0.009	0.013	0.020	0.036	0.082	0.326		0.326	0.082	0.036	0.020	0.013	0.009	0.007	0.005
ST11	0.003	0.004	0.005	0.007	0.009	0.013	0.020	0.036	0.082	0.327		0.327	0.082	0.036	0.020	0.013	0.009	0.007
ST12	0.003	0.003	0.004	0.005	0.007	0.009	0.013	0.020	0.036	0.082	0.328		0.328	0.082	0.036	0.020	0.013	0.009
ST13	0.002	0.003	0.003	0.004	0.005	0.007	0.009	0.013	0.021	0.037	0.083	0.330		0.330	0.083	0.037	0.021	0.013
ST14	0.002	0.002	0.003	0.003	0.004	0.005	0.007	0.009	0.013	0.021	0.037	0.083	0.334		0.334	0.083	0.037	0.021
ST15	0.002	0.002	0.002	0.003	0.003	0.004	0.005	0.007	0.009	0.014	0.021	0.038	0.085	0.340		0.340	0.085	0.038
ST16	0.002	0.002	0.002	0.002	0.003	0.004	0.004	0.006	0.007	0.010	0.014	0.022	0.039	0.088	0.353		0.353	0.088
ST17	0.002	0.002	0.002	0.002	0.003	0.003	0.004	0.005	0.006	0.008	0.011	0.015	0.024	0.043	0.097	0.387		0.387
ST18	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.006	0.008	0.010	0.013	0.017	0.025	0.039	0.070	0.157	0.630	

Table 3-2 The probability of alighting from the train with degree of deterrence of 2; (b) For the modified FAM; $\left(\dfrac{(D_{\max,i}-|i-j|+1)^{\lambda}}{\sum_j (D_{\max,i}-|i-j|+1)^{\lambda}}\right)$.

O/D	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
ST01		0.162	0.143	0.126	0.110	0.095	0.081	0.068	0.056	0.045	0.036	0.027	0.020	0.014	0.009	0.005	0.002	0.001
ST02	0.146		0.146	0.128	0.112	0.096	0.082	0.069	0.057	0.046	0.037	0.028	0.021	0.014	0.009	0.005	0.002	0.001
ST03	0.118	0.135		0.135	0.118	0.102	0.087	0.073	0.060	0.049	0.039	0.030	0.022	0.015	0.010	0.005	0.002	0.001
ST04	0.094	0.111	0.129		0.129	0.111	0.094	0.079	0.066	0.053	0.042	0.032	0.024	0.016	0.010	0.006	0.003	0.001
ST05	0.074	0.089	0.106	0.125		0.125	0.106	0.089	0.074	0.060	0.047	0.036	0.027	0.018	0.012	0.007	0.003	0.001
ST06	0.055	0.070	0.086	0.104	0.124		0.124	0.104	0.086	0.070	0.055	0.042	0.031	0.022	0.014	0.008	0.003	0.001
ST07	0.038	0.051	0.067	0.085	0.104	0.126		0.126	0.104	0.085	0.067	0.051	0.038	0.026	0.017	0.009	0.004	0.001
ST08	0.021	0.033	0.048	0.065	0.085	0.107	0.132		0.132	0.107	0.085	0.065	0.048	0.033	0.021	0.012	0.005	0.001
ST09	0.007	0.016	0.028	0.044	0.063	0.086	0.112	0.142		0.142	0.112	0.086	0.063	0.044	0.028	0.016	0.007	0.002
ST10	0.002	0.007	0.016	0.028	0.044	0.063	0.086	0.112	0.142		0.142	0.112	0.086	0.063	0.044	0.028	0.016	0.007
ST11	0.001	0.005	0.012	0.021	0.033	0.048	0.065	0.085	0.107	0.132		0.132	0.107	0.085	0.065	0.048	0.033	0.021
ST12	0.001	0.004	0.009	0.017	0.026	0.038	0.051	0.067	0.085	0.104	0.126		0.126	0.104	0.085	0.067	0.051	0.038
ST13	0.001	0.003	0.008	0.014	0.022	0.031	0.042	0.055	0.070	0.086	0.104	0.124		0.124	0.104	0.086	0.070	0.055
ST14	0.001	0.003	0.007	0.012	0.018	0.027	0.036	0.047	0.060	0.074	0.089	0.106	0.125		0.125	0.106	0.089	0.074
ST15	0.001	0.003	0.006	0.010	0.016	0.024	0.032	0.042	0.053	0.066	0.079	0.094	0.111	0.129		0.129	0.111	0.094
ST16	0.001	0.002	0.005	0.010	0.015	0.022	0.030	0.039	0.049	0.060	0.073	0.087	0.102	0.118	0.135		0.135	0.118
ST17	0.001	0.002	0.005	0.009	0.014	0.021	0.028	0.037	0.046	0.057	0.069	0.082	0.096	0.112	0.128	0.146		0.146
ST18	0.001	0.002	0.005	0.009	0.014	0.020	0.027	0.036	0.045	0.056	0.068	0.081	0.095	0.110	0.126	0.143	0.162	

Hereafter, the values of all variables are specified completely. The next sequence is the comparison of two trip distribution models, which is intended to investigate the model competence in the reflection of mass transit ridership characteristics.

Comparison of the Degree of Deterrence

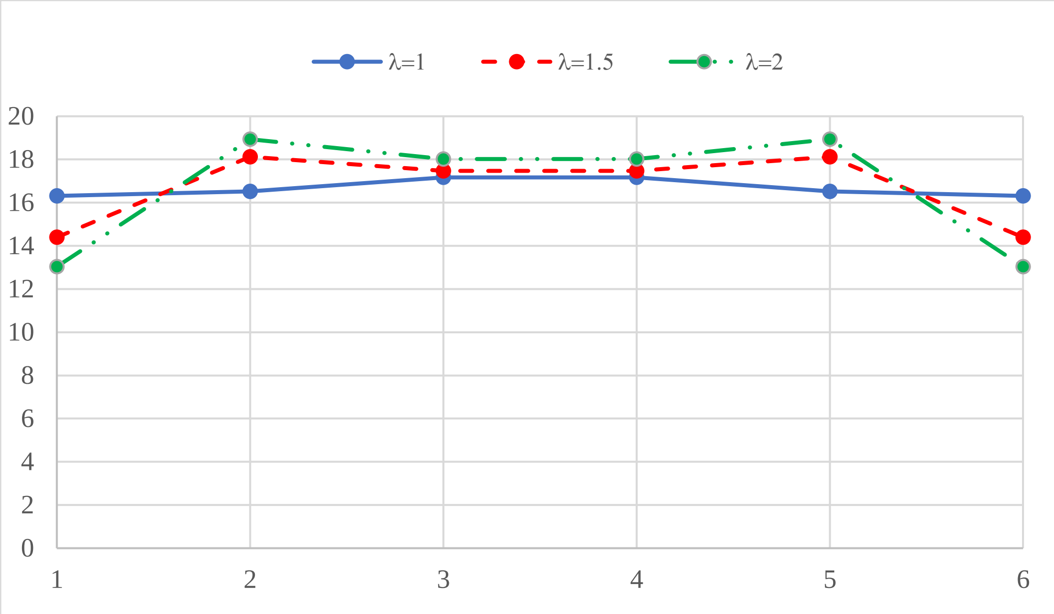
The performances of two behavioral models are compared by varying values of a degree of deterrence, λ, representing the acceleration rate of the decrease in the possibility of going a farther distance with the varying numbers of stations of 6, 9, 12, 15 and 18.

Considering more details of the influences of exogenous parameters, the degree of deterrence; λ, the variance of passengers boarding the train at each station with various degrees of deterrence is shown in Table 3-3 Initially, the higher the degree of deterrence, the lower the variance of boarding passengers at each station. Moreover, the sensitivity of the degree of deterrence for the modified FAM is less variant than the gravity model.

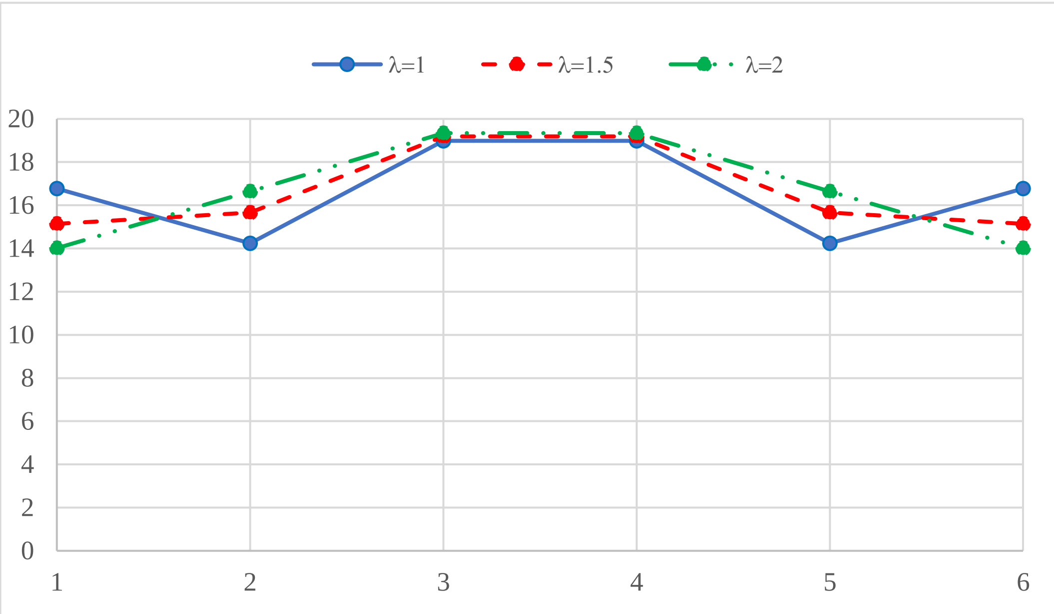
The results of ridership balancing in terms of the number of passengers boarding at each station for each degree of deterrence are shown in Figure 3-5 to Figure 3-9, expressing the fluctuation of charts.

Table 3-3 The variance of boarding passengers at each station with various degrees of deterrence, λ, for 5 cases of the number of stations (Unit: percentage)

The number of stations	Gravity Model			Modified FAM		
	$\lambda = 1$	$\lambda = 1.5$	$\lambda = 2$	$\lambda = 1$	$\lambda = 1.5$	$\lambda = 2$
6 stations	0.13	2.64	6.72	3.76	3.23	4.73
9 stations	0.51	0.40	1.66	8.81	5.37	3.82
12 stations	0.93	0.25	0.69	9.72	6.01	3.99
15 stations	1.06	0.26	0.40	9.76	6.23	4.18
18 stations	1.06	0.28	0.28	9.06	5.92	4.05

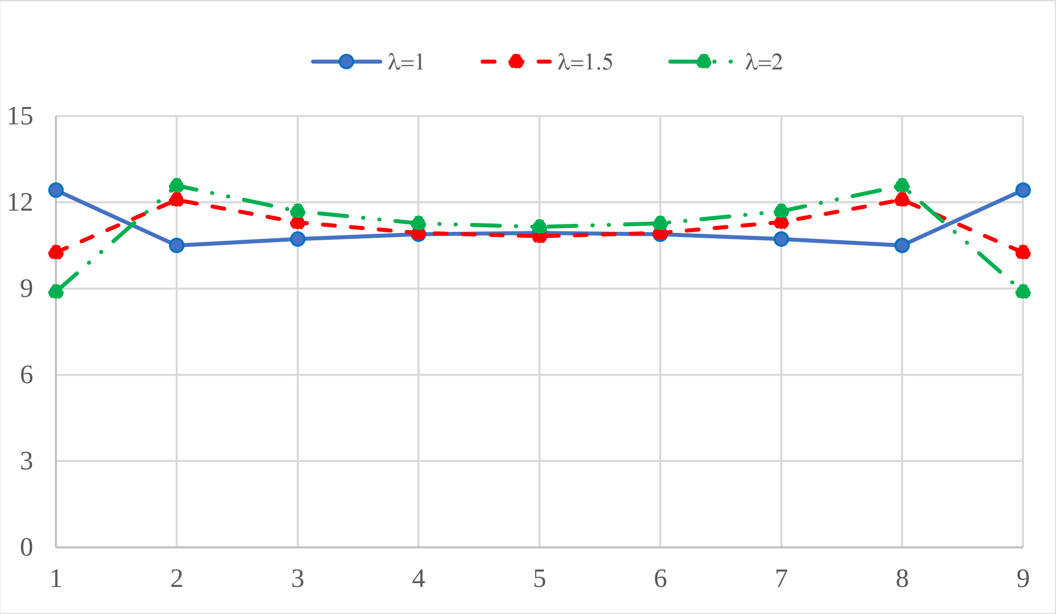


(a) The gravity model.

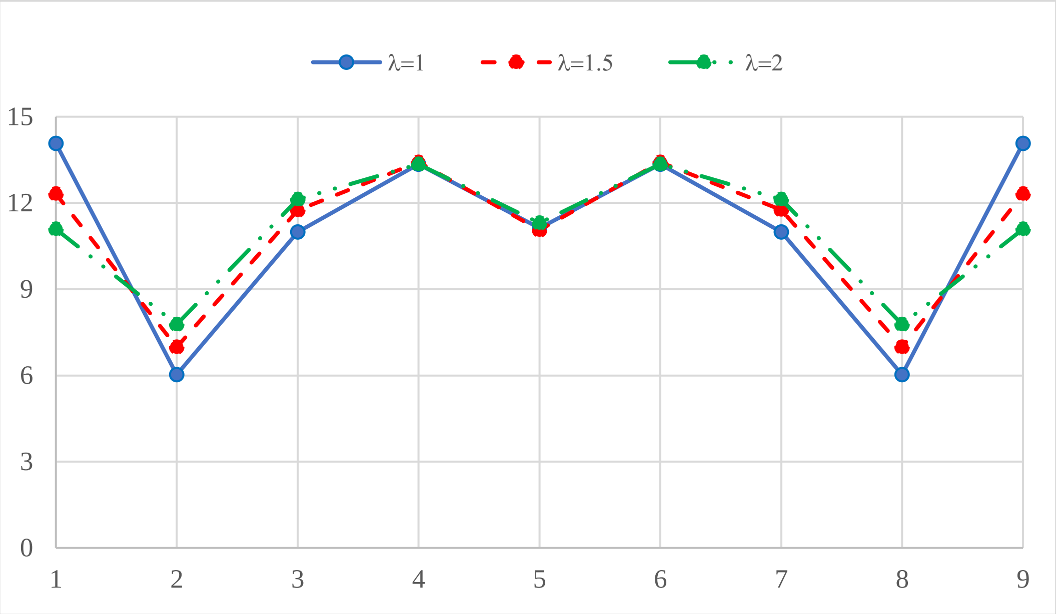


(b) The modified FAM.

Figure 3-5 The comparison of boarding passengers for 6 stations with various degrees of deterrence (Unit: percentage)**.**

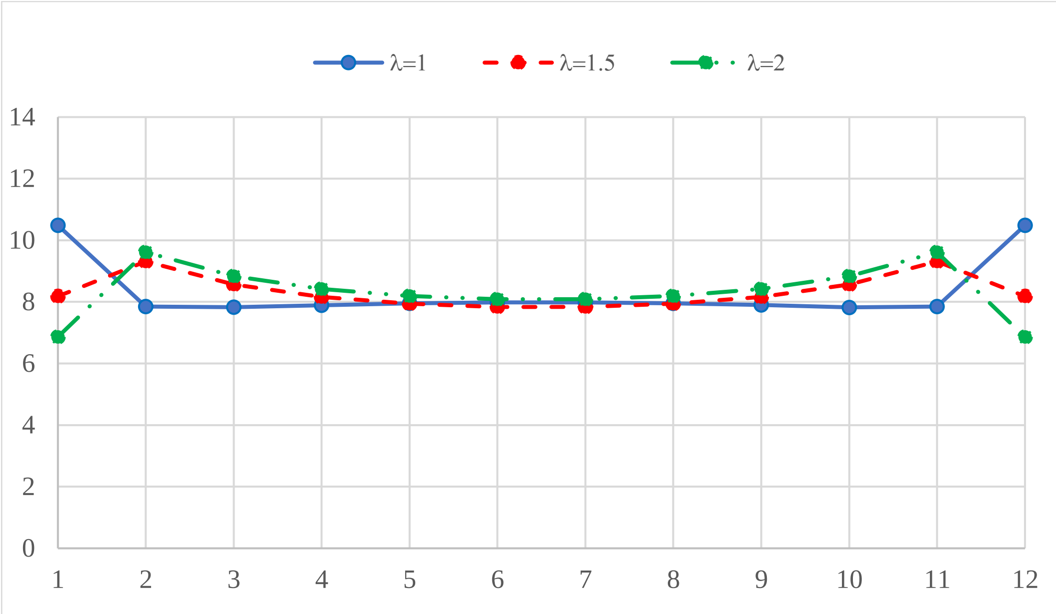


(a) The gravity model.

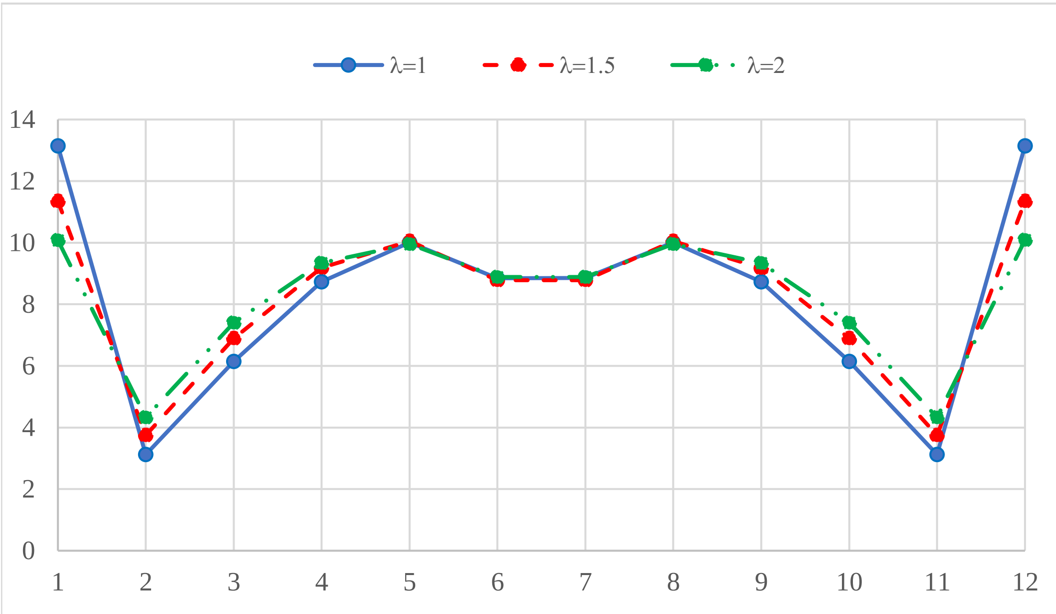


(b) The modified FAM.

Figure 3-6 The comparison of boarding passengers for 9 stations with various degrees of deterrence (Unit: percentage)**.**

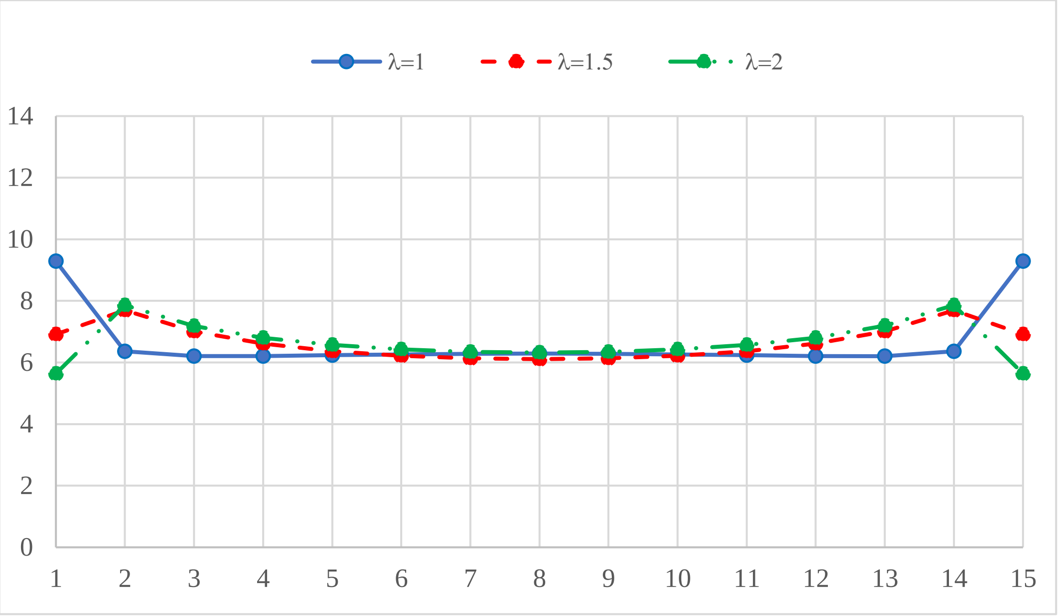


(a) The gravity model.

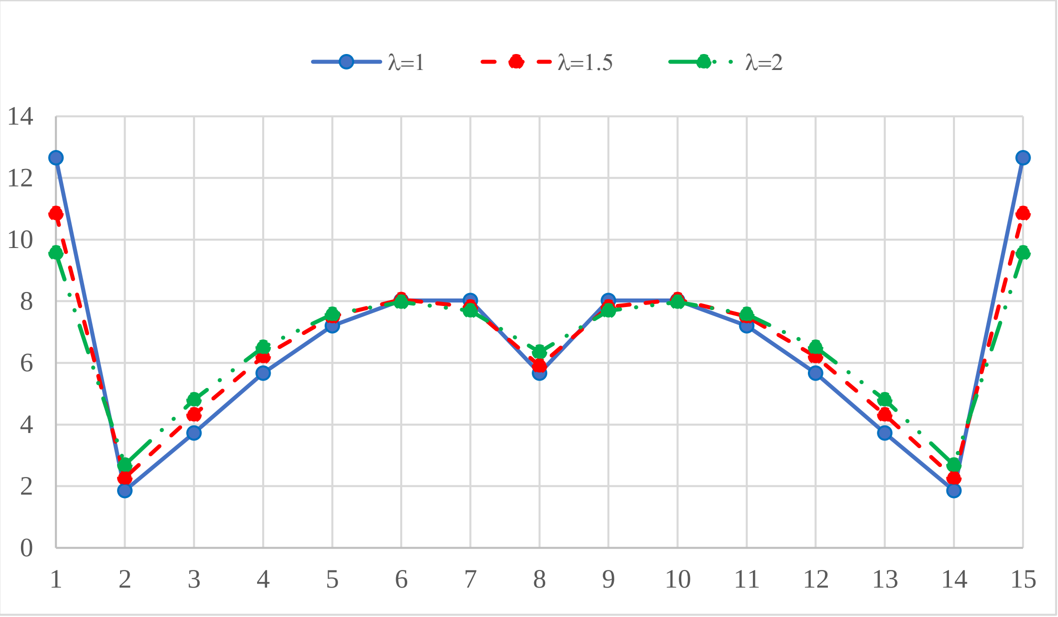


(b) The modified FAM.

Figure 3-7 The comparison of boarding passengers for 12 stations with various degrees of deterrence (Unit: percentage)**.**

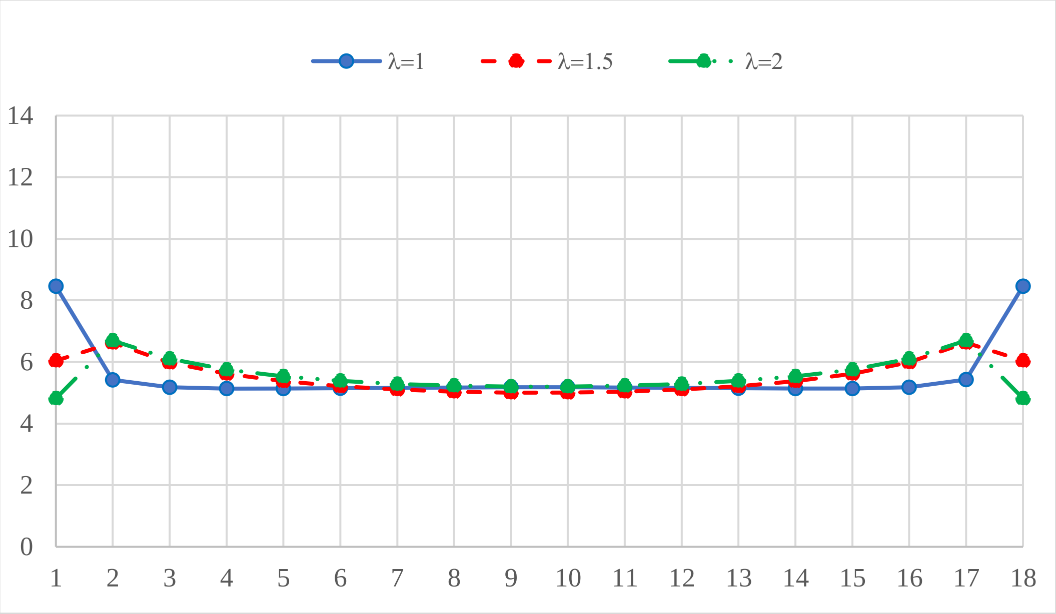


(a) The gravity model.

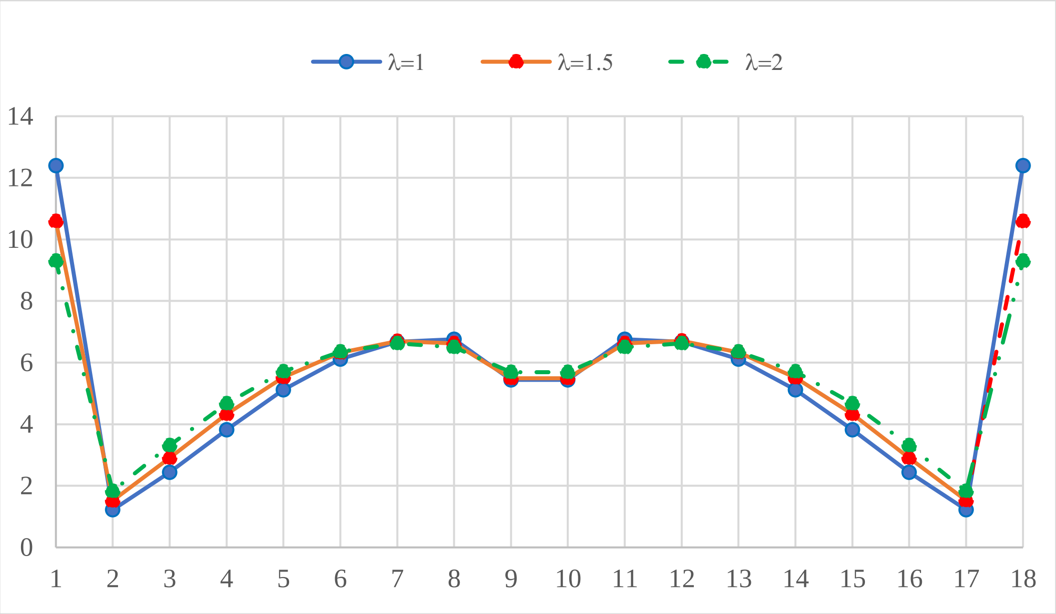


(b) The modified FAM.

Figure 3-8 The comparison of boarding passengers for 15 stations with various degrees of deterrence (Unit: percentage).



(a) The gravity model.



(b) The modified FAM.

Figure 3-9 The comparison of boarding passengers for 18 stations with various degrees of deterrence (Unit: percentage).

It can be implied that the results achieved by the modified FAM prove more robust and will be more reliable when put into practice with the supporting reasons, which are as follows:

(1) The overall patterns of boarding passenger distribution at each station for the modified FAM are not much altered by the variation in the value of degree of deterrence, compared with the gravity, where the value of degree of deterrence has a serious impact on the pattern of boarding passenger distribution. It can be seen in Figure 3-5 to Figure 3-9 for all the cases of numbers of stations.

(2) The variance of the number of boarding passengers at each station and the corresponding ridership for the whole transit route in the gravity model, as shown in Table 3-3, is much lower than the modified FAM. It seems unfeasible to put that pattern of O-D distribution into practice. The solution from the gravity model can also ascertain the difficulty of implementation.

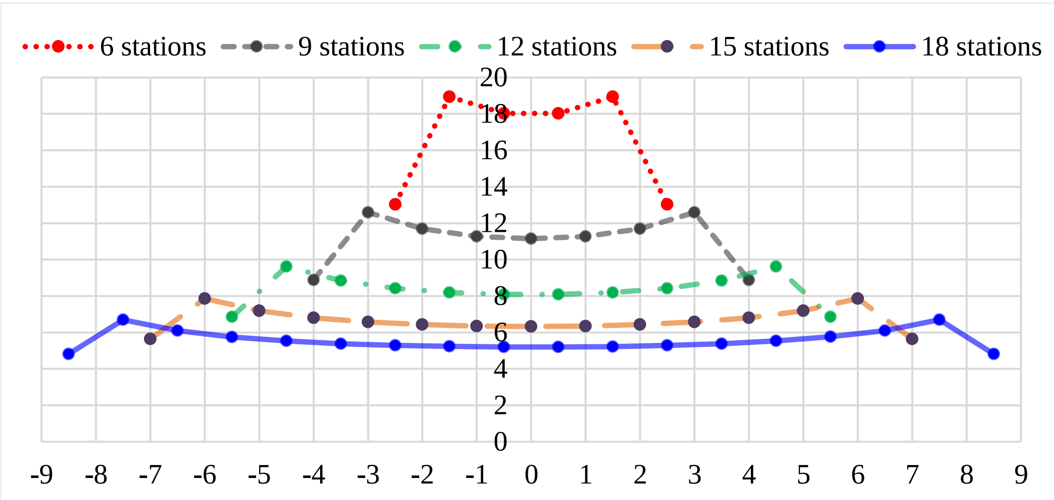
The Boarding and Alighting Passengers

The degree of deterrence will cautiously be chosen herein for more comparisons in which behavioral models can reflect the characteristics or purposes of the transit route/trip.

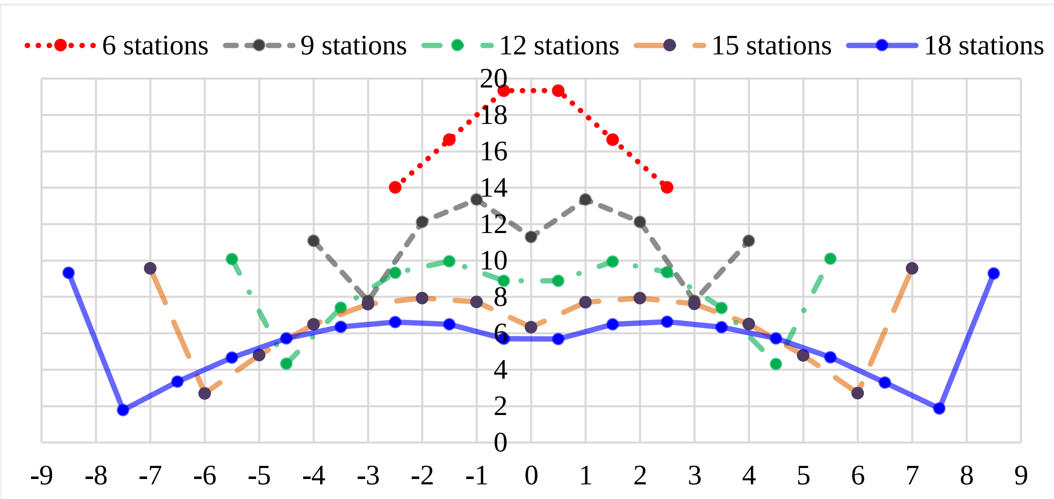
As explained in the model formulation, the higher degree of deterrence signifies the case that any passengers have a lower tendency to travel a long-distance trip than a short-distance one.

In other words, the higher degree of deterrence is more appropriate for the inner-city rail line as passengers tend to have a short trip for shopping or commercial purposes. At the same time, the lower degree of deterrence is used in a long-journey commuter train as passengers in suburban areas take a long trip to work or study in the CBD. The inner-city rail line is thus regarded as one of the characteristics of mass transit system in this study's objective. Furthermore, the results of degree of deterrence comparison have also summarized that the modified FAM has more robustness and will be more reliable when put into practice.

Consequently, the degree of deterrence, λ, of 2 is further analyzed for comparison between the gravity model and the modified FAM performance in the mass transit ridership estimation. The number of stations varies in the same way as for the five cases of 6, 9, 12, 15 and 18 stations. The results of balancing ridership and the numbers of passengers boarding charts are shown in Figure 3-10(a) for the gravity model and Figure 3-10 (b) for the modified FAM.



(a) The gravity model.



(b) The modified FAM.

Figure 3-10 The number of passengers boarding at each station for varying station numbers with $\lambda = 2$ (Unit: percentage).

Table 3-4 The results of balancing transit ridership for various cases of station number with $\lambda = 2$ (Unit: percentage).

..................(a) the gravity model.

Station No.	The number of passengers														
	6 stations			9 stations			12 stations			15 stations			18 stations		
	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.
ST01	13.04	11.15	1.89	8.89	7.24	1.65	6.86	5.46	1.40	5.64	4.43	1.21	4.82	3.76	1.06
ST02	18.94	18.96	0.02	12.59	12.19	0.40	9.61	9.17	0.46	7.86	7.43	0.43	6.69	6.28	0.41
ST03	18.02	19.89	1.87	11.69	12.50	0.81	8.84	9.33	0.49	7.19	7.53	0.33	6.10	6.36	0.26
ST04	18.02	19.89	1.87	11.27	12.09	0.82	8.42	8.90	0.48	6.81	7.14	0.34	5.75	6.01	0.26
ST05	18.94	18.96	0.02	11.15	11.95	0.80	8.19	8.63	0.44	6.57	6.87	0.30	5.53	5.76	0.23
ST06	13.04	11.15	1.89	11.27	12.09	0.82	8.08	8.51	0.43	6.43	6.70	0.27	5.39	5.59	0.20
ST07				11.69	12.50	0.81	8.08	8.51	0.43	6.35	6.61	0.26	5.29	5.47	0.18
ST08				12.59	12.19	0.40	8.19	8.63	0.44	6.32	6.58	0.26	5.23	5.40	0.17
ST09				8.89	7.24	1.65	8.42	8.90	0.48	6.35	6.61	0.26	5.20	5.37	0.17
ST10							8.84	9.33	0.49	6.43	6.70	0.27	5.20	5.37	0.17
ST11							9.61	9.17	0.46	6.57	6.87	0.33	5.23	5.40	0.17
ST12							6.86	5.46	1.40	6.81	7.14	0.34	5.29	5.47	0.18
ST13										7.19	7.53	0.34	5.39	5.59	0.20
ST14										7.86	7.43	0.43	5.53	5.76	0.23
ST15										5.64	4.43	1.21	5.76	6.01	0.25
ST16													6.10	6.36	0.26
ST17													6.69	6.28	0.41
ST18													4.82	3.76	1.06
Objective Value	2.01			1.16			0.71			0.48			0.34		
Avg. Diff.	1.26			0.91			0.62			0.44			0.33		

Table 3-4 The results of balancing transit ridership for various cases of station number with $\lambda = 2$: (Unit: percentage).

.... (b) the modified FAM

Station No.	The number of passengers														
	6 stations			9 stations			12 stations			15 stations			18 stations		
	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.	Board	Alight	Diff.
ST01	14.01	9.99	4.02	11.09	5.65	5.44	10.09	3.90	6.19	9.57	2.93	6.64	9.31	2.35	6.96
ST02	16.64	18.15	1.51	7.78	10.35	2.57	4.33	7.12	2.79	2.68	5.33	2.65	1.82	4.26	2.44
ST03	19.35	21.86	2.51	12.13	12.28	0.15	7.40	8.14	0.74	4.80	5.97	1.17	3.30	4.69	1.39
ST04	19.34	21.86	2.52	13.35	14.16	0.81	9.34	9.34	0	6.53	6.75	0.22	4.71	5.21	0.5
ST05	16.63	18.15	1.52	11.29	15.12	3.83	9.96	10.4	0.44	7.57	7.54	0.03	5.71	5.77	0.06
ST06	14.03	9.99	4.04	13.35	14.16	0.81	8.88	11.1	2.22	7.97	8.24	0.27	6.35	6.32	0.03
ST07				12.13	12.28	0.15	8.89	11.1	2.21	7.67	8.73	1.06	6.63	6.81	0.18
ST08				7.78	10.35	2.57	9.95	10.4	0.45	6.37	9.02	2.65	6.48	7.17	0.69
ST09				11.10	5.65	5.45	9.35	9.34	0.01	7.69	8.73	1.04	5.68	7.42	1.74
ST10							7.40	8.14	0.74	7.98	8.24	0.26	5.71	7.42	1.71
ST11							4.33	7.12	2.79	7.55	7.54	0.01	6.51	7.17	0.66
ST12							10.09	3.90	6.19	6.53	6.74	0.21	6.64	6.81	0.17
ST13										4.80	5.97	1.17	6.32	6.32	0
ST14										2.69	5.33	2.64	5.69	5.77	0.08
ST15										9.60	2.93	6.67	4.72	5.21	0.49
ST16													3.27	4.69	1.42
ST17													1.85	4.26	2.41
ST18													9.30	2.35	6.95
Objective Value	10.36			11.01			10.55			10.29			10.03		
Avg. Diff.	2.68			2.42			2.07			1.78			1.55		

The numbers of boarding and alighting passengers, including the differences, are shown in Table 3-4(a) and Table 3-4(b) for the gravity model and the modified FAM respectively. The objective values and the variance of onboard passengers for each case are also determined for comparison.

The results of balancing ridership can be interpreted in the performance comparison between two behavior models in the following aspects:

(1) *'The distribution of boarding passengers'* at each station for all cases in Figure 3-10, the results show that the modified FAM can describe the nature of 'catchment area' around both terminal stations, where the number of passengers is generally higher than the number of passengers boarding at the in-between stations.

In addition, it can be observed that the minimum value of boarding passengers appears at the second point and the last but one point. The last point at both ends would collect a huge number of passengers, according to the larger cover service area, the influence of park-and-ride facilities or the intersection of other major feeder lines.

The nature of a land use development in urban planning where the business and commercial areas are concentrated within the CBD and the residential areas are expanding in the suburban parts of a city. The results can ascertain the difficulty of implementing the solution from the gravity model.

However, the modified FAM can illustrate the mixed-use development along the mass transit concept by the results of ridership balancing, as shown in Figure 3-10(b). When the rail line gets longer, it can roughly be divided into three sections, which are as follows:

a) The outer bound at both ends with high boarding demand from the residential area.

b) The central part of the line locating in the CBD to generate high alighting demand for work/study purposes.

c) The in-between parts where both boarding and alighting demands are lower than the other parts due to the mixed-use development that may result in the reduction of mass transit trip generation and indirectly increases private mode split.

(2) '*The average differences between the number of boarding and alighting passengers'* as indicated in Table 3-4(a) and Table 3-4(b), the modified FAM has the higher average differences than the gravity model in all cases, with respect to the number of stations.

The difference between the numbers of boarding and alighting passengers at each station can also be a crucial factor as it exposes the fact that the number of passengers in a mass transit system during peak hours is always high only in one direction, whereas in the other direction the number is low.

(3) '*The difference of the functional form between the gravity model and the modified FAM'* The gravity model in Equation (3-5) has a reciprocal functional form, whereas the one based on the modified FAM, as shown in Equation (3-11), has the additive form of fixed and linearly variable terms.

In the context of mass transit, any passengers boarding the train at any stations are abiding by some fixed costs, such as time loss due to the ticket purchasing process and the waiting time. On the other hand, when deciding whether to leave the train or remain boarding until the next station, a passenger usually faces the additional cost in terms of time loss (value of time) linearly proportional to the distance. The combination of these two costs is suggested by the functional form of the modified FAM.

(4) *'The probability of alighting from the train'*: Figure 3-11 is created to illustrate the relationship between the probability of alighting from the train and the distance from a boarding station based on two behavioral models in case of six stations.

As noted earlier about the difference between the two behavioral functional forms, the gravity model has a reciprocal functional form, whereas the modified FAM has the additive functional form of fixed and variable terms. Therefore, the possibility of traveling a further distance based on the gravity model is rapidly decreasing with the negative exponential distribution. One more unrealistic behavior of the gravity model can be depicted, as shown in Figure 3-11(a).

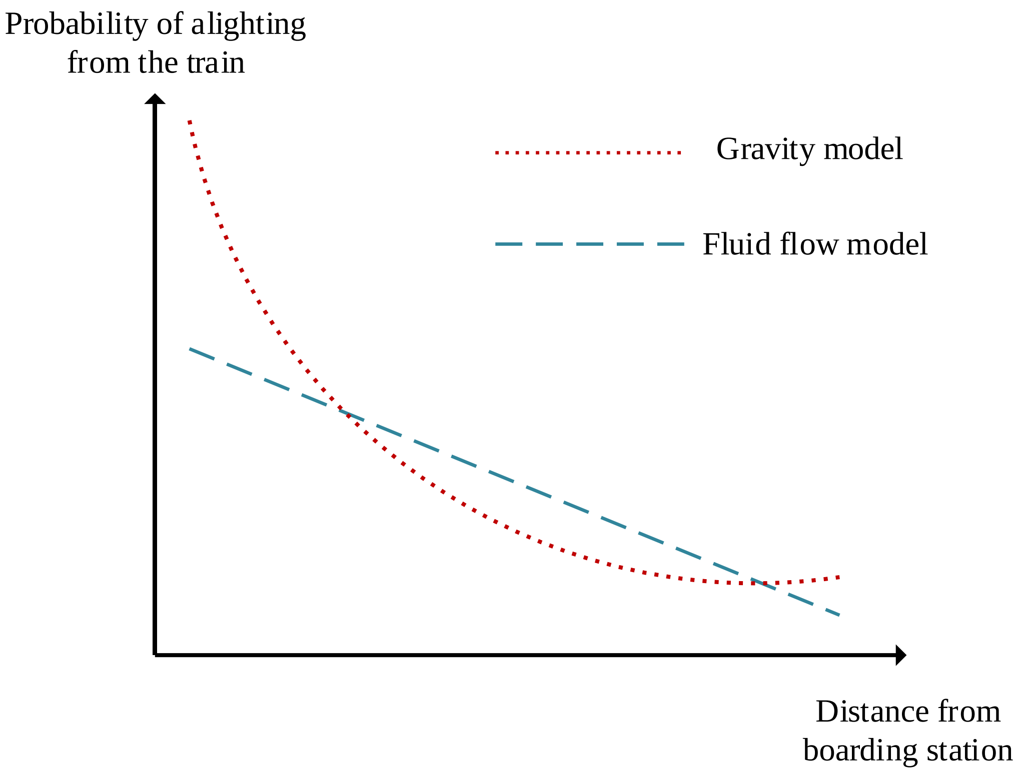
On the other hand, the modified FAM suggests a gentler rate of reduction in the possibility of going an additional distance. Figure 3-11(b) expresses the example with the cases of six stations when a passenger boarded a train from the starting station. With the modified FAM, the probability of alighting from the train is decreasing almost linearly with distance, whereas it is sharply reduced with the gravity model.

A mass transit system is actually not the immediate mode of transportation between origin and destination. Passengers have to spend some time and costs for access and egress in the transit system. The travel time, which is one of the disincentive factors of the gravity model, can be split into two intervals, which are the access/egress time and the onboard time.

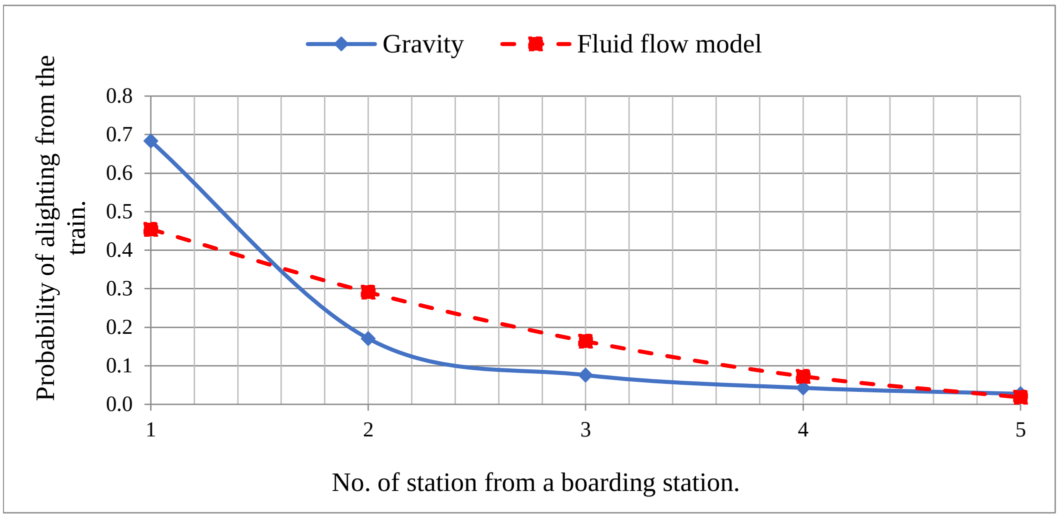
Generally, for the urban short-to-medium-length trips, the access/egress time has a greater impact on the travel time than the onboard time. Accessing a mass transit station mostly takes much longer than any other public transit system owing to differences in their coverage (Goel and Tiwari 2016). An increase in access and egress (time and/or distance) is associated with a decrease in the usage of a transit system. Therefore, prolonging a trip for one further station does not significantly lead to much longer travel time.

This behavior contradicts with the deterrence function of the gravity model, assuming that the number of trips is rapidly decreasing with the longer distance.

Accordingly, the proposed modified FAM tends to reflect the travel behavior of a mass transit trip distribution more realistically than the conventional gravity model.



(a)



(b)

Figure 3-11 Relationship between probability of alighting from the train and distance from the boarding station based on two behavioral models.

In addition, considering the effects of the number of stations within the transit route, a larger number of stations means a longer transit line. However, it is more interesting to look at the impacts on the variance of ridership along the whole route. The results show that the longer rail line tends to be easier to balance its ridership than the shorter one. The variance of onboard ridership is shown in the second to last row of Table 3-4(a) and Table 3-4(b).

In conclusion, the comparison of two behavior models shows that the modified FAM expresses more realistic characteristics of ridership distribution. For the gravity model, these kinds of trend are not so distinct. The invariance of the number of boarding passengers at each station along the whole transit line may reflect the requirement for a uniform city with the well-balanced and mixed-use practices of land development.

3.5 PROPOSED TRIP DISTRIBUTION MODEL FOR MASS TRANSIT RIDERSHIP ANALYSIS

Comparing the results of ridership balancing by employing the gravity model and the modified FAM, it can be concluded that the solution to the system of non-linear equations based on the modified FAM bears a stronger resemblance to the one achieved based on the gravity model. The supporting reasons are briefly described as follows:

(1) The sensitivity of degree of deterrence, λ, for the modified FAM is less variant than the gravity. The boarding passenger distribution is not much altered by the variation in the value of λ, making the approach more reliable when put into practice.

(2) The modified FAM can describe the nature of 'catchment area' around both terminal stations where the numbers of passengers are generally higher than the numbers of passengers boarding at the in-between stations.

(3) The modified FAM has the higher average differences between the number of boarding and alighting passengers than the gravity model in all cases with respect to the numbers of stations. It can expose the mass transit passengers' behavior during peak hours when the rail line is almost always crowded only in one direction and largely unoccupied in the other.

(4) The functional form of the modified FAM is the additive form of fixed and linearly variable terms. It can explain the mass transit passenger behavior and the fact that the passengers boarding the train at any stations abide by some fixed costs and additional costs.

(5) The modified FAM can illustrate the mixed-use development along the mass transit concept: the high boarding demand of outer bound at both ends from the residential areas, the central part of the line locating in the CBD to generate high alighting demand for work and study purposes and the lower boarding and alighting demands in the in-between parts due to the mixed-use development.

(6) The probability of alighting from the train based on the modified FAM and the additive functional form of fixed and variable terms, is more gently decreased. It can reflect the realistic behavior of trip distribution.

Theoretically, one of the optimal solutions to the balance of transit ridership can be depicted in Figure 3-12.

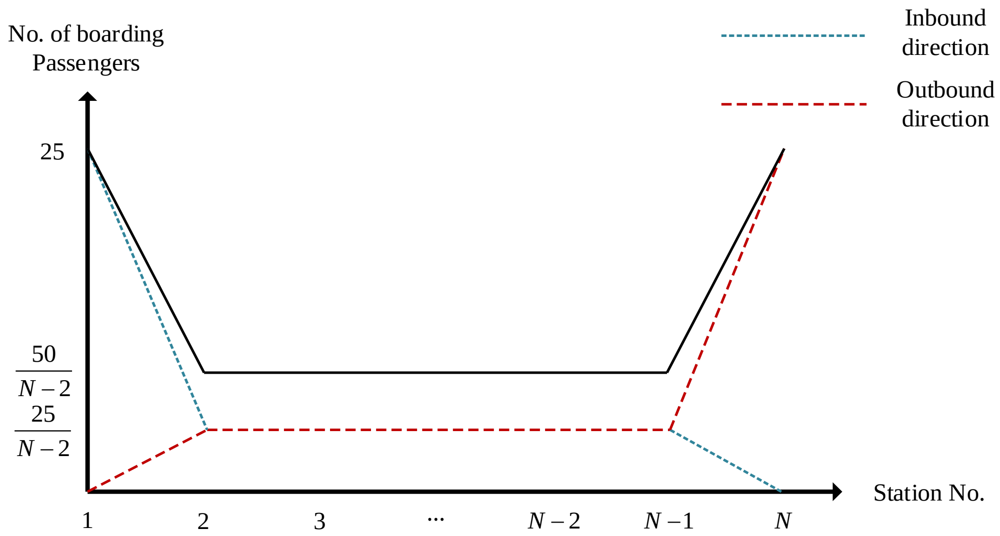


Figure 3-12 The optimal solution of balancing transit ridership along a single stand-alone transit line (Unit: percentage).

The total number of passengers within the catchment area of the mass train line is assumed to be 100. Figure 3-12 illustrates the symmetric pattern in which 25% of the passengers are boarding at each terminal station. If the train capacity can manually be adjusted, it can be set to match these 25% of passengers to minimize the unoccupied capacity of the train.

Then, to keep the maximum utilization of the train capacity, the number of passengers leaving the train at any stations must match the number of passengers boarding it.

Assuming that the possibility of alighting from the train is equally dispersed among all in-between stations, the number of boarding passengers at each in-between station is $25/(N-2)$. The train will be fully packed with passengers until the last stop, where all passengers are alighting. The same pattern is applied to the opposite direction.

However, it is extremely challenging or even infeasible to achieve this pattern of O-D distribution in actual circumstances. To shape the number of rail passengers, the concept of TOD can be implemented. The adjustment of trip generation and trip attraction rates through different types of land use is also another effective measure as several agencies have developed trip generation manuals for estimating the numbers of trips generated by specific types of land use (Manual, 2003; PTOE, 2017). There is, nevertheless, no PANACEA — a hypothetical remedy for all difficulties, given that there are far too numerous factors that influence transit demand.

The acknowledgement from the ideal case is the shape or pattern of distribution of boarding passengers along the transit line. The modified FAM is also proposed in the practical application to balance a mass transit ridership through land use development in the next chapter.

Chapter 4

BALANCING MASS TRANSIT RIDERSHIP THROUGH LAND USE DEVELOPMENT

As stated earlier in the previous chapter, the spatial factors are among the factors that affect transit ridership. They can generate, attract and shape ridership patterns based on related activities. Moreover, spatial factors regarding land use and urban development would be the most sustainable solution to the balance of ridership with the application of the TOD principle.

The modified FAM will be utilized for a land use allocation problem to determine which proportion of each type of land use should be allocated around mass transit stations along the route. The application of this model and its achievements are intended as a guideline for the sustainable development of land use and mass transit development.

In this chapter, the modified FAM, which has already been proven that the model's functional form can estimate the mass transit ridership precisely, will be adapted to deal with land use consideration. The land use characteristics will be incorporated into the modified FAM. The ridership balancing scheme through land use development will also be conducted. Subsequently, the sensitivity analysis of the generated and attracted trip rates of each type of land use is analyzed to demonstrate the robustness of simulation results.

4.1 ASSUMPTION OF THE MODIFIED FAM WITH LAND USE CONSIDERATION.

To reflect the characteristics of spatial factors, the modified FAM must be developed to cope with a land use allocation problem in order to determine which proportion of each type of land use should be allocated around mass transit stations along the route. It can thus prompt the least variance in the number of onboard passengers to enhance the efficiency of the overall system through the more balanced ridership.

The main assumptions of ridership balancing are still assumed to be the same. However, the supplementary assumptions of balancing ridership through land use development by employing the modified FAM will be described for more completion. They are as follows:

(1) The objective of the modified FAM with land use development is to determine the pattern of land use allocation that leads to the balance of mass transit ridership along the whole route for both inbound and outbound trips.

(2) The area of each type of land use surrounding each station is the only endogenous variable, which is the decision variable for this optimization problem. The optimization problem is considered the land use allocation in aspects of both transit corridor level and transit station level.

(3) Types of land use in the studied area are divided into 3 types: business, retail, and residence. However, the public areas (street, railway) and abandoned areas are excluded in this study as they play no part in determining the accurate total coverage area that can generate and attract travel demand.

(4) Each type of land use generates and attracts constant trips during a specific period of time. Therefore, the generation and attraction rates vary depending upon the area of each type available in the system.

4.2 FORMULATATION OF THE MODIFIED FAM TO DEAL WITH LAND USE CONSIDERATION

The objective function and equations related to the original modified FAM are also the same as formulated earlier.

The next sequence is to apply the modified FAM in order to deal with land use consideration, the additional variables regarding types of land use and their properties are described as follows:

K is the number of types of land use within the studied area (unit: type).

$\bar{A}_k$ is the total area of land use type k, $k = 1, 2, ..., K$ (unit: square meter).

$\bar{A}$ is the total coverage area of the whole transit route (unit: square meter).

α is the rate of trip generation for the type of land use (unit: percentage of total passengers/square meter).

β is the rate of trip attraction for the type of land use (unit: percentage of total passengers/square meter).

Each type of land use has different properties regarding the trip generation rate and trip attraction rate. To simplify the interpretation of the results, the rates of trip generation and trip attraction for each type of land use are defined as the ‘percentage’ of the total numbers of passengers currently using this transit system generated and attracted by a unit area of each type of land use.

The additional constraints are also formulated as follows:

The underlying mechanism is that the number of trips generated and attracted by all types of land use around a particular station can be expressed as a function of A_{ik}, as shown in Equations (4-1) and (4-2) respectively.

$$P_i = \sum_k \alpha_k A_{ik} \tag{4-1}$$

$$Q_i = \sum_k \beta_k A_{ik} \tag{4-2}$$

For a specific period of time, such as during the morning or evening peak hours, the conservation rule of the total number (100 percent) of passengers within the whole coverage area of the transit route is shown in Equations (4-3).

$$\sum_k \alpha_k \bar{A}_k = \sum_k \beta_k \bar{A}_k = 100 \tag{4-3}$$

Another constraint described by Equation (4-4) specifies that the allocation of a specific type of land use over all stations must be limited to the target of the total area of that type. This constraint is prevailing in the real practice of land use development, since developers should have the aimed target of the total area in their strategic plan corresponding to the activity types and purposes of the development of land within their jurisdictions.

$$\sum_i A_{ik} = \bar{A}_k \tag{4-4}$$

The total coverage area constraint is shown in Equation (4-5). By adding up the area of every type of land use together, the result must equal to the total coverage area of the whole transit route.

$$\sum_k \bar{A}_k = \bar{A} \tag{4-5}$$

For a single linear transit line, the total coverage area can approximately be determined by multiplying the number of stations, N, with the square of the walkable distance to the station, r, or N_{r^2}. However, this research may need to exclude the public areas (street, railway) and abandoned areas as they play no part in determining the accurate total coverage area that can generate and attract travel demand as referred in the assumption. Those areas will thus be excluded from N_{r^2}.

Therefore, the only endogenous variable in the model is defined as the area of land use type k within the catchment area surrounding the station i, A_{ik}, (unit: square meter).

The system of non-linear equations defined by the objective Equation (3-4) and all constraints in Equations (3-6) to (3-11) from the previous chapter, together with constraints in Equations (4-1) to (4-5), completes the mathematic optimization problem to solve the optimal area of each type of land use surrounding the station i, A_{ik}, under a given set of exogenous variables. The balancing scheme through land use development will be exhibited afterward.

4.3 RIDERSHIP BALANCING SCHEME THROUGH LAND USE DEVELOPMENT

The model formulation shows that the only endogenous variable for the optimization problem through land use development is the area of each type of land use surrounding the station i. Consequently, the values of exogenous variables in the model are specified as follows.

Firstly, the total numbers of stations in the whole transit route, N, is classified into five cases — 6, 9, 12, 15 and 18 stations.

Then, the distance between adjoining stations that are assumed to be distributed evenly, D, is set to be 1 kilometer and the degree of exponent, λ, is set to be 2, as the same reasons described in ridership balancing scheme for two behavioral models.

The types of land use in the studied area, K, are divided into 3 types — $k=1$ for business type, $k=2$ for retail use, and $k=3$ for residential purposes. Here, the total area is set to be 100 percent and equally apportioned among three types of land use. This setting is convenient when the results are converted into practical use.

Most trips in the morning hours are attracted to the business area due to working purposes, whereas other trips are generated from the residential areas. The trips generated from and attracted to retail activities are assumed to be at an equal rate. Even though this apportionment refers to the trip rates for the morning hours, these trip rates can also be applied to the evening peak hours by reversing the numbers of boarding and alighting passengers.

It can then calculate the rate of trip generation and the rate of trip attraction from the percentage of generated and attracted trips, as shown in Table 4-1, under the assumption that each type of land use generates and attracts constant trips during a specific period of time. Therefore, the values of α_k and β_k vary depending upon the area of each type of land use available in the system.

Table 4-1 The number of generated and attracted trips of each type of land use in the morning peak hours. (Unit: percentage of the total number of passengers/square meter).

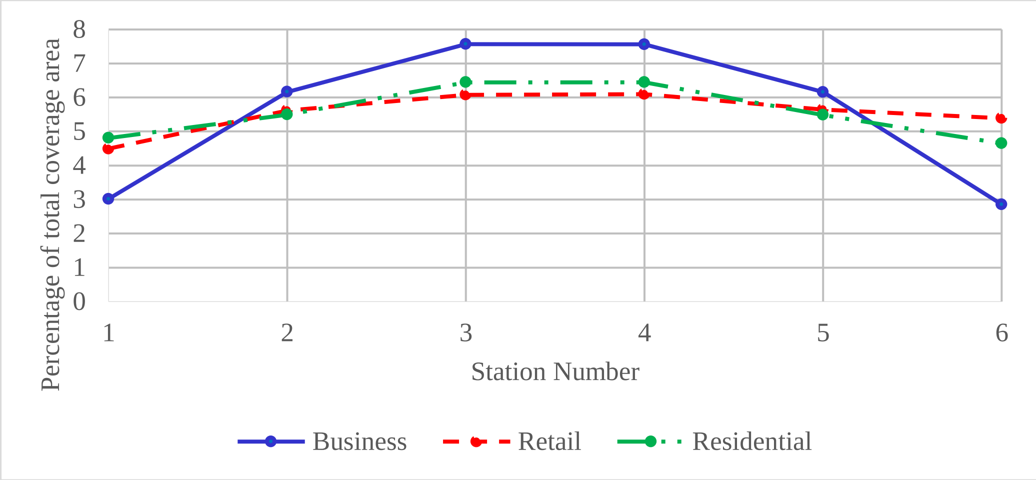
	Business	Retail	Residence
The number of generated trips (α_k)	5	15	80
The number of attracted trips (β_k)	80	15	5

As the total coverage area is a constant in this model, the results of the optimization problem can be shown as the percentage of the total coverage area for the simplicity of interpreting them.

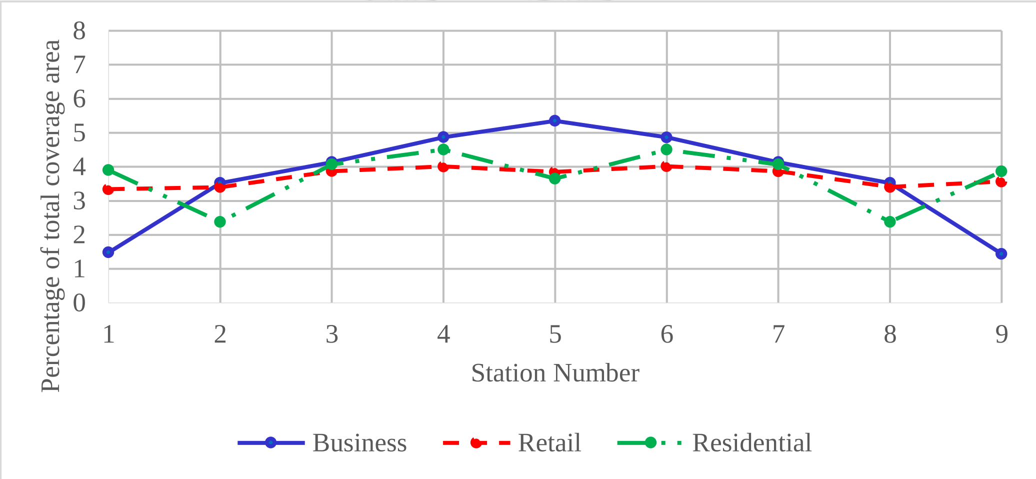
The results of an optimal land use allocation for the balanced ridership with the modified FAM model are shown in Figure 4-1 (a)-(e) and Figure 4-2, expressing the land use allocation tendency. Table 4-2 shows the proportion of each type of land use around each transit station.

When the number of stations is still low in the case of 6 stations, land uses around the terminal station are sparse and almost equally divided between residential and retail purposes. At the same time, the area around the central stations is densely packed with not only the business land but also the residential and retail land, as shown in Figure 4-1(a) and Figure 4-2. The underlying reason is the shape of boarding passenger distribution, which is a concave curve only in the case of 6 stations.

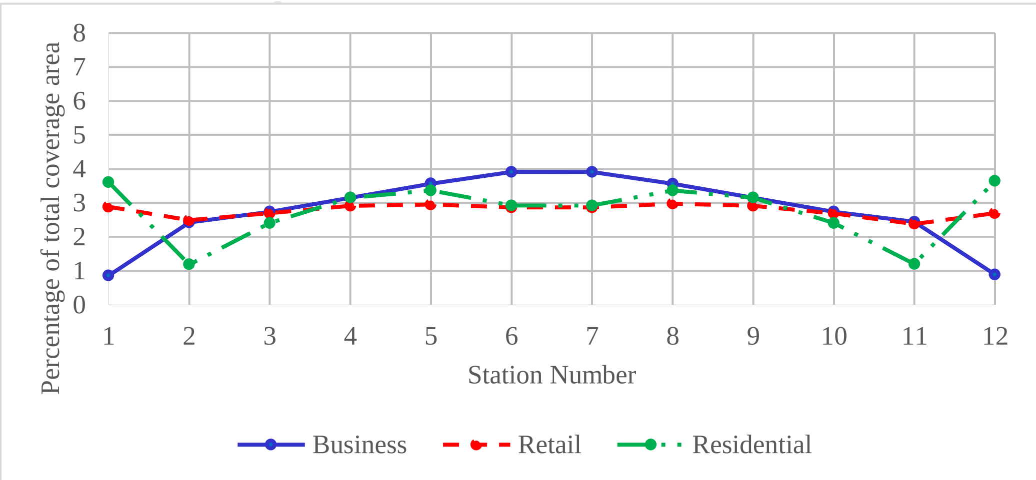
Therefore, high trip generation rates are required in the middle of the transit line and a large portion of residential and retail areas are accumulated there.


Percentage of total coverage area
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
Station Number
Business
Retail
Residential

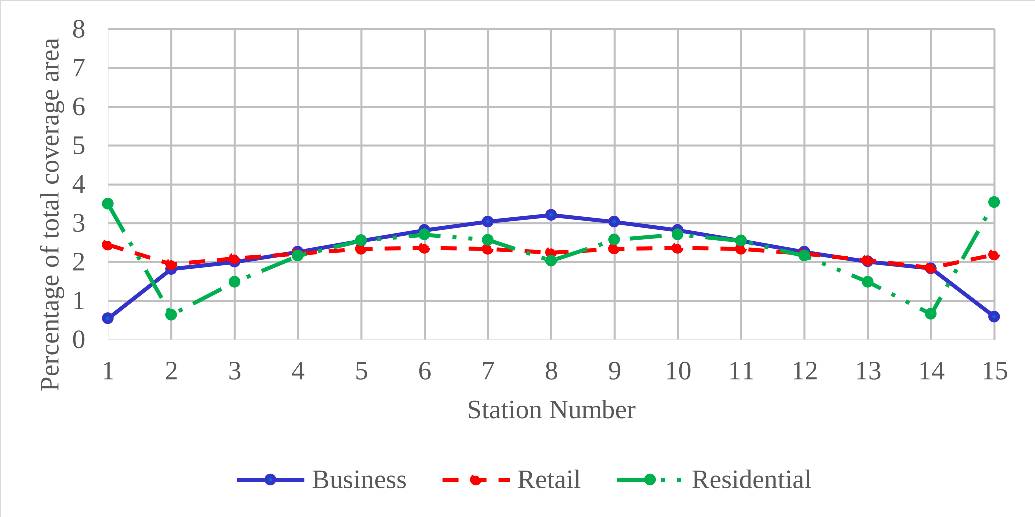
(a)


Percentage of total coverage area
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
Station Number
Business
Retail
Residential

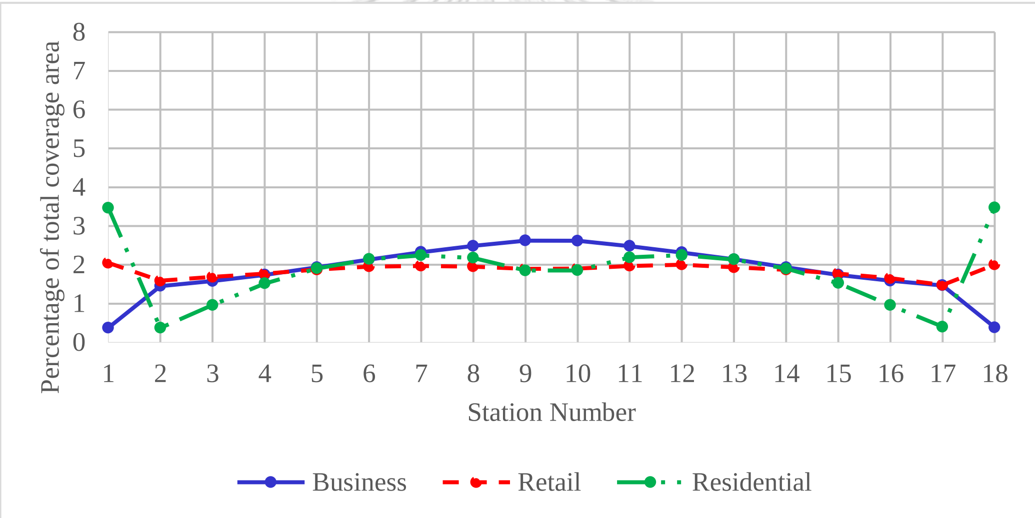
(b)


Percentage of total coverage area
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Station Number
Business
Retail
Residential

(c)



(d)



(e)

Figure 4-1 Allocation of each type of land use to balance O-D ridership with the modified FAM: (a) 6 stations, (b) 9 stations, (c) 12 stations, (d) 15 stations and (e) 18 stations (Unit: percentage of total coverage area).

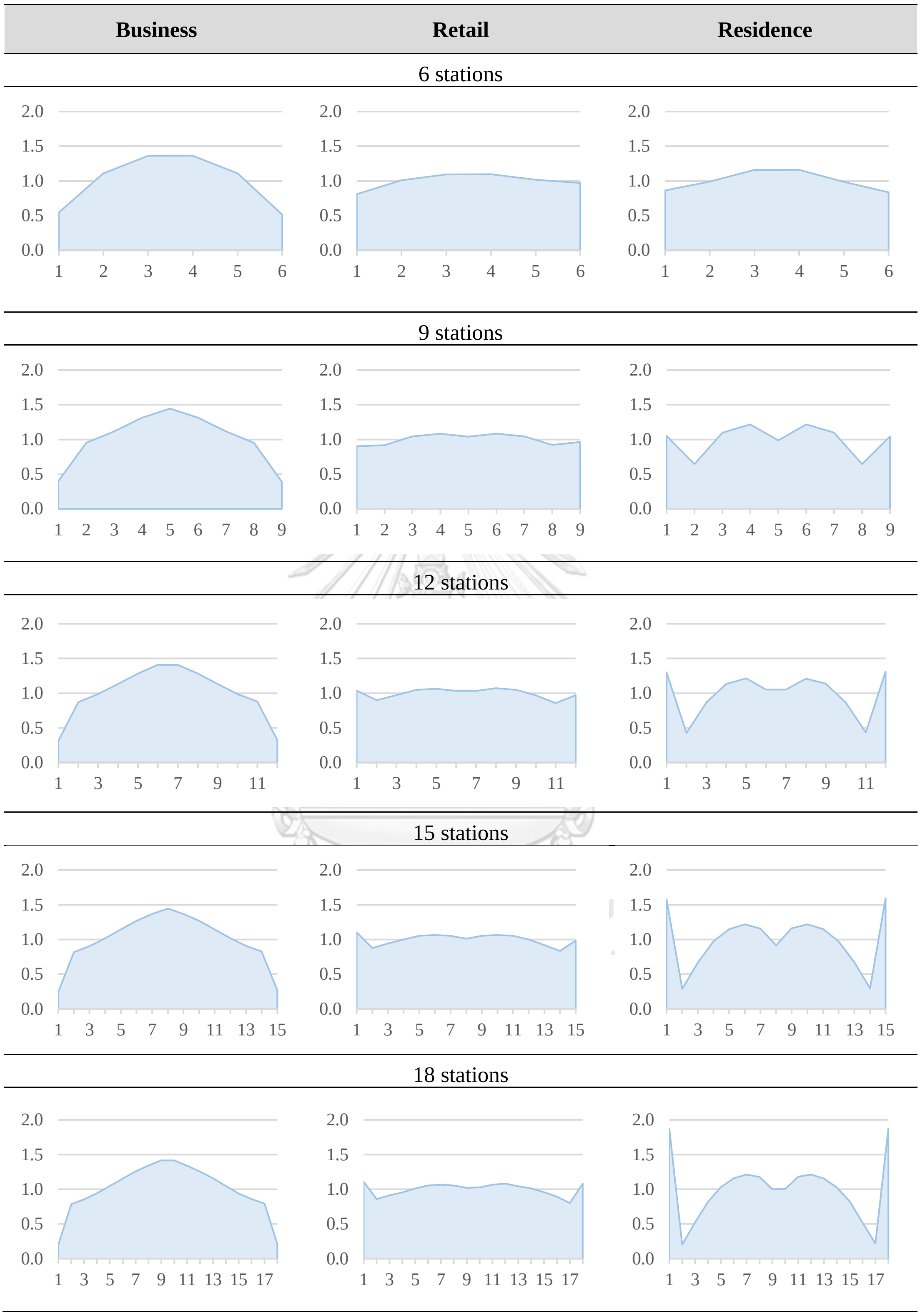


Figure 4-2 The optimal land use allocation for the balanced ridership with a modified FAM model (Unit: percentage of total coverage area).

Table 4-2 The optimal land use allocation for the balanced ridership with a modified FAM model (Unit: percentage of total coverage area).

Station No.	6 stations			Total	9 stations			Total	12 stations			Total	15 stations			Total	18 stations			Total
	BUS	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.	
ST01	3.02	4.50	4.81	12.32	1.48	3.34	3.90	8.73	0.86	2.88	3.61	7.35	0.54	2.45	3.50	6.49	0.38	2.05	3.47	5.90
ST02	6.16	5.62	5.50	17.28	3.53	3.40	2.38	9.31	2.42	2.49	1.19	6.10	1.82	1.94	0.64	4.40	1.45	1.59	0.37	3.41
ST03	7.57	6.08	6.44	20.09	4.14	3.87	4.07	12.08	2.74	2.69	2.41	7.84	2.00	2.09	1.48	5.58	1.58	1.69	0.96	4.22
ST04	7.56	6.10	6.45	20.11	4.87	4.01	4.51	13.39	3.15	2.91	3.15	9.21	2.26	2.22	2.16	6.64	1.74	1.77	1.52	5.03
ST05	6.16	5.65	5.49	17.30	5.35	3.85	3.65	12.85	3.56	2.95	3.37	9.88	2.54	2.34	2.56	7.44	1.93	1.88	1.91	5.72
ST06	2.86	5.40	4.65	12.90	4.87	4.02	4.51	13.39	3.91	2.87	2.92	9.70	2.82	2.36	2.71	7.89	2.14	1.95	2.14	6.23
ST07					4.14	3.87	4.07	12.07	3.91	2.87	2.92	9.70	3.04	2.34	2.57	7.95	2.33	1.97	2.25	6.54
ST08					3.52	3.41	2.38	9.31	3.56	2.98	3.36	9.90	3.21	2.25	2.03	7.49	2.49	1.95	2.18	6.62
ST09					1.44	3.57	3.86	8.87	3.15	2.91	3.15	9.22	3.04	2.34	2.58	7.95	2.62	1.89	1.85	6.36
ST10									2.74	2.69	2.40	7.84	2.82	2.36	2.71	7.89	2.62	1.90	1.86	6.38
ST11									2.44	2.38	1.20	6.03	2.54	2.34	2.55	7.43	2.48	1.97	2.19	6.64
ST12									0.89	2.70	3.64	7.23	2.26	2.22	2.16	6.64	2.32	2.00	2.25	6.57
ST13													2.01	2.04	1.49	5.55	2.14	1.93	2.14	6.21
ST14													1.83	1.85	0.66	4.35	1.94	1.87	1.90	5.71
ST15													0.59	2.19	3.54	6.32	1.74	1.77	1.53	5.04
ST16																	1.59	1.65	0.96	4.20
ST17																	1.47	1.48	0.40	3.35
ST18																	0.38	2.00	3.47	5.86
Total	33.33	33.33	33.33		33.33	33.33	33.33		33.33	33.33	33.33		33.33	33.33	33.33		33.33	33.33	33.33	

Note: BUS. - Business Type, RET. – Retail Type, RES.- Residence Type.

Table 4-3 The number of passengers boarding to the station generated from each type of land use (Unit: percentage).

Station No.	6 stations			Total	9 stations			Total	12 stations			Total	15 stations			Total	18 stations			Total
	BUS	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.		BUS.	RET.	RES.	
ST01	0.45	2.02	11.54	14.01	0.22	1.50	9.37	11.09	0.13	1.30	8.66	10.09	0.08	1.10	8.39	9.57	0.06	0.92	8.33	9.31
ST02	0.92	2.53	13.19	16.64	0.53	1.53	5.72	7.78	0.37	1.12	2.85	4.34	0.27	0.87	1.54	2.68	0.22	0.71	0.89	1.82
ST03	1.14	2.74	15.47	19.35	0.62	1.74	9.77	12.13	0.41	1.21	5.77	7.39	0.30	0.94	3.56	4.80	0.24	0.76	2.30	3.30
ST04	1.13	2.74	15.47	19.34	0.73	1.81	10.81	13.35	0.47	1.31	7.56	9.34	0.34	1.00	5.19	6.53	0.26	0.80	3.65	4.71
ST05	0.92	2.54	13.17	16.63	0.80	1.73	8.76	11.29	0.53	1.33	8.08	9.94	0.38	1.05	6.14	7.57	0.29	0.84	4.58	5.71
ST06	0.44	2.43	11.16	14.03	0.73	1.81	10.81	13.35	0.59	1.29	7.02	8.90	0.42	1.06	6.49	7.97	0.32	0.88	5.15	6.35
ST07					0.62	1.74	9.77	12.13	0.59	1.29	7.02	8.90	0.46	1.05	6.16	7.67	0.35	0.89	5.39	6.63
ST08					0.53	1.53	5.72	7.78	0.53	1.34	8.07	9.94	0.48	1.01	4.88	6.37	0.37	0.88	5.23	6.48
ST09					0.22	1.61	9.27	11.10	0.47	1.31	7.57	9.35	0.46	1.05	6.18	7.69	0.39	0.85	4.44	5.68
ST10									0.41	1.21	5.77	7.39	0.42	1.06	6.50	7.98	0.39	0.86	4.46	5.71
ST11									0.37	1.08	2.88	4.33	0.38	1.05	6.12	7.55	0.37	0.89	5.25	6.51
ST12									0.13	1.21	8.75	10.09	0.34	1.00	5.19	6.53	0.35	0.90	5.39	6.64
ST13													0.30	0.92	3.58	4.80	0.32	0.87	5.13	6.32
ST14													0.28	0.83	1.58	2.69	0.29	0.84	4.56	5.69
ST15													0.09	1.01	8.50	9.60	0.26	0.80	3.66	4.72
ST16																	0.24	0.74	2.29	3.27
ST17																	0.22	0.67	0.96	1.85
ST18																	0.06	0.90	8.34	9.30
Total	5.00	15.00	80.00	100.00	5.00	15.00	80.00	100.00	5.00	15.00	80.00	100.00	5.00	15.00	80.00	100.00	5.00	15.00	80.00	100.00

Note: BUS. - Business Type, RET. – Retail Type, RES.- Residence Type.

The optimal land use allocation for the balanced ridership with a modified FAM model will thus be described in each aspect step by step.

The allocation of each type of land use along the transit corridor for the numbers of stations of 5 cases, as shown in Figure 4-1(a)–(e) and Figure 4-2, reveals that when the number of stations is growing, the patterns of land use distribution have a tendency to look similar.

The residential areas are accumulated at both ends and the center of the transit line. The retail area is consistently spreading along the whole line, whereas business area is intensely concentrated in the CBD of the city. All of these three are shown in Figure 4-1(b)-(e).

These patterns represent the concept of the newly developed 'compact city with a single CBD', where the residential areas are located on the outskirts of the city, whereas a number of business enterprises, head offices and educational institutes are within the central area.

Finally, when the number of stations is large enough as it represents a big city, the city will contain two layers of residential zone. The outer residential zone is located at both ends of the transit line, whereas the inner zone is located closer to the CBD than the terminal stations, as indicated in Figure 4-1(e) by the stations No. 6-8 and No. 11-13. This inner residential zone is functioning like a satellite city where not only residential buildings but also large-scaled shopping centers, educational institutes and industrial parks are also located here as part of a mixed-use urban development.

The numbers of passengers boarding the train at the stations generated from each type of land use are shown in Table 4-3. The optimization problem with land use consideration gives exactly the same result of the numbers of boarding passengers at the stations from the original modified FAM, as shown in Table 3-4(b).

Furthermore, the optimal numbers of boarding passengers in the original modified FAM and those derived from the modified FAM with the land use allocation problem are compared for the case of 6, 9, 12, 15 and 18 stations, as shown in Table 4-4.

Table 4-4 Comparison of ridership balancing results (Unit: percentage).

Station No.	The percentage of boarding passengers									
	6 stations		9 stations		12 stations		15 stations		18 stations	
	A*	B**	A*	B**	A*	B**	A*	B**	A*	B**
1	14.01	14.01	11.09	11.09	10.09	10.09	9.57	9.57	9.31	9.31
2	16.64	16.64	7.78	7.78	4.33	4.34	2.68	2.68	1.82	1.82
3	19.35	19.35	12.13	12.13	7.40	7.39	4.80	4.80	3.30	3.30
4	19.34	19.34	13.35	13.35	9.34	9.34	6.53	6.53	4.71	4.71
5	16.63	16.63	11.29	11.29	9.96	9.94	7.57	7.57	5.71	5.71
6	14.03	14.03	13.35	13.35	8.88	8.90	7.97	7.97	6.35	6.35
7			12.13	12.13	8.89	8.90	7.67	7.67	6.63	6.63
8			7.78	7.78	9.95	9.94	6.37	6.37	6.48	6.48
9			11.10	11.10	9.35	9.35	7.69	7.69	5.68	5.68
10					7.40	7.39	7.98	7.98	5.71	5.71
11					4.33	4.33	7.55	7.55	6.51	6.51
12					10.09	10.09	6.53	6.53	6.64	6.64
13							4.80	4.80	6.32	6.32
14							2.69	2.69	5.69	5.69
15							9.60	9.60	4.72	4.72
16									3.27	3.27
17									1.85	1.85
18									9.30	9.30
Variance	10.36	10.36	11.01	11.01	10.55	10.55	10.29	10.29	10.03	10.03

Note: A* - The original modified FAM,

B** - The modified FAM with land use consideration.

4.4 THE SENSITIVITY ANALYSIS OF GENERATED/ATTRACTED TRIPS OF EACH TYPE OF LAND USE TYPE

For optimization problem in ridership balancing with land use consideration, the exogenous variables play a crucial role here. Especially, the total area of each type of land use represents the upper bound of the endogenous variable – the allocated area of each type of land use around each station.

Table 4-5 The sensitivity cases under alternative assumptions of the trip generation and attraction (Unit: percentage of total passenger/square meter).

Case		Business	Retail	Residence
base case	The number of generated trips (α_k)	5	15	80
	The number of attracted trips (β_k)	80	15	5
sensitivity analysis case A	The number of generated trips (α_k)	5	25	70
	The number of attracted trips (β_k)	70	25	5
sensitivity analysis case B	The number of generated trips (α_k)	15	15	70
	The number of attracted trips (β_k)	70	15	15
sensitivity analysis case C	The number of generated trips (α_k)	15	5	80
	The number of attracted trips (β_k)	80	5	15

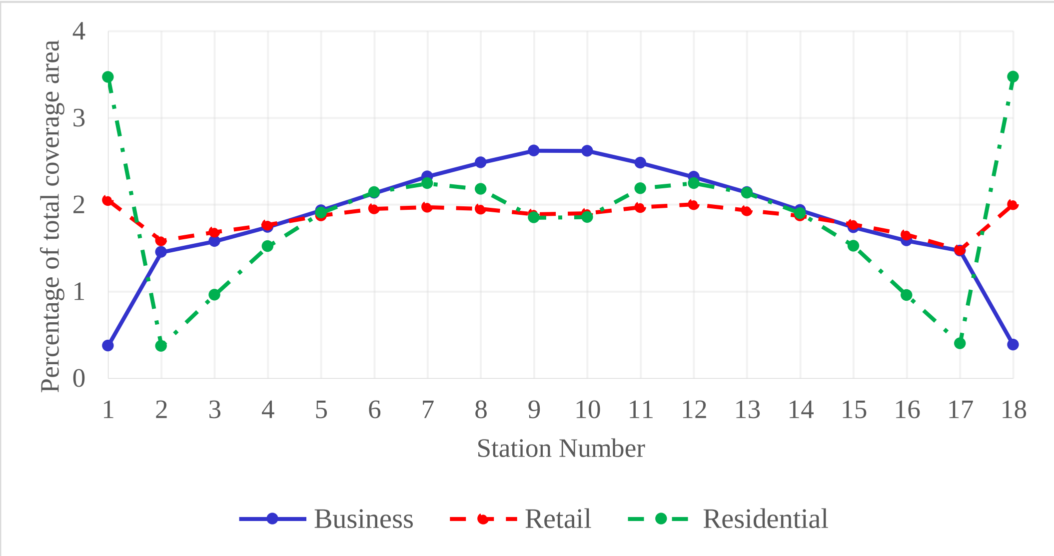
Therefore, the sensitivity analysis of the generated and attracted trip rates, α_k and β_k of each type of land use are necessary to test the robustness of simulation results.

The sensitivity cases under the alternative assumptions of the trip generation and trip attraction are specified in Table 4-5. The base case is the former assumption, which has already been applied to the optimization problem and 3 more sensitivity cases are set up under the assumption of the morning-hour trips. However, changing the trip rate of one variable will affect another variable, according to the conservation rule of the total numbers of passengers.

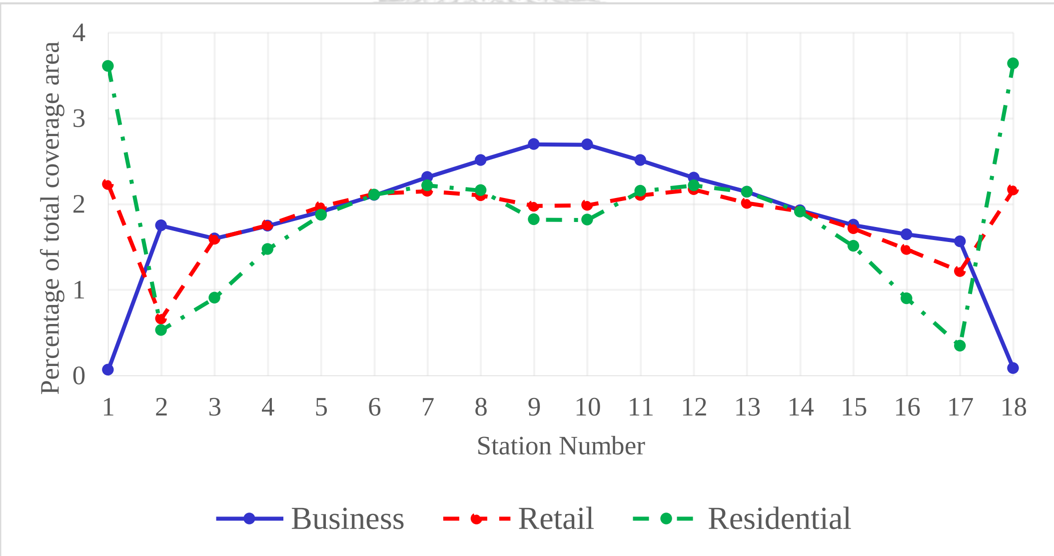
For the sensitivity analysis case A, the business area has more attracted trips and the same generation rate. The residential area has fewer generated trips and the same attraction rate, whereas the retail area has generated and attracted more trips, compared to the base case.

For the sensitivity analysis case B, the business area has more generated trips and fewer attracted trips. The residential area has more attracted trips and fewer generated trips, whereas the retail area has the same generation and attraction rates, compared to the base case.

For the sensitivity analysis case C, the business area has more generated trips and the same attraction rate. The residential area has more attracted trips and the same generation rate, whereas the retail area has fewer generation and attraction rates, compared to the base case.

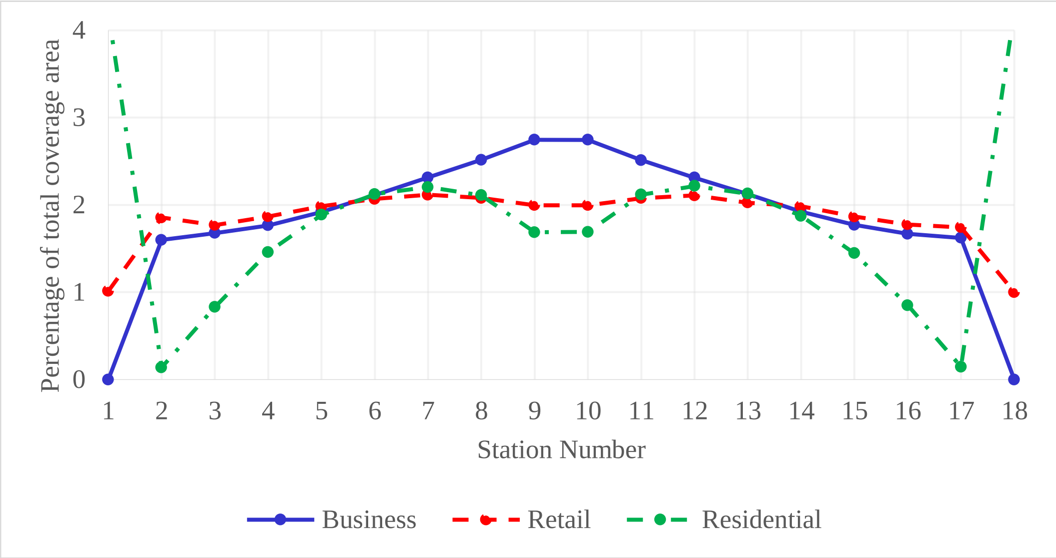


(a)

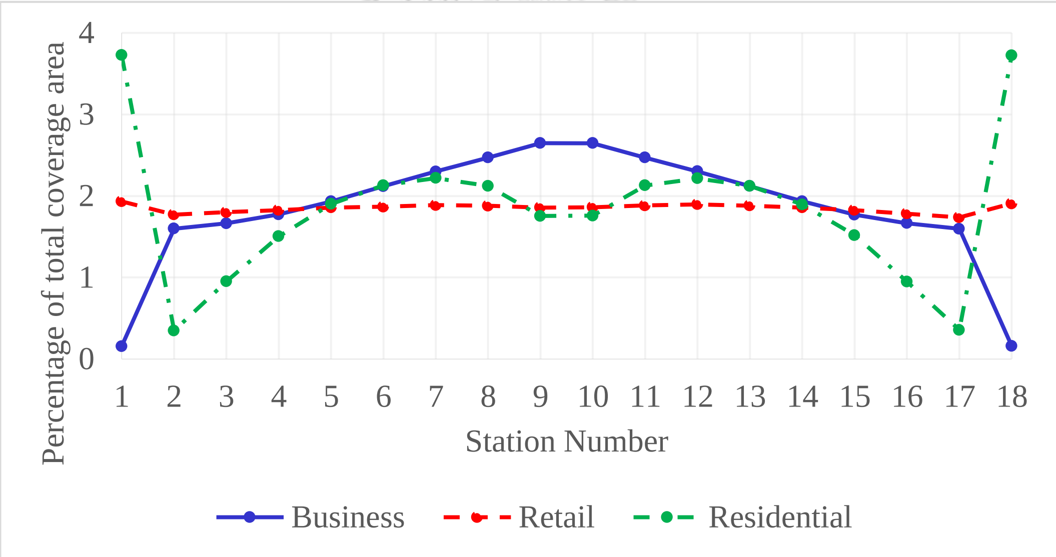


(b)

Figure 4-3 Allocation of each type of land use to balance O-D ridership for the sensitivity analysis: (a) base case, (b) case A, (c) case B, (d) case C (Unit: percentage of total coverage area).



(c)



(d)

Figure 4-3(continued) Allocation of each type of land use to balance O-D ridership for the sensitivity analysis: (a) base case, (b) case A, (c) case B, (d) case C (Unit: percentage of total coverage area).

The total number of stations applied in the sensitivity analysis is 18 stations with the same assumption that the distance between adjoining stations is distributed evenly at 1 kilometer. The degree of exponent, λ, is set to be 2.

The total types of land use in the studied area are divided into types; — $k=1$ for business type, $k=2$ for retail type and $k=3$ for residential type. Again, the total area is set to be 100 percent and equally apportioned among three types of land use.

The results of land use allocation for the sensitivity analysis are shown in Figure 4-3(a) – (d). It can be observed that the overall land use allocation of residential and business areas are similar to the former patterns of the base case in which the residential areas at both ends and the center of the transit line as sub-residential areas are concentrated.

However, the retail type is much altered by the variation in the values of trip generation and trip distribution rates. For the sensitivity analysis case A, more trips are generated and attracted by the retail type when compared to the base case. Figure 4-3(b) shows the allocation of retail type along the transit corridor, which is more concentrated at both ends, together with the sub-retail areas at stations 5-7 and 11-13 with the almost equal proportion at both ends.

For the sensitivity analysis case B, more trips are attracted by the retail type, whereas the attraction rate remains the same when compared to the base case. Figure 4-3(c) shows that the retail area is dispersedly allocated all along the transit route except both ends where the proportion has dropped.

For the sensitivity analysis case C, however, fewer trips are generated and attracted by the retail type when compared to the base case. Figure 4-3(d) shows that the retail area is smoothly and dispersedly allocated all along the transit corridor, including at both ends of the transit corridor.

The sensitivity analysis results reveal that the retail type has the characteristics of trip generation and attraction with an equal rate being a great determinant on the balance of ridership. Furthermore, the retail type also generates and attracts trips throughout the day. It is thus the perfect property of land use to balance transit ridership.

However, as the retail type is much altered by the variation of trip generation and trip attraction rate, it would be carefully planned for the land use development.

In conclusion, the results from the optimization of balancing mass transit ridership through land use development can testify to the fact that a well-planned management of land use is key to successfully balancing mass transit ridership along the transit line. The modified FAM with land use consideration proposed in this chapter can be put into practice with the case study in Thailand, which is presented in the next chapter.

Chapter 5
THE CASE STUDY IN THAILAND

One of the objectives of this dissertation is to verify the model by actual land use and mass transit ridership data. After the trip distribution models for balancing mass transit system ridership are developed and the modified FAM is theorized in the previous chapters, in this chapter the optimization problem will be utilized in practical use with the application of the case study in Thailand.

The MRT Blue Line, a mass transit system in Bangkok, has been facing the problem of the imbalance of ridership both in inbound and outbound directions. The ridership can reach the maximum capacity just only in some sections of the rail line. At present, there are several planned and developed mixed-use projects aimed to tackle this issue. This chapter will demonstrate recommended guidelines for the improvement of the MRT Blue Line so as to maximize its efficiency in balancing ridership, which can be achieved by optimizing the land use allocation of the ongoing project located in the catchment area from the MRT stations.

5.1 THE GENERAL INFORMATION OF THE MRT BLUE LINE

5.1.1 Alignment of the MRT Blue Line

The Office of Transport and Traffic Policy and Planning (OTP), which is under the Ministry of Transport of Thailand, has developed the Mass Rapid Transit Master Plan for Bangkok Metropolitan (M-Map) to implement a mass rapid transit planned from 2010 to 2029.

The MRT Blue Line is one of 10 mass transit routes in the Bangkok Metropolitan Area railway master plan. The MRT Blue Line has been operated since July in 2004. Its extension for the second phase has been completed in 2020 under the Mass Rapid Transit Authority of Thailand (MRTA) regulations. The Bangkok Expressway and Metro Public Company Limited (BEM) is the concessionaires who provide service operations and maintenances.

However, this research only focuses on the first phase of the MRT Blue Line, which will be applied for the optimization solution. The MRT Blue Line initially consists of 18 subway stations. The network length is 20 kilometers long, as shown in Figure 5-1. The station names and their abbreviations are also shown in Figure 5-1.

The alignment of the MRT Blue Line passing through the urban core area of Bangkok starts at Hua Lamphong and runs along the Rama IV, Ratchadaphisek, Rama IX and Lat Phrao zones. The other end of the route is connected to the Bang Sue Railway Station, which is Bangkok's new principal rail hub of railway lines, including city lines and inter-city lines. There are 3 stations - Chatuchak Park Station, Sukhumvit Station, and Si Lom Station - that are rail interchanges connected to the BTS Green Line.

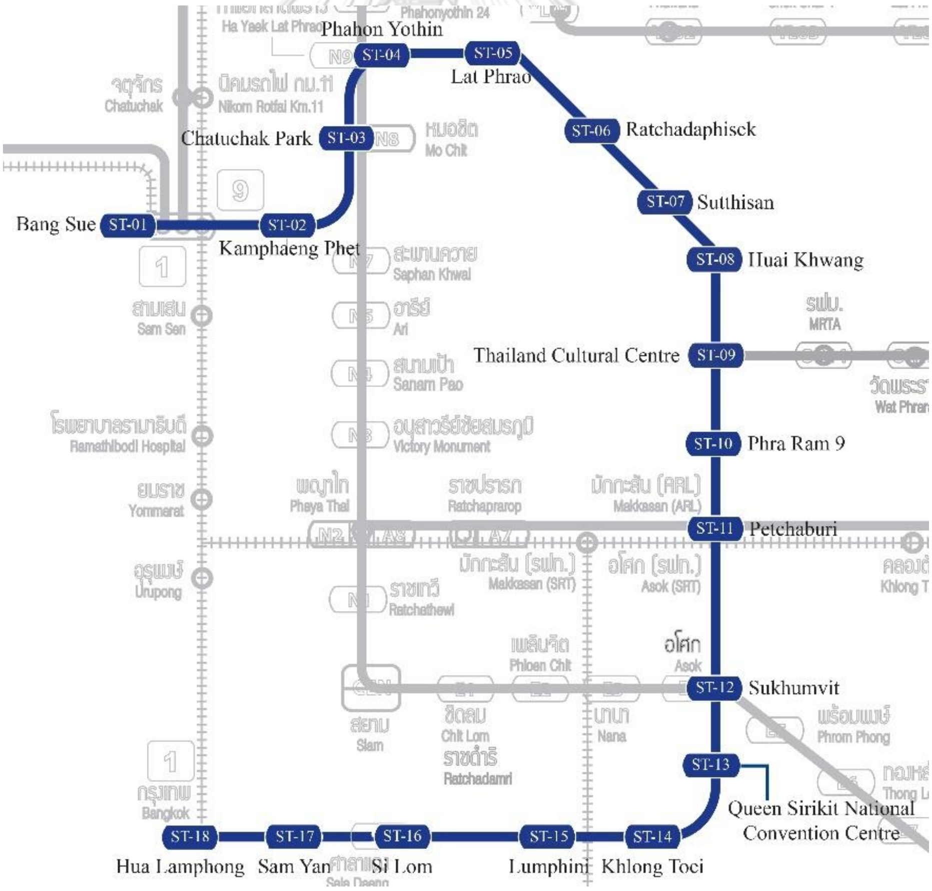


Figure 5-1 The MRT Blue Line Alignment (Source: modified from bemplc website).

Table 5-1 The MRT Blue Line station and abbreviation.

Station No.	Station Name	Abbreviation
1	Bang Sue	BAN
2	Kamphaeng Phet	KAM
3	Chatuchak Park	CHA
4	Phahon Yothin	PHA
5	Lat Phrao	LAT
6	Ratchadaphisek	RAT
7	Sutthisan	SUT
8	Huai Khwang	HUI
9	Thailand Cultural Centre	CUL
10	Phra Ram 9	RAM
11	Phetchaburi	PET
12	Sukhumvit	SUK
13	Queen Sirikit National Convention Centre	SIR
14	Khlong Toei	KHO
15	Lumphini	LUM
16	Si Lom	SIL
17	Sam Yan	SAM
18	Hua Lamphong	HUA

5.1.2 Ridership Characteristics of MRT Blue Line

The MRT Blue Line annual report 2015 provides the details of the number of onboard passengers for each quarter, together with the system capacity, according to the operation plan. The average number of passengers per hour loading in the train for weekdays, Saturdays, and Sundays and public holidays are shown in Figure 5-2(a), (b) and (c) respectively. The distribution of the average number of passengers per day between each pair of origin and destination for weekdays is also shown in Table 5-2.

The train headway is the interval of time between two consecutive trains in the same direction on the same operating route, whereas the passenger load performs the density of passengers per train space available. The capability of passenger load fluctuates upon the train headway, which is adjusted along the operating time. The lower headway means the more frequency of the train arrivals. As a result, the system can provide more volumes of passenger load during that hour.

According to the MRT Blue Line's concession agreement, the train operation requirement specifies that the system proficiency must be able to support the maximum passenger load at W4, meaning that the average number of onboard passengers (seating and standee) per space available is 8 passengers per square meter (W4 = 8 passengers/square meter).

For the weekday's operation, the system utilizes the actual passenger load at W3 (seating and standee = 6 passengers/square meter) for only 1 hour in a day (8 AM - 9 AM), whereas the utilization of other operating hours cannot be up to W2 (seating and standee = 4 passengers/square meter).

For the weekend and holiday's operation, as shown in Figure 5-2(b) and Figure 5-2(c), the train headway is adjusted to be consistent with the travel demand. However, the actual utilization of operating hours is hardly up to W2.

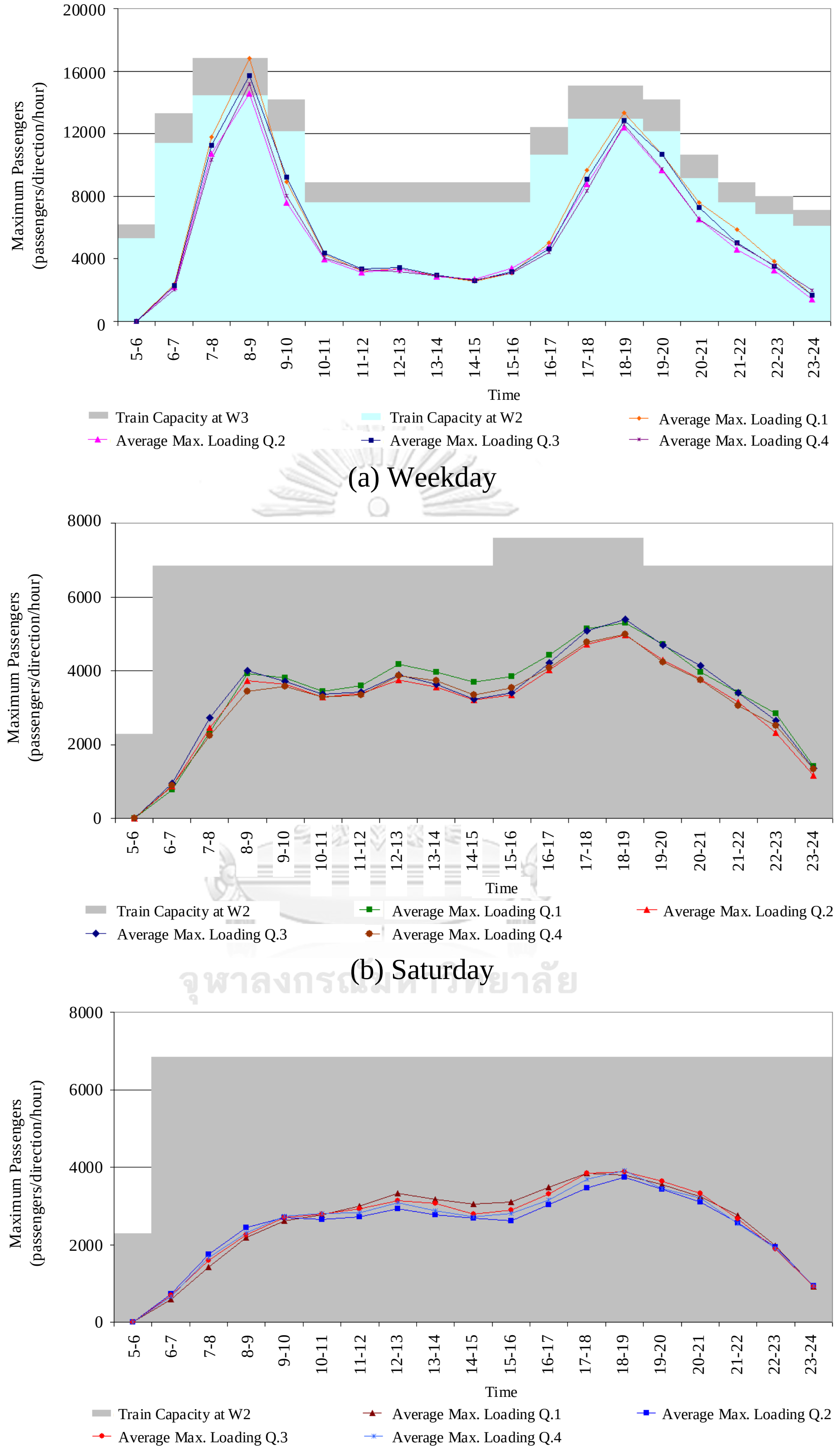
It can be observed that the number of onboard passengers is beyond the capacity of the system. The passengers of MRT Blue Line's characteristics regarding imbalanced ridership can be described as follows:

(1) The number of passengers is under the capacity of the system as the passenger load could be up to W4. In reality, the actual number of passengers can utilize only W2 or W3. It can be implied that vacant seats remain available on the train. In this aspect, adjusting the train headway will not be considered a solution, since it causes the loss of waiting time for passengers.

(2) The crowds of passengers occur only during morning peak and even peak hours. Even the passenger characteristics in peak-hour periods would be the general attributes of transportation demand. Yet, it can be shaped to be more balanced by the land use development. The off-peak periods can generate and attract more passengers, according to the mixed-use activities.

(3) From the observation, the rail line is overcrowded only in the inbound direction, whereas it is the opposite in the outbound direction during morning hours. The characteristics become reversed in the evening.

In conclusion, the ridership data can imply that the operating headway still has many unoccupied seats and standee spaces. Moreover, the number of onboard passengers does not reach the maximum passenger load specification. This shows the unutilized capability of the system, which is indicated as the imbalanced ridership in this study.



(c) Sunday and public holidays

Figure 5-2 The average hourly passenger loading in the train in Year 2015.

Table 5-2 The average daily passenger distribution between each pair of origin and destination for weekday in Year 2015. (Unit: passengers per day).

O/D	BAN	KAM	CHA	PHA	LAT	RAT	SUT	HUI	CUL	RAM	PET	SUK	SIR	KHO	LUM	SIL	SAM	HUA	Total
BAN	16	179	2,284	1,041	603	167	441	423	584	736	921	1,100	463	72	466	761	399	196	10,853
KAM	166	10	160	266	195	43	123	151	142	151	131	144	83	16	83	76	64	106	2,111
CHA	2,313	211	28	3,437	2,974	523	1,278	1,011	1,145	1,242	1,097	616	623	97	559	350	507	629	18,641
PHA	1,080	229	2,438	44	1,091	487	1,169	1,343	1,159	1,472	1,604	1,886	778	106	702	1,007	749	748	18,092
LAT	546	133	2,046	736	44	130	377	447	799	1,038	1,448	3,377	943	98	1,075	2,439	1,111	922	17,709
RAT	205	59	662	612	185	28	331	356	478	739	816	1,602	394	55	368	806	358	337	8,390
SUT	399	130	1,437	1,178	403	320	62	415	851	1,412	1,417	3,625	605	82	674	1,689	604	654	15,957
HUI	389	155	1,100	1,160	431	276	437	46	959	1,881	2,212	5,806	870	107	956	2,421	858	914	20,977
CUL	496	133	1,215	1,094	817	295	804	1,027	84	1,193	1,963	4,316	762	97	639	1,730	538	717	17,919
RAM	660	136	1,195	1,358	1,205	461	1,397	2,093	1,113	66	2,673	6,597	1,269	156	947	2,442	791	1,180	25,741
PET	757	149	1,042	1,719	1,324	442	1,281	1,812	2,071	3,253	40	3,942	1,250	173	1,394	2,209	1,039	1,248	25,144
SUK	869	152	560	1,957	3,247	991	3,132	5,150	4,213	6,890	3,362	78	1,970	323	2,155	1,510	1,508	2,348	40,417
SIR	422	96	606	874	980	226	573	822	826	1,411	1,162	2,099	19	29	365	1,104	463	824	12,903
KHO	71	20	107	113	106	37	93	118	114	197	189	347	27	4	78	302	142	286	2,351
LUM	331	86	512	715	893	162	499	703	607	1,051	1,065	2,262	336	70	41	1,602	493	786	12,213
SIL	688	91	347	1,276	2,530	505	1,538	2,197	1,778	2,804	1,767	1,600	1,116	303	1,637	45	1,439	1,959	23,618
SAM	390	67	505	889	1,161	210	541	789	561	945	880	1,542	465	145	525	1,500	27	788	11,930
HUA	202	112	571	783	988	231	658	863	751	1,248	1,105	2,435	814	290	944	2,028	798	21	14,843
Total	10,002	2,148	16,815	19,253	19,178	5,532	14,734	19,767	18,236	27,729	23,852	43,373	12,787	2,222	13,610	24,023	11,885	14,665	299,811

5.1.3 Land Use Surrounding the MRT Blue Line Corridor

Regarding the land use characteristics, this research obtains the land use data around the MRT Blue Line in 2015 collected by the Department of City Planning and Urban Development, the state agency under BMA regulations. The correctness of land use data is randomly checked by surveys and Google Street View.

The data sorted out the land use data within the 550-meter radius of the areas surrounding the MRT Blue Line stations as it represents the average walkable distance to access the nearest station. Also, it is the potential catchment area of the transit system. Nonetheless, only particular types of area that affect the trip generation and trip attraction of mass transit are examined. Therefore, the areas of roads, rivers, expressways and vacant spaces are not included in the calculation, as shown in Figure 5-3.

The verified land use data are then classified according to 3 patterns of trip generation and trip attraction as previously described. They also include the potential of creating actual activities of each building during each period of the day in terms of the Gross Floor Area (GFA), which can reflect the usability of the buildings. For instance, the ground floor of shop-houses is allocated for retail use, whereas the upper floors are for the residential use.

Figure 5-3 The categorization of land use surrounding MRT Blue Line.

The distribution of each type of land use around all stations of the MRT Blue Line is shown in Table 5-3. The abbreviations from ST-01 to ST-18 are used to denote the station names along the inbound direction from Bang Sue Station to Hua Lamphong Station correspondingly. Overall, 14.98% of the total catchment area is used for business purposes, 47.92% for retail areas, where people can both live and work there and 37.10% for residential purposes.

In conclusion, the total GFA within the catchment areas surrounding the 18 stations of the MRT Blue Line is approximately 5,000,000 square meters. The average daily ridership of the MRT Blue Line is approximately 290,000 passengers.

Table 5-3 The existing GFA around the MRT Blue Line (Unit: 1,000 square meter).

Station	Station Name	Business	Retail	Residence	Total
ST-01	Bang Sue	21.55	89.87	54.19	165.60
ST-02	Kamphaeng Phet	45.71	136.81	95.06	277.57
ST-03	Chatuchak Park	24.01	147.71	45.62	217.34
ST-04	Phahon Yothin	47.69	127.88	77.96	253.53
ST-05	Lat Phrao	22.73	97.21	153.41	273.34
ST-06	Ratchadaphisek	11.92	85.30	157.42	254.64
ST-07	Sutthisan	7.75	108.05	175.86	291.66
ST-08	Huai Khwang	10.92	151.12	194.19	356.23
ST-09	Thailand Cultural Center	10.87	181.92	73.52	266.32
ST-10	Phra Ram 9	2.79	182.85	145.14	330.79
ST-11	Phetchaburi	93.93	123.23	39.09	256.25
ST-12	Sukhumvit	12.29	265.63	108.72	386.63
ST-13	Queen Sirikit National Convention Center	45.53	135.38	97.81	278.72
ST-14	Khlong Toei	29.16	87.94	83.07	200.17
ST-15	Lumphini	39.76	93.39	63.01	196.17
ST-16	Si Lom	112.18	130.36	65.22	307.76
ST-17	Sam Yan	141.66	119.06	70.44	331.17
ST-18	Hua Lamphong	75.09	153.73	171.57	400.38
Total		755.52	2,417.44	1,871.28	5,044.25
Percentage		14.98	47.92	37.10	100.00

5.2 SUBJECTIVE CONCERNS ON THE IMBALANCE RIDERSHIP CHARACTERISTICS OF MRT BLUE LINE

One of the striking characteristics of the MRT Blue Line ridership is that a great number of passengers always crowd into only one direction whereas the other is less so. Passengers always face long queues in only one direction of the route before they board the train. Sometimes, densely packed crowds of passengers can only be seen in some particular sections of the route. The onboard ridership has reached the maximum capacity of the train only in some sections as previously described in the passenger data.

The imbalanced ridership problems are affected by many factors. However, the arrangement of land use, which is concerned with different activities caused by each type of land use, will be one of the possible solutions. The land use along the MRT Blue Line has been developed continuously in order that such management can help attract more passengers to use the system. However, the lack of planning in land use development is an important factor of the imbalance of ridership.

This section will investigate the characteristics of imbalanced ridership of the MRT Blue Line with the optimization problem by the modified FAM.

Firstly, the imbalance of ridership in the MRT Blue Line is empirically shown in Figure 5-4 by comparing it to the optimal solution derived from the modified FAM for 18 stations. The Mean Absolute Percentage Error (MAPE) indicating the percentage deviation of the number of boarding passengers at each station from the existing situation is used as the gauge of amendment. Figure 5-4 shows that MAPE of the optimal solution is 97.90%. It suggests that the whole population along the MRT Blue Line need to be reallocated in order to move toward the optimal balance of ridership.

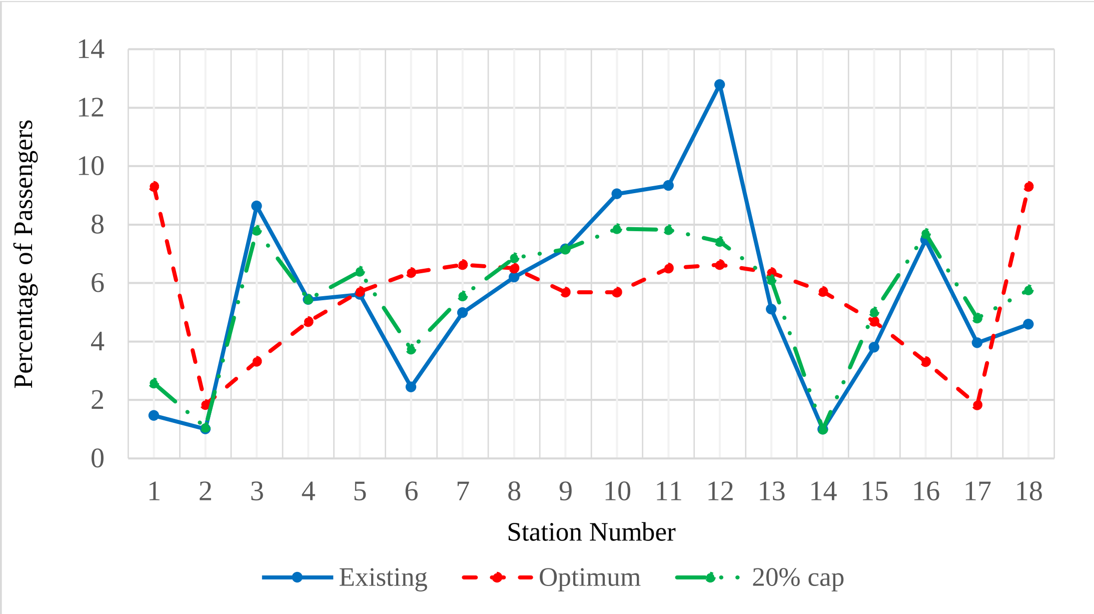


Figure 5-4 Distributions of the number of passengers boarding the train at each station for a case study of the MRT Blue Line (Unit: percentage).

However, if the limit on MAPE accounts for 20%, the results in Figure 5-4 will show that only few hot-spot stations (ST10 – ST13) require the immediate action plan. Table 5-4 also indicates that the case with 20-percent cap on MAPE can reduce the variation of onboard passengers between any adjoining stations for both the outbound and the inbound directions along the MRT Blue Line by as much as 43.6% of the optimal solution.

At this first step, the person in charge might need to apply the concept of TOD to shape the number of rail passengers. These results show how the modified FAM can improve the balance of ridership of the MRT system in the context of this primary experiment.

Table 5-4 Comparison of MAPE and variance of ridership for a case study of the MRT Blue Line in Thailand.

	Existing state	Optimal solution	20% cap on MAPE
MAPE	-	97.90	19.58
Var. of onboard passengers	17.39	10.03	14.18

5.3 THE LAND USE ALLOCATION OF HYPOTHETICAL SCENARIOS

To verify the applicability of the proposed model, the modified FAM is verified by the experiment on the MRT Blue Line as a case study of the MRT project in Thailand, according to the problem of imbalanced ridership. Therefore, this application will lead to a recommended guideline for the project development (real estate development, land sub-division and land consolidation) along the MRT route.

The total GFA along the MRT Blue Line corridor will be optimized for the proper allocation of each type of land use surrounding the stations along the corridor in order to make the ridership more balanced. In addition, the scenarios of mixed-use development are also defined to investigate the balance of ridership, according to the concentrated development of each type.

The scenarios are initiated by hypothetically categorizing the land use into three types, which are Business Oriented Development, Retail Oriented Development and Residence Oriented Development in accordance with the land use development tendency.

The land use proportion for each scenario are shown in Table 5-5. Each scenario is supposed to figure out the guideline for the development of some specific types of land use.

In this particular case study, the values of exogenous variables should be specified in accord with the characteristics of the MRT Blue Line to make them more practical. However, some of them are set to be the same, as shown previously. The details are summarized as follows.

Table 5-5 The defined oriented land use scheme (Unit: percentage).

Scenario	The percentage of each land use type			
	Business	Retail	Residence	Total
Base Case (existing of MRT Blue Line)	14.98	47.92	37.10	100
Business Oriented Development	25	40	35	100
Retail Oriented Development	10	55	35	100
Residence Oriented Development	10	40	50	100

The distance between the adjoining stations, D_{ij} is assumed to be distributed evenly at one kilometer. The degree of exponent, λ is assumed to be 2. The total types of land use in the studied area, K, are divided into 3 types, They are categorized into 3 different usability types; $k=1$ for business purposes, $k=2$ for retail type, and $k=3$ for residential use. Finally, the total number of stations in the whole transit route is set to be 18 stations, which reflect the current total number of the MRT Blue Line stations.

The results of the optimal land use allocation for the balanced ridership with the modified FAM from the base-case scenario is shown in Figure 5-5. The land use allocation here shows the same pattern as the results derived from the land use allocation problem in the previous section.

The residential area is settled into 2 layers, where the outer residential zones are located at both ends of the line and the inner zone is located closer to the CBD. The retail areas are consistently spreading in the central part, whereas the business areas are intensely concentrated in the CBD of the city.

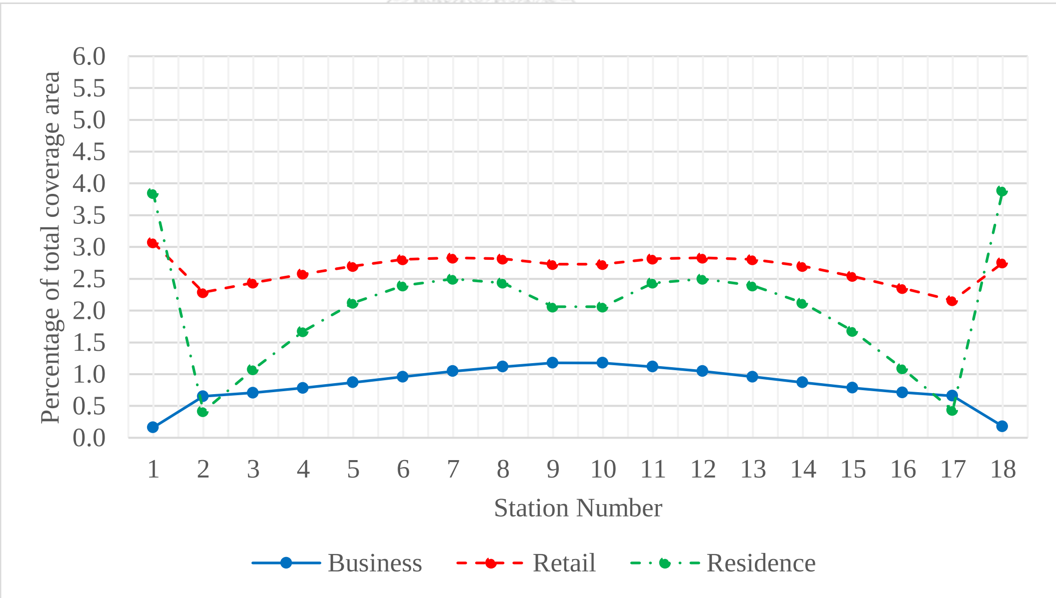
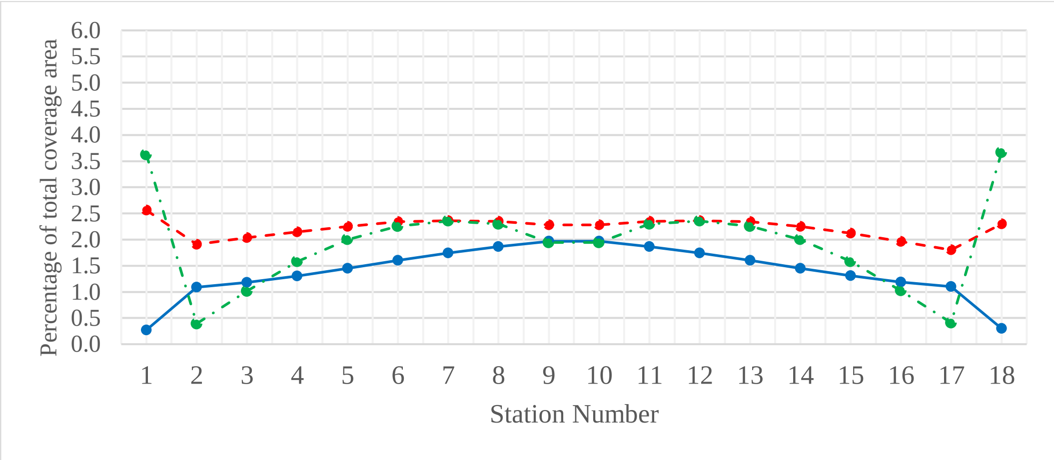
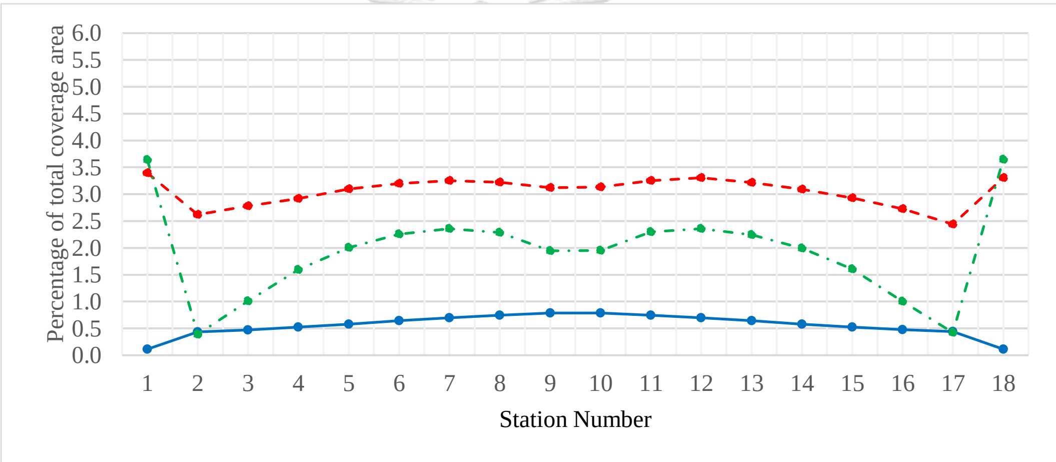


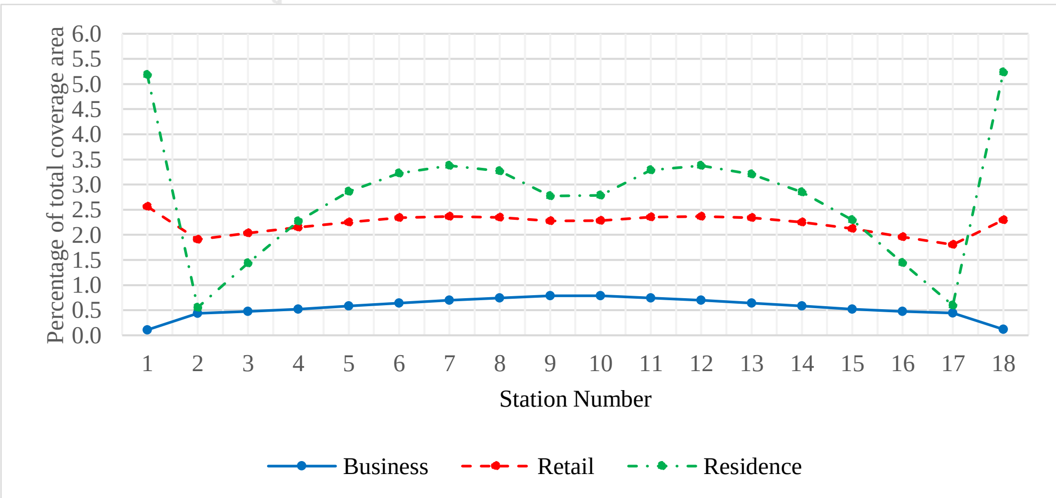
Figure 5-5 The land use allocation result of base case (Unit: percentage).



(a) Business Oriented Development



(b) Retail Oriented Development



(c) Residence Oriented Development

Figure 5-6 The land use allocation results of 3 scenarios (Unit: percentage).

The results of the land use allocation in other hypothetical scenarios are shown in Figure 5-6 (a)-(c) and Table 5-6. The objective values of all cases are equal while the assigned gross floor area has changed. It can also be observed that for the business oriented development scenario and the retail oriented development scenario where the proportion of total gross floor for residential uses is equally fixed at 35 units, the results of the distributed proportion of the residential area among the 18 stations are equal station by station.

Meanwhile, the distribution patterns of other types are also similar as previously shown. It can thus be concluded that the land use distribution remains the same pattern even if the proportion has changed. Interestingly, all allocation patterns have the same level of variance, which is the optimal degree of balanced ridership. The land use along the MRT transit route can therefore possibly be allocated to achieve the maximum efficiency of the balance of ridership in spite of the land use control regulations imposed by the government to limit the development planning.

Table 5-6 Land use allocation to balance ridership for each scenario (Unit: percentage).

Station No.	Business (BUS.) Oriented Development			Retail (RET.) Oriented Development			Residence (RES.) Oriented Development		
	BUS.	RET.	RES.	BUS.	RET.	RES.	BUS.	RET.	RES.
ST-01	0.27	2.56	3.63	0.11	3.40	3.64	0.20	0.55	5.62
ST-02	1.09	1.91	0.39	0.44	2.62	0.39	0.44	1.90	0.56
ST-03	1.18	2.03	1.01	0.47	2.78	1.01	0.47	2.08	1.44
ST-04	1.31	2.15	1.58	0.52	2.92	1.59	0.52	2.22	2.24
ST-05	1.45	2.25	2.00	0.58	3.09	2.00	0.58	2.35	2.84
ST-06	1.60	2.34	2.26	0.64	3.20	2.25	0.64	2.43	3.20
ST-07	1.75	2.36	2.36	0.70	3.25	2.36	0.69	2.51	3.34
ST-08	1.86	2.35	2.30	0.75	3.22	2.29	0.74	2.47	3.26
ST-09	1.97	2.28	1.94	0.79	3.12	1.94	0.78	2.38	2.75
ST-10	1.97	2.28	1.94	0.79	3.13	1.95	0.78	2.38	2.75
ST-11	1.86	2.35	2.30	0.74	3.25	2.30	0.74	2.46	3.26
ST-12	1.75	2.36	2.36	0.70	3.31	2.36	0.69	2.48	3.34
ST-13	1.60	2.34	2.26	0.64	3.22	2.24	0.64	2.44	3.20
ST-14	1.45	2.25	2.00	0.58	3.09	2.00	0.58	2.35	2.84
ST-15	1.31	2.12	1.58	0.52	2.93	1.60	0.52	2.23	2.24
ST-16	1.19	1.96	1.02	0.48	2.73	1.00	0.47	2.12	1.43
ST-17	1.10	1.80	0.41	0.44	2.44	0.42	0.43	2.00	0.54
ST-18	0.30	2.30	3.67	0.12	3.30	3.65	0.10	2.66	5.16
Total	25.00	40.00	35.00	10.00	55.00	35.00	10.00	40.00	50.00
Variance		10.026			10.026			10.026	

5.4 ON-FIELD EXPERIMENT WITH THE MRT BLUE LINE

Assuming that the location of the newly developed mixed-use projects along MRT transit route has considerable impacts on the balance of its ridership, this section tries to suggest the immediate action plan by identifying the hot spots that require urgent land use development plans. As suggested, the achievement of adjusting the number of boarding passengers at each station to the optimal stage requires the thorough alternation of land use schemes along the whole transit route. It is a highly challenging goal that requires strong collaboration among several stakeholders. If the severe pain points of the existing stage can be determined, however, it is possible to take some immediate actions to alleviate the highly imbalanced distribution of onboard ridership in both directions along the MRT Blue Line.

5.4.1 The Mixed-Use Development Project

Nowadays, there are many mixed-use projects initiated adjacent to a mass transit line of Bangkok. This part will briefly present the oncoming mixed-use projects along the MRT Blue Line. They consist of the Sam Yan Mitrtown project, the One Bangkok project, the Dusit Thani - CPN project and the PARQ project. These projects are located off Rama IV Road and destined to be Bangkok's next business hubs, as shown in Figure 5-7. The brief information of each project is concluded in Table 5-7.

The land use along the MRT Blue Line corridor has the potential in the development as there are many proposed projects waiting to be developed in the near future. However, each type of land use has different effects on ridership patterns and must be allocated with the suitable proportions at the appropriate locations in order to balance the ridership. Here, the mixed-use developments along the MRT Blue Line will be taken into account to work out how they affect the characteristics of the existing ridership.

Table 5-7 The oncoming mixed-use projects along the MRT Blue Line.

(Source: https://www.bangkokpost.com.)

Sam Yan Mitrtown		
	Developer	Golden Land Property Development
	Expected Completion Year	2019
	Area (Rai)	13
	Value (Billion Baht)	8.5
	Component	Residence/Office/Retail
Dusit Central Park		
	Developer	Dusit Thani & Central Pattana
	Expected Completion Year	2024
	Area (Rai)	23
	Value (Billion Baht)	36.7
	Component	Hotel/Retail/Office/Residence
One Bangkok		
	Developer	TCC Group
	Expected Completion Year	2025
	Area (Rai)	104
	Value (Billion Baht)	120
	Component	Residence/Hotel/Office/Retail Convention Hall
The PARQ		
	Developer	TCC Group
	Expected Completion Year	2020
	Area (Rai)	24
	Value (Billion Baht)	20
	Component	Office/Retail

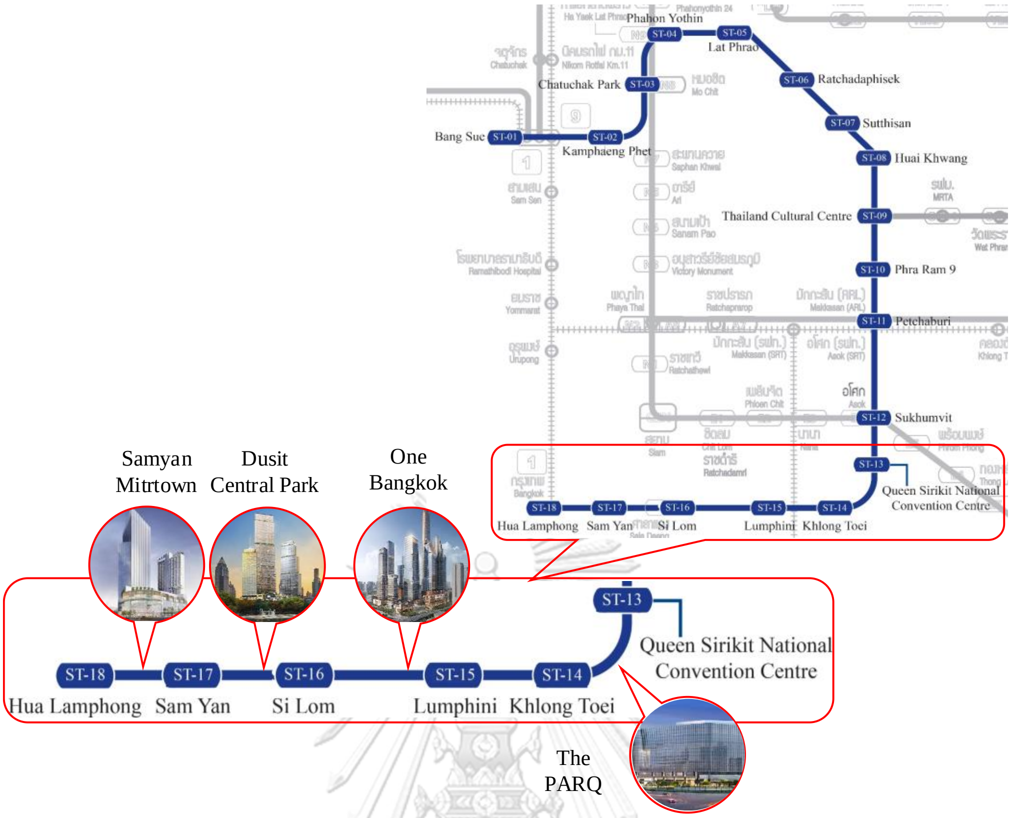


Figure 5-7 The mixed-use projects along the MRT Blue Line of the Rama IV Road.

5.4.2 The Effects of Mixed-Use Project Development on the Ridership Balance

The idea is that the mixed-use projects – the project A and project B can be developed alongside a mass transit project as they have the potential to support each other. However, some factors of the mixed-use projects may have negative effects on the balance of ridership depending on the location of the project and the area of each type of land use. This research investigates the effects of the mixed-use project development on the balance of ridership by the case study of the subway system in Bangkok. The assumption of the newly developed mixed-use projects location will analyze the impacts on the balance of ridership.

For the specific case study, the mixed-use projects are proposed to verify its effects on the balance of ridership of the MRT Blue Line through the modified FAM model with the trip generation and trip attraction rate, previously shown as the base case in the previous chapter.

Project A: The project is located at the corner of Rama IV Road and Phayathai Road intersection, connected to the Sam Yan Station of the MRT Blue Line. Its rental space is approximately 105,000 square meters, covering 3 zones, which are as follows:

(1) Office Tower with the 31-storey office building, the total office space from the 7th floor to the 31st floor and the exhibition hall from the 5th floor to the 6th floor.
(2) Residence Tower with the 33-floor residential zone, consisting of a hotel and a condominium from the 7th floor to the 33rd floor.
(3) Retail Zone with the 6-floor retail zone, complete with a co-learning space, a supermarket, restaurants, cafes, and a cinema.

Project B: The project is located at the corner of Rama I Road and Ratchadapisek Road intersection, adjacent to the Queen Sirikit National Conventional Center Station of the MRT Blue Line. It has the total lettable area of approximately 82,000 square meters, covering 2 zones, which are as follows:

(1) Office Tower with the 8-storey office building, the total lettable space from the 4th floor to the 11st floor; the low zone level 4 to 10 and the high zone level 11 to 16, covering approximately 60,000 square meters.
(2) Retail Zone with 16 stores and 2 basements, complete with the daily essentials including supermarkets, dining, banking services and event areas.

There is no residential area in the project B.

The summarized gross floor area of these two proposed projects are shown in Table 5-8.

Table 5-8 The Gross Floor Area of Developing Project (Unit: square meter).

Project	The GFA of each land use type			
	Business	Retail	Residence	Total
Project A	48,000	36,000	21,000	105,000
Project B	60,000	12,000	-	82,000

Here, the effects of the proposed projects on the balance of ridership are examined by assuming that these projects can be located at any stations of the MRT Blue Line. The land use proportion for the targeted station is then updated accordingly. In the meantime, the GFA for other stations remains the same.

The GFA of the project A and the project B are added to the MRT Blue Line station by station, according to the types of land use. The objective value expressed by the variance of onboard ridership can then be investigated on a case-by-case basis. The trip attraction and trip distribution rate are the same, as shown in Table 4-1.

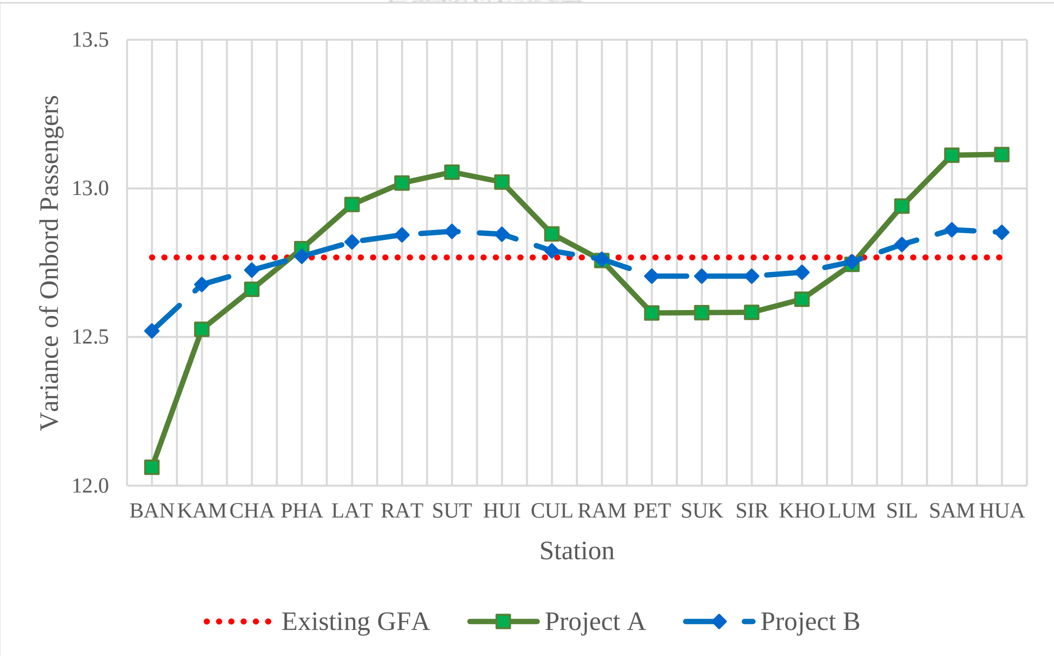


Figure 5-8 The variance of onboard ridership comparison between no development and the project implementation (Unit: square of percentage of total passengers).

Table 5-9 The variance of onboard ridership in case of the proposed project implementation (Unit: square of percentage of total passengers).

Station	Project A	Project B
Bang Sue	12.062	12.521
Kamphaeng Phet	12.526	12.677
Chatuchak Park	12.661	12.725
Phahon Yothin	12.797	12.771
Lat Phrao	12.946	12.820
Ratchadaphisek	13.018	12.844
Sutthisan	13.054	12.856
Huai Khwang	13.021	12.845
Thailand Cultural Centre	12.846	12.790
Phra Ram 9	12.758	12.762
Phetchaburi	12.581	12.705
Sukhumvit	12.582	12.705
Queen Sirikit National Convention Centre	12.583	12.705
Khlong Toei	12.628	12.718
Lumphini	12.744	12.753
Si Lom	12.940	12.812
Sam Yan	13.112	12.861
Hua Lamphong	13.114	12.853
Variance from the existing land use (without project development) = 12.768		

The effects of the project A and the project B development on the balance of ridership are shown in Figure 5-8 and Table 5-9. The variance of onboard passengers in case each project development has changed in terms of its location.

The results show that the location of these projects have huge effects on the balance of ridership throughout the whole transit system. Both projects give the results on the balance of ridership in the same tendency. When GFAs of both projects are applied to either station 1, 2, 3, 10, 11, 12 ,13, 14 or 15, it reflects the lower variance of onboard ridership compared to the present situation. If no projects are developed, the variance of ridership from existing land use around the MRT Blue Line is 12.768.

Even if the two proposed projects have different types and proportions of land use, the results of the effects on the balance of ridership are in the same direction. It can be implied that the mixed-use development of either station 1, 2, 3, 10, 11, 12 ,13, 14 or 15; Bang Sue, Kamphaeng Phet, Chatuchak Park, Phra Ram 9, Phetchaburi, Sukhumvit, Queen Sirikit National Convention Centre, Khlong Toei, or Lumphini, would be immensely instrumental in improving the balance of ridership.

It can be implied from these results that the location of the projects is a crucial factor that influences the balance of ridership. If the developed projects are located around well-chosen stations, they would substantially enhance the balance of ridership. On the other hand, the outcome could be reversed if the location of the projects is not favourable to the improvement of balanced ridership.

As a result, the mixed-use project development plan should take into account the overall perspectives, not least the impacts on the mass transit system. Moreover, the investigation of the observed data of trip generation and trip attraction rate is also essential when putting the proposed model in real practice. Nevertheless, the results presented here could be used as the guideline on the land use development plan to efficiently support the mass transit system.

Chapter 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

One of transit agencies' major problems is the non-optimality of O-D distribution, which leads to the inefficient usability of the transit system. The balance of ridership distribution along the transit route is one of the significant characteristics that support the utmost utility of the transit system. For example, both directions of the MRT system should be evenly crowded in all sections of the route. These advantages are practical ways of gaining more operation profits from transit agencies as they improve the efficiency of the transit system as a whole by approaching the maximum capability and reducing losses from an unoccupied capacity of the transit system.

In this research, balancing mass transit ridership through the land use development is meticulously researched. The trip distribution models – the gravity model and the modified FAM – are employed to determine which one is the more appropriate model for reflecting mass transit ridership characteristics. The modified FAM, which can better describe mass transit trip distribution characteristics, is further modified with land use consideration and employed with a case study – the MRT Blue Line. The balance of ridership from the existing land use development around the stations of the MRT Blue Line is also investigated. During the process, the effects of the mixed-use projects' location are also analyzed to verify the appropriate methods of development along the whole transit route. The problems of imbalanced ridership and the summarized details of balancing mass transit ridership through the land use development are thus concluded in this chapter.

There are several factors that affect the transit ridership, including spatial effects. Some types of land use, such as residences and business areas, generate trips mainly during peak hours, making the trains often crowded. At the same time, other types of land use, such as entertainment complexes, retail shops and restaurants, generate trips during off-peak hours. They thus encourage the efficiency of the rail services.

Besides, TOD is highly acclaimed for promoting the sustainable city development. It focuses on the development of areas around stations that are connected to the transit corridor. It is a mixed-use community within a walking distance of a transit stop. TOD typically has a diverse range of land uses and requires a good transit service during both peak and off-peak hours to support both work and non-work trips. Consequently, the land use development with the application of the TOD concept that influences the O-D distribution is utilized to improve the current pattern of O-D distribution and reduce the imbalance of transit ridership accordingly. The land use development is therefore the most sustainable solution to balancing ridership.

Major critical obstacles to improving the balance of ridership must be eliminated in favor of an integration between the trip distribution and the land use development with the TOD principle. The problems can be concluded as follows:

(1) The lack of appropriate trip distribution models for a mass transit system. At least one model should be formulated.

(2) The trip distribution model with land use consideration that integrates O-D distribution with land use variables together does not exist.

This research focuses on the mass transit ridership of a single and stand-alone transit line structure with no connections with any other lines. The balance of ridership is indicated by the minimum variations of onboard passengers between any adjoining stations. The summary of the primary research findings and a recommended guideline on the balance of mass transit ridership through the land use development are also concluded.

The Trip Distribution Model Performance

This research opts for *'the Gravity Model'* and *'the FAM'* as the basis for the further formulation of ridership balancing scheme as both models require no primary O-D data of the existing ridership. The performances of two behavioral models are compared by the varying values of a degree of deterrence, λ, for the various numbers of stations.

The results of the model comparison show that *the modified FAM* proves more reliable than the Gravity Model when put into practice. The reasons are as follows:

(1) The overall patterns of boarding passenger distribution are not much altered by the variation in the values of degree of deterrence.

(2) The variance of the numbers of boarding passengers at the stations is not much lower. It seems more feasible when put into practice.

(3) The model can describe the nature of the catchment areas around both terminal stations.

(4) The model conforms to the attributes of a mass transit system during peak hours when the passengers always crowd into the train only in one direction.

Actually, boarding the train is subject to a fixed opportunity cost of time, ranging from the time loss due to the ticket purchasing process to the time loss due to the train waiting time. Therefore, getting on the train for a single stop usually causes the most expensive average cost per travel distance. The behavior demonstrated by the modified FAM complies with this observation by the additive functional form of the model, which results in the gentle rate of reduction in the possibility of going an additional distance.

The Land Use Allocation for Balancing Ridership

The modified FAM is applied to cope with a land use consideration on the basis of the morning-hour period. Most trips are attracted to the business areas for working purposes, whereas others are generated from the residential areas. The results of land use allocation suggest the distribution of each type along the mass transit corridor to support the balance of ridership. The characteristics of the distribution can be summarized as follows:

(1) The residential areas should be densely located at the terminal stations. In case of the long mass transit route, the sub-residential areas should also be located in the interval in order to shorten the distance of trips.

(2) The business areas should be densely located in the middle of the mass transit route.

(3) The retail areas should be dispersedly located all along the route.

The modified FAM application with case study in Thailand

The modified FAM model is further applied to evaluate the effects of land use allocation on the ridership of the MRT Blue Line, which has been fraught with problems of imbalanced ridership. The imbalance of the MRT Blue Line's ridership is measured by the MAPE. The analysis of MAPE limitation can determine the hot-spot stations that require the immediate action plan for land use adjustment. The onboard passenger variation can then be reduced. It suggests that the whole population along the route need to be reallocated in order to achieve the optimal balance.

The actual total areas of each land use within walkable areas of the MRT Blue Line stations are put into the modified FAM, together with the defined oriented scheme. The results of the land use allocation in hypothetical scenarios show that the optimal land use allocation from all scenarios presents the same pattern. It can be concluded that the balanced level can be reached by the distribution pattern along the transit corridor.

The Effects of Land Use Development on Ridership Balance

The research has proven the effects of the projects' location on the balance of ridership by proposing two mixed-use projects and assuming that they can be located at any stations of the MRT Blue Line. The analysis results found that the location of the mixed-use projects has the substantial effects on the balance of ridership throughout the whole transit system. It is a great factor that influences the balance of ridership. If the developed projects are located around well-chosen stations, they would substantially enhance the balance of ridership. On the other hand, the outcome could be reversed if the location of the projects is not favourable to the improvement of balanced ridership.

Model Validation of Switching Between the Morning Peak Hours and Evening Peak Hours

The methodology presented in this research is applied to optimize the ridership of a single train line during morning peak hours. Also, it can be readily applied to evening peak hours by reversing the number of boarding and alighting passengers and adjusting some assumptions regarding the modeling behavior. The model validation of switching between morning peak hours and evening peak hours is demonstrated afterward.

The key point is the motivation that underlies a trip generation and a trip attraction. During morning peak hours, most of the trips are caused by travel demand for work and study, usually starting from individuals' residences. Therefore, the pattern represents the travel behavior of passengers dominated by the trip generation and the endogenous variables of the system of non-linear equations defined by the number of passengers boarding the train at each station P_i.

On the other hand, most of the passengers make trips back home during evening peak hours. The trip attraction, therefore, manipulates the travel behavior of passengers. By defining the number of passengers alighting at each station, Q_j, as the endogenous variable and reversing the behaviors of the model, the above-mentioned results can also be applied to evening peak hours.

The possibility that any passengers who want to alight from the train (and go back home) at the station i has boarded the train at the station j is proportionally decreasing by the distance between the stations i and j, as shown in Equation (6-1) for the gravity model and Equation (6-2) for the modified FAM.

$$T_{ij} = \left(\frac{\left(\frac{D_{\max,i}}{|i-j|D} \right)^{\lambda}}{\sum_j \left(\frac{D_{\max,i}}{|i-j|D} \right)^{\lambda}} \right) \times Q_j \tag{6-1}$$

$$T_{ij} = \left(\frac{(D_{\max,i} - |i-j| + 1)^{\lambda}}{\sum_j (D_{\max,i} - |i-j| + 1)^{\lambda}} \right) \times Q_j \tag{6-2}$$

The objective value is also the same for both morning and alighting optimizations. The results of balancing ridership show that the solution of the model is achieved by reversing the numbers of boarding and alighting passengers.

To optimize the method with the land use consideration, reversing the numbers of boarding and alighting passengers can switch the optimization to evening peak hours under a ceteris paribus assumption. The model verification of switching between the morning peak hours and evening peak hours will be the guideline for employing the model with other time periods.

6.2 RECOMMENDATIONS

This section provides a focused set of recommendations on how the transportation and land use sectors can advance sustainable development and the useful guideline for This section provides a focused set of recommendations on how the transportation and land use sectors can advance the sustainable development and the useful guideline on the balance of mass transit ridership by reforming the land usability. The use of the research methodology is particularly relevant as it relates to the problems of real issues. The research findings would be further addressed as to how land use planning can be used to assist transit agencies in allocating their resources and influencing the public sectors' managements.

Before discussing how the achieved results from this research would enhance the mass transit service competence, the issue of imbalanced mass transit system and land usability in Thailand will be explained.

<u>Situation of the Imbalanced Ridership in Thailand</u>

Considering the situation of imbalanced ridership of the MRT Blue Line, the mass transit passengers always encounter the problem of the train's crowdedness during peak hours. In the morning, the rail line in the inbound direction is densely-packed with passengers as a huge number of passengers travel into the inner city.

Meanwhile, the rail line in the outbound direction is barely congested. For example, traveling from Chatuchak Park Station to Khlong Toei Station during morning peak hours, the train is overcrowded with numerous passengers along the route until the train passes through Sukhumvit Station, where most of passengers egress the transit system. The remaining number of onboard passengers is then small until the train arrives at the end of the route. The passengers boarding the train at Sutthisan Station or Huai Khwang Station, for example, would have to wait for the third or fourth arriving train before boarding the train. On the contrary, the train is not congested when traveling from Khlong Toei Station to Chatuchak Park Station, especially when passing through Sukhumvit Station.

For the land usability along the MRT Blue Line, most of the business areas are densely located in the middle parts of the MRT, such as areas around Phra Ram 9 Station, Phetchaburi Station and Sukhumvit Station. Meanwhile, residential areas regarding townhouses and tenement houses are inclined to be located in the direction toward Hua Lamphong Station. Commercial or retail areas are likely to be located in the direction toward Bang Sue Station, as shown in Figure 6-1.

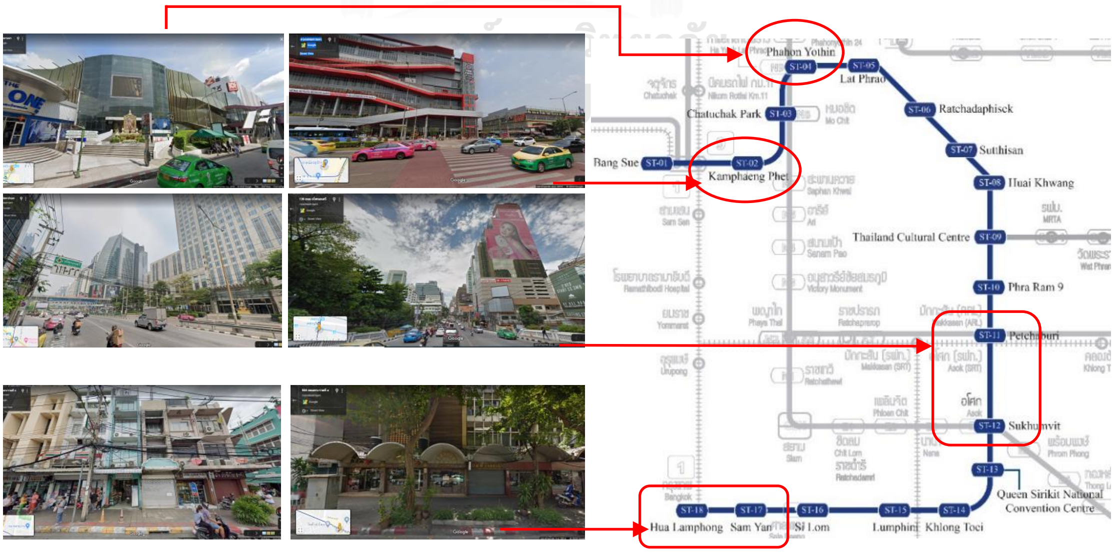


Figure 6-1 The land usability along the MRT Blue Line (Source: Google Map).

Problem of Non-Integration Between Transportation and Land Use Sectors

The roles of state agencies, who are responsible for transportations and urban planning in Bangkok will be elucidated in terms of their authorities. Actually, the urban mass transit planning and land use development cannot be separated. The reasons of those imbalanced ridership problems are evident from the real circumstances of the mass transit network and urban development in Bangkok. The mass transit system has induced the urban form as it makes a rapid urban sprawl along the mass transit corridor. However, these two evolutions have no integrated planning schemes on each other.

BMA is the local government organization under the Ministry of the Interior Regulations. It is responsible for the city planning, building control, supervision of the city's development and outlining the city's development standards.

The Office of Transport and Traffic Policy and Planning under the Ministry of Transport is responsible for creating transportation policies, providing transportation system development plans and driving the plans into practice. They include the master plan for the mass rapid transit.

The situation of land development along the transit route in early years is that the land development is growing in parallel with the mass transit system development, not least around the mass transit stations. Each project is designed individually by its developers after the mass transit system network has already been planned. The developers do take into account only that the projects must be located as close as possible to the transit stations to facilitate people flows. The TOD guidelines are barely considered for the project development, however.

Meanwhile, the mass transit projects are developed in accordance with the current mass rapid transit master plan, which has been established since 2010 for the implementation within 20 years. The extension of the network for the 2nd phase is underway. Even the future urbanization is considered one of the factors for the plan of the extended mass transit network. One of the crucial factors is the integration with its own existing mass transit and public transport network. This includes the connection with other mass transit lines, the fulfillment of missing links, the comprehension of the network throughout Bangkok and surrounding areas.

Before the implementation, most of mass transit projects are revised to adjust some details so as to make the plans more compatible with the current conditions. They include re-alignment to avoid land acquisition in community areas, where many affected people are opposed to the projects. The actual implementation of the mass transit's projects therefore always has different details from the planned network.

The independent managements of these two sectors are the main obstacle to integrating the mass transit system and urban development. The challenge of the reformation along the research findings is how to correlate these two sectors for more integration in terms of their roles and responsibilities. Each development roadmap must be coordinated for the effective conformity.

The transportation system development is one of the essential fundamentals to achieve the Sustainable Development Goals (SDGs) along the 2030 Agenda. The goal on sustainable cities and communities are included to provide transport systems for all. However, the sustainable transport development has not been given sufficient precedence. It is necessary for all sectors to push forward the transportation system, particularly in urban areas, in order to achieve the SDGs.

Recommendations Toward the Successful Integration

The main research findings conclude that the urban mass transit system and the urbanization have effects on each other. The land use allocation along the mass transit corridor has shaped the ridership pattern, according to the different activity creation of each type of land use, leading to the different patterns of ridership. The balance of ridership in any periods or entire of operating hours can be adjusted by each usability attributions. This research also identifies that the balance of mass transit ridership can be achieved by the integration of mass transit and land use, leading to the sustainable transportation system.

The mass transit and land use integration in Bangkok is relatively rare in practice. Here, the comprehension is extracted from the study to provide the specific policy recommendations and implementations as key recommendations at different levels of strategic planning and implementations. The state agencies in charge of the urbanization, mass transit system and land use development are multisectoral. Their roles can be divided into 2 sectors, which are planning and implementation. The major challenge for the transportation sectors and urban planning regulators is how to integrate their operating duties together for the united strategic plan development.

Planning level

The mass transit and land use integration are determined to induce approaches for sustainable urbanization. Both of them need to be guided by the master plan. The policy makers must have a collaborative process for the long-term planning of desirable urban forms and settlement patterns of land use.

Legislative processes would be a method that encourages planning agencies to create and enforce the master plan, as well as enabling the plan for specific sectoral actions. It is also great to make the implementation of a master plan as a lawful requirement for the land use development.

The details of the urbanization master plan for mass transit and land use development should specify the regulations of both developments in accordance with the TOD practice. Based on this perspective, the primary essential issues for the planning level are examined as follows:

- *Cross sector coordination:* Theoretically, the mixed-use projects tend to generate the mass transit ridership when the overall integration is entirely planned, making them mutually dependent on each other. However, it is hardly possible to organize the collaboration to integrate mass transit and land use as no institution and government sector responsible directly for such project has been established in the first place.

The process of cross sector coordination, which identifies the related problem and empowers some sectors, would be a helpful channel for more coordination. The technical capacity of transport planners and implementers should be built to ensure the effective collaboration. At the initial stages, the coordination between land planners and transit planners should work together to formulate a long-term plan that needs to be endorsed by both sectors. The short-term development would then be investigated to follow this plan at the implementation level.

- *Developing strategic plan of mass transit and land use integration:* The great compatible integration should be initiated by developing a strategic plan, which is the most essential composition of the successful integration between the mass transit network and urban development. The plan should emphasize that the transit system and the urban form must be dependent on each other in order to shape the community and connect people with the communities through the sustainable transport development. The undesirable or negative effects on mass transit system should also be investigated for the improvement.

- *Promoting TOD*: The diversity of TOD handbooks needs to be developed for the community's conditions. The prototypes of TOD projects should be introduced in terms of regulations and the combination of high density. Diverse land uses include pedestrian-friendly environments, which should be promoted as well. It is an effective way to induce sustainable urbanization.

- *Specifying the TOD typology for mass transit station*: A typology of TOD should be specified for each station to achieve the balance of ridership when considering the mass transit network for the large-scale TOD. The location of mass transit stations must be examined for a typology specification as the results that different types of usability are proper to be located at different sites.

- *Encouraging the mixed-use project development that supports the balance of ridership:* The mixed-use projects should be examined and encouraged to improve along the CBD concept, which supports the balance of ridership as recommended in the research.

The ideal distribution should be that the residential areas are located in the outer zones at both ends, a number of head offices and educational institutes are densely situated at the central area, whereas the retail areas should be consistently spreading along the whole line.

Implementation level

Each local sector might develop a different form of TOD, according to the area's conditions and characteristics. The main strategies and regulations of the master plan must be held strictly. The participants on this level are local authorities, mass transit agencies and land developers, all of whom should be responsible for the roles and responsibilities, which are as follows:

- *Implementing and creating TOD:* The development of mixed-use projects must conform to the strategic plan and the specified typology of TOD for each developed location along the mass transit route. The typology specification should be focused from the very beginning as the changes in the development cannot be a convenient reconsideration. Each class of the TOD typology should therefore be implemented as a prototype for the future development as well.

- *Adapting the core usability of mixed-use projects*: Each type of land use has a different induction of transit demand. It is appropriate for each mixed-use project to be located at some specific locations so as to support the balance of ridership. Therefore, the mixed-use projects must be considered when it comes the precise location, together with the existing proportion of each type of area along the transit corridor. The developers should adapt the core usability of the projects, according to the proper characteristics of available land for promoting the balance of ridership.

- *Land use and mixed-use project development control:* The local authorities, such as BMA for Bangkok Metropolitan Region, should exercise their administrative powers to regulate and supervise the project development in order to implement the strategic plans and the well-integrated mass transit network. In addition, the local authorities should have the right to regularly investigate or assess the conformity of buildings or mixed-use projects proposed by developers in terms of their usability.

- *Land consolidation and readjustment:* The existing land usability in Bangkok is at odds with the research findings in terms of functions and locations. The consolidation and readjustment of the land would thus be a well-planned method, which comes together with the new development control. However, the consolidation and readjustment cannot be a convenient management. The local authorities and property owners must therefore work cooperatively with each for better circumstances of land usability, with the minimum effect on the primary owners.

- *Developing the connection to the mass transit system:* The feeder systems, first mile and last mile, are a challenge for the transportation network to achieve sustainable transport. However, the major problem is the lack of convenient feeders. The transit operators should thus collaborate with each other for the fulfillment of linkage, which can completely feed or hand on to the passengers of the mass transit system.

Future Work

There are some excluded studies in this research which should be further studied to figure out the impacts on the balance of mass transit ridership. The further studies to extend the science and knowledge on trip distribution and land use development for balancing mass transit ridership can be concluded as follows:

Apart from the land use development, there are other factors that affect mass transit demand in terms of the policies, such as pricing policy on the mass transit fare structure, an off-peak fare discount policy, etc. They should be investigated for an additional guideline on balancing mass transit ridership.

The proposed modified FAM is well applicable to a distance-based fare structure as the deterrence functions are assumed to be linearly varied by distance-related factors, such as travel time, travel cost, and travel utility. The future research should therefore be conducted to find other functions beyond the distance-based fare structure.

As the trip generation and trip attraction data of mass transit trips in Bangkok are not available, the number of those trips should be meticulously surveyed for a more accurate set of database.

The modified FAM functions well when being employed with the simple transit route and linear route, both of which are the basis of this this research. However, it is interesting to also study how to develop and improve other different patterns and more complex mass transit networks, such as intersection or circular lines. They could possibly cause ridership induction at the connecting transit stations and the demand incentive affected by factors other than distance between adjoining transit stations. Therefore, the other railway structures should also be investigated in order to support the railway networks, which are to be completed in the near future to achieve the balance of ridership through the land use development.

The drivers of changes for the transportation system planning and land use development regulations would gain the preliminary method to promote the balance of ridership through the land use development with the challenge of the successful key that an effective cooperation between two major authorities for the sustainable urbanization would be achieved. The dissertation has raised several contributions to the mass transit system and land use planning. The findings in this research could be used as the recommended guideline, which can bring a better understanding of the land use development and the transit ridership modeling.

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