Development of TOD readiness index and its application to transit station in Bangkok

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A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy in Logistics and Supply Chain Management
Inter-Department of Logistics Management
GRADUATE SCHOOL
Chulalongkorn University
Academic Year 2020

การพัฒนาดัชนีวัดความพร้อมของการเป็น TOD และการประยุกต์ใช้กับสถานีขนส่งสาธารณะใน
กรุงเทพมหานคร

นายศรีสัมฤทธิ์ ศุภประเสริฐ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาการจัดการโลจิสติกส์และโซ่อุปทาน สหสาขาวิชาการจัดการด้านโลจิสติกส์
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2563

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การศึกษาเกี่ยวกับการพัฒนาชุมชนเมืองในเขตพื้นที่รอบสถานีขนส่งสาธารณะ (TOD) สำหรับกรุงเทพมหานครพบว่ายังไม่เป็นที่แพร่หลายในกลุ่มงานวิจัย ซึ่ง TOD ถือเป็นแนวคิดที่สนับสนุนแนวทางการพัฒนาชุมชนเมืองเพื่อลดปัญหาด้านการคมนาคมในพื้นที่ชุมชนเมือง ขณะเดียวกันก็ส่งเสริมให้ประชาชนทั่วไปเดินทางสัญจรโดยใช้ระบบขนส่งสาธารณะแทนการใช้รถยนต์ส่วนตัว โดยที่บริบทของ TOD สำหรับกรุงเทพมหานครนั้น อยู่ภายในกรอบของการออกแบบด้านโครงสร้างพื้นฐานให้มีความกระชับรวมไปถึงความหลากหลายของการใช้ที่ดินรอบบริเวณสถานีขนส่งสาธารณะโดยอ้างอิงจากสถานีขนส่งในต่างประเทศที่ประสบความสำเร็จภายใต้กรอบแนวคิดนี้ การศึกษาในครั้งนี้ใช้สถานีขนส่งสาธารณะจำนวน 18 สถานีในเขตกรุงเทพมหานครเป็นกลุ่มตัวอย่าง โดยที่ดัชนี TOD Readiness จะทำการประเมินผลคะแนนของแต่ละสถานี โดยสถานีใดที่มีคะแนนสูงกว่าจะมีความพร้อมในการสนับสนุนการเดินทางสัญจรด้วยวิธีการเดินเท้าไปยังพื้นที่สถานีนั้นได้ดีกว่าสถานีใดที่มีคะแนนน้อยกว่า และในภายหลังสถานีที่มีคะแนนสูงสุด 4 สถานีได้ถูกวิเคราะห์ด้วยแบบจำลองการถดถอยโลจิสติกพหุนาม ซึ่งผลการวิเคราะห์พบว่าคะแนน TOD และความถี่ในการใช้งานรถไฟฟ้า ส่งผลให้ผู้ที่สัญจรอยู่รอบบริเวณสถานีขนส่งตัดสินใจหันมาใช้ระบบขนส่งสาธารณะแทนการใช้รถยนต์ส่วนตัวกันมากขึ้น ผลการศึกษาในครั้งนี้ถือเป็นความสำเร็จในการทำความเข้าใจเกี่ยวกับพื้นที่รอบสถานีขนส่งสาธารณะด้วยการประยุกต์ใช้แนวคิด TOD และสามารถใช้เป็นแนวทางในการศึกษาสถานีอื่นในประเทศไทยได้ต่อไปในอนาคต

สาขาวิชา	การจัดการโลจิสติกส์และโซ่อุปทาน	ลายมือชื่อนิสิต ....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5987799420 : MAJOR LOGISTICS AND SUPPLY CHAIN MANAGEMENT
KEYWORD: Transit-Oriented Development, TOD, Multinomial logistic regression

Srisamrit Supaprasert : Development of TOD readiness index and its application to transit station in Bangkok. Advisor: Assoc. Prof. MANOJ LOHATEPANONT, Sc.D. Co-advisor: Asst. Prof. KRISANA VISAMITANAN, Ph.D.

Studies on the Transit-Oriented Development (TOD) for Bangkok are found sparingly. The TOD concept is a supportive development for the rapidly changing city in order to reduce urban transport problems while encouraging people to shift transport modes to use public transportation instead of private cars. This study discusses the context of TOD in the density, the design, and the diversity of land use around transit stations among successful stations in many countries. There were 18 station areas in Bangkok which, by using the TOD Readiness score, the assessment of the stations implies that the higher scoring transit stations are more compatible to supporting pedestrian use of the transit station with lower car dependency. The 4 top-scoring stations were assessed by using a multinomial logistic regression model. The study has found the TOD scores and the frequent uses of the stations encourage the commuters around the station areas to rely on public transport instead of car dependency. This is an effort to overcome the understanding of the station areas by reducing the complexity of the TOD contexts to any transit station in Thailand to be eligible for future study.

Field of Study:	Logistics and Supply Chain Management	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....
		Co-advisor's Signature ....

ACKNOWLEDGEMENTS

During this study, I have made some very good experiences and have got the supports by all of whom I would like to express my sincere gratitude in this dissertation.

To start with, my sincere thanks are due to Assoc. Prof. Manoj Lohatepanont, my advisor who showed trust and supportive confidence in me when I started my PhD study in this program. His critical thinking and viewpoint toward the transportation always brought a new perspective to my work. His take on the topic of discussion would encourage me that made sure I completely understood my work inside out. That is what discussions should do and I am very grateful for his guidance and comments that help me shape this dissertation better.

My co-advisor, Assist. Prof. Krisana Visamitanan has been a complete pillar of support in every which way. She is not just the kindest mentor, but also the most encouraging and appreciating. She has been extremely helpful throughout the dissertation process. I had a great experience working with her and would like to thank you for her help and trust.

Furthermore, my sincere gratitude for Prof. Kamonchanok Suthiwartnarueput, chairman of this dissertation who always guide me during the entire process of study. I loved to spent my Friday morning discussed with her about thesis studies during the sophomore. I also would like to send out my sincere thanks to my thesis committees; Assoc. Prof. Pongsa Pornchaiwiseskul, Assist. Prof. Tartat Mokkhamakkul, Assoc. Prof. Thananya Wasusri, and Dr.Kerati Kijmanawat, who considerably guided and helped me since the proposal until the final examination. I also got a wonderful opportunity to working along with Kiatirat Sreemongkol, a PhD candidate who often helped me sort out many practical and administrative issues during my PhD study in Chulalongkorn University.

Finale, I am very appreciated to my family for their trust with no hesitation. There has been some lovely addition to my family, thus far special thanks to Somjai Supaprasert and Wanvisa Chaipipatworakij, my study would not have succeeded without theirs help and supports.

Srisamrit Supaprasert

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Introduction

1.1 Rationale

Making the city an opportunity for everyone, by ensuring accessibility to basic services, affordable housing and transportation, is a challenge. Of undoubted importance is how people will travel when the world population is increasing every year. According to the UN's World Urbanization Prospect (2018), the United Nations claims that the world population is projected to rise to 8.5 billion by 2030, whereas the number of people living within cities is projected to rise to up to 5 billion people. In Thailand, Bangkok, the major city, has an estimated population of 10.3 million according to data from the 2018 census. This number was up from the 8.26 million recorded in 2010, and is also estimated to increase to 12.1 million by 2030 (National Statistical Office, 2019). Bangkok is an important city that is considered as a primary center for various systems, such as government offices, and tourist attractions, and is a top sites for both jobs and educational institutions. This cause people from all across the region to immigrate to Bangkok city to conduct business, study, find accommodation, and to do any other activities; this trend is steadily increasing.

Table 1: Population and growth projections in Bangkok from 2005-2035

Year	Population	Growth Rate (%)	Growth
2035	12,679,614	0.94%	579,002
2030	12,100,612	1.21%	708,908
2025	11,391,704	1.57%	852,289
2020	10,539,415	1.87%	383,099
2018	10,156,136	2.60%	753,545
2015	9,402,771	2.60%	1,133,726
2010	8,269,045	2.60%	997,029
2005	7,272,016	2.60%	876,578

Source: National Statistical Office; Available from http://web.nso.go.th/en/stat_theme_socpop.htm

The population growth that changes cities usually brings with it urban challenges, including traffic congestion, a shortage of proper housing, and a declining infrastructure that is insufficient for providing basic services (Arrington et al., 2008). There are questions regarding the rapid changes of the city, especially regarding how people will travel when the population number is increasing continuously. There is curiosity about what travel patterns of Bangkok citizens will looks like in the future. Currently, there are four major forms of travel in the urban areas of Bangkok: walking, using personal vehicles, using local taxi services (e.g. Grab taxi, taxi, motorcycles), and using public transportation. Despite the use of a variety of forms of travel, Bangkok is a city that uses a lot of roads especially for the use of personal cars as travel vehicles. According to the Ministry of Transportation, the number of registered cars in Bangkok is approximately 10 million vehicles[1], with the number of driving licenses and personal transport licenses at more than 5 million licenses[2]. These statistics do not include cars registered outside the city.

Regarding walking in Bangkok, an interesting study was done on 399 pedestrians in Bangkok who switched to use the metro system regularly for their work and educational purposes. It found that the pedestrians who increased their walking which the average distance is 612.18 meters whereby total traveling time was reduced to an average of 22 minutes going and 28 minutes for the return trip (Ronghanam, 2013). Nevertheless, not many people, especially the elderly and disabled can easily access the metro station because most footpaths in Bangkok are inability to provide pedestrian system services.

There is evidence that increased use of the Metropolitan Rapid Transit (MRT) at all Bangkok stations with an average usage of passengers of more than 300,000 times per day in 2019[3]. Furthermore, the Bangkok Transit System (BTS) has also become a trend for the past few years, during which they had an average number of passengers using the BTS as a travel vehicle more than 600,000 times since 2016[4].

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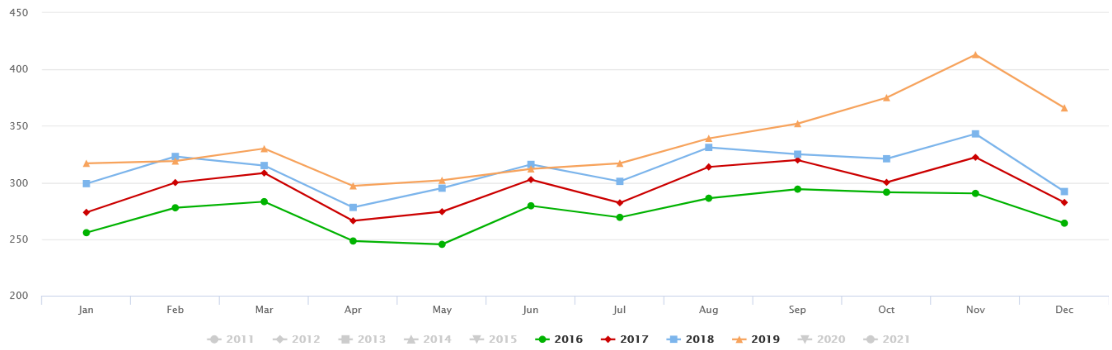
[1] Transport Statistics sub-division. 2019, Number of Vehicle Registered in Thailand as of 28 February 2019, Ministry of Transportation, Planning Division; https://web.dlt.go.th/statistics/#%E0%B9%88 (retrieved date February 2019)

[2] Transport Statistics sub-division. 2019, The Number of Driving Licenses and Transport Personnel Licenses Classified by Type as of 28 February 2019, Ministry of Transportation, Planning Division. https://web.dlt.go.th/statistics/#%E0%B9%88 (retrieved date February 2019)

[3] Bangkok Expressway and Metro. 2019, Investor relations, Ridership report. https://investor.bemplc.co.th/en/ridership-report/ridership (retrieved date February 2019)

[4] BTS Group. 2019, Investor relations, BTS ridership. http://www.btsgroup.co.th/en/investor-relations/bts-ridership. (retrieved date February 2019)

Figure 1: Average MRT ridership by passengers on a daily basis during 2016 – 2019



Source: Bangkok Expressway and Metro; Available from https://investor.bemplc.co.th/en/ridership-report/ridership

Is there any problem when a city's population increases? The question has yet to be answered, but certainly the use of urban transportation always produces minor traveling problems. Aforementioned trends have been associated with the amount of car consumption, and the growth of transportation has affected the development of living space due to being influenced by the dense traffic on the road (Boschmann and Brady, 2013). Secondly, social problems have arisen from car use causing residents to experience health problems, such as respiratory system diseases and stress. Third, environmental issues are related to the fact that air pollutants are emitted from cars and cars are the transport mode that uses most space and resource (Black, 2001; Whitelegg, 2003; Reusser et al., 2008). Traffic congestion, health problems, air pollution and global warming are the effects of cities using too many automobiles. Therefore, maintaining the city in a way that continues to create jobs and prosperity without straining land and resources is improbable because when the city population increases, there will be more problems in regards to traveling within the city area.

One of the things that becomes apparent in the literature review is that there are two universally accepted premises about how to solve the urban transportation problems. The first premise is to encourage people to shift their mode of transport from private vehicles to non-motorized (e.g., walking, bicycle) vehicles, or to use public transportation instead (Huang et al., 2018; Kay et al., 2014). The achievement of transport mode shifting is a result of both the development at the station and the ability of public transit created by the development of transit-orientation (Lund, 2005). Another premise is a concept called Transit-Oriented Development (TOD) that considers using policy intervention as a solution to the aforementioned challenges (Boschmann and Brady, 2013), especially when promoting a model for urban design and planning in areas around transit stations (Vale, 2015). TOD has been planned or constructed around rail, light rail transit and bus transit stations, and stops in urban areas which generally have higher levels of transit service, and consequently, have higher transit ridership generation potential (Galeloa et al., 2014).

1.2 What is Transit Oriented-Development?

Transit-Oriented Development (TOD) is a concept of city development that integrated with a development of transportation infrastructure, especially to focus in the area around the importance transit stations. The TOD concept was introduced and published in the Next American Metropolis (Calthorpe, 1993), which is typically defined as compact development within (5-10 minutes) walking distance of transit stations that contains various land use patterns such as housing, jobs, shops, etc. In addition, the TOD definitions were defined in studies from past decades that conceptualized as urban development with the integration of the Node index (e.g. transit stations) and Place index (e.g. land uses) in order to create non-motorized communities for peoples of all ages and incomes, and in order to provide more transportation and housing choices (Bertolini,1999; Reusser et al., 2008). Schlossberg described TOD as a planning approach which consolidates land use and transport planning to be suitable for pedestrians (Schlossberg and Brown, 2004). Hence, TOD is an urban planning and design that promoting the use of public transports and supporting pedestrian-friendliness by threshold the land use pattern.

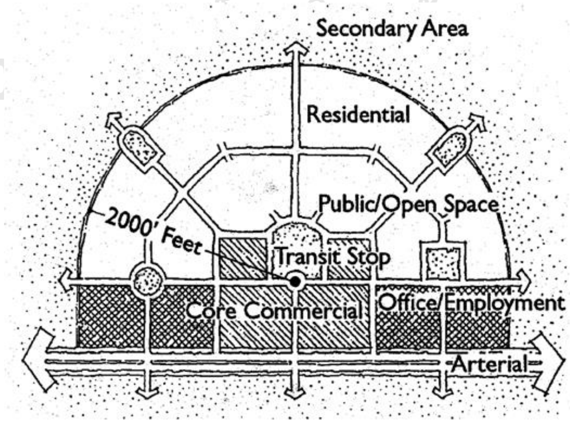


Figure 2: Land use patterns around the station according to Calthorpe's TOD concept

The concept of TOD is general in its prescriptions for policy and planning, but is likely to be have great diversity in implementation. Recently, a number of researchers have stated that TOD is a planning and design strategy that consists of promoting urban development that is compact, mixed-use, pedestrian-friendly, and closely integrated with mass transit by clustering jobs, housing, services, and amenities around public transport stations (Higgins and Kanaroglou, 2016; Kamruzzaman et al., 2014). Thus, TOD motivates people to use public transit instead of private vehicles (Widyahari and Indradjati, 2015).

1.3 Why Transit Oriented-Development for Bangkok?

TOD has been successfully applied on a city scale in cities around the world[5], including Stockholm, Copenhagen, Brisbane and Tokyo but Bangkok. Meanwhile, several studies show that people living around TOD are more likely to travel by transit service than non-TOD residents (Arrington et al., 2008; Boschmann and Brady, 2013; Chen et al., 2017). For individuals, those who prefer walking instead of driving may prefer to live in a satisfactory location where public transport services are readily available. Other benefits include potentially lower household transportation expense (Higgins and Kanaroglou, 2016).

Bangkok city covers more than 1,500 square kilometers., with a population of over 5 million citizens, or 10 million total population which includes non-citizenship (National Statistical Office, 2019). Traffic congestion has intensified as the city has grown. Meanwhile, the need for mass rapid transit has been increasing. Previously, a Royal Decree establishing the Mass Rapid Transit Authority of Thailand B.E. 2543 (2000) was announced. The Mass Rapid Transit Authority of Thailand (MRTA) was tasked with operating the mass rapid transit system in Bangkok and its vicinity, including other provinces, in accordance with this Royal Decree[6]. As a result, the MRTA's mass transit is a system that provides alternative public transportation for city people in the past decade.

Notwithstanding, each day in Bangkok, there will always be people experiencing minor problems related to urban transportation and the issue tends to increase along with the growing city population. Consequently, this problem is considered an obstacle to promoting the use of public transportation, which may result in failure to encourage people to change behavior and switch to using public transport instead of driving. Moreover, there are few studies which seek to develop a general guideline, which are accountable for a variety of different city scales, locations and transit types. The Transit-Oriented Development concept can take a variety of forms (Atkinson-Palombo,

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[5] Salat, Serge; Ollivier, Gerald. 2017. Transforming the Urban Space through Transit-Oriented Development: The 3V Approach. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/26405 License: CC BY 3.0 IGO

[6] Mass Rapid Transit Authority of Thailand. 2019, About MRTA, Background. https://www.mrta.co.th/en/ (retrieved date March 2019)

2010), and therefore, should be applied to Bangkok to support the population increase because it is characterized by: 1. moderate to high density residential buildings and/or employment, 2. moderate to high mixture of land use patterns, and 3. enhanced public transport accessibility and pedestrian friendliness (Guo et al., 2018; Pal, 2018); Bangkok meets all of these requirements to do so.

1.4 Defining gaps and TOD studies in Bangkok

Bangkok is the primary urban center in Thailand aims to stimulate a modal shift from cars to public transport and the city environment is appropriate for transit-oriented development, which could be an ideal strategy to bring success regarding the goal of increasing the numbers of people using public transport.

Fortunately, the transit stations in Bangkok have different features. For example, Silom MRT station is located in the business district, whereas Ratchadapisek and Sutthisan MRT stations are located in residential areas, while Chatujak Park and Phetchaburi MRT stations offer a change of traffic line. Nevertheless, there is a need to understand the unique character of each station which is an important issue for Bangkok as far as future transportation development and planning is considered.

Table 2: Studies on the development of the area around transit stations in Bangkok, Thailand

Topic	Authors	Sources Available from:
A Study of Land Use Change around On-Nut BTS Station within the Concepts of Transit-Oriented Development	Songyot Yusok Wanarat Konisranukul	http://ejournals.swu.ac.th/index.php/JOS/article/viewFile/7025/6540
Design and planning guidelines for Transit Oriented Development (TOD) to housing and public space: A case study of Thammasat University, Rangsit Campus	Wittaya Daungthima,	http://www.erp.mju.ac.th/openFile.aspx?id=MjI0NDIw&method=inline
Evaluating accessibility to Bangkok Metro Systems using multi-dimensional criteria across user groups	Duangporn Prasertsubpakij Vilas Nitivattananon	https://doi.org/10.1016/j.iatssr.2012.02.003
Bangkok's mass rapid transit system's commuter decision-making process in using integrated smartcards	Peerakan Kaewwongwattana Vinai Panjakajornsak Paitoon Pimdee	https://doi.org/10.1016/j.kjss.2015.07.002

After reviewing various related articles about transportation in Bangkok, it was found that there have been no studies on criteria for the development of transit orientation, which are able to identify and evaluate the station area in order to understand the station typology.

1.5 Developing a TOD index for transit stations in Bangkok

For Bangkok, there is no actual typology of the transit stations while clearly the station areas and transportation networks are capable of transit-orientation. In order to achieve a better understanding of the station areas, their diversity and associated outcomes, the complexity of the contexts must be reduced (Higgins and Kanaroglou, 2016). Numerous studies show that in order to achieve an understanding of the context of the TOD station, the heterogeneity of the context of the transit station should be simplified by using a specific evaluation index to create a station typology (Bertolini, 1999; Reusser et al., 2008; Zemp et al., 2011; Kamruzzaman et al., 2014; Lyu et al., 2016; Huang et al., 2018).

In an effort to overcome the challenges, the initial phase is to develop a TOD index and identify the station areas in Bangkok. The second step will be to compare the potential stations by measuring the relative TOD components around the transit station. The results of this study will include a calculation which will generate a TOD score for each station. This score will contribute to the understanding of each station area, its diversity and its associated heterogeneity, reducing the complexity of the contexts by the use of the TOD Readiness Index.

The focus of this study is to measure an area within a 500-meter radius of transit stations in Bangkok using the TOD Readiness Index and evaluating the potential for TOD stations. The results of the study of different station areas will be compared and the researcher will identify the causality for low or high scores.

1.6 Research Objectives

1. To develop a TOD readiness index and identify the station areas in order to understand the different type of transit stations in Bangkok
2. To compare the potential TOD stations in Bangkok with TOD readiness index.
3. To evaluate the readiness of the station areas in Bangkok city in order to promote stations as TOD-compatibles station based on reasonable and available indicators

1.7 Expected contribution

This study is an effort to overcome the understanding of the station areas, their diversity and associated heterogeneity by reducing the complexity of the contexts using TOD readiness index. For this reason, TOD index can be used to explore a readiness of the transit station and the results are expected to be a guideline for establishing the criteria for evaluating any transit station in Bangkok. Furthermore, the TOD Readiness Index can be used to verify the readiness of a station and improve on inefficient features of the station in order to promote a station as a TOD-compatible station.

Chapter 2

Literature review

2.1 About Transit-Oriented Development

This following section discusses the concept, definitions and components of TOD, the built environments that make a successful TOD, the methods of TOD evaluation and measurement.

Transit-Oriented Development is a concept of city development that is integrated with the development of transportation infrastructure, especially to focus on the area around the important transit stations. It is urban planning and design that promotes the use of public transport and supports pedestrian-friendliness by threshold the land-use pattern. For this reason, the concept of TOD has been studied, explored, discussed and implemented in many cities since the conception of Carlthorpe’s TOD, published in 1993. Peter Carlthorpe, an American architect, started the concept of compact urban development in the late 1980s with his co-writer, Van der Ryn Norpp. Later in 1993, the concept of Transit Oriented Development, (TOD) which aims to develop the area around public transport stations to support the transit system, was officially published in The Next American Metropolis.

TOD has various definitions given by various authors. Even though several definitions for TOD have emerged over the years, the original concept defines TOD as “a mixed-use community within an average 2,000-feet walking distance of a transit stop and core commercial area”. Moreover, TODs mix residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, or on foot (Calthorpe, 1993).

> Boarnet and Crane (1997) described TOD in their narrowed work about residential areas near rail station as “the practice of developing or intensifying residential land use near the stations”. They also expand the idea that the area around transit stations should be developed in ways that encourage the best use of transit system.

> According to Schlossberg and Brown (2004), defined that “Transit-Oriented Development represents an integrate approach to transportation and land use planning”; while Parker et. al. (2002) further described “TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use”.

Hale and Charles (2006), described a sophisticated version of TOD as "a vibrant, relatively dense and pedestrianized mixed-use development precinct, featuring quality public space and immediate access to high frequency public transit"

Sung et al. (2011) also described 'TOD is a planning technique that aims to "*reduce automobile use and promote the use of public transit"* and human-powered transportation modes through high density, mixed use, environmentally-friendly development within areas of walking distance from transit centres'.

Singh et al. (2014) concluded that TOD is an integration of land use and transit, which encourage the best use utilization of transit, creates compact development, creates a modal shift from cars to transit, and promotes sustainability of city living. Furthermore, some TOD definitions relate to modal shifting, according to Arrington, GB & Cervero, R., (2008): 'TOD concept is an approach to expansion that aims to encourage the development of mixed use and compact, increasing the number of passengers of public transport and creating more livable communities'. Some more TOD definitions as followed table:

Table 3: TOD definitions by authors

Authors	TOD definitions
Calthorpe, 1993	a mixed-use community within an average 2,000-feet walking distance of a transit stop and core commercial area
Salvesen, 1996	Development within a specified geographical area around a transit station with a variety of land uses and a multiplicity of landowners
Still, 2002	A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving
Cervero et. al., 2004	a tool for promoting smart growth, leveraging economic development, and catering for shifting housing market demands and lifestyle preferences.
Vale, 2015	a solution to the aforementioned challenges especially when promoting as a model for urban design in areas around transit station
Maryland Department of Transportation, 2019	A place of relatively higher density that includes a mixture of residential, employment, shopping and civic uses and types located within an easy walk of a bus or rail transit centre.

Adapted from Singh et.al. (2014)

Some of these definitions emphasize the idea of improving the transport provision of a transit station by improving accessibility, creating conditions favorable to the further development of the location. However, Arrington and Cervero (2008) and Sung W. (2011) confirmed TOD as the effort to *reduce numbers of car usage* through mixed land use and high density development complemented by a built environment that supports non-motorized options. Hence, the quality and the design of the transit service also has a major impact on the success potential of TOD (Singh et al., 2014). They also argued that numerous studies of TOD projects found that people are more likely to choose transit over private vehicles if the transit is rail-based and as long as the service is an efficient, reliable and accessible system. Therefore, it is important to keep in mind that successful TOD also depends on the quality and design of the transit system.

Therefore, this study of transit-oriented development has been cast in the context that **promotes the use of public transport while supporting pedestrian-friendliness** by threshold the land-use pattern under the measurement of (1) the density, (2) the mixture of the land use pattern around the station area, and (3) the design that is built to support transit commuters.

2.2 The TOD Evaluation Method

There are number of methodologies for evaluating TOD at a station area using existing land use and density information within a given station area; this makes it possible to determine the TOD potential of the selected area. (Bertolini, 1999; Reusser et al., 2008; Zemp et al., 2011; Kamruzzaman et al., 2014). However, because of station typologies, it is hard to simply adopt a TOD evaluation methodology based on an approach done in the past (Zemp et al., 2011). Nevertheless, a study in the Netherlands developed a TOD index that quantifies the transit orientation of TOD station areas using variables (Singh et al., 2014; Singh et al., 2015). For the index to be effective and accurate, all variables must be measurable. The variables should be diverse and include both development and transit characteristics in a TOD index.

Several studies measuring indicator related to transit development; there were few tools to analyze and manage the relation between place and node properties. An interesting starting point is the Bertolini's Node-Place model, which has been developed in Netherlands as a method to examine the relationship between multimodal transportation hubs and land use. (Bertolini 1996; 1999; 2003). The authors suggest that Node should be in balance with the Place for all station areas; therefore, this is the origin of the station typologies that were created depending on that balance, and stations are used as part of Nodal indices.

Some more examples of studies on TOD analysis and evaluation not only evaluate assessments of existing TOD examples, but also identify the station type and design TOD guidelines as shown in the following table:

Table 4: TOD evaluation and its methodologies and finding by authors

Author	Approach	Evaluation method	Finding
Cervero, R. and Kockelman, K., 1997	Travel demand and the 3Ds	a set of indicators, representing the 3D s, was selected to pursue a regression analysis to evaluate the influence of built environment (3D's) on travel behavior.	the indicators can explain the relationship between land use and transport, they might not be sufficient to evaluate TOD
Schlossberg, M., et al., 2004	Spatial-temporal Analysis	a series of spatial indicators is used to visualize and quantify eight TOD areas by measuring transit usage, urban form, and socio-demographic change prior and subsequent to the incorporation of light rail and transit-oriented development policies in these two regions.	the report makes extensive use of geographic information systems (GIS) technology to both visually and quantitatively capture a series of phenomena related to TOD areas.
Renne and Wells, 2005	Reviewing proposed measures of TOD success	1.visualizing a TOD Index by highlighted fifteen success measures (using the opinions of 30 professionals) that were considered 'very useful' 2. added in findings from a literature that brought out transit ridership (the number of passengers who ride a public transport system) as the most important indicator.	Most of the indicators are suitable for use in either classification and consolidation approaches , as show in a summary of the identified key indicators
Jay et al., 2007	Transit Oriented Development Index	considering the degree to which a particular project is intrinsically oriented toward transit was developed the important elements of "successful" TOD would be captured in such an index.	suggested values for essential indicators of a "TOD Index" to describe development project "TODness"

There are several indicators that are used for TOD evaluation. According to Bertolini (1999), Renne and Wells (2005), Reusser et al. (2008), Atkinson-Palombo and Kuby (2011), Zemp et al. (2011), Kamrruzzaman et al. (2014), Widyahari and Indradjati (2015), Higgins and Kanaroglou (2016), Lyu G et al. (2016), Guo et al. (2018) and Pal (2018), a method was developed to measure the TOD in many countries in both Europe and Asia. The most common indicators used by these authors and suggested by this study are given below (non-ranked).

1) Transit Ridership
2) Density of development (include population, job and business density)
3) Quantity of a mixture of land use
4) Quality of street availability

5) Pedestrian activity and safety

In addition to suggested indicators, Renne J. and Wells J. (2005) also investigate and recommended some useful indicators for TOD evaluation that are show in the following:

Indicator (Adapted from Renne, J. & Wells, J., 2005)	Percentage verifying as "very useful"	Secondary Ranking
Transit Ridership (e.g. boarding)	70	1
Population and Housing density	67	2
Employment density (number of jobs per acre)	53	2
Qualitative rating of street scape	77	3
Mixed-use structure (number of square footage)	60	4
Pedestrian activities count	77	5
Number of street crossing improved for pedestrian safety	60	5
Estimated increased for property value	63	6
Public perception (e.g. administered survey)	63	7
Number of bus or shuttle connecting to transit station	63	8
Number of parking, space for residents, visitors, and shared	53	9
Number of service retail establishment (e.g. dry cleaner)	53	-

2.3 Factors in TOD evaluation

There are few examples where TOD results were quantified to confirm if the study failed or succeeded (Singh et al., 2017). Moreover, urban indicators in built environment as composite index are measured separately and may be unaware of which levels of TOD can be measured. A group of variables, which are Density, Diversity and Design, have become a model variable in the context of the transit-area classification of this study because the variables are commonly used to measure the TOD and have been suggested by various authors for the past decade.

2.3.1 Density

The ideal density for the TOD is wide because the degree of density is difficult to define and depends on the compactness of the surrounding area. Density, in general, refers to the degree of compactness of substances, such as people, buildings or services, that are active in a given area or space. According to the literature, Higgins and Kanaroglou (2016) and Guo et.al. (2018) defined density, in the context of TOD, as the number or concentration of opportunities per square kilometer, or another surface indicator, such as dwellings, households, people or jobs. Furthermore, TOD density is often categorized by 1) density of the ground area around the station, such as the density of housing, shops, schools, etc., and 2) economic density, such as the number of jobs in the area[7]. In addition, the density tends to improve public transport through higher potential patronage around each stop. Density, thus, influences the ability to generate and attract trips on the transit network (Renzaho, 2007; Higgins and Kanaroglou, 2016).

Table 5: Example of residential density in TOD measured by Boston's urban planning department.

Type of Residential TOD	Minimum Dense
Traditional urban neighborhood closer to the core (isolated tower in Kansas city)	30-50 units per acre
Mix of row houses, flats, and lofts (Riverview, Goodland Clancy)	30-50 units per acre
Traditional higher-density urban neighborhoods	50-100+ units per acre
Lower-rise development in an historic district (Boston's historic South End, Langham Court)	50-100+ units per acre

Note : An area of one square kilometer consists of 100 hectares each hectare containing 2.4711 acres.

Source available from; http://www.mdf.org/documents/mdc_demog_div.pdf (retrieved March 2019)

Furthermore, the density for land use, according to the Metropolitan Atlanta Rapid Transit Authority (MARTA), has categorized all transit stations into groups based on their characteristics. MARTA (2010) has developed a station typology, based on building density and the majority of land use types, which intends to illustrate thematic similarities and their differences. However, in addition to density control related to land use diversity, MARTA suggested commercial types such as vehicle dealers, which require land use spaces, and low-density facilities such as gas stations should not be in the TOD center, except for ones that require special permits to b inside the zone (i.e., hospitals, laboratories, etc.). The suggestion also encourages facilities such as high-density housing and grocery markets to be in the TOD zone.

Table 6: Appropriate density of land use in different transit stations according to MARTA

Station typology	Floor Area Ratio (FAR)	Residential Unit per Acre	Number of Floors
Urban Core	8.0-30.00	75+	8-40
Town Center	3.0-10.00	25-75	4-15
Neighborhood	1.5-5.0	15-50	2-8
Arterial Corridor	1.0-6.0	15-50	2-10

Available from https://www.itsmarta.com/uploadedFiles/More/Transit_Oriented_Development/TOD%20Guidelines%202010-11.pdf (retrieved March 2019)

[7] Paul Mees. 2010. Transport for Suburbia: beyond the automobile ages, London, Earthscan publisher. ISBN 978-1-84407-740-3

In addition to this study, Density is measured as the total population within 500 meters[8] around a transit station; the buffer of 500-meter radius represents a suitable 10-minute walk for pedestrians and transit commuters according to the Office of Transport and Traffic Policy and Planning, Ministry of Transport of Thailand.

2.3.2 Diversity of land use

In the context of TOD, diversity is usually used in relation to the land use mix or the diversity of housing types. Diversity in TOD will vary according to the area's unique characteristics and the changing dynamics that occur in an urban area over time. According to the literature, there can be many types of diversity in an urban environment, for example: social diversity (different social groups, such as the elderly or low income people), land use diversity, housing diversity, employment diversity, retail diversity, and diversity in the public domain (e.g., streets, plazas and open space). In addition, diversity is used to describe a mix of different uses and the degree of balance between a varied physical design, an expanded public realm, and multiple social groupings of different races, ethnicities, genders, ages, occupations, and households (Lund, 2005; Lyu et al., 2016; Singh et al., 2017). Diversity, thus, is seen to be achieved where people with different demographic, socio-economic, cultural, employment and visitor characteristics live in an inclusive, interactive and harmonious manner (Pal, 2018).

Diversity in an urban environment will not occur through a residential precinct alone, nor do full business types need to be found at every station. In Queensland Territory of Australia, the land use patterns addressed a wide range of factors to promote diversity.

The factors that are influential in promoting community diversity are found as follows (non-ranked):

- Urban form and land-use
- Access to diversified local employment (job diversity)
- Retail diversity (a mix of shops offering different levels of affordability)

Therefore, in this study, diversity is measured as the total employment and businesses that are located within 500 meters around a station. In addition, the availability of activities and amenities are considered the aspects that underpin successful TOD. This broad mixture is considered to be synonymous with the term 'diversity' for TOD.

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[8] Office of Transport and traffic policy and planning .2019, Thailand TOD; Available from: www.thailandtod.com

2.3.3 Design

Design measures in TOD integrate land use, zoning, and transportation planning elements to promote higher-density, mixed-use development that is easily accessible by various modes of transportation through a process of infrastructure modification and construction management. The development of a transit orientation that is designed to decrease the reliance of residents on car ownership includes: carefully articulated land-use mixtures; safe and smooth accessibility to transit stations (enabled by foot paths, cycle paths, and street lights, for example); and amenities such as benches, parks, and landscaping; which all contribute to the development of a good built environment (Pojani and Stead, 2015).

According to Kong and Pojani (2017), the essential characteristics for the design measure in TOD should encourage the transit stations and area around the stations to be residential, and commercial, with employment opportunities that provide proper accessibility for pedestrians, the elderly and people with disabilities, for example, a proper streetscape and walking-friendly footpaths which enhance walkability that attracts pedestrian traffic. These are common fundamental elements of transit-oriented design.

Therefore, in this study, the design is measured as the availability of amenities are considered the aspects that supports pedestrian accessibility such as followed:

- Adequate street lighting for safety and convenience
- Overhangs for weather protection for aesthetic purposes
- The elevator units for elderly and disabled persons
- Safe pedestrian crossings at intersections
- The entrance to commercial and buildings should be oriented to the street to minimized the distance between sidewalks and the entrance

2.4 Developing indicators

TOD indicators from this study present what is happening in the area around a transit station, including the station itself. The indicators that have been created are a mathematical combination of a dataset based on statistical principles, according to Wall (1995), who implied that a high level of aggregation is required when confronted with the judgement, such as weighting indicators in order to draw conclusions for possible courses of action (Wall, Ostertag, & Block, 1995)

However, Saisana and Tarantola (2002) confirmed that in spite of the aforementioned, the indicators are nevertheless useful to provide experts, stakeholders and decision-makers with the direction of developments, an assessment of states and trends in relation to goals and targets, and identification of areas for action (Saisana and Tarantola, 2002). The indicators present multiple dimensions to each potential transit station to support decision-making. However, the indicators may send misleading messages if they are poorly developed or misinterpreted (Pearce and Atkinson, 1993).

2.4.1 Normalization technique for station component calculation

This is the simple part of calculating the index. Before computing any indicators, each piece of raw data from each station, which are measured in different units, must be converted into the same unit. The following is the equation for calculating the standardized values.

Where $f(min) = a\ , f(max) = b$.

For this study, a would be the lowest value of the station component and b would be the highest value, for the applied scale range of scores between 0 to 5 of `[min,max]` into the range `[0,10]`. Therefore, to accept `min` into a function in order to get 0 would be as follows:

$$f(x) = x - \min = 0$$

Meanwhile, to see `max`, would give `max - min`, so the scale would be

$$f(min) = 0\ ;\ f(max) = \frac{\max - min}{\max - min} = 10$$

Hence, the aggregation can verify that putting in `min` for x now gives a, while putting in `max` gives b. Therefore, there is a scaling function that could get any arbitrary values of a and b from any station and its component, as follows:

$$f(x) = \frac{(b - a)\ (x - min)}{\max - min} + a$$

This method is more robust when dealing with outliers than a method that takes the average of the percentages around the stations' component mean for each indicator.

2.4.2 Analytic Hierarchical Process

The Analytical Hierarchy Process (AHP) was invented around the end of the 1970s as a decision process used to diagnose choices to find reasons as one of the Multi Criteria decision-making methods. This is a process that helps to make simplified decisions on issues that are complicated by mimicking the human decision-making process to derive ratio scales from paired comparisons. AHP is a technique used to divide the elements into sections in the form of hierarchical charts, and then give the weight values for each component using online software (Goepgel, 2018). By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process (Salty, 1980).

2.4.2.1 Using AHP for weighting the component

AHP generates a weight for each evaluation criteria according to the decision making; the higher the weight, the more important the corresponding criterion. The input can be obtained from an actual measurement, such as the number of the transit ridership, or of the population density, or from a subjective opinion, such as satisfaction preference. Next, the AHP assigns a score to each option according to the decision maker's pairwise comparisons of the option based on that criterion. Finally, AHP combines the criteria weights and the option scores, thus determining a global score for each option. The global score for a given option is a weighted sum of the scores obtained with respect to all of the criteria.

2.4.2.2 Checking the consistency

10 criteria, according to the literature, are considered, and the first criterion is more important than the second one, while the second criterion is slightly more important than the third criterion based on Salty's 1986 intensity of importance scale.

The AHP incorporates an effective technique for checking the consistency of evaluation made by the decision maker when establishing each pairwise comparison matrix. The technique relies on the calculation of a suitable Consistency Index (CI), which is obtained by first computing the scalar x as the average of the elements of the vector. Then,

$$CI = \frac{x - n}{n - 1}$$

A perfect consistent decision maker should obtain *CI=0;* however small values of inconsistency may be tolerated. Consistency Ratio (CR) is a comparison between Consistency Index and Random Consistency Index, as in the formula:

$$\frac{CI}{RI} = CR$$

The inconsistencies are tolerable, and a result may be expected from the AHP. In the equation, *RI* is the Random Index. The values of RI for small problems (n<=15) are shown in the table below.

Table 7: Values of the Random Index (RI) for small problems.

n	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If the value of the Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. However, when the Consistency Ratio is greater than 10%, the imitation needs to revise the subjective judgment.

2.5 TOD measurements and common indicators

For several years, many researchers have attempted to characterize different transit stations in many countries. The literature reviews accordingly found that most researchers measure the stations with those sets of similarities, such as the density (i.e., population density or total number of passengers), diversity and the design around the station-area, as variables to conduct the analysis to find the results. These variables are well applied to many transit stations for urban development around the world. Hence, the measurements from the following study (Table 8) are considered very crucial to achieving the criteria of the transit stations in Thailand and the objectives of this study.

2.5.1 Measuring the density and the diversity of land use

Due to the details of the density of populations, jobs, businesses and total length of walkable foot-paths within a reasonable radius being complicated, the collection technique needs a specific geographical information system, such as ArcGIS, to compile those raw data. Furthermore, the number of passengers and other measurements that are related to the passenger load can be collected by contacting the authorized office, such as the BEM, for reliably in-depth data.

2.5.2 Measuring the design that provides the station accessibility

In order to achieve the goal of finding what will encourage people to shift their modes of transport, a questionnaire will be distributed in order to capture opinions from the transit user about their reflection on the amenities and the safety at the transit station. In addition, the BEM office provides support for their data integrity on parking utility and availability of transit connections.

2.6 Calculation of the TOD score

This study has selecting the indicators, of which potential indicators are reasonably strong and possible to collects within Bangkok contexts. Hereupon, the TOD readiness score derives from the two main steps of weighting and normalizing the unit are required and explain as followed.

a) Weighting the indicators

The weight of each station component is an indication of its importance based on the literatures in order to calculate the TOD score. The conclusion from researcher will be uses to rank the indicators, where all indicators are ranked in terms of their importance from the result of their studies. Once all necessitate indicators have been ranked, the ranking will be select as an input for AHP process to generates the weight for each indicator.

b) Normalize the unit of indicators

The measurement indicators in this study will have different units. The analysis therefore using aforementioned technique to standardize the units for each indicator. By using normalization method, all indicators will be valued from 0 to 5 and thus far enable to create a hexagonal diagram in order to visualize the station more tangible. There is another normalization that is required to explains a characteristic of the station by which indicator that is available at the station, the value will equal to 1 instead of 0 if not available.

Table 8: The measurement and its frequent indicator found in transit orientation studies from 1999 – present

ID	Year	Title	Method	Findings / Outcomes	Measurement variables
[1]	1999	Spatial Development Patterns and Public Transport: The Application of an Analytical Model in the Netherlands.	The node±place model introduced by using Deconcentrated Clustering analysis	TOD four economic clusters C1 retail/hotel and catering C2 education/health/culture C3 administration and services C4 industry and distribution	<u>Node Index</u> y1 = number of end stations reachable by train y2 = number of trains departing from the station y3 = number of stations reachable within 20 min y4 = number of end stations reachable by bus and tram y5 = number of buses and trams departing y6 = distance to next highway exit y7 = bike path length within 2 km around the railway station <u>Place Index</u> x1 = number of residents within 700 m x2 = number of full time position equivalent workers within 700 m of the railway station in the secondary sector x3 = number of full time position equivalent workers within 700 m of the railway station in the tertiary sector x4 = 1-((a-b/d)-(a-c/d)) / 2, with a = max[x1, x2, x3], b = min[x1, x2, x3], c = 1/3(x1+x2+x3), d = (x1+x2+x3)
[2]	2004	Comparing Transit Oriented Developments Based on Walkability Indicators.	An evaluation and categorization of street type and purpose along the road network within the TODs called "Network Classification" in ArcGIS. The identification of the Impedance	11 TODs were classified as good or poor on each indicator. If a particular TOD was ranked among the top or bottom three TODs for a given indicator, it received a positive or a negative score respectively.	<u>6 built environments</u> Quantity of accessible paths Quantity of impedance paths Pedestrian catchments areas (PCA) Impedance PCA

			Arcs is based on the GIS-based road classification system.		Intersection density Density of dead ends <u>2 separate scales</u> Quarter mile (5 minutes walkable) Half mile (10 minutes walkable)
[3]	2008	Classifying railway stations for sustainable transitions – balancing node and place functions	Cluster analysis groups the sample set (railway stations) by the variance in the indicators (y_i and x_i) which are minimum within clusters and maximum in between clusters. Hence, 2-steps cluster has been used to define the distance matrix that is the input to a standard hierarchical clustering procedure	5 clusters of transit stations C1 - C5 from smallest to large station	<u>Node index</u> Passenger frequency Type of train services Staffing <u>Place Index</u> Conference rooms and educational facilities Distance to town centre Commercial services
[4]	2011	The geography of advanced transit-oriented development in metropolitan Phoenix, Arizona, 2000–2007	Factor analysis and cluster analysis are applied to GIS-based parcel level data to identify five distinct station-area types. Later, using ANOVA to verify statistically significant relationships between station-area type and the value of advanced TOD	5 station-area types, ordered from highest to lowest advanced TOD per station. 1. Employment centers 2. Middle-Income Mixed-Use areas 3. Transportation (park-and-ride) nodes 4. High population/rental areas 5 Urban poverty areas.	<u>Transportation-related characteristics</u> (Binary variable) Park-and-ride Airport Terminal <u>Social and demographic characteristics</u> Numbers of jobs Population Percentage of people with bachelor's degree Household income

					Percentage of housing units owner-occupied Percentage of land-use in each station area Residential Vacant TOD-compatible TOD-incompatible (being TOD-compatible if the land-use category was specified in zoning ordinance as an allowed or conditionally-allowed future use)
[5]	2011	Classifying railway stations for strategic transport and land use planning	Using a Hierarchical cluster analysis on 10 standardized indicators.	7 class TOD stations: C1 central stations C2 large connectors C3 medium commuter feeders C4 small commuter feeders C5 tiny tourist stations C6 isolated tourism nodes C7 remote destinations	I1 Number of jobs within a 700 m radius I2 Number of residents within a 700 m radius I3 Average distance to jobs and residents within a 700 m radius I4 Main station of a regional centre I5 Passenger frequencies at weekends compared to weekdays I6 Arriving tourists per 1000 residents of the municipality I7 Number of reachable railway stations in 20 min I8 Number of departing intercity trains I9 Number of departing regional trains I10 Number of departing buses
[6]	2014	Advance transit-oriented development typology: case study in Brisbane, Australia	Two Step Cluster Analysis was conducted to identify natural groupings of the census collection districts (CCDs) with similar profiles	4 TOD clusters C1 residential TODs C2 activity centre TODs C3 potential TODs C4 TOD non-suitability.	Net employment density Net residential density Intersection density Cul-de-sac density Land use diversity

					public transport accessibility
[7]	2014	Measuring transit-oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen	Identification of Criteria and Indicators that characterized TOD. Data collection and calculating through ArcGIS Comprehensive calculation of TOD index using SMCA	TOD index levels Density indicators Land use diversity indicator Land use mixed-ness indicator Number of business establishments	1a. Residential density 1b. Employment density 1c. Commercial intensity/density 2. Land use diversity 3a. Level of mixed-ness of land uses w.r.t residential land use 3b. Quality and suitability of streetscape for walking 3c. Quality and suitability of streetscape for cycling 3d. Density of controlled intersections/street crossings 4a. Private investment in the area 4b. Number of business establishments 4c. Tax earnings of municipality 4d. Unemployment levels
[8]	2016	Alternative transit-oriented development evaluation in sustainable built environment planning	The fuzzy Delphi method was adopted to select TOD evaluation criteria satisfying the principle of sustainable transportation, and the fuzzy analytic network process (FANP) was applied to determine the weights of relevant planning criteria.	The weighted evaluation criteria: the environmental carrying capacity in high-density development was the most crucial evaluation criterion, whereas the least critical criterion was equality in residence accessibility.	A-1 Population density in the development region A-2 Spatial density of commercial and retail facilities A-3 Design of pedestrian spaces with up-scalable traffic volume B-1 Environmental carrying capacity for high-density development B-2 Externality resulting from mixed land use B-3 Density of open spaces for improving quality of life C-1 Inhibition capacity of floor area incentives against house prices C-2 Equality in residence accessibility for all people C-3 Daily living safety of the development region
[9]	2016	Developing a TOD typology	1. Apply principal component analysis	Six types of metro station areas	T1 Number of directions served by Metro

		for Beijing metro station areas	(PCA) to generate seven uncorrelated variables. 2. Apply hierarchical cluster analysis following the Ward method (Ward, 1963) to the scores of the seven principal component in order to build up a cluster tree of cases based on their dissimilarities. 3.Use the Duda Test to define the optimal number of clusters	TOD typology C1- C6	T2 Number of directions served by bus T5 Daily frequency of Metro services T12 Number of stations within 20 min of travel by metro T15 Travel times to major employment and activity centres by Metro (seconds) T19 Car parking capacity O1 Average distance from station to jobs O2 Average distance from station to residences O9 Length of paved foot-path per acre O12 Intersection density (number of points) O14 Average block size (meters) O17 Walk scores D1 Number of residents D7 Number of jobs D9 Number of workers in retail/hotel and catering D10 Number of workers in education/health/culture D11 Number of workers in public administration and services D29 Degree of functional mix
[10]	2017	Measuring TOD around transit nodes - Towards TOD policy	Measuring the nodes Multiple Criteria Analysis calculates TOD index Questionnaire listed the criteria for TOD index of their importance in	Highest score gets highest rank in TOD-ness	DENSITY LAND use DIVERSITY* WALKABILITY ECONOMIC DEVELOPMENT TRANSIT CAPACITY*

			realisation of TOD (Borda count method, election by order of merit) 21 indicators from secondary sources		USER-FRIENDLINESS ACCESSIBILTY PARKING at station*
[11]	2018	Measuring transit-oriented development (TOD) network complementarity based on TOD node typology	1. Apply correlation matrix among measurement variables 2.Using Latent Class Cluster Method (LCCM) identify TOD typology 3.Validate the rank with numbers of passenger	Clustered result of all stations into 3 TOD typology: C1 suburban residential C2 urban residential C3 urban mixed core	1. Population, Job, and Business density (all were calculated for the area within 800 meters) 2. Land use diversity (Singh et.al's Entropy) 3. Mixed-ness of land uses 4. Intersection density and length of pedestrian & cycling network
[12]	2018	Measuring Transit-Oriented Development of Existing Urban Areas around Metro Stations in Faridabad City	1. Identify the indicators for measuring the TOD index around the transit station 2. Categorize the elements based on the TOD index using a. land use data and b. population data for analysis in GIS 3.TOD measurement and analysis Land use analysis and walkability analysis	TOD score from 0 to 1 of: Diversity of land use Residential density Commercial density Walkability (400m radius) Walkability (800m radius) Criteria used to establish station area rankings: Summary points & average station ranking	1. Population DENSITY 2. Number of population per type of land use DIVERSITY 3. Public Transport connectivity and DESIGN

** TOD refers to Transit-Oriented Development

[1] Luca Bertolini, [2] Mark Schlossberg and Nathaniel Brown, [3] Dominik E. Reusser, Peter Loukopoulos, Michael Stauffacher and Roland W. Scholz, [4] Carol Atkinson-Palombo and Michael J. Kuby, [5] Stefan Zemp, Michael Stauffacher, Daniel J. Lang, and Roland W. Scholz, [6] Md. Kamruzzaman, Douglas Baker, Simon Washington and Gavin Turrell, [7] Yamini Jain Singh, Pedram Fard, Mark Zuidgeest Mark Brussel and Martin van Maarseveen, [8] Wan-Ming Wey, Heng Zhang, Yu-Jie Chang, [9] Guowei Lyu, Luca Bertolini and Karin Pfeffer, [10] Yamini Jain Singh, Azhari Lukman and Johannes Flacke, [11] Runjie Huang, Anna Grigolon, Mafalda Madureira and Mark Brussel, [12] Paul Sat

2.7 Indicators used for TOD station measurements

The following tables (Table 9 and Table 10) represent common indicators and measurement variables that are applied for quantification by many researchers in urban transport development for many years since the TOD concept was accepted around the world. The common variables were identified from TOD studies, academic journals and research papers by urban transportation experts. This systematic summary of common indicators was conducted to describe the frequent index that was used for evaluating the area around the transit stations, including other equivalent dimensions in the TOD study.

The table has described the indicators relevant for the assessment of station areas as identified during the literature review. In Table 9, the criteria that presents the density context are the population around the station area, and also the number of passengers for each active station. Secondly, the contexts describe diversity of land use patterns, such as the number of jobs and businesses that are activated within a catchment area around transit stations. The design contexts describe properties of the design to access transport services at the station, including a holistic quality of streetscape for pedestrian accessibility to the station, as well as safety, basic amenities and the availability of the station to connect with other transport modes.

Table 9: Common indicators for quantification of context factors

Indicators	Exemplary influences on station-area assessment	Related context
D1 Population density	Number of the population within a catchment area	Density
D2 Total ridership	Number of commuters for each active station	Density
D3 Employment around transit	Number of jobs within a catchment area.	Diversity of land use
D4 Commerce around transit	Number of commercial businesses within a catchment area	Diversity of land use
D5 Walkability	Availability of walkable foot-paths around the station area	Design
D6 Distance to transit station	Estimation of length from an origin to the station	Design
D7 Built Environment Design	Quality of street crossing improved for pedestrian accessibility to station, including ped-shed, lighting around the station area	Design
D8 Station Accessibility	Basic amenities, commuter safety at the transit station	Design
D9 Station capacity	Availability of the station to connect with other transport modes	Design
D10 Parking lots	Availability of car parking in the area of transit station	Design

The ten criteria of D1 to D10 illustrates in table 10, according to the literature, are displayed, and the first criterion is more important than the second one, while the second criterion is slightly more important than the third criterion based on Salty's 1986 intensity of importance scale of 1 to 9.

Furthermore, Table 10 also provided an in-depth compilation of the index prioritization of successful stations in TOD studies from various researchers. The context of Density, Diversity and Design that are revealed within a catchment area around a transit station, have clearly been applied for research from many countries for many years. For indicators, D1-D10 are considered very crucial in achieving an assessment on a potential TOD station and to fulfill the objectives of this study.

Table 10: A compilation of the index prioritization of successful TOD studies from 2005-2018

Author	Frequent TOD indicators and their importance as verified by researcher									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Renne J. and Wells (2005)	Rank 2	Rank 1	Rank 3	-	Rank 5	-	Rank 4	-	-	Rank 6
Zemp S. et al. (2011)	Rank 2	Rank 4	Rank 1	-	-	Rank 3	-	Rank 5	-	-
Kay A. et al. (2014)	Rank 3	-	Rank 2	-	-	Rank 1	-	-	-	-
Pojani D. and Stead (2015)	Rank 1	-	Rank 2	-	Rank 5	Rank 6	Rank 4	Rank 3	Rank 7	Rank 8
Lyu G. et al. (2016)	Rank 3	-	Rank 4	Rank 5	Rank 6	Rank 7	-	Rank 2	-	Rank 1
Wey W.M. et al. (2016)	Rank 2	-	Rank 3	Rank 4	Rank 5	-	Rank 1	-	-	-
Kong W. and Pojani (2017)	Rank 2	-	-	-	Rank 3	Rank 1	Rank 5	Rank 6	Rank 4	-
Singh Y.J. et al. (2017)	Rank 3	Rank 2	Rank 4	Rank 1	Rank 6	-	-	Rank 5	-	Rank 7
Huang R. et al. (2018)	Rank 3		Rank 2	Rank 1	Rank 6	-	Rank 5	Rank 4	-	-
Pal S. (2018)	Rank 2	-	Rank 1	Rank 3	-	-	-	Rank 4	-	-

2.8 Evaluate the station areas using Multinomial Logistic Regression

The logistic regression model is basically the coefficient can be estimated from data that assumed a linear relationship between the predictor variable and the odds of the probability of the event at the station whereas the dependent variable to predict should be categorical data, which is being use for this study in order to verify the TOD scores. Therefore, Multinomial Logistic Regression (MLR) is a method that used to predict the probabilities of the discrete outcomes of a dependent variable, by a set of the predictors as the independent variables (Hosmer & Lemeshow, 2000a) will be a model in the study to evaluate the TOD stations.

An initial step of MLR model was similar to the logistic regression, nonetheless the difference is that dependent variables must be categorical rather than binary, in this case there are 3 possible outcomes of the commuter's decision around the station regarding the travel mode choices; the equation for the probabilities should be as followed:

$$\hat{Y} = \frac{e^{u_i}}{\sum_{k=1}^{j} e^{u_k}}$$

where;

$\hat{Y}$ equals a probability of the event at the station, u equal the parameter of the model, e is the exponential function, i were outcome variable I, and for j represented all dependent variable.

The studies of the relationship between travel behavior and the categorized TOD factor of density, diversity, design, destination accessibility, and distance to transit were found in Ewing & Cervero's comprehensive review (Ewing & Cervero, 2010) and the review was mentioned self-determination may occur without means. Despite the MLR uses a linear predictor function to predict the probability of the outcome variable, the model was able to modelling the choices such as travel mode choice in this case.

Hence, the MLR framework employed to examined the travel choice behavior is presented in this section. Let c be the index for commuters (c = 1, 2, …, C) and i be the index for travel choice alternatives (i = 1, 2, …, I). With this notation, the formulation takes the following form:

$$\hat{Y}_{ci} = \alpha'\beta_{ci} + \varepsilon_{ci}$$

The equation, $\hat{Y}_{ci}$ represents the mode selection obtained by the cth commuter in choosing the ith alternative. β_{ci} is column vector of attributes affecting the travel mode selection framework. α is a corresponding coefficient column vector of parameters to be estimated, the ε_{ci} is an error term assumed to be standard type-1 value distributed. Then, the commuter c will select the alternative and the probability expression for choosing alternative i is given by:

$$\mathcal{P}_{ci} = \frac{\exp(\acute{\alpha}\beta_{ci})}{\sum_{j=1}^{i} \exp(\acute{\alpha}\beta_{cj})}$$

The log-likelihood function will be constructed based on the recent probability expression, and maximum likelihood estimation is employed to estimate the parameter α.

Chapter 3

Research Methodology

This chapter describes typical indicators that will apply in TOD assessment and evaluations for this study, as well as the method to answer the question on how to develop a TOD index to verify the readiness of a transit station in Bangkok that can improve the features of the transit station to be efficient, in order to promote a station as a TOD-compatible station.

3.1 Research Framework

In order to promote the use of public transit, the study aims to develop TOD score to evaluate transit stations and their opportunity for TOD by

1) Identifying criteria and indicators for evaluating transit stations in Bangkok.
2) Calculate a score for the station based on criteria and indicators related to the literature.
3) Evaluate the TOD score, and to find what affects the commuter around the station-area, a discussion can be conducted and recommendations can be made on how to improve the stations and transit areas to move toward being the TOD stations.

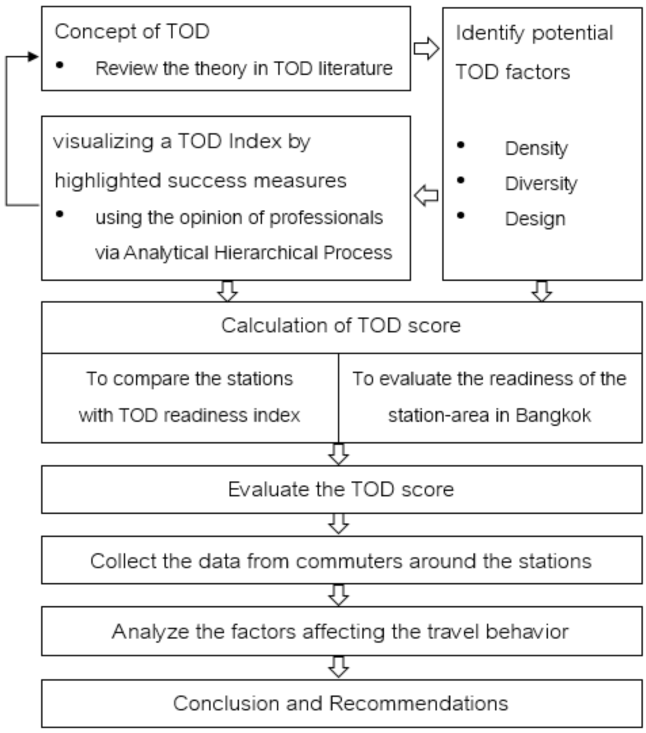


Figure 3: Conceptual framework

3.2 Calculating the TOD Readiness score

Technique that imitates participatory methods of evaluating the weights from the literature is sought; then, a proper weighting system is found, as follows:

$$\frac{x_1w_1 + x_2w_2 + \ ... \ + x_iw_i}{\Sigma w_i} = \text{TOD Readiness Score}$$

Where

x_i = station component score

w_i = weighted score

a) The **Station component score** can be applied after a proper scaling. Equal weighting works well if all sub-indicators are uncorrelated, or they are all highly correlated. This method is based on the standardized scores for each indicator which equal the difference in the indicator (e.g., for each stations' components) divided by the standard error. The range between the minimum and maximum observed standardized scores may vary for each indicator.

b) The **Weight score** is an aforementioned technique for multi-attribute decision making and as a weighting method, enables the station component to derive weights as opposed to arbitrarily assigning them. The advantage of using this technique is that the decision making based on AHP's ranking tolerates inconsistency in the way people think through the amount of redundancy. This imitation is analogous to estimating a number by calculating the average of repeated observations. The resulting weights are less sensitive to errors of judgement.

3.3 Data and measurements

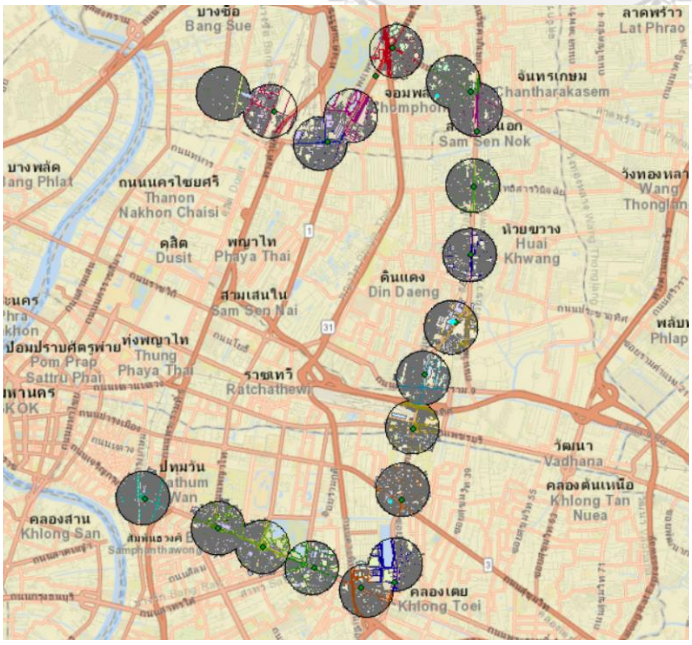
3 types of data were used in this research: (1) the 2019 census data from The Bangkok Department of City Planning and Urban Development for typology of neighborhood in land use for commercial and residential patterns; (2) spatial datasets to derive the station component of built environment and walkability for commuters; and (3) the annual dataset from Bangkok Expressway and Metro to derive the total ridership and the station accessibilities and amenities for the relevant components. Note that this study includes the building construction for residential and commercial use and the pavement within a 500-meter radius around the station. To predominantly define the station components, the boundaries are according to The Office of Transport and Traffic Policy and

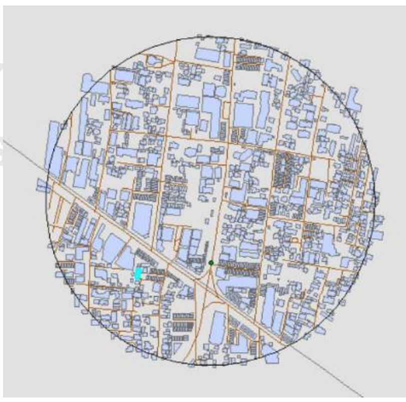
Planning. The GIS shapefiles of census land use building were used for spatially processing the dataset, and later, for the data aggregation techniques prior to statistical modeling.

3.3.1 Station component data collection

The transit stations used for this study are on the “Chaloem Ratchamongkhon Line”, of which there is a total distance of approximately 20 kilometers. It is an underground project throughout the line. There are 18 stations which have operated for over 3 years, starting from the front of Hua Lamphong station to the east along Rama IV Road, passing Sam Yan, Lumpini Park and Ratchadaphisek Road. The line then turns left to the north along Ratchadaphisek Road, passing in front of the Queen Sirikit National Convention Center, Asoke intersection, Rama 9 intersection, Huay Kwang intersection, and Ratchada-Ladprao junction. It then turns left along Ladprao Road until Ladprao intersection, and turns left again onto Phaholyothin Road, finishing through Chatuchak Park and straight to the end of the area at Bang Sue railway station. The average distance between stations is 1 kilometer (MRTA, 2019).

To calculate station components, the spatial dataset of 18 transit stations was used for analysis. The catchment area is 500 meters with the transit station at the centre. This 500-meters radius represents a suitable 10-minute walk for pedestrians and transit commuters.





Right: Example station with catchment of Sukhumvit MRT station in a zoomed view. *Left*: Transit stations in Chaloem Ratcha-mongkhon Line within a 500-meter radius.

Figure 4: The transit stations of the study area

3.3.2 TOD Readiness Indicator Reference Sheet (TRIRS)

The indicator reference sheet in this study is to use a formation to define characteristics and performance indicators by ensuring data consistency and precise description are correct. In order to promote data quality, the TRIRS is consistent across all activities collecting data for the same indicator within the transit system. When possible, the TRIRS should be completed within 6 months of the start of indicator data collection. The TRIRS can be described as follows:

Indicator Reference Sheets for the development of TOD readiness		
1.	Indicator	Population density
	Precise Definition	Population was expressed by population density for the area around each of the transit stations within a 500-meter radius of the MRT station and reflects the density per square kilometer.
	Unit of Measure	Number of resident units within the catchment area.
	Disaggregated by	Resident/non-resident living in the transit adjacent area, or rural area.
	Data Source	Department of City Planning, Bangkok Office
2.	Indicator	Total ridership
	Precise Definition	Total Transit Ridership expressed the number of rides taken by people using the public transit system in a given period of time
	Unit of Measure	Total number of annual passengers per month at each station on the blue line
	Disaggregated by	-
	Data Source	Bangkok Expressway and Metro (BEM) office
3.	Indicator	Employment around transit
	Precise Definition	Employment is described as the amount of job activity around the station area that encompasses occupations in different sectors located around transit stations within the catchment area and reflecting the intensity of employment that brings commuters to the station area. The employment units are small offices, trading companies, department stores, enterprises, warehouses and wholesalers.
	Unit of Measure	Number of employment sites within 500 meters of the MRT station
	Disaggregated by	Format of employment conditions for the jobs are not for residential use.
	Data Source	Department of City Planning, Bangkok Office

4.	Indicator	Commerce around transit
	Precise Definition	A variety of businesses were expressed by commercial type in the area around the transit station that encompassed a number of stores, supermarkets, groceries, cafes, laundromats, barbers and pharmacies. Businesses within the catchment area are used to reflect the variety of business-related land use around transit stations that provides convenient daily needs for people who are mobile around the station area.
	Unit of Measure	Number of businesses within 500 meters of the MRT station
	Disaggregated by	By the format of the shop building for commercial use, limited to the ground or must not be above a residence. *Note*** Street food businesses may be excluded for this evaluation.
	Data Source	Department of City Planning, Bangkok Office
5.	Indicator	Walkability
	Precise Definition	The extent of availability of walkable pavement which is friendly to the pedestrian measured in total length of foot-paths within a 500-meter radius of the transit station.
	Unit of Measure	Meters
	Disaggregated by	Cul-alley (Y/N)
	Data Source	Department of City Planning, Bangkok Office and Google Earth – Maps
6.	Indicator	Distance to transit station
	Precise Definition	Distance to transit station expressed the travel duration from the origin to the station entrance. The distance reflects the length between a commuter and a station that can distinguish commuter types.
	Unit of Measure	Travel time duration in minutes
	Disaggregated by	-
	Data Source	Google Earth - Maps
7.	Indicator	Built environment design
	Precise Definition	Quality of transit station features viewed as a pedestrian support facility, and accessibility to station or nearby landmarks. The design environment includes ped-shed and lighting around the station area.
	Unit of Measure	Proportion of convenient exits per total exits that directly connected to buildings or have weatherproof structures.
	Disaggregated by	-
	Data Source	Bangkok Expressway and Metro (BEM) office

8.	Indicator	Station accessibility
	Precise Definition	Service levels of a transit station that provides support to commuters with elevators ready to transfer users from the station to the platform. Supports use for disabled and elderly, or travelers with heavy luggage.
	Unit of Measure	Proportion of elevators per total exits that directly transport the commuters between ground level and the station platform.
	Disaggregated by	-
	Data Source	Bangkok Expressway and Metro (BEM) office
9.	Indicator	Station capacity
	Precise Definition	Performance levels of a transit station that provide support to commuters with basic amenities such as toilets, signage, ticketing machines, shops, lighting and safety for pedestrians at the transit station area.
	Unit of Measure	Availability of the amenities or convenient points in the station where the commuter can access service without leaving the station *Note*** If none available in the station, the value equals 0
	Disaggregated by	-
	Data Source	Bangkok Expressway and Metro (BEM) office
10.	Indicator	Parking lots
	Precise Definition	An area that is provided by the station for commuters to park any motorized transport.
	Unit of Measure	Availability of car parking in the area of the transit station *Note*** If none available in the station, the value equals 0
	Disaggregated by	-
	Data Source	Bangkok Expressway and Metro (BEM) office

Due to the details in the density of populations, jobs, businesses and total length of walkable foot-path within reasonable radius are complicated, the collection technique need a specific geographical information system such as ArcGIS to compile those raw data. Furthermore, the number of passenger and other measurement that related to the passenger load can be collected by contact to the authorized office such as BEM for reliably in-depth data. In addition, to consulting with the BEM office or website regards the data integrity on parking utility and availability will be matters.

Chapter 4

Data Calculations and Analysis

4.1 Calculating the TOD weight score

4.1.1 Initiation to divergent weight calculation

The study of the TOD Readiness Index is a very new topic in Thailand, making it more complicated to find experienced specialists. Therefore, the results from qualified researchers were applied for imitation to the intensity of importance as decision making. According to the literature, ten researchers have ranked the TOD station measurement index as successful. The number in the following tables (table 11-12) indicate the level of importance of the station components, where each dash means the components are no importance or invisible.

Table 11: Index level of importance of the station components by various researchers

	I	II	III	IV	V	VI	VII	VIII	IX	X
[D1] Population density	2	2	3	1	3	2	2	3	3	2
[D2] Total ridership	1	4	-	-	-	-	-	2	-	-
[D3] Employment around transit	3	1	2	2	4	3	-	4	2	1
[D4] Commerce around transit	-	-	-	-	5	4	-	1	1	3
[D5] Walkability	5	-	-	5	6	5	3	6	6	-
[D6] Distance to transit station	-	3	1	6	7	-	1	-	-	-
[D7] Built Environment design	4	-	-	4	-	1	5	-	5	-
[D8] Station accessibility	-	5	-	3	2	-	6	5	4	4
[D9] Station capacity	-	-	-	7	-	-	4	-	-	-
[D10] Parking lots	6	-	-	8	1	-	-	7	-	-

I.	Renne J. and Wells (2005)	VI.	Wey W.M. et al. (2016)
II.	Zemp S. et al. (2011)	VII.	Kong W. and Pojani (2017)
III.	Kay A. et al. (2014)	VIII.	Singh Y.J. et al. (2017)
IV.	Pojani D. and Stead (2015)	IX.	Huang R. et al. (2018)
V.	Lyu G. et al. (2016)	X.	Pal S. (2018)

Table 12: The level of importance of all ranked indicators from the researchers

	I	II	III	IV	V	VI	VII	VIII	IX	X
[D1]	22.3%	24.1%	17.6%	**26.3%**	15.9%	24.1%	22.3%	15.9%	17.3%	25.2%
[D2]	**28.7%**	11.9%	2.5%	1.3%	1.2%	1.6%	1.3%	22.5%	1.3%	1.9%
[D3]	17.3%	**30.8%**	26.5%	20.5%	12.3%	17.3%	1.3%	12.3%	22.3%	34.4%
[D4]	1.3%	1.6%	2.5%	1.1%	8.7%	11.9%	1.3%	27.0%	**28.7%**	17.3%
[D5]	8.4%	1.6%	2.5%	9.0%	6.0%	8.0%	17.3%	6.0%	5.6%	1.9%

[D6]	1.3%	17.3%	38.3%	6.4%	4.0%	1.6%	28.7%	1.2%	1.3%	1.9%
[D7]	12.3%	1.6%	2.5%	11.7%	1.2%	**30.8%**	8.4%	1.2%	8.4%	1.9%
[D8]	1.3%	8.0%	2.5%	16.8%	22.5%	1.6%	5.6%	8.7%	12.3%	11.6%
[D9]	1.3%	1.6%	2.5%	4.3%	1.2%	1.6%	12.3%	1.2%	1.3%	1.9%
[D10]	5.6%	1.6%	2.5%	2.9%	**27.0%**	1.6%	1.3%	4.0%	1.3%	1.9%
CR	**0.137**	**0.112**	0.049	**0.163**	**0.158**	**0.112**	**0.137**	**0.158**	**0.137**	0.082
Index count	6	5	3	8	7	5	6	7	6	4

The principles of the weight for each station component are according to Saaty's index scale from 1 to 9 in the AHP in which the highest order is extremely important, and this then decreases respectively, while the lowest (or 1) is equally important using the pairwise comparison technique. However, the consistency ratio (CR>10%) indicates that the components are inconsistent when the index count has too many components. The station components must be re-adjusted as in the following Table (13) to calculate the CR<10% before the eigenvalue is used.

Table 13: The level of importance of each visible ranked indicator of various researchers

	I	II	III	IV	V	VI	VII	VIII	IX	X
[D1]	26.3%	29.5%	7.5%	31.0%	16.0%	29.5%	26.3%	16.0%	17.9%	28.7%
[D2]	38.3%	7.5%	-	-	-	-	-	26.5%	-	-
[D3]	17.9%	44.0%	25.1%	22.6%	11.2%	15.9%	-	11.2%	26.3%	54.4%
[D4]	-	-	-	-	6.7%	7.5%	-	33.7%	38.3%	12.3%
[D5]	5.1%	-	-	7.9%	3.8%	3.2%	17.9%	3.8%	2.4%	-
[D6]	-	15.9%	67.3%	5.0%	2.0%	-	38.3%	-	-	-
[D7]	10.0%	-	-	11.1%	-	44.0%	5.1%	-	5.1%	-
[D8]	-	3.2%	-	17.7%	26.5%	-	2.4%	6.7%	10.0%	4.5%
[D9]	-	-	-	3.0%	-	-	10.0%	-	-	-
[D10]	2.4%	-	-	1.7%	33.7%	-	-	2.0%	-	-
CR	0.081	0.086	0.170	0.097	0.098	0.086	0.081	0.098	0.081	0.111
Index count	6	5	3	8	7	5	6	7	6	4

In contradiction to the previous table, AHP was repeated to address the hierarchy of the index that grouped TOD stations into indicators by the experts' selection. This imitation found that the consistency ratio will no longer be an issue because CR is not exceeding 10% when the experts have found the index to be between 5 to 7 for the measurement of TOD stations. However, the index count shows that using 6 indicators is optimal because the CR will be 0.081, which is the longest distance to the CR of 10%.

4.1.2 Convergence weight calculation

This section demonstrates the method for generating the weight score that will be applied to any transit station by ranking, once again, the current station components by their level of importance. Notwithstanding, only the weights which have a supreme value from each consistent component (CR<10%) will be selected for further calculation. Table 14 shows the weight of each station component within the TOD contexts as follows:

Table 14: All component indicators were prioritized using AHP software to see the consistency level

Global TOD Component	*Bangkok Transit Station Component*	*Component ranking based on weighting value*	*Highest weighting value for CR<10% from earlier*	*Weight for CR<10% After prioritize using AHP*
DENSITY	D1 Population density	4	31.0%	6.2%
	D2 Total Ridership	2	38.3%	9.9%
DIVERSITY of land use	D3 Employment around transit	1	44%	23.6%
	D4 Commerce around transit	2	38.3%	9.9%
DESIGN	D5 Walkability	6	17.9%	2.3%
	D6 Distance to transit station	2	38.3%	9.9%
	D7 Built Environment design	1	44.%	23.6%
	D8 Station accessibility	5	26.5%	3.8%
	D9 Station capacity	7	10.0%	1.3%
	D10 Parking lots	3	33.7%	9.5%

The context of Density, Diversity and Design that was revealed in the reviews chapter are clearly involved with those D1-D10 components in order to assess the potential for TOD stations. Table 14 shows the attachment of TOD components and the station components of their weighting value before and after compliance with Saaty's index scale. In the computerized AHP process, the result of the 45 comparisons was arranged in a matrix and shown in the following figure (5):

Figure 5: A decision matrix with resulting priorities of weights for the score calculation

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Employment	23.6%	1	7.5%	7.5%
2	Built Design	23.6%	1	7.5%	7.5%
3	Total Ridership	9.9%	3	2.2%	2.2%
4	Commerce	9.9%	3	2.2%	2.2%
5	Distance	9.9%	3	2.2%	2.2%
6	Parking Area	9.5%	6	2.7%	2.7%
7	Population	6.2%	7	2.6%	2.6%
8	Station Accessibility	3.8%	8	2.3%	2.3%
9	Walkability	2.3%	9	1.5%	1.5%
10	Station Capacity	1.3%	10	0.8%	0.8%

Number of comparisons = 45
Consistency Ratio CR = 5.7%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5	6	7	8	9	10
1	1	1.00	3.00	3.00	3.00	4.00	5.00	6.00	7.00	8.00
2	1.00	1	3.00	3.00	3.00	4.00	5.00	6.00	7.00	8.00
3	0.33	0.33	1	1.00	1.00	1.00	2.00	4.00	6.00	8.00
4	0.33	0.33	1.00	1	1.00	1.00	2.00	4.00	6.00	8.00
5	0.33	0.33	1.00	1.00	1	1.00	2.00	4.00	6.00	8.00
6	0.25	0.25	1.00	1.00	1.00	1	2.00	4.00	6.00	8.00
7	0.20	0.20	0.50	0.50	0.50	0.50	1	3.00	5.00	7.00
8	0.17	0.17	0.25	0.25	0.25	0.25	0.33	1	4.00	6.00
9	0.14	0.14	0.17	0.17	0.17	0.17	0.20	0.25	1	5.00
10	0.12	0.12	0.12	0.12	0.12	0.12	0.14	0.17	0.20	1

Principal eigen value = 10.759
Eigenvector solution: 7 iterations, delta = 4.7E-9

The results show a consistency of CR = 5.7%. This indicates that the station components by this weighting and eigenvalue are consistent. Nevertheless, the initiative method persisted in stating that to have 6 station components instead of all D1 to D10 for weight calculation is the optimal solution. Concurrently to a duplication of the index characteristics by its description according to the indicator reference sheet (TRIRS), D5 to D6 and D7 until D10 need to merge because they are arguably using the same dataset, and thus can reduce the components, in order to complete the objectives. Hence, the TRIRS should readjust the measurement to make it compatible, as follows:

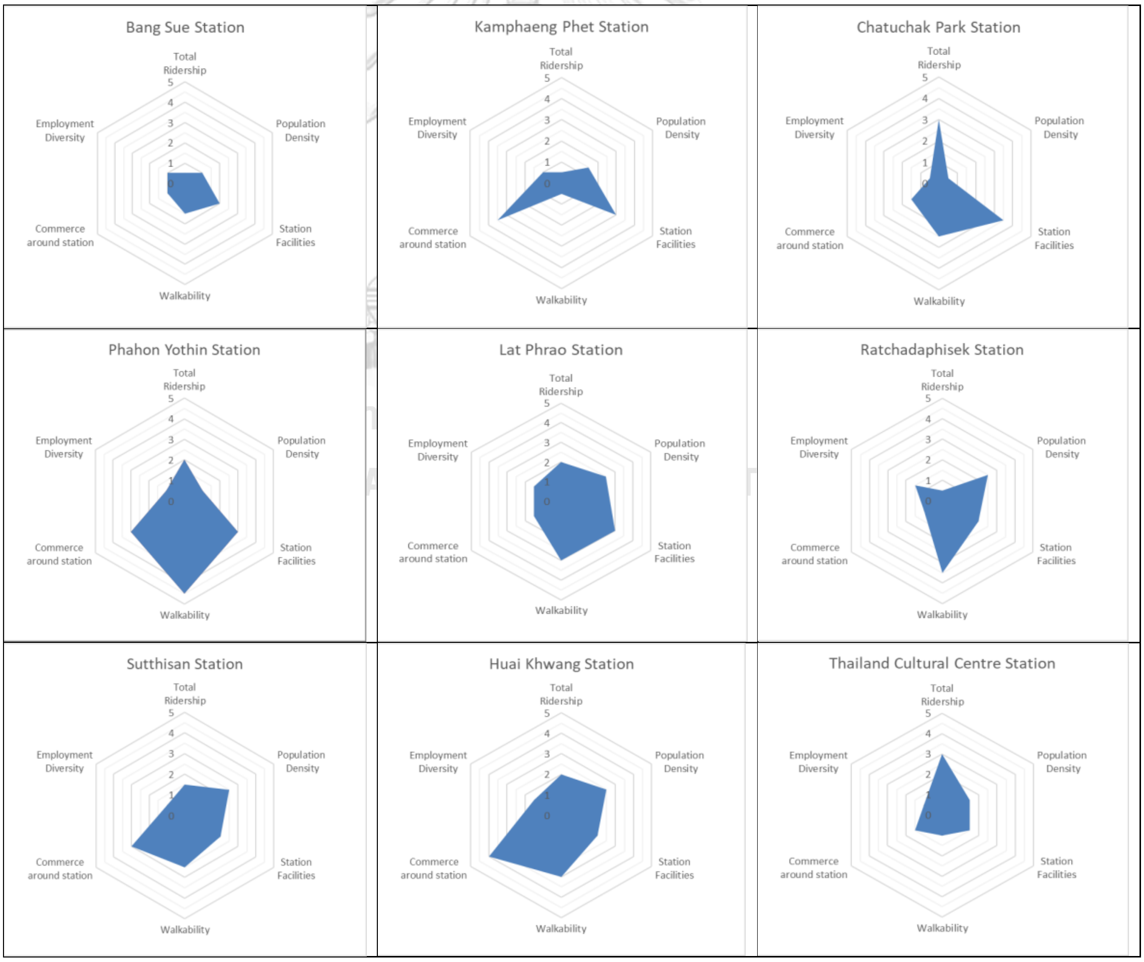
TOD CONTEXT	STATION COMPONENT	Measurements
DENSITY	Total ridership	Total number of rides taken by people using the public transit system for each active station in a given period of time
	Population density	Number of residences within a 500-meter radius around the station
DESIGN	Station facilities	The quality of the station amenities, safety for commuters using the services, including ped-shed and car parking, as well as the availability of the station to connect with other transport modes.
	Walkability	The availability of walkable pavement within catchment area that supporting pedestrians to use the transit system and services.
DIVERSITY OF LAND USE	Commerce around station	The number of business types, such as stores, supermarkets, groceries, cafes, laundry, barbers and pharmacies within the catchment area that encompasses the variety of business-related land use around transit stations that provides for the daily convenience needs of people who mobilize around the station area.

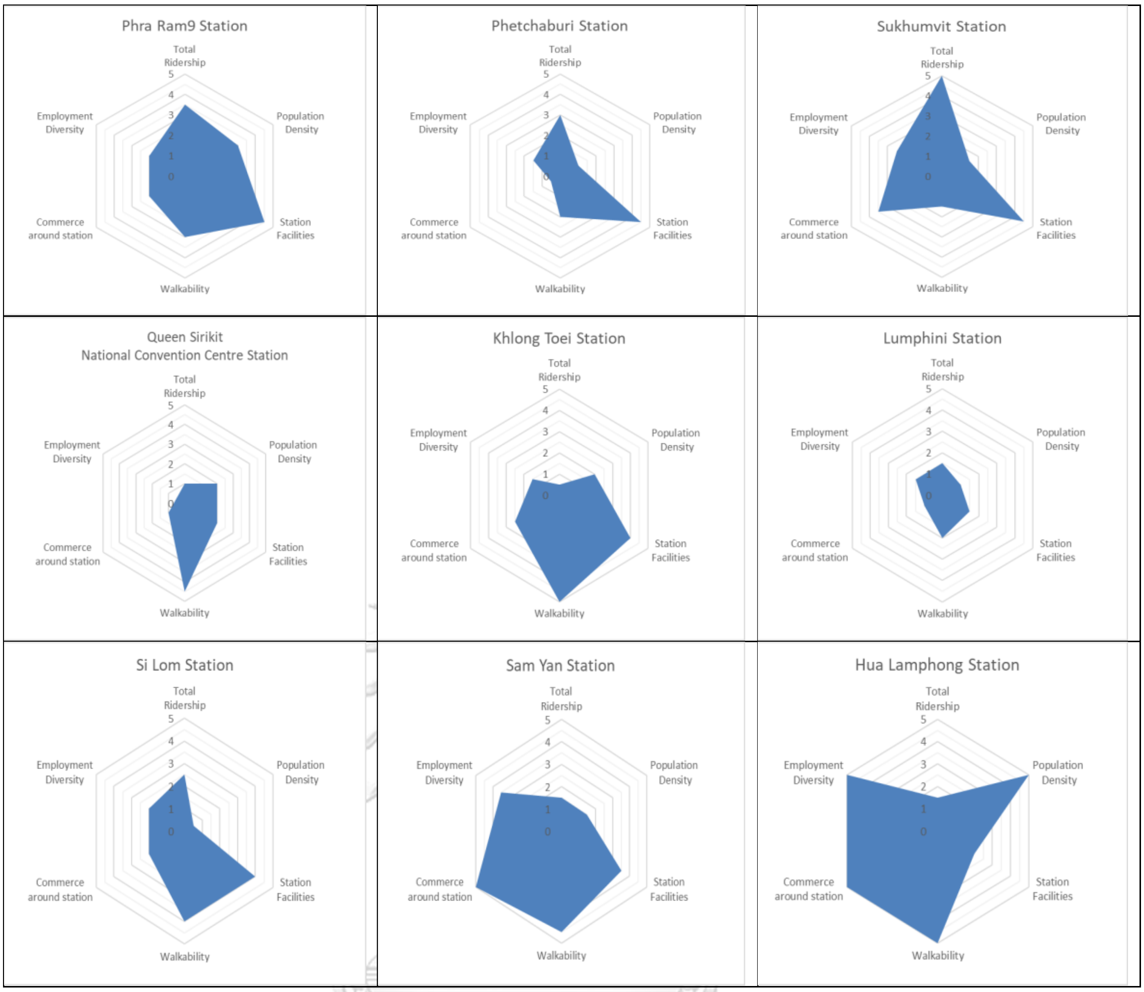
	Employment diversity	The number of employment sites such as offices, trading companies, department stores, enterprises, warehouses and wholesalers within the catchment area that encompasses occupations in different sectors located around transit stations and reflect the intensity of job employment that brings commuters to the station area.

4.1.3 Station Component score

This section has illustrated the characteristics as raw data for 18 MRT stations in Chaloem Ratchamongkhon Line. The following figure has summarized the characteristics for each station in hexagonal diagram scaled by the equal weighting techniques. Each diagonal corner represents the score for each component of the station scaled from 0 to 5 in the same standardized unit. At this point, Figure 6 presents multiple dimensions to each transit station that can be seen as followed:

Figure 6: Hexagon diagrams showing the characteristics for each transit station sorting by locations





Notes: current dataset for TOD readiness index as of 2020

4.1.4 Calculate the TOD Readiness score for each stations

The results for each station are tabulated in Table 15. Since this study is calculating a TOD readiness index for station areas in Bangkok for the first time, there are no references available from the literature. For this reason, the TOD readiness scores need to be compared with each other for better understanding. The total lowest and highest ranges of TOD readiness scores for 18 stations are between 1.393 and 3.507 on a total scale of 0 to 5.

Table 15: Criteria and TOD Readiness scores of the 18 transit stations for this study

Station Name (ascending in order from the score)	TOD Readiness Score	Criteria (‘ w ’ in each column represents the weight value of TOD criteria)					
		Total Ridership (w=.099)	Population Density (w=.062)	Station Facilities (w=.382)	Walkabili-ty (w=.122)	Commerce around station (w=.099)	Employ-ment Diversity (w=.236)
Hua Lamphong	3.507	1.5	5.0	2.0	5.0	5.0	5.0
Sam Yan	3.448	1.5	1.5	3.5	4.5	5.0	3.5
Sukhumvit	3.426	5.0	1.5	4.5	1.5	3.5	2.5
Phra Ram 9	3.287	3.5	3.0	4.5	3.0	2.0	2.0
Si Lom	2.964	2.5	0.5	4.0	4.0	2.0	2.0
Khlong Toei	2.913	0.5	2.0	4.0	5.0	2.5	1.5
Phetchaburi	2.725	3.0	1.0	4.5	2.0	0.5	1.5
Phahon Yothin	2.488	2.0	1.0	3.0	4.5	3.0	1.0
Lat Phrao	2.367	2.0	2.5	3.0	3.0	1.5	1.5
Chatuchak Park	2.236	3.0	0.5	3.5	2.5	1.5	0.5
Huai Khwang	2.233	2.0	2.5	2.0	3.0	4.0	1.5
Kamphaeng Phet	1.932	0.5	1.5	3.0	0.5	3.5	1.0
Sutthisan	1.905	1.5	2.5	2.0	2.5	3.0	1.0
Ratchadaphisek	1.848	0.5	2.5	2.0	3.5	1.0	1.5
Queen Sirikit National Convention Centre	1.753	1.0	2.0	2.0	4.5	1.0	0.5
Lumphini	1.480	1.5	1.0	1.5	2.0	1.0	1.5
Thailand Cultural Centre	1.469	3.0	1.5	1.5	1.0	1.5	1.0
Bang Sue	1.393	0.5	1.0	2.0	1.5	1.0	1.0

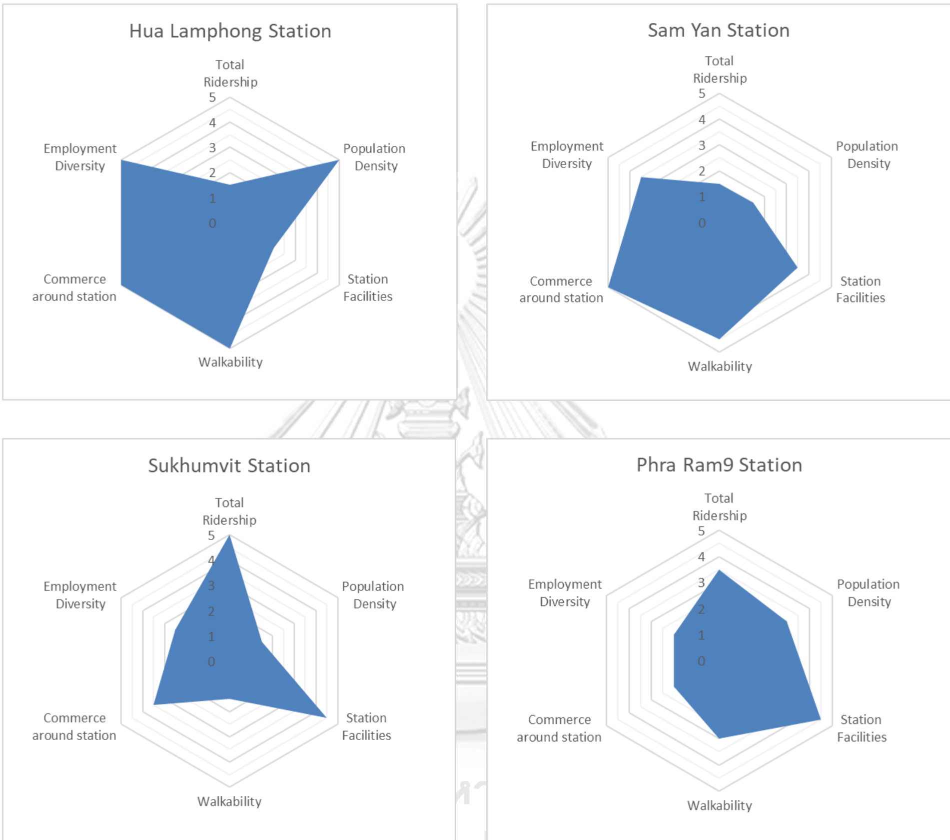
Due to the characteristics of the components surrounding the stations, the scores for individual criteria such as walkability, station facilities, and employment around the station are considered as high. Thus, it is according to the design components and the diversity of land use criteria that leads to high total scores. A higher TOD readiness score implies that a transit station is more eligible for application of the TOD concept, in order to support pedestrian use of the transit station with less car dependency.

4.2 Evaluate the station area with TOD score

The TOD Readiness Index has been completed to measure 18 station areas along the Chaloem Ratchamongkhon Line. The TOD Readiness Index results can now be used as a guideline to evaluate any transit station in Bangkok. To promote a station as a TOD-compatible station, however, each case station, with its TOD readiness score, must be evaluated as to the level of car dependency for commuters. Hence, Hua Lamphong station, Sam Yan station, Sukhumvit station, and

Phra Ram 9 station were selected as the case stations that were compatible with a TOD station according to their scores. Figure 7 has illustrated the characteristics for the four top-scoring stations in a hexagonal diagram. Each diagonal corner represents the score for each criteria of the station as scaled from 0 to 5 in the same standardized unit.

Figure 7: The hexagonal diagrams for the stations with high TOD readiness scores



In Bangkok, the choices between public transport and private vehicle for everyday mobility were competitive options. However, transit commuter behavior could be changed due to the construction around the area of transit stations (Rahman and Baker, 2018). With the increase of population and traffic congestion in Bangkok, there must be a mechanism to promote the use of public transportation. The results in this section are expected to verify the TOD readiness score for the case stations, not only to reduce car dependency, but to create a reliable TOD development system. Therefore, a study on the development of a TOD readiness index and its application to transit stations in Bangkok will be presented with descriptive statistics using tables as follows:

(1) Socio-demographic data and the use of transit station characteristics of the commuters, (2) Level of opinions toward the station use and living around the station area, explained using inferential statistics, and (3) a multinomial logistic regression model to perform an analysis to identify factors affecting travel mode selection of commuters in Bangkok.

In addition, a summary of notation for variables and symbols which apply to this section is included below:

X_1	for	Gender
X_2	for	Age
X_3	for	Accommodation types
X_4	for	Estimate travel time to station by walking
X_5	for	Station score
X_6	for	Reason to use the station
X_7	for	Frequency of use of the station
X_8	for	Monthly cost of travel by MRT
n	for	Number of observations
$\bar{x}$	for	Observation mean
σ	for	Observation standard deviation
χ^2	for	Chi-square
$\hat{Y}$	for	Probability of the travel mode choice of the commuter
α	for	Corresponding coefficient of parameters
β	for	Regression coefficient of attributes
ε	for	Error term
$\mathcal{P}$	for	Probability of the event
j	for	All independent variables

4.3 Explanation of the descriptive statistics

Sociodemographic data and the use of transit station characteristics of the commuters around Hua Lamphong station, Sam Yan station, Sukhumvit station, and Phra Ram 9 station.

Table 16: A summary of demographic data and the station use by commuters

Variables	Classification	Frequency	Percentage (%)
Sociodemographic characteristics			
Gender	Male	110	55.0
	Female	85	42.5
	Not specific	5	2.5
Age	Under 14 years	1	0.5
	14-22 years	40	20.0
	23-59 years	148	74.0
	Over 60 years	11	5.5
Accommodation	Single house	37	18.5
	Shop house	43	21.5
	Town house	31	15.5
	Apartment	46	23.0
	Condominium	43	21.5
Estimated travel time to station by walking	Under 5 minutes	22	11.0
	5 – 10 minutes	68	34.0
	Over 10 minutes	110	55.0
The use of transit station characteristics			
Station score	3.507 (Hua Lamphong station)	50	25.0
	3.448 (Samyan station)	50	25.0
	3.427 (Sukhumvit station)	50	25.0
	3.288 (Phra Ram 9 station)	50	25.0
Reason for using the station	No use	1	0.5
	For meals or leisure	70	35.0
	For work or school	101	50.5
	For shopping or business	28	14.0
Station use frequency	No use	1	0.5
	Less than once a week	22	11.0

	1-2 trips a week	80	40.0
	3 or more trips a week	97	48.5
	Under 100 THB	11	5.5
	100 – 300 THB	54	27.0
Monthly cost of travel	300 – 500 THB	67	33.5
	500 – 1,000 THB	60	30.0
	Over 1,000 THB	8	4.0

Table 16 shows the demographic data of the participants: 110 (55.0%) of the respondents were male and 85 (42.5%) were female; 40 (20.0%) of the respondents were between 14-22 years using a student card, 148 (74.0%) were between 23-59 years using an adult card, and 11 (5.5%) were aged over 60 years using an elderly card, while, lastly, only 1 (0.5%) was under 14 years using a child's card. 37 (18.5%) of the respondents are living in a single house, 43 (21.5%) are living in a shop house, 31 (15.5%) are living in a townhouse, 46 (23.0%) are living in an apartment, and 43 (21.5%) are living in a condominium.

Likewise, the travel behavior of 50 participants from each station including Hua Lamphong station (25.0%), Sam Yan station (25.0%), Sukhumvit station (25.0%), and Phra Ram 9 station (25.0%) were collected and illustrated as follows: 22 (11.0%) of the respondents walked to the station in less than 5 minutes from their accommodation, 68 (34.0%) walked to the station within 5 to 10 minutes, and 110 (55%) took over 10 minutes to walk to the station from the accommodation. For the station use, 28 (14.0%) traveled by MRT for shopping or business; 101 (50.5%) traveled by MRT for work or school, and 70 traveled by MRT for meals or leisure. Only 8 respondents (4%) spent over 1,000 baht for the ticket fare, 60 respondents (30.0%) spent between 500 – 1,000 baht for the fares, 67 respondents (33.5%) spent from 300 – 500 baht for the fares, 54 respondents (27.0%) spent from 300 – 100 baht for the fares, and the 11 remaining (5.5%) spent less than 100 baht per month on their travel costs.

In addition, the following Table 17, illustrated the rate of opinions toward the use and the living around the station area at Hua Lamphong station, Sam Yan station, Sukhumvit station, and Phra Ram 9 station, in 2020. The degree of opinion for the different aspects of the area around the station used a Likert scale. The overall median score was 3.54 for the impression that living near the station can help reduce their travel expenses. The survey observed that the metro station service helps commuters reduce their travel times, and the quality of footpaths around the station which affects their decisions to walk to the station with mean ratings of 3.62 and 3.59. Nonetheless, concerning living nearby stations increasing the convenience of purchasing daily needs and station facilities affecting your decision to walk and use the services, these were relatively less presumed, with mean ratings of 3.40 and 3.48, respectively.

(n=200)

Content	Level of opinion, No.(%)					Mean Score $\bar{x}$	σ	Rated opinion
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree			
Living nearby station helps reduce travel expenses	1 (0.5%)	-	11 (5.5%)	66 (33.0%)	122 (61.0%)	3.54	.648	Strongly Agree
Living nearby station increases the convenience of purchasing daily needs	-	3 (1.5%)	14 (7%)	82 (41.0%)	101 (50.5%)	3.40	.688	Agree
Metro station service helps reduce your travel time	-	-	13 (6.5%)	50 (25.0%)	137 (68.5%)	3.62	.606	Strongly Agree
Footpaths around the station area affects your decision to walk to the station	-	-	13 (6.5%)	55 (27.5%)	132 (66.0%)	3.59	.610	Strongly Agree
Station facilities affects your decision to walk and use the services	-	-	7 (3.5%)	89 (44.5%)	104 (52.0%)	3.48	.566	Agree
Overall						3.54	.648	Strongly Agree

Table 17: Level of opinions toward the use and the living around the station area

4.4 Factors affecting travel mode selection of commuters in Bangkok with the TOD Readiness Index

The multinomial logistic regression (MLR) model was used to analyze the travel mode decision of using public transport or using cars by observation. The analysis was conducted through a computerized software package. There are three alternative choices for the observation (No, Maybe, or Yes) to identify their selection to use public transport instead of a private vehicle for their travel mobility. The choice will be selected by the respondent as a decision; later, the respondents' travel choice will be transformed into a nominal data, outcome variable.

4.4.1 Outcome variables

The selection of rail mode over car when needed by respondents was used as a dependent variable in this study to investigate the travel mode selection behavior in order to verify the TOD Readiness Index along with promoting the station as TOD-compatible which supports pedestrian friendliness. The respondents were asked to indicate their selection level of the MRT service compared to car use when needing to commute. There are three selection options, No, Maybe, and Yes, explaining their preference for use of the rail mode services.

The survey gathered data from 200 respondents across four ranked stations to indicate their decision on whether they choose public transport services or cars when needed. Responses (Table 18) showed that 76.0% of the commuters decided to use the MRT services instead of the car; 7.0% declined to use the MRT service when needed, and 17.0% of the commuters were mutual, either Yes or No, but were likely to reply 'Maybe' to reduce their car dependency because of their current situation at the station area.

Table 18: Commuter travel selection between public transport services and car uses

Outcome Variable	Classification	Frequency	Percentage (%)
MOREMRT	No, not to select MRT over car use when needed	14	7.0
	Maybe, to select MRT over car use when needed	34	17.0
	Yes, to select MRT over car use when needed	152	76.0

4.4.2 An examination of correlations among manifest variables

The existing literature has identified that the reason to use the MLR is because the outcome variable had more than two categorical outcome variables which had been used to analyze the travel choice behavior of the individual trip maker (Eluru et.al., 2012). In addition, the following table 19 illustrates the correlation co-efficient amongst the demographic and travel behavior variables. The independent variables were applied in the analysis to verify the induced travel choice behavior of the commuters. Nevertheless, the gender variables exhibit no sign of significance. This study has set the statistical significance at a 0.05 significant level using the MLR model. These predictors' variables were applied to verify the TOD readiness score to encourage the commuters to reduce their car dependency.

Table 19: Correlation matrix among the variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	-	-.104	.020	-.084	-.127	-.022	.131	.086
X_2	-.104	-	.051	-.034	-.148[b]	-.021	.120	.143[b]
X_3	.020	.051	-	-.526[a]	-.075	.020	.144[b]	.151[b]
X_4	-.084	-.034	-.526[a]	-	-.163[b]	.104	-.149[b]	-.143[b]
X_5	-.127	-.148[b]	-.075	-.163[b]	-	.101	-.183[a]	-.119
X_6	-.022	-.021	.020	.104	.101	-	.050	.144[b]
X_7	.131	.120	.144[b]	-.149[b]	-.183[a]	.050	-	.680[a]
X_8	.086	.143[b]	.151[b]	-.143[b]	-.119	.144[b]	.680[a]	-

Note: 'a' and 'b' indicate the Pearson correlation is significant at the 0.01 and 0.05 level (2-tailed), respectively. Note 2: X_1 = Gender, X_2 = Age, X_3 = Accommodation types, X_4 = Estimated travel time to station by walking, X_5 = Station score, X_6 = Reason to use the station, X_7 = Frequency of use of the station, X_8 = Monthly cost of travel by MRT

4.4.3 Verifying the TOD readiness score using multinomial logistic regression

A formulation of the multinomial regression model to represent the factors affecting travel mode selection of commuters with the TOD index was derived using the following equation:

The MLR framework employed to examine the travel choice behavior is presented in this section with *c* being the index for commuters (*c* = 1, 2, …, *C*) and *i* being the index for travel choice alternatives (*i* = 1, 2,…, *I*). With this notation, the formulation takes the following form:

$$\hat{Y}_{ci} = \alpha'\beta_{ci} + \varepsilon_{ci}$$

The equation, $\hat{Y}_{ci}$, represents the mode selection obtained by the *c*th commuter in choosing the *i*th alternative. β_{ci} is the column vector of attributes affecting the travel mode selection framework. α is a corresponding coefficient column vector of parameters to be estimated, while ε_{ci} is an error term assumed to be a standard type-1 value distributed. Then, the commuter, *c*, will select the alternative and the probability expression for choosing the alternative *i* is given by:

$$\mathcal{P}_{ci} = \frac{\exp(\acute{\alpha}\beta_{ci})}{\sum_{j=1}^{i}\exp(\acute{\alpha}\beta_{cj})}$$

The log-likelihood function will be constructed based on the recent probability expression, and maximum likelihood estimation is employed to estimate the parameter α.

For the hypothesis of:

H_0 = there is no significant impact in the travel mode selection of the respondent on the station score.

H_1 = there is significant impact in the travel mode selection of the respondent on the station score.

4.4.3.1 Model fit

The analysis using the likelihood ratio test to assess model fit in MLR as in the following tables, the -2 log likelihood is computed for the Intercept Only model, or the null model, and the final model with all the sociodemographic and travel behavior variables.

Table 20: Model Fitting Information

Model	Model fitting Criteria AIC	BIC	-2 Log Likelihood	Likelihood Ratio Tests Chi-Square	df	Sig.
Intercept Only	270.480	277.076	266.480			
Final	251.029	270.819	239.029	27.450	4	.000

Table 21: Step Summary

Model	Action	Effect(s)	Model fitting Criteria AIC	BIC	-2 Log Likelihood	Likelihood Ratio Tests Chi-Square[b]	df	Sig.
0	Entered	<all>[a]	268.580	354.337	216.580			
1	Removed	WALKETA	264.647	343.807	216.647	.067	2	.967
2	Removed	WHYMRT	259.127	318.497	223.127	6.480	6	.372
3	Removed	COST	257.193	309.966	225.193	2.066	2	.356
4	Removed	AGE	256.189	302.366	228.189	2.996	2	.224
5	Removed	LIVING	251.029	270.819	239.029	10.840	8	.211

Stepwise Method: Backward Elimination; a. This model contains all effects specified or implied in the MODEL subcommand; b. The chi-square for removal is based on the likelihood ratio test.

Table 22: Likelihood Ratio Tests

Effect	Model fitting Criteria AIC of Reduced model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Likelihood Ratio Tests Chi-Square	df	Sig.
Intercept	253.507	266.700	245.507	6.477	2	.039
SCORE	252.997	266.190	244.997	5.968	2	.051
FREQUENT	272.385	285.578	264.385	25.355	2	.000

The analysis in table 20 shows the final model is significantly different from the model without independent variables, therefore accepting the alternative hypothesis, which there is significant impact in the travel mode selection of the respondent on the station score.

Basically, the full factorial model in MLR contains only all main effect and all factor interactions, except for covariate interactions. A specific method may be required to make appropriate interaction. Using a stepwise procedure to check the importance of variables by either entering or deleting the variable on the basis of decision rules is appropriate when the outcome variable is 'polychotomous' with *k* levels (Hosmer and Lemeshow, 2000b). Thus, this study requested a custom model by applying the station scores the variable as a forced entry list that is always included in the model, then later requests the stepwise selection method.

The backward elimination method, as shown in Table 21, begins by entering all terms specified on the stepwise list into the model. At each step, the least significant predictor variable is removed from the model until all of the remaining predictor variables have a statistically significant contribution to the model. Only those interaction terms which are significant and contributing to the final model as the predictor will appear in the results in Table 22.

The amount of change between these models suggests a slight improvement in model fit from Table 20. The model fitness was assessed by the chi-square test: the -2 log likelihood for each are subtracted from one another to create the chi-square (266.48 – 239.03 = 27.45), and the p-value was less than .10, [$\chi^2(4)=27.45$, p=.000]. Using the conventional significant level at .10 thresholds, the group of independent variables (Table 22) were the significant predictors in the model that contribute to predictions of the outcome variable. The final model is significantly different from the model without independent variables. Hence, there is a significant relationship between the predictors and the outcome variables in the final model. More generally, TOD score and Frequency use were 2 variables that significantly impact the travel mode selection.

4.4.3.2 Goodness of fit

	Chi-Square	df	Sig.
Pearson	338.492	324	.279
Deviance	227.704	324	1.000

The Goodness of fit table determines if a model exhibits a good fit with the data, although non-significant test results are indicators that the model fits the data well (Tabachnick and Fidell, 2007). However, Deviance's chi square test indicates that the model does fit the data well [$\chi^2(324)=227.704$, p=1.00], whereas Pearson's chi square test shows the model having a poor fit with the data [$\chi^2(324)=338.492$, p=.279]

4.4.3.3 Effect size

There are three statistics that have been summarized by the software as followed: Cox and Snell's R^2 of .128; Nagelkerke's R^2 of .171 indicates a relationship between prediction and grouping; and McFadden's R^2 of .099. Cox and Snell's pseudo R^2 is based on the log likelihood that cannot achieve a maximum value of 1, whereas the pseudo R^2 statistics by McFadden was a transformation of the likelihood ratio statistic with a value from .2 to .4 which, for McFadden are considered highly satisfactory (Homer and Lemeshow, 2000, Tabatchnick and Fidell, 2007). The McFadden pseudo R^2 in the study (Table 23) would be considered weak.

Table 23: Pseudo R-Square

Cox and Snell	.128
Nagelkerke	.171
McFadden	.099

The model accounts for 9.9% to 17.1% of the variance and represents relatively marginally acceptance. However, the likelihood ratio tests illustrated the significance of the predictor computed for each of the independent variables from table 20 to table 22. This tests the improvement in the model fit with each of the predictor variables when eliminated; hence, those were the case for the predictor variables in this study.

4.4.3.4 Parameter Estimates for the final model

Table 24: Parameter Estimates

Select MRT over Car when needed (The reference category is: No)		B	Standard Error	Wald	Exp(B)	95% Confidence Interval for Exp(B)	
						Lower Bound	Upper Bound
Maybe	Intercept	6.530	13.064	.250			
	SCORE	-1.467	3.765	.152	.231	.000	369.311
	FREQUENT	-.325	.441	.545	.722	.304	1.714
Yes	Intercept	-14.380	11.976	1.442			
	SCORE	4.230	3.439	1.513	68.707	.081	58146.691
	FREQUENT	1.012	.407	6.195	2.751	1.240	6.105

According to Table 20, a test of the full model against the null model was statistically significant; the table indicates the predictor as a set, reliably discriminate between Yes, Maybe and No of the travel mode choice selection (chi-square=27.450, $p < 0.001$), despite Table 24 providing results of information comparing each travel selection group against the reference category (decision to No). The regression coefficient *B* indicates which predictors significantly discriminate between (1) the commuters who decided Yes and those who decided No; and between (2) the commuters who decided Maybe and those who decided No.

The Exponentiation of the coefficients (*Exp(B)*) indicates how the risk of the outcome falling in the comparison group (Yes and Maybe) compared to the risk of the outcome falling in the reference group (No) changes with the score variable and the frequent variable.

(1) The set of coefficients were compared between the Yes and No groups, and the predictor ‘score’ showed a positive coefficient of 4.230. In addition, the exponential beta of 68.707 indicated that for every 1 unit increase on the score, then the odds of a commuter who prefers to rely on the MRT than a car increased by a factor 68.707. This is the odds or relative risk for a one-unit increase in TOD score for Yes relative to No group would be expected to increase by 68 times more likely when the other variables in the model are held constant.

(2) Secondly, only the 'frequent' use was a significant predictor in the model due to the p-value (not appearing in Table 4.10) and the coefficient (b=1.012) being positive. In addition, the odd ratio of 2.751 indicated that for every 1 unit increase in frequency use, the odds of a commuter who preferred the MRT over car use increased by a factor of 2.751. This is the odds for a one-unit increase in the frequency uses for Yes relative to No group would be expected to increase by 2.75 times more likely when the other variables in the model are held constant.

(3) The set of coefficients was compared between the Maybe and No groups. The score variable is a predictor (b=-1.467) in the model and the coefficient was a negative sign. The negative sign in the coefficient means that the odds of the 'Maybe' group are smaller than the reference group. In addition, for every 1 unit on the score, the odds of the 'Maybe' group changed by 23.1%. This is the odds or relative risk ratio for a one-unit increase in TOD score for MAYBE relative to NO group given that the other variables in the model are held constant. If a subject were to increase for TOD score by one unit, the relative risk for preferring MAYBE to NO would be expected to decrease by a factor of 0.231 given the other variables in the model are held constant.

(4) At last, the predictor 'frequent' (b=-.325) in the model and the coefficient were also negatives. The negative values of the regression coefficient indicate that the odds ratio is smaller than 1. In addition, for 1 unit of frequency, the odds of the 'Maybe' group decreased by 72.2%. This is relative risk for a one-unit increase in 'frequent' for MAYBE relative to NO group given that the other variables in the model are held constant. If a subject were to increase for frequency uses' score by one unit, the relative risk for preferring MAYBE to NO would be expected to decrease by a factor of 0.722 given the other variables in the model are held constant.

4.4.3.5 Classification

Table 25: Classification table

Observed	Predicted			
	No	Maybe	Yes	Percent Correct
No	0	1	13	0.0%
Maybe	0	5	29	14.7%
Yes	0	3	149	98.0%
Overall Percentage	0.0%	4.5%	95.5%	77.0%

Finally, Table 25 is the result of cross classified cases of the outcome variable based on the MLR in Table 23; the value is derived from the estimated logistic probabilities. The station scores (X_5) and the frequency use of the station (X_7) are able to predict the variations on the commuter's decision-making towards the selection of what transport mode they needed for their travel (Nagelkerke's R^2: 17.1%).

The overall model accurately predicted 77.0% of the cases; however, correct classification was only 14.7% for the 'Maybe' group and no 'No' cases were correctly classified. The prediction of the 'Yes' group of the commuters who select to use the MRT over cars had a higher level of accuracy prediction at 98.0% compared to the 'Maybe' and 'No' groups. According to Hosmer and Lemeshow (2000), the MLR produced a better prediction of the largest group.

Chapter 5
Discussion and Recommendations

5.1 Summary of the calculation process of the TOD readiness score

The TOD Readiness Index has been completed to measure 18 station areas along the Chaloem Ratchamongkhon Line. The study concludes that a higher score for a transit station implies that the station is more eligible for the TOD concept to be applied in order to support pedestrians by requiring less car dependency if they use the station regularly. Notwithstanding, the growing number of cars used, along with the urbanism movement in Bangkok, creates frustration with traffic congestion and sprawl. The TOD concept must become a great recognition of the advantages of consolidating policy development and transition to the city growth and transportation networks. Since the TOD application in Bangkok is found sparingly, the goal of this study is to bring the TOD Readiness Index up to scale in terms of being applicable for everyone to ensure accessibility to basic services, affordable transportation and walkability. For this reason, it is a must to describe a vision of transit-oriented development that is suitable to Bangkok's contexts and that establishes a TOD assessment that is forethought and realistic.

a) The weight score

The results from analytic hierarchical process (AHP) technique suggested that there were six attributes to comply with the TOD readiness station. The study in Section 3 insists that having six components to measure is the optimal solution, by reducing duplications on the index that have repeated descriptions, according to the TRIRS. Consequently, the measurement of the distance to transit was combined with walkability, and station accessibility, station capacity and availability of car parking were combined with the built environment design into the station facilities measurement because they were similar in character and were using the same dataset.

The context related to the density for Bangkok's TOD, the total passengers using the station in a given period of time and the number of residences within the catchment area account, respectively, for the total ridership weight of 9.9% and the population density weight of 6.2%.

The context related to the design for Bangkok's TOD, the total availability of walkable pavement within the catchment area for pedestrians to use the station, accounts for the walkability weight of 12.2%. In addition, the station facilities have a component weight of 38.2%, narrated by the quality of the station amenities that cordially support commuters, including the elderly and disabled. The station facilities component consists of elevator units per stations, and the ratio of convenient exits that connect to buildings, and how connected the station is with other transport modes.

The context related to the land-use diversity for Bangkok's TOD, the commerce around station weight of 9.9% narrated by the variety of commerce that provides for the daily convenience needs of people around the transit stations, the format of the shop building for commercial use must be limited to the ground level or must not be above a residence. The business types include stores, supermarkets, groceries, cafes, laundromats, barbers and pharmacies. However, those street food businesses were not including due to uncertainty about the location and cleanliness issues. In addition, the employment diversity weight of 23.8% narrated by the intensity of job employment sites that encompasses occupation in different sectors located around transit stations. The building conditions must not be for residential use and open during business hours, such as offices, trading companies, department stores, enterprises, warehouses and wholesalers.

As mentioned in the chapter 4, this study is a first instance; thus, the degree of attributes that derived weight scores in compliance with the component scores used the AHP technique in order to generate a weight score for the context of Bangkok city. It is essential to follow the TOD Readiness Index Reference Sheet (TRIRS) as a guideline for each attribute according to the measurements by making sure that the data integrity and unit of measures are correct.

b) The station's component score

The process begins by acquiring the raw dataset from the Bangkok metro office authorities for the stations' integrity and from the department of city planning for the land-use patterns. The figures appear in chapter 4 summarized the characteristics for each station in hexagonal diagram scaled by the equal weighting techniques. Each diagonal corner represents the score for each component of the station scaled from 0 to 5 in the same standardized unit.

Even though the component scores of the stations have delivered final scores for verification in the previous section, Hua Lamphong station (3.507), Samyan station (3.448), Sukhumvit station (3.426) and Phra Ram 9 (3.287) are the top scorers and were ranked respectively. However, the low scoring stations, such as Bang Sue (1.393), Thailand Cultural Centre (1.469), and Lumphini (1.480) stations should be more highly significant improvement when infrastructure development is finished. The areas around these stations are now under construction and it is expected to be finished in 1-2 years; hence the TOD scores are expected to be higher than the current scores.

In addition, this study was expected to support the authorities in considering the creation of the TOD zones within a 500-meter radius of the stations, allowing Bangkok to ensure that the TOD policy or plan being prepared is aligned to improve the features of the transit station to be inefficient. TOD planning can be considered to support the use of transit stations within walking distance of any MRT station in Bangkok.

5.2 Summary of the descriptive statistics

The dataset contains variables on 200 commuters across the 4 top-ranked stations. The predictor variables are sociodemographic data (i.e., gender, age, and housing genre) and the travel behavior, such as travel cost per month, station usage frequency, and reason for using the station, in which the variables contain categorical and continuous variables.

a) The sociodemographic data shows 55.0% male, 42.5% female, and 2.5% who did not describe their identity. 20.0% of the commuters were between 14-22 years old, using the student card when commuting by MRT, 74.0% were between 23-59 years old, using the adult card, and 5.5% were aged over 60 years old, using the elder card, while only 0.5% were under 14 years old, using the child card. This possibly means that more men were found using the station than women, while adult card users are the majority of the 4 top-scoring stations' users.

b) For housing genre, 18.5% are living in a single house, 21.5% are living in a shop house, 15.5% are living in a townhouse, 23.0% are living in an apartment, and 21.5% are living in a condominium. Moreover, regarding the ownership level of the respondents in the housing genre, 45% were the owner or family member of the house, while 31.5% were residents, such as relatives or cousins. The final 23.5% were tenants of their current accommodation. Nevertheless, these variables as predictors were finally eliminated during the stepwise terms in the MLR.

Hence, the housing genre and the ownership could be recommended for future study from another perspective, such as the issue of living around the station.

c) At the station, there were only 11.0% who walked to a station for less than 5 minutes from their accommodation, while 34.0% walked to the station from their accommodation within 5 to 10 minutes, and over 55% spent over 10 minutes to arrive at the station by foot from the accommodation. According to the literature review, the 500 meters of catchment will take approximately less than 10 minutes to walk, in which most of the commuters, up to 55% who used a station, were living outside the catchment area and still walking to the station. This study recommends that the city planning authorities be prepared for any development that could enhance the comfort and sense of feeling of walking to a station, as well as the environmental friendliness and any health-related benefits of walking.

d) Only 4% of commuters spent over 1,000THB on ticket fares per month which was the highest travel cost in the study, whereas the lowest travel cost was less than 100 baht per month, representing only 5.5% of those observed. The majority were found between 27%, 30% and 33.5% are similar, since they were range between 100 – 1,000 THB for their travel cost per month. According to the results of chapter 4, frequent use was found to highly influence the travel mode choice of the commuter and it is absolutely related to the ticket fares and types. This study recommends that the Bangkok expressway and metro be prepared for any development that could support the people in the sense of fair ticket prices for long term usage of MRT services.

5.2.1 Opinions toward the station use and living around the station area

Moreover, in Section 4, the level of opinions toward the station use and living around the station area showed that (i) strong confidence has been found in the commuters about the station services helping them reduce everyday travel time ($\bar{x}$=3.62, σ=.606). Nevertheless, (ii) the quality of walkable footpaths around the station areas affected commuters' decisions to walk to the station ($\bar{x}$=3.59, σ=.610), whereas (iii) the option of living close to the station could save them money on travel expenses ($\bar{x}$=3.54, σ=.648).

In addition, (iv) commuters accept that living near the station helps them to purchase services or items for their daily needs ($\bar{x}$=3.40, σ=.688) and (v) station facilities, such as elevators and weatherproof pavement connecting stations could affect commuter use of station services when they were walking to the station ($\bar{x}$=3.48, σ=.566). These were relatively less than the previous overall ratings (overall: $\bar{x}$=3.54, σ=.648).

5.3 Summary of the MLR process for the TOD readiness score

Regarding the results in Section 4, the chi-square ratio test from the fitted model yielded a value of 27.450 (p=0.000), indicating a good model fit. The predictions show that the multinomial logistic model was suitable because the model correctly classified 77% of the total observations. According to Tabatchnick and Fidell (2007), a lower AIC for the final model compared to the intercept model suggests a good fit. Nevertheless, decent-sized values were obtained for the pseudo-R2 of Cox and Snell: 128, Nagelkerke: 171, and McFadden: 099.

The MLR model was used to a model nominal outcome variable in this study. The outcome variable was the decisions of the commuters of their travel mode selection, between Yes, Maybe, or No, to choose the MRT or car use in which the odds of the outcomes are modeled as a linear combination of the predictor variables. In the MLR process, the model assigns a reference group (the 'No' group) to which all other levels of the variable ('Yes' and 'Maybe') are compared.

5.3.1 Recommendation of frequent uses of the station

Among the commuters in the 'Yes' group, the frequency of station usage has a significant impact on the travel choice decision of the commuter around the station areas. The statistical analysis found that commuters in this group at the top-scoring stations were likely to use the metro instead of a car up to 2.7 times more than usual. In addition, the study found that more usage of the MRT can improve the acceptance decision regarding the use of the MRT services by the commuters who were in the 'Maybe' group by up to 72% from being hesitant.

It is clear that the travel frequency of the stations was associated with travel ticket costs. This study, therefore, suggests that the idea regarding the cost and travel frequency-related decisions of commuters around stations should be taken into account when studying or evaluating new transport infrastructure. The benefits of promotion in monthly ticket fares should also be evaluated. Likewise, the aspect of travel mode choice decisions for the elderly and disabled users should be integrated into urban transport policy when developing new transport infrastructure. More emphasis should be placed on individuals to use the MRT instead of a private car. Otherwise, traffic congestion will continue due to an increase in private transport. Furthermore, Sidek J. (2020) showed that travel characteristics of the commuters influence the TOD station ridership recently, and this could useful for the authorities as hints in which any terms of travel character, such as accommodating type, jobs related, and educations will be found to be the major activities involved at the station area. Another implication for TOD policy regards the frequent use of the station could be more rely on the activity such as leisure traveling could also be concerned to an opportunity to increasing the uses for non-regular users. In order to encourage people to use more public transport, an effective public transport policy is required parallel to the assessment of public transport performance measures by the authorities, such as the Bangkok municipality and the Bangkok Expressway and Metro offices.

5.3.2 Recommendation of the TOD scores

Hua Lamphong station, Samyan station, Sukhumvit station, and Phra Ram 9 stations are the top-scoring stations that were forced in the model as predictors; nevertheless, the frequent users in the 'Yes' group are more likely to choose the MRT services over car use up to 68.7 times due to an increase in the TOD score's unit. Then the travel mode preference's odds also increase. Finally, the study also found that a high TOD score affected the commuters by reducing their hesitation in selecting the MRT over car use by 23%.

Meanwhile, the TOD scores were formed using a reliable mathematical process by which data on each component of the station are calculated to obtain a result for each station. The design components are the largest weighted among total TOD station scores. This study suggests that future studies on the attitudes (comfortability, convenience, costs, safety, and service reliability) towards station services could also influence transport mode choices. As a result, there is a benefit to investigating the public transport users and whether these attitudes have any impact on the travel choice decisions of regular users or non-frequent users.

Another aspect should be on how individuals use public transport at the time of planning and implementation of new station infrastructure. The new station infrastructure policy could be to assess health impacts, such as the walking distances are inputs to health assessment models in order to potentially improving health concerns of living around station issues (Ewing and Cervero, 2010). It is importance for the authorities, such as the city planners and the BEM to be aware of commuter attitudes or pedestrian experience regarding the use of walkable pavement and facilities at the area around the station, in order to improve on inefficient features of the transit station. Nonetheless the recent study showed the examinations to loud noise exposure that could affect within the accommodation in TOD area could be the advanced issues when implementing the new potential TOD station (Yildirim and Arefi, 2021).

5.3.3 Limitations to the analysis

The limitations of MLR includes large observations across all levels of the outcome variable and predictors are needed (Hosmer and Lemeshow, 2000; Tachibanik and Fedell, 2007), the observation numbers were subduing in which an epidemic of the virus spreading leads to many commuters were staying at home. Thus, the sample size was reduced due to the frustration in data collecting. Moreover, selecting the observation was sometime from inside the station because of weather condition such as raining and nightfall. Hence, the data collection may contain selection bias, such as those observations who are already inside the station within the station's premises, who are more likely to choose public transport service instead of the private car.

REFERENCES

Arrington, G. B., Cervero, R., National Research Council (U.S.). Transportation Research Board., United States. Federal Transit Administration., Transit Development Corporation., & Transit Cooperative Research Program. (2008). *Effects of TOD on housing, parking, and travel*. Washington, D.C.: Transportation Research Board.

Atkinson-Palombo, C. (2010). Comparing the Capitalisation Benefits of Light-rail Transit and Overlay Zoning for Single-family Houses and Condos by Neighbourhood Type in Metropolitan Phoenix, Arizona. *Urban Studies, 47*(11), 2409-2426.

Bertolini, L. (1999). Spatial Development Patterns and Public Transport: The Application of an Analytical Model in the Netherlands. *Planning Practice & Research, 14*(2), 199-210. doi:10.1080/02697459915724

Black, W. R. (2001). An unpopular essay on transportation. *Journal of Transport Geography, 9*(1), 1-11. doi:https://doi.org/10.1016/S0966-6923(00)00045-4

Boschmann, E. E., & Brady, S. A. (2013). Travel behaviors, sustainable mobility, and transit-oriented developments: a travel counts analysis of older adults in the Denver, Colorado metropolitan area. *Journal of Transport Geography, 33*, 1-11.

Calthorpe, P. (1993). *The next American metropolis : Ecology, community, and the American dream*: New York : Princeton Architectural Press, 1993.

Chen, F., Wu, J. R., Chen, X. H., & Wang, J. J. (2017). Vehicle kilometers traveled reduction impacts of Transit-Oriented Development: Evidence from Shanghai City. *Transportation Research Part D-Transport and Environment, 55*, 227-245. doi:10.1016/j.trd.2017.07.006

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association, 76*(3), 265-294. doi:10.1080/01944361003766766

Galeloa, A., Ribeiro, A., & Martinez, L. M. (2014). *Measuring and evaluating the impacts of TOD measures - Searching for Evidence of TOD characteristics in Azambuja train line. .* Paper presented at the EWGT2013 – 16th Meeting of the EURO Working Group on Transportation

Guo, J., Nakamura, F., Li, Q., & Zhou, Y. (2018). Efficiency Assessment of Transit-Oriented Development by Data Envelopment Analysis: Case Study on the Den-en Toshi Line in Japan. *Journal of Advanced Transportation*.

Higgins, C. D., & Kanaroglou, P. S. (2016). A latent class method for classifying and evaluating the performance of station area transit-oriented development in the Toronto region. *Journal of Transport Geography, 52*, 61-72. doi:https://doi.org/10.1016/j.jtrangeo.2016.02.012

Hosmer, D., & Lemeshow, S. (2000a). Introduction to the Logistic Regression Model *Applied Logistic Regression* (pp. 1-30).

Hosmer, D., & Lemeshow, S. (2000b). Model-Building Strategies and Methods for Logistic Regression *Applied Logistic Regression* (pp. 91-142).

Huang, R. G., A. , Madureira, M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. *The Journal of Transport and Land Use, 11*(1), 304-324. doi:http://dx.doi.org/10.5198/jtlu.2018.1110

Jaafar Sidek, M. F., Bakri, F. A., Kadar Hamsa, A. A., Aziemah Nik Othman, N. N., Noor, N. M., & Ibrahim, M. (2020). Socio-economic and Travel Characteristics of transit users at Transit-oriented Development (TOD) Stations. *Transportation Research Procedia, 48*, 1931-1955. doi:https://doi.org/10.1016/j.trpro.2020.08.225

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2014). Advance transit oriented development typology: case study in Brisbane, Australia. *Journal of Transport Geography, 34*, 54-70. doi:https://doi.org/10.1016/j.jtrangeo.2013.11.002

Kay, A. I., Noland, R. B., & DiPetrillo, S. (2014). Residential property valuations near transit stations with transit-oriented development. *Journal of Transport Geography, 39*, 131-140.

Lund, H. M. W., Richard W. . (2005). *Development Strategies. Location Decisions and Travel Characteristics along a New Rail Line in the Los Angeles Region; United States*.

Lyu, G., Bertolini, L., & Pfeffer, K. (2016). Developing a TOD typology for Beijing metro station areas. *Journal of Transport Geography*, 40-50. doi:http://dx.doi.org/10.1016/j.jtrangeo.2016.07.002

National Statistical Office, Ministry of Information and Communication Technology (2019). Retrieved from http://web.nso.go.th/en/stat_theme_socpop.htm

Pal, S. (2018). Measuring Transit Oriented Development of Existing Urban Areas around Metro Stations in Faridabad City. *International Journal of Built Environment and Sustainability, 5*(1), 115-126. doi:10.11113/ijbes.v5.n1.251

Pearce, D. W., & Atkinson, G. D. (1993). Capital theory and the measurement of sustainable development: an indicator of “weak” sustainability *Ecological Economics, 8*, 103-108. doi:https://doi.org/10.1016/0921-8009(93)90039-9

Pojani, D., & Stead, D. (2015). *Transit-Oriented Design in the Netherlands* (Vol. 35).

Rahman, M. L., & Baker, D. (2018). Modelling induced mode switch behaviour in Bangladesh: A multinomial logistic regression approach. *Transport Policy, 71*, 81-91. doi:https://doi.org/10.1016/j.tranpol.2018.09.006

Reusser, D. E., Loukopoulos, P., Stauffacher, M., & Scholz, R. W. (2008). Classifying railway stations for sustainable transitions – balancing node and place functions. *Journal of Transport Geography,* *16*(3), 191-202. doi:https://doi.org/10.1016/j.jtrangeo.2007.05.004

Ronghanam, P. (2013). *walking behaviors of commuters who have switched to use the Bangkok mass transit system (BTS).* Chulalongkorn University.

Saisana, M., & Tarantola, S. (2002). *State-of-the-art Report on Current Methodologies and Practices forComposite Indicator Development*. Retrieved from

Salty, T. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Schlossberg, M., & Brown, N. (2004). Comparing Transit Oriented Developments Based on Walkability Indicators. *Transportation Research Record Journal of the Transportation Research Board*. doi:10.3141/1887-05

Singh, Y. J., Azhari Lukman, Johannes Flacke, Mark Zuidgeest, M.F.A.M. Van Maarseveen, & van, M. (2017). Measuring TOD around transit nodes - Towards TOD policy. *Transport Policy, 56*, 96-111. doi:10.1016/j.tranpol.2017.03.013

Singh, Y. J., Fard, P., Zuidgeest, M., Brussel, M., & Maarseveen, M. v. (2014). Measuring transit oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen. *Journal of Transport Geography*(35). doi:http://dx.doi.org/10.1016/j.jtrangeo.2014.01.014

Tabachnick, B., & Fidell, L. S. (2007). *Using Multivarite Statistics* (Vol. 3).

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography, 45*, 70-80.

Wall, R., Ostertag, K., & Block, N. (1995). *Synopsis of selected indicator systems for sustainable development.*

Whitelegg, J. (2003). *Transport in the European Union: Time to Decide*. Basingstoke, UK: Palgrave Macmillanr.

Widyahari, N. L. A., & Indradjati, P. N. (2015). The Potential of Transit-Oriented Development (TOD) and its Opportunity in Bandung Metropolitan Area. *Procedia Environmental Sciences, 28*, 474-482. doi:https://doi.org/10.1016/j.proenv.2015.07.057

Yildirim, Y., & Arefi, M. (2021). How does mixed-use urbanization affect noise? Empirical research on transit-oriented developments (TODs). *Habitat International, 107*, 102297. doi:https://doi.org/10.1016/j.habitatint.2020.102297

Zemp, S., Stauffacher, M., Lang, D. J., & Scholz, R. W. (2011). Classifying railway stations for strategic transport and land use planning: Context matters! *Journal of Transport Geography, 19*(4), 670-679. doi:https://doi.org/10.1016/j.jtrangeo.2010.08.008

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