



**A STUDY ON EFFECTS OF BUS RAPID TRANSIT
OPERATION IMPROVEMENT IN BANGKOK**

BY

MR. ANOUSONE SISOUTHAM

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)**

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

ACADEMIC YEAR 2019

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THESIS

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ENTITLED

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IMPROVEMENT IN BANGKOK

was approved as partial fulfillment of the requirements for
the degree of Master of Science (Engineering and Technology)

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Thesis Title	A STUDY ON EFFECTS OF BUS RAPID TRANSIT OPERATION IMPROVEMENT IN BANGKOK
Author	Mr. Anousone Sisoutham
Degree	Master of Science (Engineering and Technology)
Faculty/University	Sirindhorn International Institute of Technology/ Thammasat University
Thesis Advisor	Associate Professor Mongkut Piantanakulchai, Ph.D.
Academic Years	2019

ABSTRACT

Bus Rapid Transit (BRT) is considered to be one of the sustainable transportation modes to mitigate congestion problem in many megacities as well as developing cities. BRT requires low cost of construction and operation compared to other modes of mass transit systems. This present study consists of five major objectives, which were to identify problems occurring on the BRT corridor in Bangkok, create and calibrate a traffic simulation model to represent the realistic condition, suggest appropriate solutions and evaluate their effects using the developed simulation model, identify the influenced factors to improve the BRT service based on the perceptions of the BRT users using exploratory factor analysis (EFA), and provide recommendations for BRT improvement for city planners and decision-makers. Data for evaluation of BRT operation was collected from the on-site and on-board survey, and data for evaluation travel characteristics and influence factors were collected using questionnaires. This present study developed the microscopic simulation model by using AIMSUN software and calibrated by adopting the simple two-parameter search algorithm. According to the operational problem, the study proposed three possible solution to improve the operation of BRT in Bangkok, which were applying transit signal priority (TSP), enforcing fully segregate lane (FS), and adding additional lane as

a reversed lane (RL). The evaluation of this study concerned the two hours in the morning peak (7:00 am – 9:00 am) and two hours in the evening peak (16:00 pm – 18:00 pm).

Regarding EFA result of the study, it indicated that the factors that should be improved in order to gain more attractive of using BRT, which were the operational improvement factor, service improvement factor, and other improvement factor with regards to cost and safety issue. The operational factor was prioritized to improve prior to other factors. This factor consisted of applying ITS system at the at-grade intersections, upgrading the condition of buses and stations, operating in the segregated lane (BRT lane only), and accessing the BRT information easily. In which, the factor helped to confirm that the operational issue should be deeply in concern.

Regarding the evaluation of traffic simulation analysis, it revealed TSP solution was beneficial for both BRT and cars in the corridor. While the FS solution could provide the positive impact only for the BRT. Since one lane from inbound direction and outbound direction were dedicated to the BRT. Besides, the RL solution returned the positive impacts to the direction that the lane is reversed, since this solution was to add one additional lane by reversing the lane in the opposite direction that was not congested as another lane. Therefore, this present study recommended the TSP solution as the most recommended solution to improve the operation of the BRT in Bangkok. Since this solution had the most positive impact to the network in term of travel time saving among three solutions. The findings from this study could be applied as a baseline information for decision making and transportation planning in improving BRT operation in Bangkok.

Keywords: Bangkok Bus Rapid Transit, Microscopic simulation, Traffic Simulation, Exploratory Factor Analysis (EFA), Aimsun simulation

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge Dr. Mongkut Piantanakulchai for being my advisor and leading this research successfully. Since from the beginning until the end of my master degree study in Sirindhorn International Institute of Technology, Dr. Mongkut Piantanakulchai has always been a supportive supervisor in mentoring and guiding me directions of doing research in the correct track. During the time with his kindness, I felt that I am lucky to have him as my advisor because he has provided me such valuable knowledge and encouragement to deal with the research. I appreciate him to be my role idol and I once again would like to express my sincere thank to him for everything, without his support I would not complete my research.

I also would like to thank Dr. Kriengsak Panuwatwanich, my thesis committee, who provided me some comments and suggestions during my time of doing the statistics part of my research. I also thank Dr. Varameth Vichiensan, my external thesis committee from Kasetsart University, for his time of being the chairman of my thesis defense as well as providing me comments since the day of my proposal. I appreciate all their suggestions to improve my research perfect.

Special thank also goes to AUN/SEED-Net for providing me a scholarship to pursue my master degree and support me a budget of conducting research. Another thank also goes to Sirindhorn International Institute of Technology for providing me a place to study as well as support and facilitate me completing my degree smoothly.

I also wish to thank Mr. Tharathorn Kanjanakorn (Bangkok Metropolitan Administration officer) and Mr. Thanabodee Soontronwatee (The Krungthep Thanakom Co.,Ltd. staff) for helping in the stage of collecting Bus Rapid Transit's data in Bangkok.

Thanks a lot to all staff members in Sirindhorn International Institute of Technology especially Ms. Pattanun Manachitrungrueng who always helped and supported me for the document work. Many thanks go to all my seniors, colleagues and friends for helping me in many stages of collecting data especially when conducting the survey interview and hard time during the research.

Lastly, I also would like to thank my parents, Mrs. Manola Sisoutham and Mr, Aung Swe, who always stay beside me shoulder by shoulder. I appreciate their support,

encouragements and love during my time of pursuing master degree. Moreover, I especially thank my lovely mom, Mrs. Manola Sisoutham, due to her hard-working during my study and be always my inspiration all the way long to complete my study.

Mr. Anousone Sisoutham



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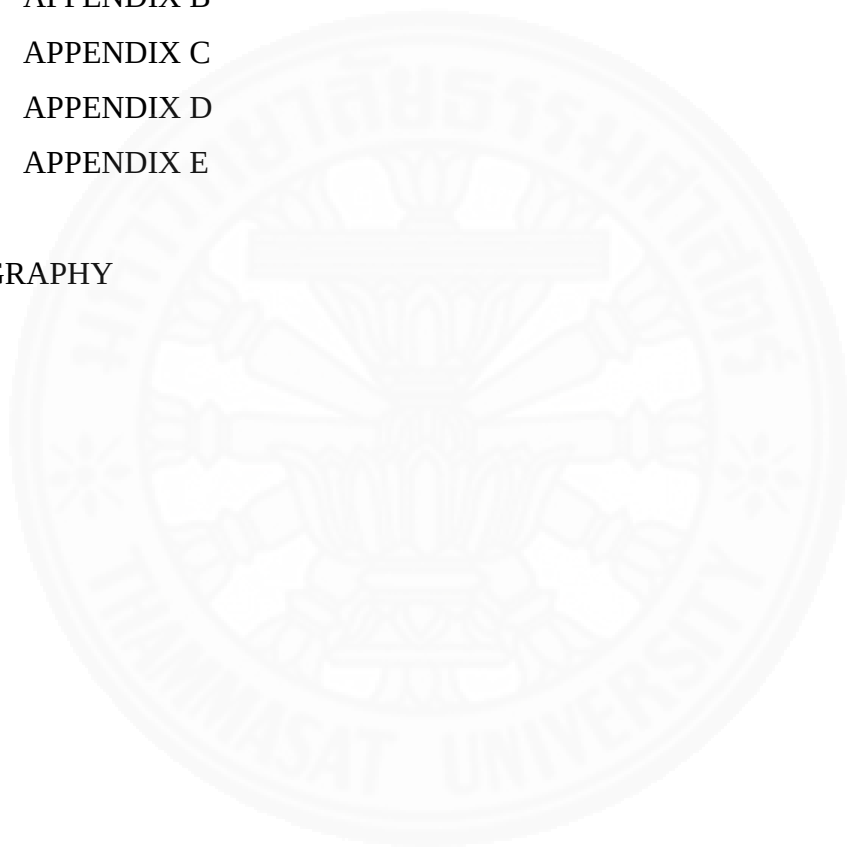
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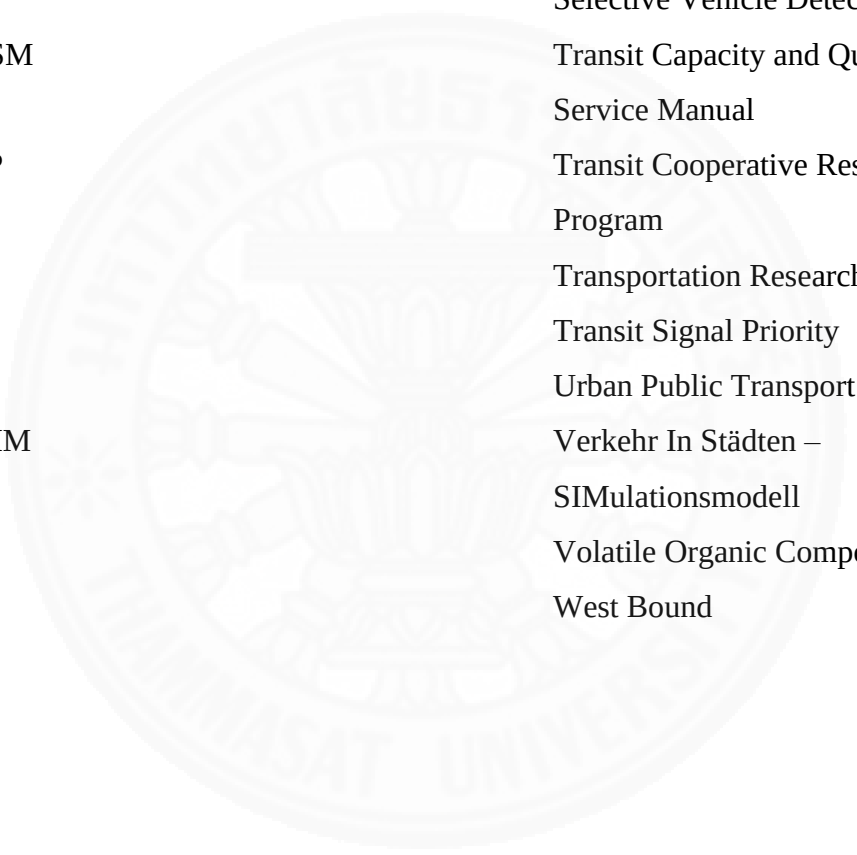
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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
ACS	Advanced Communication System
AIMSUN	Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks
ANOVA	Analysis of Variance
ASDS	Advanced Scheduling Dispatch System
AVL	Automatic Vehicle Locating System
BLIP	Bus Lanes Intermittent Policy
BMA	Bangkok Metropolitan Administration
BRT	Bus Rapid Transit
BRTS	Bus Rapid Transit System
BTS	Bangkok Mass Transit System
BTSC PCL	Bangkok Mass Transit System Private Company Limited
CAD	Computer-aided Design
CCTV	Closed-Circuit Television
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Confidence Interval
CO	Carbon Monoxide
DBL	Dedicated Bus Lane
DF	Degree of Freedom
DSI	Department of Special Investigation
EB	East Bound
EFA	Exploratory Factor Analysis
FS	Fully Segregated

GEH	Geoffrey E. Havers
GFI	Goodness-Of-Fit Index
HCM	Highway Capacity Manual
HD	High Definition
HOV	High-Occupancy Vehicle
ITS	Intelligent Transportation Systems
KMO	Kaiser-Meyer-Olkin
LOS	Level of Service
LRT	Light Rail Transit
MAPE	Mean absolute percentage error
MITSIM	Microscopic Traffic Simulator
MOE	Measures of Effectiveness
MPE	Mean Percentage Error
MRT	Mass Rapid Transit
MSE	Mean Squared Error
NAASRA	National Association of Australian State Road Authorities
NB	North Bound
NOx	Nitrogen Oxide
OSM	Opened Street Map
OTP	Office of Traffic and Transport Policy and Planning
PARAMICS	PARAllel MICroscopic Traffic Simulator
PCA	Principal Component Analysis
PCU	Passenger Car Unit
PE	Percentage Error
RL	Reversed Lane
RMSEA	Root Mean Square Error of Approximation
RMSP	Root Mean Square Percentage
RP	Revealed Preference



RRMSE	Relative Root Mean Squared Error
SB	South Bound
SEM	Structural Equation Modelling
SP	Stated Preference
SPSS	Statistical Package for the Social Sciences
SUMO	Simulation of Urban Mobility
SVD	Selective Vehicle Detection
TCQSM	Transit Capacity and Quality of Service Manual
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
TSP	Transit Signal Priority
UPT	Urban Public Transport
VISSIM	Verkehr In Städten – SIMulationsmodell
VOC	Volatile Organic Compound
WB	West Bound

CHAPTER 1

INTRODUCTION

This present thesis introduces a master study which is set the objectives to evaluate the impacts from the improvement of Bus Rapid Transit (BRT) operation system, and analyze the characteristics and attitudes of the BRT users for the proper BRT improvement. The primary focus of this study is to propose a suitable strategy to upgrade the BRT operation system through the analyzed results from the developed microscopic simulation model. The overview of this study is presented in this chapter with respect to the background of this study, the key issues influenced to the purposes of this study, scopes, and significances of this study. This chapter commences with section 1.1, which describes the background of Bangkok BRT. Section 1.2 explains the key issues of the problem of conducting this study. Section 1.3 details the objectives to complete this study. Section 1.4 details the scopes and briefly describes the method undertaken in this study. Section 1.5 addresses the significance and contribution of this study to society. Section 1.6 presents the layout of this study chapter by chapter.

1.1 Background of the Study

Presently, the extended rush hours, road accidents, contaminated air by especially high carbon-emission and driver-stress due to the occurring of congestion caused a sharply increased portion of social, economic, physical and mental health and environmental problems which many countries are encountered dramatically with those increasing. In the past, the only and wrong way of solving problems of congestion was to build more roads or expressway, being that it seemed to be the best way of solving problem at the beginning (short term), in fact, the more roads were built the more congestion was created because people were attracted to use more private cars (Papageorgiou, Maimaris, Ioannou, & Aghamias, 2012). Therefore, transportation plays an important role to the urbanization improvement in many countries especially in Asian developing nations due to their rapid and uncontrolled development, leading them to be under serious pressure of diverse environmental and human welfare problems including emissions, traffic accidents and congestion (Satiennam, Fukuda, &

Oshima, 2006a). Nowadays, with the sustainable and ecologically friendly transport mode, many nations are seeking the best and effective way to lessen those problem. Therefore, in the sustainable development age and restricted area accessible in urban cities, several modes of rapid transit systems are being designed as a solution to the problems by urban planners in order to ensure and provide reliable mobility to all inhabitants (Gahlot, Swami, Parida, & Kalla, 2012).

Globally, in response, sometimes the huge amount of construction cost of the mass transit alternatives, for instance, rail-based metros was spent to build only a few lengths of rail infrastructure due to the high cost. In return, the system that had been built does not meet spacious needs of transport of the population. However, BRT becomes as a significant alternative to mass transit owing to its performance and predominance attributes of an ultramodern rail-based system but charging low cost in term of construction and service (Wright, 2004). Consequently, Bus Rapid Transit System (BRTS) has become a popular transit mode in more than 40 countries worldwide especially in the western countries, and particularly in Asia, on account of its inexpensive bus-based alternative to other Light Rail Transit (LRT) modes metro and tram systems. The system of BRT imitates the modern rail-based transit systems' performance and amenities, including exclusive right-of-way lanes, enclosed stations, Rapid boarding and alighting, Automatic Vehicle Location (AVL) technology, and pre-board ticketing. According to these characteristics, they drive BRT to be defined as an effective alternative to improve Urban Public Transport (UPT) more than the regular bus services in term of reliability, comfort and saving travel time (GlobalBRTdata, 2018; I. Wu & Pojani, 2016).

Bangkok is a capital city of Thailand, and being a center of economic, education, employment, and public utility. As being a heart of driving Thailand forward, the city has a potential to drive Thailand economy growing up continuously because of the growth rate of the population and the migration from rural area into the city causing denser populace. Obviously, as the effect of getting denser of occupants the trend of using private cars increased, causing extremely traffic problems especially in the peak hours. Nevertheless, Bangkok Metropolitan Administration (BMA) is seeking ways to solve the jam-packed problems by setting the policies of expanding and improving mass transit system in accordance with providing new alternatives of

traveling as a cheap, convenient and fast transport option. Previously, the Office of Transport and Traffic Policy and Planning (OTP) had conducted the feasibility of building 14 routes of BRT throughout Bangkok as a master plan. The 15.9-km Chong Nonsi-Ratchapruk route, the first Bangkok BRT route, was operated in the one of the busiest area in the city. The first BRT line as the Bangkok BRT pilot project was aimed to embark implementation in 2007 with a total cost of 2 billion baht. So, the deadline was postponed two times due to some delays. After the delays were clearly inspected, the project launched the service on May 2010. The reasons of the delay were by the irregularities in the buses procurement process, and the time consumed of constructing pedestrian walkway on the bridge to link with the BRT Sathorn Station and the Chong Nonsi Bangkok Transit System (BTS) station and of the segregated bus lanes construction for BRT buses (Pcl, 2018). Bangkok BRT is owned by Krungthep Thanakom PCL, a Bangkok Metropolitan Administration's (BMA) subsidiary and holdings enterprise, and operated by Bangkok Mass Transit System PCL (BTSC), the operator of the BTS Skytrain. Nevertheless, the BRT master plan had been prepared since 2005, yet it took approximately 5 years to officially open the first line in 2010. Afterward, the remaining five BRT lines were abolished. The only line of operation stretches 15.9 km, without any express services, and conveys merely 1,200 passengers per hour per direction during the rush hours. Both start and end stations are connected to BTS Skytrain stations. The trial runs of the pilot route were opened on 29 May 2010 and officially opened on 14 February 2011. After the initial phase, a 10-baht flat rate of service charge was collected since 1 July 2011 but a number of passengers were not as a target set of 20,000 passengers per day until Mr. Paribatra was re-elected to be a Bangkok governor of the year. The fare of 10-baht was lowered to 5-baht on 17 April 2013 as in his election campaign that was pledged to people. Seven years after it was launched, Bangkok BRT had loss-ridden and under-used service forcing to be closed at the end of April 2017 with a significant financial burden of 200 million baht per year during the first six years of operation. However, on 1 September 2017, BMA made a contract with BTSC to carry on operating with the new increasing flat fare to 15-baht fixed per passenger for a period of 6 years without any support paid to the operator.

As being a current problem, Bangkok BRT has been incapable to provide a full BRT system causing unattractiveness to many passengers to use it which affects to BRT

operator not reaching the expectation of approximately 30,000 passengers per day. In addition, BRT was confronted with two main reasons causing the delay to passengers – some motorists and motorcycle users are impetuous with the heavy traffic, break into BRT lane aspiring to move faster caused buses had to spend a longer time than usual, and BRT is not provided as convenient as it should be including being stuck at traffic for a long time due to waiting time at the traffic light intersections. These key factors considerably affect to BRT to continue operating in comparison to the last 7 years of losing more than 1 million baht.

As stated above, it can be seen that BRT has encountered with surrounded problems, and it is essential to conduct the research in order to find the appropriate way to solve the occurring problems in Bangkok. The result of the research can be a guideline for BRT planner. Additionally, the attitude study of this research can help the contemplation of acknowledging the satisfaction to continue using and shift to use BRT from other vehicular users.



Figure 1.1 Bangkok Bus Rapid Transit (Photo taken on 19th October 2017)

1.2 Statement of the Problem

The Bangkok BRT has the plan to establish the existing bus-based mass transit system with the purpose to relieve the traffic congestion. However, the operation of the BRT has been being failed to improve the traffic condition in Bangkok unlike other countries have been able to implement the full BRT system. After BRT's inception in the first phase, it is no less controversial. There are several key factors which caused BRT not be able to enhance the performance – the first factor is from the disconnected segregation of BRT lane, meaning that the barriers which meant to segregate BRT buses from other vehicles are placed discontinuously along the BRT corridor, for instance, on the Rama III Road where road barriers exist for solely some distances. Another factor for the incapability of BRT operation is that buses are being suffered from sharing traffic lanes with other road users on bridges, meaning that several lanes of BRT are occupied by other vehicles, for example, on Narathiwat Road at the first BRT station there are some motorcycles or even cars blocking the entrance to BRT stations. One more factor to the inefficient operation is that BRT buses are not provided the priority especially traffic signal priority at the at-grade intersections which means that they have to spend the time of waiting for the traffic light permission for some period of time. From these key factors, they showed that Bangkok BRT has been incapable to operate a full BRT system reflexing that they have ostensibly relieved the system's capability by means of increasing the delay to travel time, and also the decreasing the time reliability. From those key factors, it seemed to reduce the satisfaction of the commuters to use BRT system. In contrast, other modes such as buses, taxis, motorcycle taxis and boats could provide the sufficient access from the major transit systems of the city to smaller streets.

As a matter of fact, there is a plan to improve the operation of Bangkok BRT in order for implementing the full system of BRT and to broaden the use of BRT in all over Bangkok. Thus, there are many alternative ways to overcome those occurred situations in Bangkok, but on the other hand, they require cost and time restraints. Nevertheless, transportation engineers and planners are required to get involved in order to come up with various efficient management strategies and recommendations.

The use of traffic simulation studies can be considered as one of the strategies to overcome the occurring problems and be an appropriate approach to evaluate the BRT performance along the selected corridor. The result can reveal the impacts which are going to happen to the surrounding traffic conditions of each alternative. In addition, by conducting the questionnaires to survey the attitude of the commuters and non-commuters on the brainchild of using BRT system. From this, it can identify the possibility to people who are going to use BRT after improvement by identifying the attitude impact-factors. Papageorgiou et al. (2012) stated that with the service improvement to reach the needs of people the benefit of BRT, of course, is not only for those people who have already used or those who just shifted to use bus mode for their traveling activities but also for others who still prefer a private car forasmuch they will not suffer from the traffic congestion.

1.3 Objectives of the Study

The objectives of this research were to conduct the simulation study on the traffic conditions before and after testing different scenarios and to study the problems occurring along Bangkok BRT corridor which affects to the commuters' attitude of using it after the appropriate improvement. The impacts from each scenario were discussed and evaluated using the result obtained from the simulation. Eventually, the most effective and suitable solution is recommended. With this intention, the detailed purposes of this research were:

- 1) To identify problems occurring on the BRT corridor in Bangkok;
- 2) To create and calibrate a microscopic traffic simulation model to represent the realistic condition;
- 3) To suggest appropriate solutions and evaluate their effects using the developed microscopic simulation model;
- 4) To identify the influenced factors to improve the BRT service based on the perceptions of the BRT users; and
- 5) To provide recommendations for BRT improvement for city planners and decision-makers.

1.4 Scope of the Study

This study area is limited to solely along the 15.9-km Bangkok BRT corridor with a total of 12 stations as shown in Figure 1.2– start from Sathon station to Ratchaphruek station, and there are together 13 intersections with traffic signal control; 4 intersections with no flyover connected, and 7 flyovers at the intersection. Thus, this research study considers the rush hours (morning rush hour 7.00 – 9.00 and evening rush hour 16.00 – 18.00) since these peak periods are the parts of the day that traffic congestion shows the highest jam-packed on the studied area.

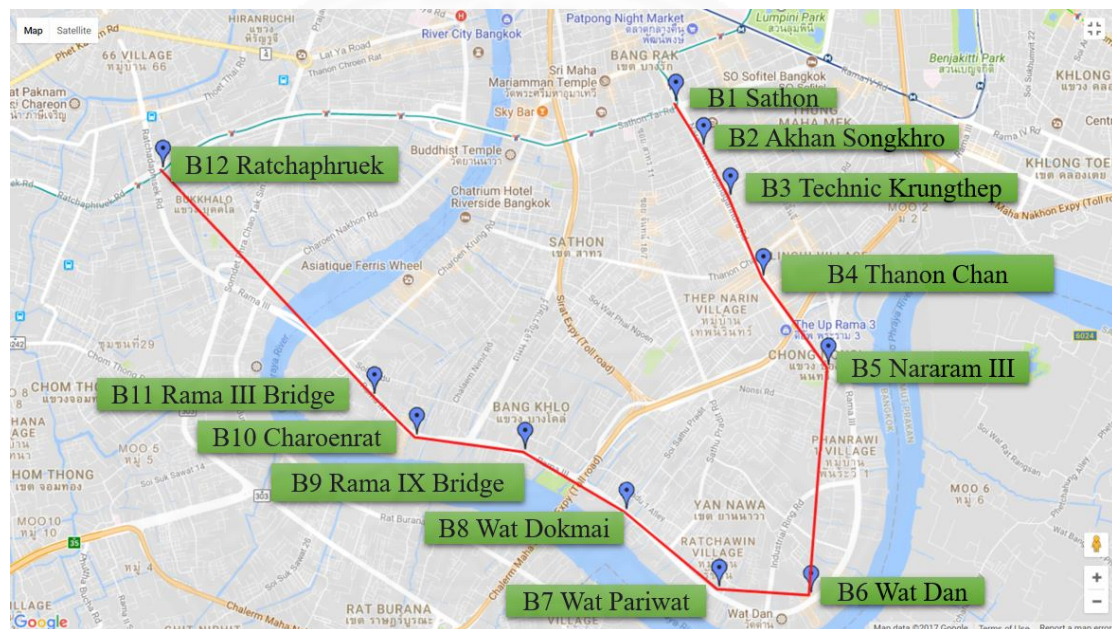


Figure 1.2 15.9-km Bangkok BRT Corridor

The study employed the traffic simulation program, Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN), to help simulate to get realistic and feasible improvement by considering 3 scenarios which are using transit signal priority, fully lane segregation, and adding additional lane as a reversed lane.

Data input in the simulation model is collected from 2 parts. The first part data comes from BMA (Bangkok Traffic and Transportation Department), in which the data consists of the traffic volume and turning movement percentage used as the secondary data. The second part is from the field collection, especially collect the queue length

and traffic capacity. The data collection in the field is conducted only in the weekdays but not weekends and holidays due to the deformation of people's traveling. Through this study, highway capacity manual (HCM) and transit capacity and quality of service manual (TCQSM) were applied in the process of field collecting data, and the traffic analysis toolbox is used to be a guideline for calibrating microscopic simulation model. For the result of the simulation analysis, the delay, travel time and speed are considered to be the most beneficial indicators to interpret the result to both BRT commuters and other road users.

Another part of this study is focused on the study of the attitudes of the BRT users. Thus, questionnaire was developed to survey the fundamental perspectives of the BRT users. Hence, the statistical technique is later adopted to analyze factors that caused to the attitude of the BRT passengers through Statistical Package for Social Sciences (SPSS) software version 23. With this regard, the Transit Capacity and Quality of Service Manual (TCQSM) is employed in this study in order to determine the current level of service of Bangkok BRT. Also, the advance statistical method namely Exploratory Factor Analysis (EFA) is analyzed to uncover the influenced groups of factors to be improved the BRT operation.

1.5 Significance of the Study

This research study provides information and solution regarding improving BRT operation. Further, this study can be a review of how simulation technology can handle and identify the impacts before actual implementation. Together with the attitude study, it can reveal the actual impact factors which have direct and indirect effects on the commuters' attitude of using BRT. Significantly, the result of this study would provide the necessary information to increase the efficiency of BRT system management. It can also be used for further development ideas to recommend the appropriate solution with the relating to transportation's urban planning by considering the advantages and disadvantages of each solution regarding simulation results. Also, it can be a guideline for upgrading the BRT services to both usual and newly used commuters by considering the influenced factors from the attitude study. In addition, the solution of this study can apply to be as the baseline information for policy

development, and also the useful knowledge to the transportation planners as well as the BRT planners to be the action plan of solving the similar problems on the recent status of Bangkok BRT.

1.6 Organization of the Thesis

This thesis totally consists of 5 chapters. In which, this chapter is the first chapter that overviews the research study by addressing to the background of the study, problem statement, purpose of study, scope, and significance of conducting this present study, as well as this chapter also provides the outlines of the thesis.

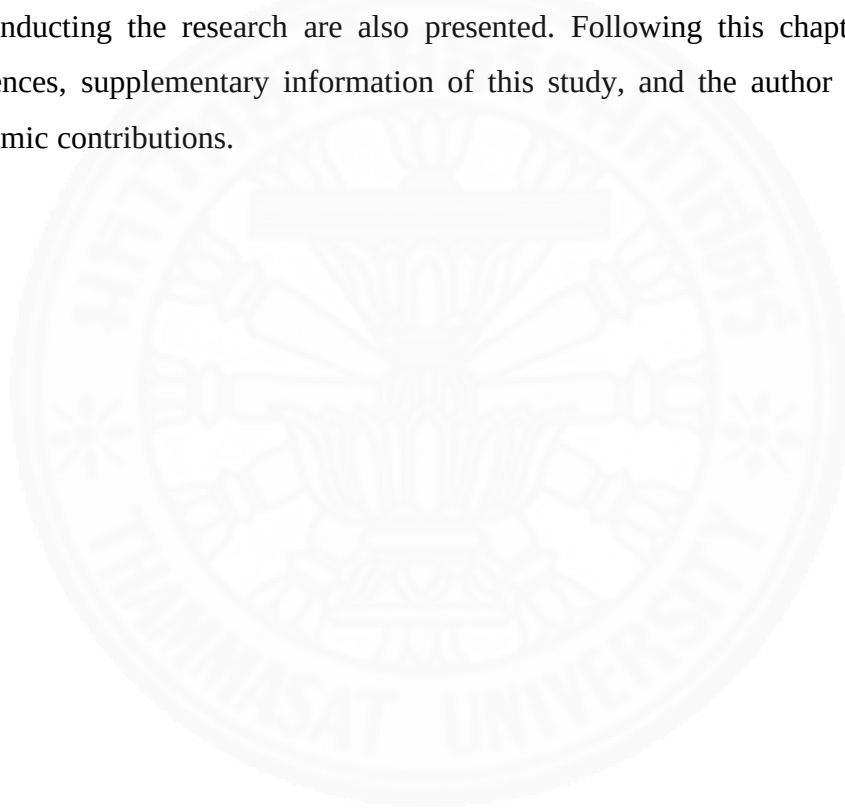
Chapter 2 summarizes the critical review of literature relating to this study. This includes the review of fundamental features of BRT as well as the system performance of BRT, Bangkok BRT's situation, traffic simulation model development with regards to calibration and validation the developed model, and how the results are analyzed and measured. Furthermore, the chapter also critically reviews the literature regarding the measures of the level of service (LOS) of BRT and the attitude and perception of the users.

Chapter 3 presents the research methodology adopted in this study. This commences with the first part of this study, which is the operational analysis part. This part is mainly focused on traffic simulation. It includes area selection, data collection, microscopic simulation model development, simulation model calibration, and validation, and simulation results evaluation. The second part of this study is users' perception analysis part, in which the level of service of the current BRT and the perspective of the users to the BRT system are included. Therefore, this second part begins with the questionnaire design and hypotheses, data validity test and the attitude data analysis.

Chapter 4 presents the results of the simulation analysis, which addresses the results of calibration and validation, and the impact evaluation results of the proposed solutions regarding the delay, travel time and speed. Moreover, this chapter also recommend the advantages and disadvantages of each solution, together with providing the recommendation for establishing the solutions.

Chapter 5 presents results of the BRT service assessment. The chapter addresses the LOS of the BRT in Bangkok and the LOS from the perspective of BRT users. Furthermore, this chapter also presents the demographic profiles of the BRT users (i.e. age, income, education background, access mode, egress mode), and highlights influence factors affecting to the use of BRT users from the results of EFA.

Chapter 6 summarizes the paramount outcomes from this present study and the contribution of this study. The recommendations for improving BRT quality in Bangkok are presented in this chapter. Additionally, the limitations and future direction of conducting the research are also presented. Following this chapter is a list of references, supplementary information of this study, and the author biography and academic contributions.



CHAPTER 2

LITERATURE REVIEW

The major objective of this chapter is to critically review the existing literature regarding the use of public transit especially BRT. The chapter begins with Section 2.1 provides a comprehensive review of BRT context as well as public transit. Section 2.2 outlines the fundamental knowledge of using BRT, which involves the definition and history of BRT, the principle elements of BRT, and the system performance of BRT. Section 2.3 describes the Bangkok BRT situation. Section 2.4 addresses on the BRT operational performance with regards to the successful and unsuccessful cases. Section 2.5 details on the traffic simulation model, which regards to the type of traffic simulation model, the data used in the microscopic simulation and existing tools for establishing and calibrating the microscopic simulation model. This is followed by Section 2.6, which describes the BRT operation enhancement. Section 2.7 suggests the measures of effectiveness to evaluate the transit system operation. Section 2.8 outlines the relevant studies on the attitude and perception of using BRT by addressing the influencing factors of BRT service quality, the method of collecting data and designing questionnaire and analysis method to evaluate the users' attitude and perception.

2.1 Comprehension of Bus Rapid Transit Context

Public transportation or public transit is a general term used to describe all kinds of transit service modes (Mass transit, Paratransit, and Ridesharing) available to urban and suburb inhabitants. Therefore, it does not consist of merely one single-mode but it has a diversity of traditional and innovative services, which should work and support each other in order to provide systemwide mobility to any and all commuters. Principle advantages of public transportation such as high-capacity (safe, rapid, comfortable, and convenient), economical and sustainable use in term of energy-efficient movement are considered as dominant points in densely traveled corridors. According to its advantages, public transportation has become an important element and a fundamental of the total transportation services provided in different scales in metropolitan areas. Together with its accessibility, it covers all medium- and low-density areas by

providing an alternative for choice riders (riders who own automobile and do not wish to drive), and an essential service to captive riders (riders who have no choice to access an automobile – schoolchildren, senior citizens, single-auto families, and others who may be economically or physically disadvantaged) (Garber & Hoel, 2014).

As the number of populations, as well as a number of motorizations especially in urban areas, increased rapidly, it has caused the traffic congestion meaning that traffic gets into congestion condition when the demand of commuters surpasses the transportation system capacity. Whereby, planners need to take into action to find some ways to solve the problem by providing different policies to relieve the dramatic increase in traffic congestion, air pollution, etc. However, to mitigate the congestion problem, it has several ways to respond to the problem. In the past, for instance, the only way to solve the traffic-packed issue was to build more capacity (expand more road). This approach seemed to be practical in the short term because after some times the traffic was increased again as the capacity of the road had been expanded wherein the congestion was reoccurred. To build more road, however, it always has limited funding or capital cost of construction either in developed or developing countries. Therefore, transportation planners in many cities across the world are trying to address the effective transportation mode such a rail system to improve public transportation implementation and screen vehicles from sophisticated traffic. But doing so, it is viable in some areas/cities but not in developing cities due to the construction cost constraint. Being stuck in the constraint, transportation planners in developing countries typically give a predominant role to improve the capacity of bus system as a sustainable transportation rather than the rail system due to the low establishment and operating cost (Sivakumar, Okamura, Tsutomu, & Nakamura, 2006; Van, Nakamura, Fujii, & Emori, 2007).

Thus, to place this into perspective, Bus Rapid Transit (BRT) has been presented as a practical example in order for upgrading transit performances and systems effectiveness. While the cost of construction and operating BRT systems are not that expensive than other rail-based systems but it provides the high capacity of service in the areas of transit service by its efficient performance (M. D. Eichler, 2005). Additionally, BRT is known as a bus-based mass transit system that well integrates the rail-based transit (i.e. an exclusive right-of-way lanes, timeless boarding and alighting,

enclosed station with safety and comfortableness, applying an Intelligent Transportation System) along with relatively inexpensive construction and operation cost (Tao, Corcoran, Mateo-Babiano, & Rohde, 2014). Whilst the terms of BRT may be defined heterogeneously from country to country based on the basic of understandings. Therefore, to grasp the fundamental premise of BRT is that offering high quality, consumer-based needs by yielding fast, comfortable, convenient, safety and low-cost consumption for moving from place to place (Sharma, Swami, & Swami, 2012; Wright, 2004). This has been led to the success of BRT operation. In which, after launching BRT in several cities all around the world with an adequate knowledge of its successful implementation allied with the low cost and staged of development potentials, BRT system is now turning into a very famous approach among the developing cities due to seeking of plenty of advantages of its system. Besides, the impartial road space allocation of BRT systems is being brought out in an efficient way that the traffic condition can be decreased obviously as well as the air pollution and other health problems. So, there is an instantaneous need to improve the transportation systems in urban cities all over the world (Raj G, Sekhar, & Velmurugan, 2013).

2.2 Fundamental Knowledge of Bus Rapid Transit

2.2.1 Definition of Bus Rapid Transit

Bus Rapid Transit (BRT) definition is described as a high-quality bus-based transit system that provides customers with the rapidity, comfort and low-cost consumption to move from one place to another through the concept of lane segregation infrastructure, rapid and frequent operations, and well-managed marketing and customer service. The characteristics of BRT are emulated from a modern rail-based transit system and the ordinary bus with an excellent integration yet its main concept is together with the low capital cost of construction and operation. Basically, BRT building cost is lower than other modes of Light rail transit system approximately 4 to 20 times and 10 to 100 times for a metro system.

BRT's application has been developed and applied mostly in North America and Europe. The conveyance of its, nevertheless, are employed worldwide with different names, including:

- High-Capacity Bus Systems
- High-Quality Bus Systems
- Metro-Bus
- Surface subway
- Express Bus Systems
- Busway Systems

While the name of it may be called differently in different places, the same basic point of it is followed: high quality and service at an affordable price for public transportation mode. For straightforwardness, BRT term is utilized in this study to generally portray these types of systems. Hence, there will be a lot more and more concepts and terms of use to describe BRT due to the non-stop evolvement of operating according to the previous studies. Through the several years of the popular use in the BRT system, there are several definitions that were contributed by worldwide researchers in different perspectives. There are Levinson et al. (2003) defined that BRT is rapid transit mode that has a great combination of stations, ways of running, vehicles, Intelligent Transportation System (ITS), and services to become as a system with a notable and unique picture; Wright (2002) defined that BRT is one of the transit modes that aimed to be the high-quality service, customer-cared transit to deliver fast, any comfort and inexpensive cost in traveling from place to place; Thomas (2001) described that BRT is a rapid transportation mode with the combination of rail transit quality and buses' flexibilities; R. B. Diaz (2000) addressed BRT as obvious from other modes of the conventional bus transit in a manner it merges the advance technological control mode, practical operating plan, and customer interface to provide a quality service in a higher level; Levinson, Zimmerman, Clinger, and Rutherford (2002) defined BRT is likely a Light Rail Transit (LRT) but operated with the rubber-tired system in such a way that the operation is more flexible and reduces capital costs potentially.

In short, all aforementioned definitions prove that BRT is different from the services of a conventional bus. Obviously, all definitions of BRT tend to recommend that it is fairly different from rail-based systems regarding customer service and operating service. Presently, BRT is really a constituent to what has been achieved in many urban rail systems in preference to represent lower quality interests up until the

rail interests. BRT has made an attempt to emulate such cherished aspects of LRT and metro systems and put all these attributes into a wider range in term of accessibility to various cities. These days, BRT has become a practical solution for a cost-effective transit mode and be an answer for many developing countries to solve the traffic problem. The BRT's quality improvement developers are keeping an attempt to upgrade its services to be a generalized system that applies for any cities in the world with the objective to move people effectively, swiftly, and cost-effectively instead of using private cars (Hook & Wright, 2007).

2.2.2 Bus Rapid Transit History

The original concept of BRT was introduced and used in 1937 when Chicago city had the framework plans to transform three rail lines inside the city to use bus corridors. The plans of having the segregated bus-lane or exclusive busway were developed for many cities through the United States, including Washington DC, St. Louis, and Milwaukee in the year of 1955-1959, 1959, and 1970 respectively (Levinson et al., 2003). Nonetheless, the proper measures of bus priority for the actual implementation did not appear until the 1960s that the “bus lane” concept was introduced. In 1963, New York City has introduced a way to implement the bus lane with the opposite direction to the roadway called “counter-flow express bus lane”. A year later, in 1964, Paris City implemented the “with flow” bus lane as the first bus lane.

In 1966, the United States implemented the first dedicated median busway in St. Louis and in Liege (Belgium) with the objective to convert tram systems bus system. After a few years, in 1969 the early high-speed busway was established in Northern Virginia with a total length of 6.5 Kilometers on Shirley Highway Busway. In 1971, Runcorn's busway corridor, a city in the United Kingdom, was opened to be as an incitement for new town development. Next arrival of the concept of “only-bus” street was introduced to London's Oxford Street with the conversion from the main traffic street to a bus-and-taxi only street in 1972. Another year later in 1973, Los Angeles urban development teams constructed the El Monte Busway with a length of 11 kilometers.

However, the full concepts or characteristics of BRT were not realized until the Bus system in Curitiba, a city in Brazil, namely “surface metro” was developed. The 20-kilometers of the system was planned, built and opened in 1972, 1973 and 1974 respectively. It was introduced to be a low-cost bus service but provided a high level of quality utilizing the advanced technology of bus service. The Curitiba BRT has been very successful in a way of operating and service. It is an excellent example of BRT that leading to make several other Brazilian cities followed the basic concept of it. Moreover, regarding Curitiba’s success on BRT operation, it has a strong influence to many cities either in developed or developing countries all over the world such as Seoul in 2004, Beijing in 2005 and so forth (Hook & Wright, 2007).

Traditionally, the BRT system is divided into two main systems – Full BRT and General BRT. A Full BRT system is determined by specific characteristics as minimum following below:

- Busway segregation over the centre corridors or trunk of the system
- Busways’ location rather be in the median of roadway than in the curb lane
- An integrated network existence of routes and corridors
- Stations’ facilities enhancement including convenience, comfort, security, and weather protection
- Level of access at stations is provided between the floor of vehicle and station platform
- Physical Integration along the centre of the corridor, feeder services, and other modes of the mass transit system is necessary to provide the facilities at the exclusive stations and terminals
- Fare collection and verification are a pre-boarding system
- The integration of fare and physical connection along routes, corridors, and feeder services
- The system entrance is prescribed to be a close system
- Marketing identity sets to be the predominant system
- Using ecotechnology vehicle (Euro III or higher)
- Applying ITS application such as automatic vehicle location (AVL) system to manage the system through the centralized control centre

- Special physical provisions are available for any disadvantaged group of customers such as disabled people, children, senior citizen, etc.
- The displays of route maps, information, and signs have to be ostensibly placed inside both stations and vehicles

While one of the aforesaid characteristics that the General BRT needs to always consider as the following:

- Busway segregation over the centre corridors or trunk of the system

And, two minimum characteristics from the aforementioned features of the full BRT (Hook & Wright, 2007).

2.2.3 Principle Elements of Bus Rapid Transit

R. Diaz (2004) prepared the report of the characteristics of BRT for decision-making to be basic guideline information and data for supporting the transportation planners a decision-maker on the concepts of BRT development and evaluation by describing the BRT's complement elements regarding the operational, physical, cost, performance and potential benefits, including:

- **Running Ways** - it indicates the speed of travel, identity, and reliability to separate the transitways of BRT as a fully-grade lane from the normal traffic lanes;
- **Stations** – are considered as the entrance of the system and the most important points for the customer interface. It is a connection between the customer and the BRT system and other feeders. Thus, the stations' design indicates the better service to customers and be able to adapt with other feeder modes that can affect many factors such as reliability, accessibility, system images, comfort, safety, and security.
- **Vehicles** – BRT buses have to be able to meet the required speed for moving passengers rapidly, use the eco-friendly vehicle and provide good comfort to passengers. These factors can create the attractiveness to passengers for using the service and can be the brand identity of the system.
- **Fare Collection** – the way of collecting fare from customers can affect to the perspective of them in term of the proving service so that the well-

organized marketing and operation are very essential to reduce the dwell times (boarding and alighting time) in each station which leads to increase the service reliability and passenger security. The fare collection can be collected with a flat rate or depended on zones/distances. The used methods can range from pay-on-board to pre-board payment method with the electronic fare media (smart cards).

- **Intelligent Transportation Systems (ITS)** – The system of ITS technology can upgrade the BRT system performance apart from other traditional buses, for instance, it provides more time saving, reliability, operational efficiency, comfort, safety and security to customers. Additionally, the installed ITS system on buses and along the corridors will let the system be able to improve for better quality due to the received information from the system. With the ITS system, the operator can examine and maintain the status of the working buses. This is to provide the best customer care service in term of safety and security.
- **Service and Operations Plan** – To meet the needs of people and matches the demand for service, the good plan and management are the key step to make people grasp the concepts of its services. These include the system is understandable, comfortable, and reliable, the operation needs to be flexible to any circumstances i.e. different cities or conditions which depends on many factors such as budget, customers' needs, service routes or even policy.

2.2.4 Bus Rapid Transit System Performance

Hinebaugh (2009) proposed six attributes about BRT performance to describe how much benefit that passengers gain from BRT implementation. The six attributes are described in the following sub-sections.

2.2.4.1 Travel Time

Travel time is the duration of time that passengers spent on vehicles from their origin to their destination. Travel time is one of the most factors that passengers care

while traveling by any transit modes and is especially important for trips of those who are discretionary or recurring trips i.e. working trips. Relatively increasing the speeds of travel and decrease dwell times at stations make BRT services gain more attractiveness from any kind of customers, especially for the choice riders and captive by choice riders. Another factor is the time of waiting for the next arrival buses or else the time of transferring effects importantly. To minimize those factors, BRT service plans need to serve more frequent, the whole day, and directly. There are four considered components regarding travel time, including:

- **Running time:** a time that vehicles spent for traveling from one station to another station;
- **Dwell time:** a stopped time that vehicle spent at a station;
- **Wait time:** a time that passengers spent to wait for the next arrival buses for boarding a transit service;
- **Transfer time:** a time that passenger spent on transferring from BRT service to other feeder services.

2.2.4.2 Reliability

Being able to provide consistent levels of service (short travel times) makes passengers attracted to the offered service if not there will lessen a number of passengers. Hence, Reliability is influenced by a number of uncertainty sources including traffic status, length of the route, recovery times, number of stops, the balance of passenger need, and unforeseeable wheelchair use, and vehicular engine problems both mechanical or non-mechanical issues. There are three major aspects of reliability, including:

- **Running Time Reliability:** a capacity that a consistently high speed of BRT service needs to be maintained frequently to provide a short travel time
- **Station Dwell Time Reliability:** a capacity that the BRT vehicles need to spend dwell time for loading passengers as short as possible and minimize the duration of time spent at the station. The loading passengers time depends on the day and peak hours

- **Service Reliability:** a capacity of a transit operation to deliver the consistency of service with the specific plans and policies along with the customers' expectations.

2.2.4.3 Image and Identity

One of the important objectives of BRT is to create a notable image and identity for truly separation from the conventional or traditional bus operation. Previously there are many researches indicate that to capture the choice riders' attractiveness, it is not enough to just offer the high-quality service and short travel time yet it is important to have an attractive image. There are two aspects to take into account creating image and identity, including:

- **Brand identity:** an idea that can turn the packaging of BRT system into a well-known product for the transit patrons
- **Contextual Design:** an idea of the well-integrated BRT physical design elements that can express the aesthetic design of the existing system and the environment in urban.

2.2.4.4 Passenger Safety and Security

Passenger safety and security is another factor to consider among the transit system attribute that affect the customers' service attractiveness, costs of operating, and whole performance. These two factors reflect various attributes differently to the comfort of transit patron with using a BRT system. The level of safety for whole BRT systems has to ensure circumstances from any dangers means that its system should be able to protect the passengers, pedestrians, employees, other vehicle riders, and others who have an interaction with the transit system. Meanwhile, the level of security should also be able to protect any users of the system, transit employees, and properties from any criminality or other deliberate dangerous actions.

2.2.4.5 System Capacity

System capacity is a maximum passenger carrying capacity through the system under some specific operating conditions. When the number of passengers' demand has over the system capacity, it will affect directly to the degree of services such as reliability, speed drop due to a high number of passengers. Therefore, the system needs to carefully manage the capacity of carrying passengers meaning that the level of service and the system capacity need to have some correlation. If the level of service varies, it will affect the capacity of the system and other factors. Virtually there are some measurable elements to examine the system capacity by considering the frequency, standee density, span and coverage, travel time, and reliability.

2.2.4.6 Accessibility

Accessibility is described as the points of access to the system (entrance and exit of stations and stops) for transit customers. There are three main ways to measure the impacts to the accessibility from the transit system elements, including:

- **Physical accessibility:** eliminating any physical obstacles and providing the facilities for entering into stations and vehicles
- **Accessibility of information:** Providing available information to all transit users particularly to those who are disabled users
- **Safety:** enhancing the safety treatment and protecting any dangerous circumstances by offering warnings or other treatments regarding to safety protection.

2.3 Bangkok Bus Rapid Transit

In recent years, Bangkok has been completed many mega projects in term of public investment regarding transport infrastructures such as motorways, expressways and various highways with high quality and standards. The transport sector has been improved extremely by government coordination since the early 1990s. Two remaining mass rapid transits (MRTs) as rail-based are being operated with high quality and developed and operated by the private sector finance under the supervision of Thai

government. Thus, the transport management in Bangkok is greatly developing. The most predominant success through the recent past has been a guideline of a technical regulation to make the vehicle and fuel standards better concerning the air quality improvement.

Therefore, Bangkok Metropolitan Administration (BMA) promotes alternative modes of transport in lieu of private car to mitigate the traffic congestion problem and importantly reduce global warming under the mission “reduce car usage, save energy and environment” by proposing the following nine traffic and transportation measures, including 1) Set new street Privileges, 2) Extend the Mass Transit, 3) Develop Bus Rapid Transit (BRT), 4) Initiate Monorail/Light Rail System, 5) Extensive Canal Transport, 6) Transportation Facilities development, 7) Pavement Refurbishment, 8) Bicycle Network Development, 9) Create a Public Participation Network (Hemachudha, 2010). According to the aforementioned policies, BRT was considered as the notable public transit with the concept of delivering high-quality comparable with other rail system but low-cost service.

Bangkok BRT had been discussed for twenty years ago as the basic idea of building a BRT system (Van et al., 2007). The first introduction of BRT was recommended as a guided bus in Bangkok Transit System (BTS) proposal in 1991. In 1992, the exclusive Bus lane is known as Chong Nonsi – Ratchapruet Road was introduced. Until the year of 2004, the Office of Traffic and Transport Policy and Planning (OTP) conducted BRT master plan Study with ten routes in the mixed traffic sections and extension to 14 routes in 2005. Consequently, the first line of Bangkok BRT (Chong Nonsi-Ratchapruet) was approved to construct by the Governor of Bangkok on January 3, 2007, with a cost of 2 Billion Baht and planned to open after 1-2 year(s) from the construction date. However, the opening date was not followed as plan meaning that the opening date was delayed due to examining the irregularities of bus procurements by a Department of Special Investigation (DSI). Other reasons causing the construction delay was the pedestrian bridge construction which connects BTS Chong Nonsi station with BRT Sathorn station, and also the segregating an exclusive bus lanes for BRT buses from the existing corridor. The project started to provide service on 29 May 2010. The current BRT that being operated is the first route of the master plan in Bangkok known as a pilot project, its service is provided along

Naradhiwas road Rama III road Rama III bridge and Ratchadapisek-Thapha road with a total length of 15.9-kilometer consisting of 12 stations (Sathorn, Akan Songklo, Technique Krungthep, Thanon Chan, Nararam 3, Wat Dan, Wat Pariwat, Wat Dokmai, Rama IX bridge, Charoenrat, Rama III bridge, and Ratchapruek). The Bus lane is segregated from the local road at the same level but not on the Rama III bridge because buses need to share a lane (High-Occupancy Vehicle / HOV lane) with other vehicles that carry more than 3 passengers, and at some intersections (Pcl, 2018).

Bangkok BRT has 25 buses to serve in-service operation which carry approximately 18,000 passengers within the route of two terminals at each end of the trunk line – Sathorn and Ratchapruek. The running speed is at the average of 30 km/hr with an average headway of 5 minutes during peak period and 10 minutes during non-peak period. BRT buses and two terminals are air-conditioned service but the rest of the stations are non-air-conditioned or as other regular bus stops. BRT Ticketing uses the Contactless Smart Card system. Every station and bus have electronic displays known as “Light Destination Indicator” to provide next-stop and arrival information to passengers. As the safety issue, every bus was installed two CCTVs, emergency button, two fire extinguishers, and automatic sensor slide door for the boarding and alighting comfort (Kodukula, 2010).

2.4 Bus Rapid Transit Operational Performance

In general, BRT has been widely used in many small or megacities due to its flexible operation, reliability service, and cost-effective in operation and service. Thus, there are several research publications about BRT operation in various aspects. Those were to realize the advantages from successful cases and disadvantages from the failure of implementation in order to be the lesson learned for improving the BRT performance. The distinctive issues that have been considered are the introduction of strategies for supporting BRT implementation, the evaluation of BRT system performance, and the reviewed problems of BRT system after implementation in different countries. For instance, Satiennam, Fukuda, and Oshima (2006b) found that the urban sprawl in Asian developing countries especially in Bangkok is growing very fast and uncontrollably. Yet, they are still lack of good management of land use

integrated with transportation system causing many problems such as traffic congestion, worsen environment by the increasing emission and noise from vehicles which is the main gap between successful and unsuccessful projects. Also, there are some difficulties of having a good system operation planning for BRT particularly having an exclusive lane for BRT or applying the transit signal priority (TSP) at intersections and having less of public participation due to a lack of understanding of BRT concepts. Therefore, the appropriate strategies to enhance the BRT operation are essential to take into account by considering paratransit as a feeder of BRT with a well-integrated design plan, decreasing the frequency of the local buses, spreading more information to inhabitants and city planners and decision-makers, reducing the any negative impacts to BRT operation, including more performance indicators, and having a long-term planning to cover whole area of the city. Having the appropriate strategies to enhance the BRT operation in urban cities especially in developing cities can be the best mean of sustainable public transportation development. This is owing to its notable points as the fact that it can provide the high quality under the low capital cost of construction comparing to other modes such as rail-based transit (metro, LRT, tram, etc.). Siedler (2014) addressed that BRT is one of the appropriate rapid transit in term of sustainable development to implement compared with LRT or tram that existing in some cities i.e. Islo even though these two transport systems have similar characteristics (Deng & D. Nelson, 2011) but BRT can perform higher and it needs lower cost consumption. In Thailand, some of transport planners and decision-makers preferred to use BRT more than tram because some of BRT aspects are more interesting and attractive than tram not just only the low investment cost and maintenance but the aspects of engineering construction, and traffic management (Jaensirisak & Klungboonkrong, 2009).

Regarding the widespread of using BRT all over 6 regions in the world (GlobalBRTdata, 2018), there are many projects that can achieve the successful operation, but some are encountering with different obstacles leading to the failure. Beijing southern Axis BRT line 1 is known as the first BRT line in China that can operate BRT with the full-featured system (Deng, Ma, & Nelson, 2016). The Beijing BRT line was succeeded because it could satisfy the demand of people's travelling activities by providing the high-capacity (speed, frequency, comfort, convenience and

safety) and high-quality service which can change the behaviors of Beijing people to use more and more day by day due to the less travel time consumption than a conventional bus service (Deng & Nelson, 2013). Another similar research, Combs (2017) examined the relationships between the accessibility of the low wealth households to the BRT TransMilenio system's feeder network in Colombia and the travel behavior among those people. As the BRT TransMilenio system (Bogotá) was considered to be a great public transit in Colombia due to its positive effects to the transit system, relieving traffic congestion, safety, and being an environment-friendly (less emission release). The study indicated that there was no significant influence on the lower wealth households' ability of their diary travel needs.

On the other hand, there are several BRT projects facing the obstacles for operating the system (Gunawan, 2014) or in other word is that those projects are having barriers to lead them to operate successfully such as BRT in Brisbane (Australia), Lima (Peru), Bangkok (Thailand) and so forth. The reasons of failing in operation are owing to specific reasons based on different regions including weak political leadership, poor cooperation among the internal mass transit operations, poor public participation, low perceptions of people, unable to provide the well quality of service to commuters etc (Lindau, Hidalgo, & de Almeida Lobo, 2014; Mallqui & Pojani, 2017). Especially to Bangkok, I. Wu and Pojani (2016) addressed the case of Bangkok BRT operation that the crucial thing leading it could not achieve the success in operation was from poor political leadership and competing modes to the street riders.

2.5 Microscopic Traffic Simulation Modelling

2.5.1 Type of Traffic Simulation

A simulation model plays a paramount role as it is a tool to represent the actual situation and implement some strategies in the model. The purpose of applying simulation is to enhance the performances or operations since it can use from small to large scale under the dynamic system. However, there are 3 levels of simulation such as macroscopic simulation, mesoscopic simulation, and microscopic simulation. They all have a distinct use regarding how much detailed is required in accordance with the effort to spend on them as described in Figure 2.1.

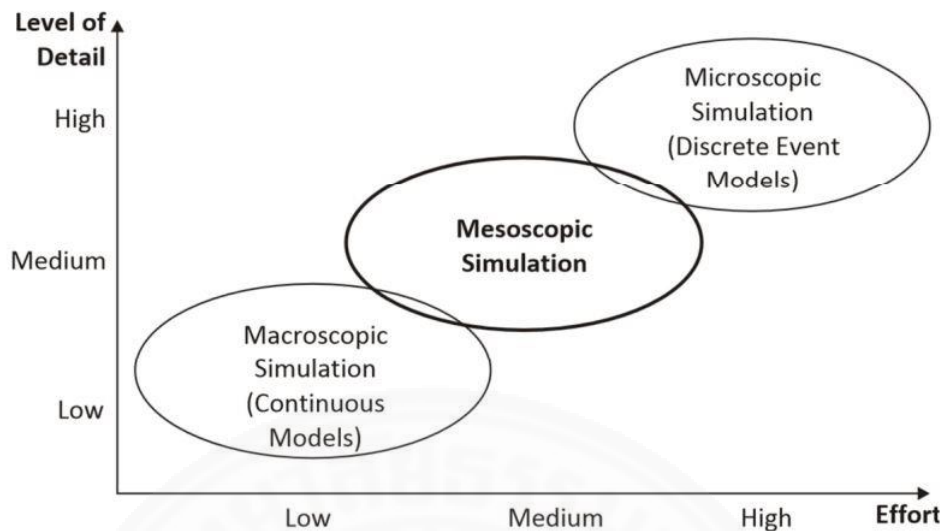


Figure 2.1 Microscopic, Mesoscopic and Macroscopic Simulation Approaches
(Lang, Reggelin, & Wunder, 2017)

To put the simulation modeling into perspective, Banks (2002) explained that microscopic models depict the movement and interaction between individual vehicles and other vehicles. In general, every microscopic simulation model consists of two main models – car-following models and gap-acceptance model. The car-following models depict the vehicular motions that attempt to follow another vehicle in the congested traffic model which includes the position of vehicles, velocity, acceleration, deceleration, etc. The gap-acceptance models employ to in situations that any vehicles need to cross through gaps in conflicting traffic flows at signalized or non-signalized intersections. On the other hand, macroscopic simulation models depict the relationships among flow, speed, and density. However, because of the mathematical form of the models, it is not always possible to determine the macroscopic implications of a particular microscopic model or vice versa. One recent development in traffic simulation modeling is interest in microsimulation models intended to connect the gap between microscopic and macroscopic models. These provide second-by-second representations of an entire regional network and in some cases make use of so-called mesoscopic models or defined as an intermediate between microscopic and macroscopic models (Ehlert, Schneck, & Chanchareon, 2017; Weiner & Ducca, 1999). Nevertheless, microscopic simulation is widely used in engineering applications owing

to its abilities to create a very complicated model and it can lessen the time and labor-consuming (Chiappone, Giuffrè, Granà, Mauro, & Sferlazza, 2016).

This study, hence, is preferred to adopt the microscopic simulation to create the traffic model by considering various parameters into account such as traffic flow, driving behaviors, traffic signal control systems, etc. Since, it requires many different parameters to describe and analyze the traffic flow characteristics, driving behaviors, traffic control systems, and so on. However, to create a model of microscopic simulation, it requires an appropriate approach of data collection for modeling traffic simulation and the model also needs to be calibrated to truly represent the real problem or local situations.

2.5.2 Traffic Data Collection for Microscopic Simulation

Basically, the process of data collection is as the first stage that needs to be done before any other steps in term of traffic simulation modeling. To reduce the negative impacts or any errors to the model, it is crucial to have an adequate or suitable approach of collecting data otherwise the model would meet a hard time to represent the real-world problem. In general, the practical and workable data to apply in the simulation models need to be collected from traffic field surveys (flows, turning movement, speed, etc) with a well-organized method of data collection. For the stage of data collection, (Garber & Hoel, 2014) categorized the traffic studies into three major groups: (1) inventories – regarding physical and control system of roads such as widths, lengths, parking lots, routes of transit, traffic regulations, and so forth; (2) Administrative studies – this data is usually provided by the specific government agencies who take in charge of the engineering data records. Normally this data includes the results of field surveying data such as field measurements or the advanced data as the aerial photographic data; (3) Dynamic traffic studies – this data collection is collected through operational conditions including traffic flows, traffic movement, speed, travel time, queue length, delay, etc. Since the dynamic studies are very sensitive and crucial which can affect directly to the model, therefore, it needs to be conducted by the traffic engineer.

Papageorgiou et al. (2012) classified the traffic data into two main types – static data and dynamic data. Static data describes the infrastructure of roadways while dynamic data describe the traffic volume, turning movement and priority, signal control system, public transport routing, departure times, etc. However, there are several methods to conduct for the traffic data collection depends on how much accuracy of the needed data, and manpower of collecting data to support the research studies– for example manual method which involves one or more persons recording observed vehicles using a counter to record the turning movements at the intersection, another convenient, accurate and fast method for collecting data is known as automatic method which use the automatic counter help counting the interested data (traffic volume, speed of vehicles passing) at intersections. Another interesting study is used high definition (HD) video cameras to collect the traffic data including traffic volume, traffic movements, queue lengths and vehicular time spending in a queue at an intersection (Sharma et al., 2012).

Regarding the appropriate time for collecting the traffic data, there are numerous of researches recommended that peak hours (morning peaks and evening peaks) are the effective time to have a practical and usable data due to the heavy congestion around those periods of times. Liao and Davis (2007a) and Sharma et al. (2012) conducted the traffic surveys during the peak hours 7 am to 9 am and 4 pm to 6 pm, and 9 am to 10 am and 6 pm to 7 pm, respectively. While (Raj G et al., 2013) conducted the traffic volume count survey for 16 hours continuously 6 am to 10 pm. They collect the traffic volume, turning movement, and traffic signal durations at each intersection. Those data can be further analyzed the travel time, delay time, and level of service (LOS).

2.5.3 Traffic Simulation Modeling

As a matter of fact, there are many difficulties and impossibilities that could have happened in the real-world situations through many aspects of traffic flow which extremely consume both time and cost. Moreover, some case studies are very complicated to solve and get the appropriate solutions to the problems. Therefore, traffic simulation modeling plays an important role to overcome those obstacles to

enhance the performance of any public transport operations especially BRT operations. Moreover, traffic simulation can be an effective and efficient tool for evaluating the appropriate plans to handle with the traffic congestion problems. Regarding the advantages of using simulation, it can be tested many the alternatives and depicts the positive or negative changes so that the planner and decision-makers are able to realize the suitable alternative before implement in the real world (Arasan & Arkatkar, 2010).

Thus, in transportation simulation field, several advancements of technology have come and played an important role in term of traffic models development. The advanced and notable traffic simulation models are obviously developed by the simulation program that widely used in the world namely AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks), MITSIM (Microscopic Traffic Simulator), PARAMICS (PARAllel MICroscopic Traffic Simulator), SUMO (Simulation of Urban Mobility), and VISSIM (Verkehr In Städten – SIMulationsmodell). Liao and Davis (2007a); Zyryanov and Mironchuk (2012); Vilarinho, Soares, Macedo, Tavares, and Rossetti (2014) and Chiappone et al. (2016) used AIMSUN software in their study for enhancing the performances of bus priority strategy. While in Thailand Jongudomkarn (2009) conducted the study to analyze and evaluate the effectiveness of various transit signal methods that has the effect on Bangkok BRT operation through simulation program, AIMSUN. Other similar studies Papageorgiou et al. (2012); Raj G et al. (2013); Sharma et al. (2012) and Zhou, Wang, and Liu (2017) used VISIM software to conduct their research by providing the traffic priority strategies to accommodate BRT buses at the intersections and optimizing the reasonable distance of dedicated busway for solely BRT buses. While Mavi, Zarbakhshnia, and Khazraei (2018) used Arena V.14 software to develop the model and assess the BRT performance by applying various alternatives. Nevertheless, all of the traffic simulation modeling programs are able to perform interesting outputs in similar aspects. Yet, AIMSUN is one of the suitable application software and distinct from other software with the fact that the transport model developers can keep multiple geometries in a single file. AIMSUN can let the users build the model based on aerial photos (i.e. OpenStreetMap) and the road geometry and infrastructure maps (CAD files, GIS files etc). One of the notabilities of AIMSUN is that the output from the simulation

is highway capacity manual (HCM) 2010 based. Moreover, AIMSUN can work with other simulation softwares such as VISSIM, Synchro, Paramics, etc very effectively.

Since Ronaldo (2012) compared the two distinct microscopic simulation softwares which were AIMSUN and SUMO in his research. The study was compared the two softwares with various aspects such as simulation performance, animation displays, interpretational values, set of parameters to calibrate. The author concluded his study that the model that created by using AIMSUN software could perform better than SUMO. As a matter of fact, SUMO has much more complex system to build the model meaning that users have no needs to spend long time for creating infrastructures features. Also, the study mentioned on creating replication or seed, in which AIMSUN could calculate the average values of several replications but SUMO could calculate only one replication. Furthermore, AIMSUN could perform better than SUMO in term of model calibration and validation.

2.5.4 Microscopic Simulation Model Calibration and Validation

According to the advantage of traffic simulation, this present study is employed the traffic microscopic simulation model under the proposed strategies to depict improvement impacts to the BRT operations. Traditionally, these simulation models provide default parameters, for example, AIMSUN provides the set of default parameters that calibrated under the condition in the United Kingdom (Rajasakran, 2008). Therefore, to achieve the accurate model to represent the field condition, it is crucial and necessary to calibrate and validate the created model until the models fit the reasonable values after the process of model development. This is to perform the developed model being able to represent the real traffic condition. Obviously, there was no single model that can represent every aspect of the real traffic condition by considering all variables, but the main variables are important to consider.

However, this step of calibration and validation can be a time-consuming process owing to the models' sophistication and complexities. Also, the processes of traffic simulation calibration are recommended by (Dowling, Skabardonis, & Alexiadis, 2004). In which, there are three steps to calibrate the parameters includes (1)

calibration of capacity parameters, (2) calibration of route choice parameters and (3) calibration of overall system performance.

There are various studies of microscopic simulation model calibration that have been conducted aimed to make the model close enough to the local traffic condition. R. L. Cheu, Recker, and Ritchie (1992) proposed a trial-and-error approach to optimize the parameters of calibration by applying the computational effort. Yet, this method is unable to ensure the calibrated parameters are the best optimal value. Afterward, the systematic approach was introduced namely a genetic algorithm (GA) to find the best-satisfied parameter values (R.-L. Cheu, Jin, Ng, Ng, & Srinivasan, 1998; Chiappone et al., 2016). This method was approved to be the reliable approach of searching the optimal value, but it requires a long time to objective the complexity of the algorithm. Nonetheless, to be able to guaranteed the calibrated parameters as the optimal values Dowling, Skabardonis, Halkias, McHale, and Zammit (2004) proposed a search algorithm for the model calibration process. This proposed approach has been widely used in several practices (Gomes, May, & Horowitz, 2004; Zhang, Ma, & Dong, 2008).

Dowling, Skabardonis, and Alexiadis (2004) introduced three different search algorithms including single-parameter search algorithm (golden section) which to find the optimal value by considering one parameter with minimizing the squared error between the observed and simulation data as shown in Figure 2.2. Simple two-parameter search algorithm which to optimize the two model parameters value by applying the contour plot approach under the consideration of squared error computation as shown in Figure 2.3. And the last search algorithm is Dual-objective two-parameter search algorithm which can consider two model calibration objectives separately; this method the analyst needs to plot the squared error contour plot two sets for each pair of parameters as shown in Figure 2.4.

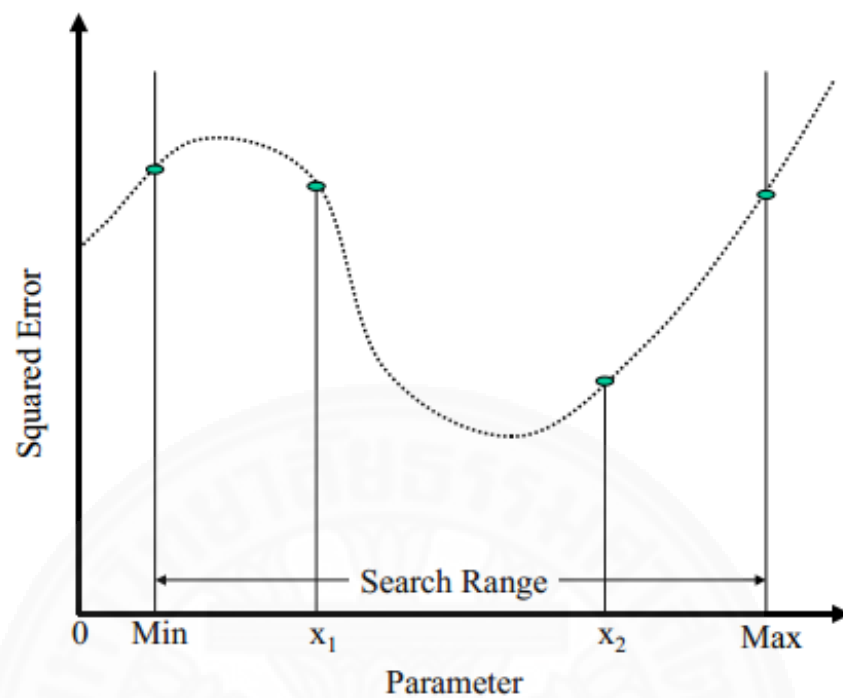


Figure 2.2 Single-Parameter Search Algorithm (Golden Section)
(Dowling, Skabardonis, & Alexiadis, 2004)

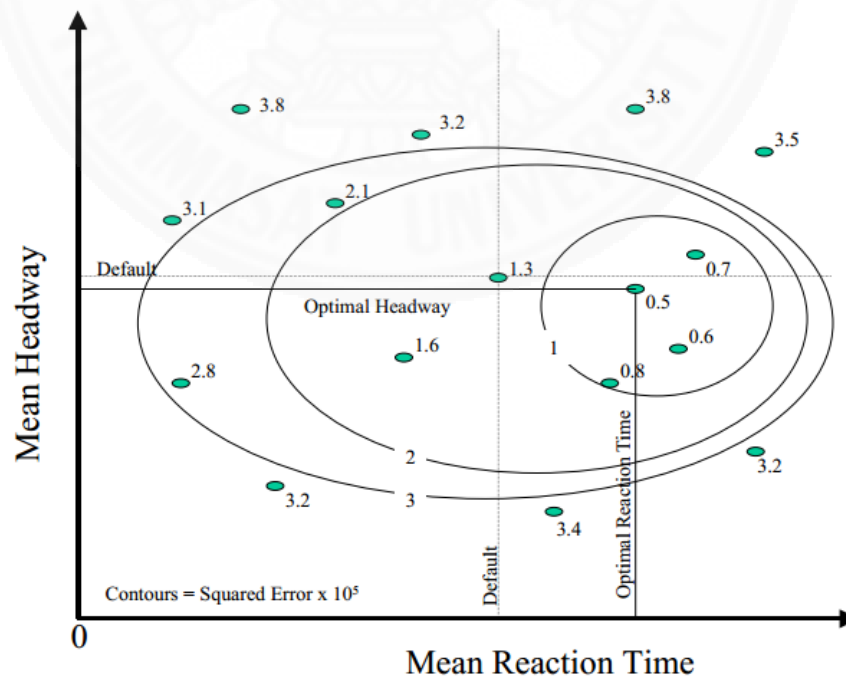


Figure 2.3 Simple Two-Parameter Search Algorithm
(Dowling, Skabardonis, & Alexiadis, 2004)

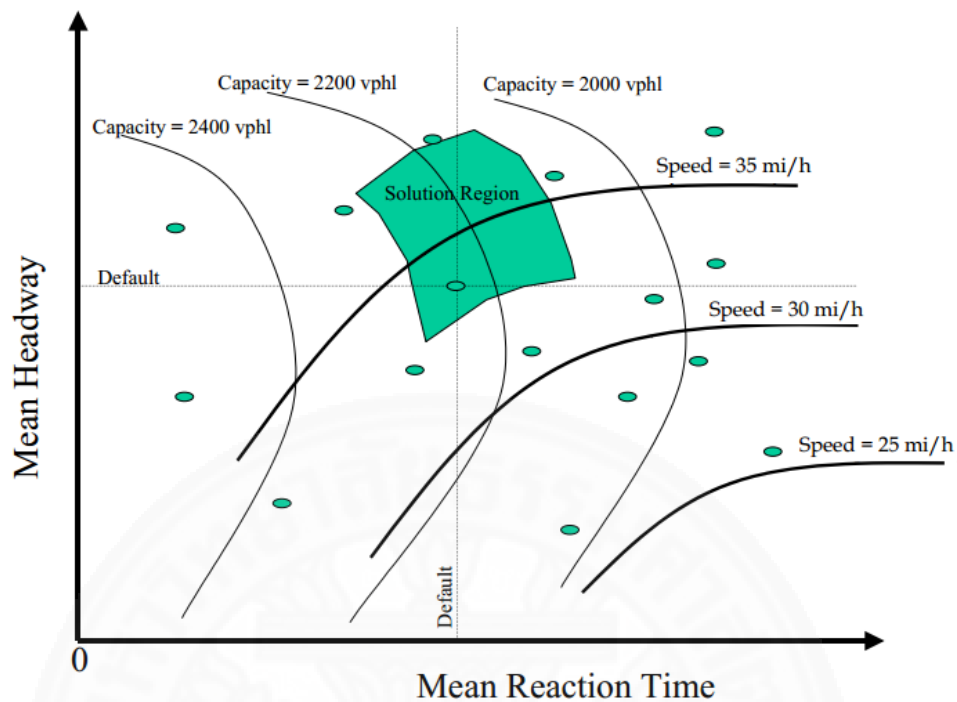


Figure 2.4 Dual-Objective, Two-Parameter Search Algorithm
(Dowling, Skabardonis, & Alexiadis, 2004)

In the calibration process, there are two main categories to be calibrated including global parameters and local parameters. The global parameters involve driver reaction time, reaction time at traffic, reaction time at stop, queue up speed, queue leaving speed etc, and local parameters which involves vehicular types, vehicle speed limits, and section gradients (Rajasakran, 2008). Under those circumstances, there are several studies conducted to calibrate the parameters used in the traffic simulation (Ciuffo, Miola, Punzo, & Sala, 2012; Punzo & Ciuffo, 2009). Later Figueiredo, Seco, and Silva (2014) conducted several simulation tests in AIMSUN to understand the effects of calibration parameters errors on the models' performance. The selected parameters to be tested were reaction time, reaction time at traffic light, reaction time at stop, maximum acceleration, and minimum distance between vehicles. The results obtained by applying input errors to a single calibration parameter concluded that reaction time has the most important impact on the models' performance with relationships between input and output errors ranging from 4:3 to 4:4. Meanwhile, those of the other parameters ranged from 4:1 to 4:2.

There was a study conducted in South Africa by Rajasakran (2008) using AIMSUN to calibrate parameters for highway model. The research found the suitable parameters that could use and represent the local condition such as 0.68sec for reaction time adjusted from 0.75sec as a default value, 1.00sec for reaction time at stop adjusted from 1.35sec as a default value, 8m/s for queue leaving speed adjusted from 4m/s as a default value. While there was a study in Bangkok conducted by Jongudomkarn (2009) to calibrate thirteen sets of parameters to be used in the model of Bangkok traffic condition. And the research revealed the adjusted parameter values that reaction time at stop and queue leaving speed were 1.90 sec and 7.50m/s, respectively. Furthermore, queue up speed was used to minimize the mean squared error (MSE) of the modeled average queue lengths.

Some common parameters used in model calibration and their definition defined in AIMSUN 8.1 User's Manual (TSS, 2014) are listed in Table 2.1.

Table 2.1 Definition of Parameters Used in Model Calibration

Calibration parameter	Definition
Reaction time at stop (in sec)	The time it takes for a stopped vehicle to react to the acceleration of the vehicle in front, lower reaction time at stop gives higher section capacities
Reaction time at traffic light (in sec)	The time it takes for the first vehicle stopped after a traffic light to react when the traffic light changes to green
Queue entry speed (in m/s)	The minimum speed threshold to consider if a vehicle enters a queue
Queue exit speed (in m/s)	The minimum speed threshold to consider if a vehicle has left a queue

Another determination which needs to take into consideration is to determine the simulation seeds or simulation run numbers. Chu, Liu, Oh, and Recker (2003) proposed the method to define the simulation seeds to ensure the obtained data run by the simulation software is usable.

The number of simulation replication or seed is defined as:

$$N = \left(t_{\alpha/2} \cdot \frac{S.D}{\bar{X} \cdot \varepsilon} \right)^2 \quad (2.1)$$

Where N is number of simulation seed, $\bar{X}$ is mean of the performance after already run simulation, $S.D$ is standard deviation of the performance after already run simulation,

ε is Allowable error specified as a fraction of the mean, and $t_{\alpha/2}$ Critical value of the t-distribution at the confidence interval of $1 - \alpha$

Another method of determining the replication numbers of the microscopic simulation model with regards to the confidence level was recommended by Dowling, Skabardonis, and Alexiadis (2004). The method recommends to identify the confidence interval (CI) index in accordance with the desired confidence level to determine the appropriate number of replications used in the model. Since, this process also plays an important role for interpreting how statistically valid of the research result performs.

The minimum number of runs is determined by using the following equation:

$$CI_{1-\alpha\%} = 2 \times t_{(1-\frac{\alpha}{2}), N-1} \frac{s}{\sqrt{N}} \quad (2.2)$$

Where $CI_{1-\alpha\%} = (1 - \alpha)\%$ is confidence interval for true mean where alpha equals the probability of the true mean not lying within the confidence interval, $t_{(1-\frac{\alpha}{2}), N-1}$ is student's t-statistic for the probability of a two-sided error summing to alpha with N-1 degree of freedom where N equals the number of replications, and s is standard deviation of the model results

The replication numbers can be determined after the CI index is computed. The minimum number of replications that will use in the model is determined by the desired rang and desired confidence as summarized in Table 2.2.

Table 2.2 Minimum Number of Replications Used in the Microsimulation Model

Desired range	Desired confidence	Minimum replications
0.5	99%	130
0.5	95%	83
0.5	90%	64
1.0	99%	36
1.0	95%	23
1.0	90%	18
1.5	99%	18
1.5	95%	12
1.5	90%	9
2.0	99%	12
2.0	95%	8
2.0	90%	6

Calibrating a model is usually performed through measuring the goodness-of-fit. In other words, determining if the model is acceptable or representable to the real condition. Several criteria were adopted. The common indicator is minimizing the mean percent error (MPE) or mean square error (MSE) of the modeled and the actual flow rates (Lu et al., 2014; Rajasakran, 2008).

MPE is defined as:

$$MPE = 100 \times \frac{1}{n} \sum_{r=1}^n \frac{M_r - C_r}{C_r} \quad (2.3)$$

Where M_r is modeled flow rate at time r (in veh/hr), C_r is actual flow rate at time r (in veh/hr), and n is number of repetitive model runs

Besides of MPE, another common objective function is the mean squared error (MSE). This type of error is mentioned in the works of Jongudomkarn (2009) as well as Dowling, Skabardonis, and Alexiadis (2004).

MSE is defined as:

$$MSE = \frac{1}{R} \sum_{r=1}^R (M_{ltpr} - F_l)^2 \quad (2.4)$$

Where M_{ltpr} is modeled capacity at location l and time t , using parameter p for repetition r (in veh/hr), F_l is field measurement of capacity at location l (in veh/hr), and R is number of repetitive model runs

An additional method that is commonly used for calibration criterion is the GEH statistic. The GEH statistic was developed by Wisconsin DOT to apply in their simulation model. It is set to be a goodness-of-fit measurement standard to compare the difference of observed flow data and modeled flow data. The GEH statistic is distinct from comparing the percentage difference (Dowling, Skabardonis, & Alexiadis, 2004).

The GEH statistic is defined as:

$$GEH = \sqrt{\frac{2(w_i - v_i)^2}{(w_i + v_i)}} \quad (2.5)$$

Where w_i is simulated flow rate at location i (in veh/hr), and v_i is observed flow rate at location i (in veh/hr)

To put the GEH statistic into more understandable, (Dowling, Skabardonis, & Alexiadis, 2004) suggested the interpretation of the GEH statistic of individual traffic flow on a link and the acceptable targets as in Table 2.3 and Table 2.4, respectively.

Table 2.3 Interpretation of the GEH Statistic for Individual Traffic Flow on a Link

GEH statistic 0 – 5	Model is in a good fit
GEH statistic 5 – 10	Model requires further investigation
GEH statistic > 10	Model is unacceptable

Table 2.4 Suggested Criteria for Using the GEH Statistic for a Model

Criteria	Acceptance Targets
$GEH \leq 5.0$	At least 85% of freeway and arterial mainline links
$GEH \leq 5.0$	At least 85% of entrance and exit ramps
$GEH \leq 5.0$	At least 75% of intersection turn volumes
Individual flows within ± 400 veh/hr for flows exceeding 2,700 veh/hr	At least 85% of applicable mainline links
$GEH \leq 4.0$ for total flows on screenlines.	All (or nearly all) screenlines
Total screenline flows within $\pm 5\%$.	All (or nearly all) screenlines

Additionally, another useful measurement is Theil's U-Statistic which is the measure to overcome the drawbacks of the root mean squared percentage error (RMSP) index when it is adopted in a study (Barceló & Casas, 2005).

Theil's U-Statistic is defined as:

$$U = \frac{\sqrt{\frac{\sum_{i=1}^m (Y_i - X_i)^2}{m}}}{\sqrt{\frac{\sum_{i=1}^m Y_i^2}{m} + \frac{\sum_{i=1}^m X_i^2}{m}}} \quad (2.6)$$

Where X_i is observed flow rate at location i (in veh/hr), Y_i is simulated flow rate at location i (in veh/hr), and m is number of repetitive model runs

U is bounded between 0 and 1, the closer of value to 0 the greater accuracy of the model simulated.

Subsequence from the model calibration stage, the model validation process is either essential to test the model with the statistical technique. Casas, Ferrer, Garcia, Perarnau, and Torday (2010) and Barcelo and Casas (2004) summarized the recommendation for conducting model validation. The research of the aforementioned papers used AIMSUN software in their study. They addressed that at first prior to the model calibration, the data should be separated into two parts, one for model calibration and another for the model validation. The set of data used either in the calibration process and the validation process are flows, occupancies, speeds, travel times, queue length, etc.). Also, the model validation should be conducted iteratively with a specific objective function (MAPE, MSE, RMSE) to compare the error differences between the calibration and validation. Chu et al. (2003) adopted MAPE to compare the travel time in the process of validation. Whilst Ronaldo (2012) split the data used in the study into two main parts – morning data and evening data. The morning data was used in the calibration model and the evening data was used in the process of validation. For the validation of the study, flow data were used to test the validity of the model under the statistical test of t-test.

2.6 Bus Rapid Transit Operation Enhancement

The concept of improving the operation of public transit especially BRT is increasingly required to get more comfortable and convenient for urban mobility. Thus, there are numerous ways to enhance the operation of BRT by providing several strategies to relieve the traffic congestion that caused pollution to air quality. (Deng & Nelson, 2013); Papageorgiou et al. (2012) stated that by the mean of improving the operational efficiency it has to apply the use of advanced technology known as Intelligent Transportation System (ITS) in order to achieve and provide high capacity and high-speed service to the operation and BRT commuters, respectively. The aforementioned ITS includes (1) transit signal priority (TSP) to detect the arriving buses at the signalized intersection and facilitate them to pass faster instead of waiting at the intersections, (2) automatic vehicle locating system (AVL) to help the transit control

center enables to track and get information of the buses in real-time and be able to adjust the time schedule of next arriving information for them, (3) advanced scheduling dispatch system (ASDS) to help improving scheduling activities and adherence, and (4) advanced communication system (ACS) to help the transit dispatchers enable, in combination with AVL systems, to maintain bus system efficiency by performing service restoration activities and communicating with drivers. Further, there are some other efficient priorities to deal with congestion solving which are dedicated bus lane (DBL), and bus lanes intermittent priority (BLIP) (M. D. Eichler, 2005; D. Wu, Deng, Song, Wang, & Kong, 2017). Most of those aforementioned studies, the popular technique or strategy to improve BRT operation is to adopt the TSP technology. This way, BRT can receive the facilitation directly from the strategy at the intersections that they commute through.

The concept of using TSP system is to employ GPS devices that installed in buses to send a signal to get some priority approach of green time or shortening the amount of bus stop times at a red light for facilitating buses pass through at the signalized intersection from a traffic management center. In New York City, 14 intersections along Staten Island's Victory Boulevard were installed and applied the use of TSP system as the first time of the city in the year of 2008. The adopted Signal priority was able to reduce bus travel times by 16% during the peak period in the morning and 11% during the peak period in the evening (Miller, 2015). Liao and Davis (2007b) also found that by applying TSP to Franklin Avenue in the city of Minneapolis, the bus travel times were reduced by about 12% to 15% and 4% to 11% during the morning and the evening peaks, respectively. Moreover, the average bus delay time was decreased from 16% to 20% and 5% to 14% during the morning and the evening peaks, respectively. H. Liu, Skabardonis, and Li (2006) tested eight different strategies of TSP application which included those with uses of AVL and point detection or selective vehicle detection (SVD). It was found that for fixed detectors (SVD), placing the bus detectors 200 meters upstream of the intersections gave the minimum bus intersection delay, which could save time by 14.7% comparing to the intersections without any system of signal priority. While in China the city of Jinan Zhou et al. (2017) conducted the research by applying the active signal priority method to improve the travel speed and reduce the delay time. The result indicated that the average delay time was reduced

from 13.43% to 25.27% and travel speed of BRT buses was increased by 7.10% to 7.55%. Besides, Vilarinho et al. (2014) enhanced the capacity of the signal timing control as a real-time control based on the Webster method. This study was conducted in the city of Porto in Portugal. The study was stimulated by AIMSUN and it considered travel time, system speed, delay, and queue length. By proposing the method of signal timing, it resulted that the system travel time in total, system speed total delay time and queue length were in the positive impacts. Dion, Rakha, and Zhang (2005) developed the integration of TSP simulation approach by applying an adaptive method of a traffic control system. The study was considered three distinct scenarios of signal control, and the study found that the adaptive signal control decreased the negative effects for the general traffic system and had a positive impact to buses when commuting under the proposed priority.

In the large city like Bangkok, Jongudomkarn (2009) studied the effectiveness of the signal priority methods by comparing four methods of transit signal priority: no priority, passive (not require any detection or priority request), active (require vehicle detection to activate the priority request), and conditional active or differential priority (similar to active method but it considers conditions to request a priority by taking person delay, transit delay, vehicle delay and so on into account). The study was conducted in order to know which one of those proposed priorities has the most efficient impacts on the BRT operation at studied intersections along Bangkok BRT corridor. From the analysis results of this study, it revealed that Transit Signal priority can effectively reduce delays regarding BRT operation at intersections. Wherein the active priority method showed the huge difference of delay reduction, whereas the passive method affected traffic delay on main roads. Whilst, the active priority method and differential method excessively impact traffic delay on side streets. Another interesting differential method was that it can clearly increase frequency adherence.

2.7 Measures of Effectiveness on Transit System Evaluation

Measures of effectiveness (MOE) is being as an indicator to indicate the changes in the proposed strategies to meet with the project objectives. The MOE can be conducted after the scenarios are simulated. Normally, it is compared with the local

condition (base condition) to realize the size of differences between base condition and the alternative conditions. However, the appropriate MOEs can be discussed under the project objectives and the agency performance regulations regarding the acceptable range. Recently, several reviewed researches adopted some common traffic indicators when they evaluated the performance/ effectiveness of a strategy. The basis for evaluation mostly focuses on (Dowling, Skabardonis, & Alexiadis, 2004):

- Vehicles travel times
- Vehicles delay times
- Vehicles speeds
- Vehicles stop times

In the last decade, there are several studies conducted the researches on how to enhance the performance the traffic capacity in term of relieving the traffic congestion. Papageorgiou et al. (2012); Zhou et al. (2017); Liao and Davis (2007b); H. Liu et al. (2006) used the average travel time, dwell time, speed, and average network speed as their MOEs. Similar studies, Chalak, Al-Naghi, Irani, and Abou-Zeid (2016); Sharma et al. (2012); Kun and Lei (2007) also considered their research's MOEs as maximum and average queue length, average delay time per vehicle, average network speed, network emissions (VOC, NO_x, CO) etc. Jongudomkarn (2009) also analyzed the effect of transit signal priority at individual intersections. He investigated mainly the effects on intersection delays and personal travel times on both the BRT buses and other vehicles. Whilst, Roaj-assawachai (2013) considered the Level of Service of BRT in terms of bus frequency and travel time, respectively. Additionally, M. Eichler and Daganzo (2006) determined their MOEs that affected to time-saving as traffic saturation level, frequency of bus service, bus travel time, and bus and car ratio in term of occupant flows.

Additionally, (HCM, 2000); Hunter-Zaworski (2003) suggested more criteria to measure the capacity of the service of the transit system as the potential thresholds by considering transit travel time, travel speed, transit frequency, and vehicle delay. Those criterions are measured in term of level of service grades (LOS) which indicates from LOS A to LOS F. It is measured on the basis of LOS A determines the best performance to the operating system when LOS F is vice versa as shown in Table 2.5, Table 2.6, and

Table 2.7. While Deb and Ali Ahmed (2018) adopted the five levels of LOS to measure the perceived and expectation level as shown in Table 2.8.

Table 2.5 Level of Service Indicator for Transit/Auto Travel Time

LOS	Travel time difference (min)	Comment
A	≤ 0	Faster by transit than by automobile
B	1-15	About as fast by transit as by automobile
C	16-30	Tolerable for choice riders
D	31-45	Round-trip at least an hour longer by transit
E	46-60	Tedious for all riders; may be best possible in small cities
F	> 60	Unacceptable to most riders

Table 2.6 Level of Service Indicator for Scheduled Transit Service

LOS	Headway (min)	Veh/h	Comments
A	< 10	> 6	Passengers don't need schedules
B	$\geq 10-14$	5-6	Frequent service; passengers consult schedules
C	$> 14-20$	3-4	Maximum desirable time to wait if bus/train missed
D	$> 20-30$	2	Service unattractive for choice riders
E	$> 30-60$	1	Service available during hour
F	> 60	< 1	Service unattractive to all riders

Table 2.7 Level of Service Indicator for BRT Hours of Service

LOS	Hours per Day	Comments
A	$> 18-24$	Night or owl service provided
B	$> 16-18$	Late evening service provided
C	$> 13-16$	Early evening service provided
D	$> 11-13$	Daytime service provided
E	$> 3-11$	Peak-hour service/limited midday service
F	0-3	Very limited or no service

While Deb and Ali Ahmed (2018) adopted the five LOS scale ranges which ranges from LOS 1, LOS 2, LOS 3, LOS 4 and LOS 5. The LOS was used for determining the difference between the expectation and perceive of the customers. Thus, there is a formula to determine the LOS by calculating the percentage deviation value, which defined as:

$$\text{Percentage deviation value} = \frac{\text{expected } x_i - \text{percieved } x_i}{\text{expected } x_i} \times 100 \quad (2.7)$$

Where x_i is examined factor

Table 2.8 Level of Service (LOS) Indicator Between Expectation Level and Satisfaction Level of the BRT Users

Range of the percentage deviation values	Assigned linguistic service levels	Descriptions
0%-20%	LOS 1	• Best service level • All the respondents are happy with all the performance indicators of the service • Coty bus service is very much efficient in the city
20%-40%	LOS 2	• All the respondents are happy with maximum of the service indicators • City bus service good in the city
40%-60%	LOS 3	• All the respondents are somewhat happy with the performance of the city bus service • Some of the service indicators are not performing as per the respondents' expectations
60%-80%	LOS 4	• A major portion of the respondents is not happy with the performance of the service • Though the bus service is available in the city, it performing poorly compared to other modes of transport • A poor quality of the service of the bus service will force the maximum passengers to avoid the bus service
80%-100%	LOS 5	• This is the worst service level • City bus service is almost negligible in the city

2.8 Attitude and Perception Studies on Bus Rapid Transit Service Quality

The necessity of attitude studies has come and played a crucial role in order to grasp the customers' perceptions and the level of satisfaction of the provided services including the availability, comfortableness, and convenience to access and use the service. Regarding public transportation services that were being widely served the people mobility in different countries in the world especially BRT, it is very important to understand the feedback from the riders in term of quality of the service. This is in order to gather those data to help improving service quality. By enhancing the service quality of the public transport system to meet with the needs of inhabitants, it needs to convince more people to use the public transit service. This means that it has a potential to reduce the number of private vehicles and increase the number of people who do not possess any private vehicles and for those who are not able to afford the uncertain fares of paratransit or taxi. This way various problems such as traffic congestion, noise and air pollution, parking spaces, and even fuel consumption would reduce (Nocera, 2011; Nwachukwu, 2014). Nonetheless, customers' attitudes and perceptions cannot access directly to understand their perspectives. Thus, to discover the customers' attitudes and perceptions, it requires to conduct the questionnaire survey in order to analyze and identify the relationship between people and provided service. After the stage of the survey, all the surveyed data are needed to evaluate the influence factors in which reason convinces them to use or not use the service in order to uncover the latent factors of improving the transit quality.

2.8.1 Influential Factors of BRT Service Quality

Passenger satisfaction on the bus quality of service influences to the successful operation of public transportation as well as BRT. Through the investigation of many researches, they revealed that there were some similarities set as the criteria to evaluate the quality of service based on customers' perceptions. Transportation research board (TRB) summarized the criteria of customer's perceptions into 10 determinants of quality of service as following (TCRP, 1999):

- (1) Reliability of the service includes the consistence of performance and trustiness of the service;

- (2) Responsiveness of service providers (service employees) to have willingness and readiness and service to customers should be served in time;
- (3) Competence of particular skills and knowledge to provide the service;
- (4) Access has to be easy for using and contact with;
- (5) Courtesy means that the service is needed to served politely, respectfully, and friendly to the customers;
- (6) Communication includes providing information to customers in any understandable and suitable language for particular areas;
- (7) Credibility of the provided service to get the trustiness, faithfulness, and loyalty from customers;
- (8) Security means that the provided service has to keep away from any dangerous things or circumstances and any risks causing to life or treasure;
- (9) Understanding/knowing the customers' requirements and expectations; and
- (10) Tangibles of the service including the physical environment and representation.

Recently, similar studies were conducted by several researchers to identify the influenced factors from the perceptions of customers. Rohani, Wijeyesekera, and Karim (2013) outline the importance and influenced factors for determining the service quality of bus operation under the passenger decision. The research addressed that the factors that could influence the use and access of customers are reliability, safety, comfort, and cleanliness. Deb and Ali Ahmed (2018) has been through the study of intra-city bus service quality on the users' perceptions and expectations in Agartala, India. He found four latent factors that affected hugely to the satisfaction of users including safety, comfort, accessibility, and timely performance. According to the reviews of public transit users' perceptions with the aim to enhance service quality, they revealed that there are some similarities among the studied factors which could affect the service quality for instance accessibility, bus stop, cleanliness, comfort, convenience, driver, facilities, fares, frequency, information, interest on new service route, maps, number of seats, reliability, safety, sufficient space, and ticketing (Kim, Lee, Kim, & Kwon, 2005; W. Liu & Teng, 2014; Mazzulla & Eboli, 2006; Nakamura, Morita, Vichiensan, Togawa, & Hayashi, 2017; Paulley et al., 2006; Perk, Flynn, & Volinski, 2008;

Semchugova, Zyryanov, Negrov, & Nikitina, 2017; Suwardo & Kamaruddin, 2010; TRB, 2007).

In Bangkok, there are a few studies to assess the service quality of the bus as well as BRT. Yongyat (2013) conducted the study to assess the factors influencing to the accessibility of the BRT passengers. The result of the study revealed that the distances to access the BRT stations were the crucial factor of the inhabitants in the area to use the BRT. Besides, from the analysis result it found that if there is an increase of one townhouse in 500 meters within stations, it increases more distance for BRT passengers around 70 meters to access the service; and if there is an office building occurs in the area, the distance of access raises up to 120 meters. Another similar study in Bangkok, Purahong (2011) conducted research with aiming to improve the accessibility of BRT stations using non-motorized transportation in Yan Nawa district, Bangkok. The results of the study showed that most of the respondents were traveling by public bus and private cars before BRT was implemented. Presently, most of the BRT passengers were traveling to BRT stations by walking, hired motorcycles and public buses respectively. Problems and obstructs from traveling by bicycles and walking were the weather conditions, bicycle and pedestrian routes were unsafe, a high number of cars and motorcycles. The study also found that if the bicycle and pedestrian routes were improved, the number of the respondents who ride bicycles and walk to BRT Station, would increase by 19.7% and the number of BRT passengers would increase by 5.4%. Meanwhile, Roaj-assawachai (2013) found that there were some external factors that diminish efficiency and reliability of BRT, for instance, the system could not give a priority to BRT in free flow passing through intersections and could not inhibit the aggressive passenger cars from using BRT lanes. The study of commuters' satisfaction also indicated that there were several factors influenced the complacency such as passenger density, waiting time, safety, and comfort and convenience of the systems. While Ayutthaya (2011) studied the BRT passengers' behavior in term of relationship between economic and social characteristics of BRT commuters by considering the behavior and impact factors to the choice of a trip. The results of this study indicated the residents who reside in the selected area did not choose BRT as their trips. They still preferred a private car for their trips even in the rush hour that full of traffic packed since it is the direct transit to their destination. When

combined several of factors (travel time, the station access time, dwell time, and transit to other modes time) together, it showed that there was not much different in term of travel time that affecting to the population in the area prefer using private cars rather than BRT. The other reasons behind this story were that the inhabitants' working places are widespread within the city nodes and public transportation could not cover their traveled places. For the travel behavior study case of BRT, commuters revealed that the main objective of their trips was to their working places and school trips respectively. The study also found that some trips were traveled different from BRT's intention meaning that the trips which connect to BTS from BRT were used for shopping trips instead of work and school trips because BTS trunk link passes many department stores, not their working places. However, through the critical review of literature, there has not been any studies that could indicate which factor(s) should be prioritized when conducting the BRT improvement. In which, this study was conducted to uncover the factors that should be improved together or parallelly improved.

2.8.2 Questionnaire Development and Data Sampling

In the stage of designing a questionnaire, it needs to be designed clearly and covers most of the dimensions of customers' requirements. Customers' requirements are essential to take into study's consideration. They make the researchers understand the perceptions and relationship between customers and providing services in a better position from the respondents' data. Therefore, the questionnaire should include the specific information that the researchers want to assess the customers' attitudes and perceptions based on the service quality determinants such as reliability, safety, cleanliness, comfort, service frequency, etc. Moreover, the questionnaire questions should be designed in the way that they are easy and understandable to answer. Otherwise, if the respondents do not understand or get confused with the questions, it will directly affect the desired collected data (Hayes, 1998). Deb and Ali Ahmed (2018) designed their questionnaire by considering three parts. First, questions related to users, social-economic characteristics (sex, age, income, owned vehicle). Second, questions related to bus service attributes that asking bus passengers to rate the services based on their perceptions or expectations using Likert scale 1 to 9 by considering 9 is the most

satisfied and 1 is the least satisfied. Third, questions were designed to ask the passengers to rate the overall performance of the current provided services at the same scale of rating. Therefore, questionnaire should be carefully designed and organized the contents to against the bias, inaccurate and unusable data from the respondents.

Another consideration to be taken into account is the process of collecting data. Traditionally, data collection is of the most important part to conduct any researches on the transit service quality enhancement. Therefore, to conduct the data collection of customers' attitude and perception, questionnaire survey plays a crucial role in the context of qualitative data. The questionnaire survey method which is employed to ask the respondents' views on the available transit service. On the basis of questionnaire survey, there are two main types to inquire people's perspective including (1) revealed preference (RP) – when there is a plan to implement the transport system in some particular area, the RP survey is required to collect the data from the people before the system comes into operation; (2) stated preference (SP) – this is to handle with the hypothetical researches and it becomes a very popular technique to identify the preferences from the respondents to analyze the possibility of the future project before the transit system is planned so that this way can save the time and resources. There are various of researchers applied the SP technique in their studies, for instance, Sivakumar et al. (2006) applied the SP method to understand BRT users' attitude in developing countries. Normally, the SP questionnaire is in the form of text to ask the respondents yet in the process of designing a survey for the study. Two trivially heterogeneous ways to explain the system to respondents as in the form of text-explanation and Image-explanation. With these ways, the researcher was able to know the media effects, users' literacy, segmentary variation, and the significance of variables. The result of this study found that the slightly different design could affect the response of the users considerably. Later, Van et al. (2007) proposed three educational methods to examine the efficiency of the proposed methods on the perceptions of local transport officials to understand more about BRT implementation in Bangkok. Three methods include (1) provide the result information on the BRT operation and concept from the public attitudes and percepts of the inhabitants (2) provide the information of BRT operation system in other countries directly to the officials (3) request the transport planners to propose the potential route to implement BRT from their perspective by drawing on a

city map. Whist, in Bangkok most of the reviewed studies have applied the questionnaires to interview respondents. Roaj-assawachai (2013) used a questionnaire to interview the respondents who used BRT service in order to identify the satisfaction to the BRT operational management. Purahong (2011) determined the scope of study of 500 meters which is the appropriate distance for accessibility mode especially walking mode and 500-3,000 meters for bicycling distance which is the suitable distance for people to access the stations without any other transport modes. The method used in this study was to interview the respondents within the selected area (surrounding 4 aforementioned stations) and the local residents.

However, to collect the questionnaire data, it is impossible and not necessary to administer surveys to the whole population. Therefore, there is a necessity to determine the appropriate and sufficient size for collecting the sample. The size of the sample has a strong meaning to the process of analysis meaning that if there is insufficient data, it affects the level of reliability of the results. To determine the size of the sample, there is a formula for the sample size for the mean or Cochran's formula to estimate the number of samples that needs to be collected (Barlett, Kotrlik, & Higgins, 2001; Israel, 1992).

The formula is defined as:

$$n_0 = \frac{z^2 \sigma^2}{e^2} \quad (2.8)$$

Where n_0 is sample size, z is abscissa of the normal curve that cuts off an area α at the trails, σ^2 is variance of an attribute in the population, and e is desired level of precision

Another study for determining sample size, Deb and Ali Ahmed (2018) reviewed the formula of Johnson and Wichern (2002) to determine the minimum sample size.

The formula is defined as:

$$n \geq N \left[1 + \frac{N-1}{P(1-P)} \left(\frac{d}{z_{\alpha/2}} \right)^2 \right]^{-1} \quad (2.9)$$

Where n is minimum sample size, N is number of populations in the city, P is quality characteristics, d is margin of error which take as 5%, and $Z_{\alpha/2}$ is 1.96 for 95% confidence interval

After the data collection process, the obtained data has a necessity to check the validity of data by considering the reliability of the data, the Cronbach's alpha value (Hair, Black, Babin, & Anderson, 2010). The value is suggested to be in the range of 0.5 to 0.9 with distinct definitions as shown in Table 2.9.

Table 2.9 Cronbach's Alpha Value

Cronbach's alpha value	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$\alpha < 0.5$	Unacceptable

2.8.3 Analysis Method of Attitude and Perception Study

Selecting an appropriate method to analyze the satisfaction of the collected survey data is very essential to interpret the results. Recently, several researches have used different methods to analyze their collected data to understand the influenced factors on the provided services of transit based on perceptions and attitudes of passengers. The popular techniques that are widely used to identify the key factors which affect distinct attributes of service quality of transit including structural equation modelling (Eboli & Mazzulla, 2012; Lai & Chen, 2011), cluster analysis (Ramon-Gonen & Gelbard, 2017; Rodriguez Cote & Diana, 2017), exploratory factor analysis (Hu, Zhao, & Wang, 2015; Nwachukwu, 2014), confirmatory factor analysis (Jomnonkwao & Ratanavaraha, 2016), etc. All aforementioned methods are considered as the statistical multivariate analysis. By applying SEM, causal relationships among the variables are hypothesized to identify the manifest and latent factors through the causal models with a linear regression system. Another notable technique named as cluster analysis is one of the notable statistical technique that combined several of algorithms together in the form of grouping the similarity of objects into respective

categories. The method of data categorization in cluster analysis can discover the structures in data without giving any explanations (Statsoft, 2018).

Previously, there were several studies applied these two kinds of statistical technique in their researches. For instance, Eboli and Mazzulla (2012) adopted the SEM to analyze the passengers' perceptions on the services of railways in the north of Italy in order to improve quality of service of Italian transit transportation. The research was considered 36 equations with the latent exogenous variables (Additional services, cleanliness, comfort, information, safety, and personnel) and latent endogenous variable (service quality) to solve a system. After solving the SEM of the research problem, the result revealed that on-time of arriving and departing, schedule-based service, comfortability, provided information, and cleanliness were found as in the positive impact. Whilst, the cluster analysis indicated the useful information that excessive car use in France has to be reduced, meanwhile, new transport services should be promoted.

However, factor analysis also plays a paramount role in the context of exploring latent factors. Since it is one of the statistical techniques which is suitable for analyzing the complexed pattern or multidimensional relationships of a vast amount of variables into a smaller set of components (Hair et al., 2010). Hence, there are 2 main techniques used in factor analysis to identify the underlying factors – exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EFA is a technique applied to explore the factors that have never found clearly by the researcher before. In the EFA, the number of variables is reduced and the relationship between observed variables and latent factors are identified. While CFA is a special use in the factor analysis in which it is commonly applied to examine whether the hypotheses of the model fit with the understanding of the researchers or not. Therefore, before conducting the CFA, the EFA should be specified with the specific results (Deb & Ali Ahmed, 2018). In the past decades, there were several studies proposing the methodological criterion of examining the goodness of fit when applying EFA, such as the adequacy of the samples using Bartlett's test and Kaiser-Meyer-Olkin (KMO) test, factor extraction, data rotation using Varimax or Promax, cut-off point of factor loadings to obtain the appropriate groups of latent factors, percent variance explanation, and communality value (Deb & Ali Ahmed, 2018; Law, Daud, Hamid, & Haron, 2017; Wipulanusat,

Panuwatwanich, & Stewart, 2017). Whilst, in the CFA, there are five common indicators of goodness fit used to determine how fit of the model including Chi-square (χ^2/df), comparative fit index (CFI), goodness-of-fit index (GFI), root mean square error of approximation (RMSEA), and incremental-fit index (IFI). Deb and Ali Ahmed (2018) conducted a research to discover the service quality of the bus service in Agartala, a small city in India. The research was conducted by using a combination of statistical tools such as EFA and CFA, linear regression analysis, structural equation modeling (SEM) to reveal the latent factors which affect the users' perception and expectation. The result of this study revealed that there were four underlying factors affecting the users' perceiving and expectation including safety, comfort, accessibility, and scheduled performance. Another study of Law et al. (2017) conducted a research with an aim to establish a safety performance index to help reducing the risk of travel for the intercity buses in Malaysia. The study was applied EFA to explore the underlying factors by considering road environment conditions, the behavior of the bus driver and the safety conditions of the bus. From the empirical result, the study indicated that the environment conditions contributed as a strong risk to the safety of the intercity bus on the east coast rather than on the west coast of the city.

Besides the aforementioned studies, there was a study that Roaj-assawachai (2013) investigated influenced factors to users' satisfaction by applying impact score techniques and quadrant analysis as tools. The result from the study found that there were some external factors that diminish efficiency and reliability of BRT, for instance, the system could not give a priority to BRT in free flow passing through intersections and could not inhibit the aggressive passenger cars from using BRT lanes. The study of commuters' satisfaction also indicated that there were several factors influenced the complacency such as passenger density, waiting time, safety, and comfort and convenience of the systems. Neamkul (2010) was been through the research to study correlations between information exposure, perceived attributes of innovation and tendency of using Bangkok BRT among Bangkok residents, and compared perceived attributes of innovation and tendency of the BRT passengers who had the difference in demographic characteristics. This research was also to study the variables that were explainable to the tendency of using the BRT with statistical significance. The obtained data were collected by questionnaires from a total of 400 samples. Percentage, mean,

Pearson's product-moment correlation coefficient, t-test, one-way ANOVA and multiple regression analysis were employed for the analysis process. SPSS program was also used for data processing. From the result of this study, it revealed that Bangkok inhabitants from a different background (age, education, income) had different perceived attributes of using the BRT.



CHAPTER 3

METHODOLOGY

This chapter consists of the processes of conducting this research aiming to attain the objectives of the study. This chapter is divided into 6 sub-chapters. It commences with the section 3.1 research framework design, which details the stages of conducting this study with regards to the input and output along with the research activities. Section 3.2 briefly describes the selected area of conducting this present study. Section 3.3 explains what type of data used in this study, how to collect the data and the purpose of using each data. Section 3.4 presents the method for conducting problem investigation. Section 3.5 delineates the processes conducting the simulation study, which details on the model establishment, model calibration and validation, the scenarios proposed in this present study, and the indicators used for result evaluation of simulation. Section 3.6 elaborates the attitude study part of this study with regards to the questionnaire development, sample selection, data validity and data analysis.

3.1 Research Framework Design

The process of designing the research framework is one of the most important parts of a study, as it is a blueprint to achieve the objectives of the study. Moreover, it truly helps the researchers to track their works which have been done, and know what to move on in the next step in an effective way. Basically, the research framework is designed by researchers with sensibly choosing the decision-making choices regarding the aim of the study. The three common things to be considered when designing the schematic research diagram includes the input data, research activity, and the output.

As shown in Figure 3.1, it shows the detailed tasks to be conducted in this present study in order for achieving the objectives of this study. First and foremost, the field survey was conducted to investigate the current condition of Bangkok BRT and the existing literature was reviewed to find the research gaps from both national and international books, reports, and publications. After identifying the problem causing to the BRT system operation, the solutions and hypotheses were proposed based on

knowledge from reviewed literature in order to identify ways to improve the BRT operations. The output of this stage helps the first purpose of this study.

The following stage was the operational analysis part, which considered as the first part of this study undertaken by developing the microscopic simulation model. The model was input the traffic data including traffic flow, traffic geometry, and vehicle types using in the developed model. By obtaining the input data, the model was calibrated to perform as a base model of this present study. Therefore, the calibrated model was validated to the local situation of traffic along the BRT truck line. By doing this way, the base model was ready to apply the proposed solutions to evaluate the impacts of the proposed ones. The comparison of the obtained results was then performed and concluded in term of improvement policies regarding the BRT operation. With regard to this stage of operational analysis part, the outcomes of this stage helped to fulfill the second and third objective of this current study, which sought to develop a model and evaluate the impacts from the empirical analysis results.

Following the stage from operational analysis part, the users' perception analysis part was conducted in order to arrive at the answer of the fourth objective of this study. This stage, the questionnaire was developed and validated by the experts to help to refine the complete set of questionnaires. The developed questionnaire was gathered the data from the BRT users in all stations. The statistical analyses were then performed to identify the travel characteristics and the attitudes of the BRT users. The exploratory factor analysis (EFA) technique was employed to conclude the influenced factors affecting to the use of BRT.

In the last stage of this present study, the policies from the simulation part and from the perception of the BRT user's analysis part concluded in term of recommendations. This would contribute as a guideline for the policymakers for improving the BRT operation in Bangkok. Finally, this study's limitations were addressed for future development.

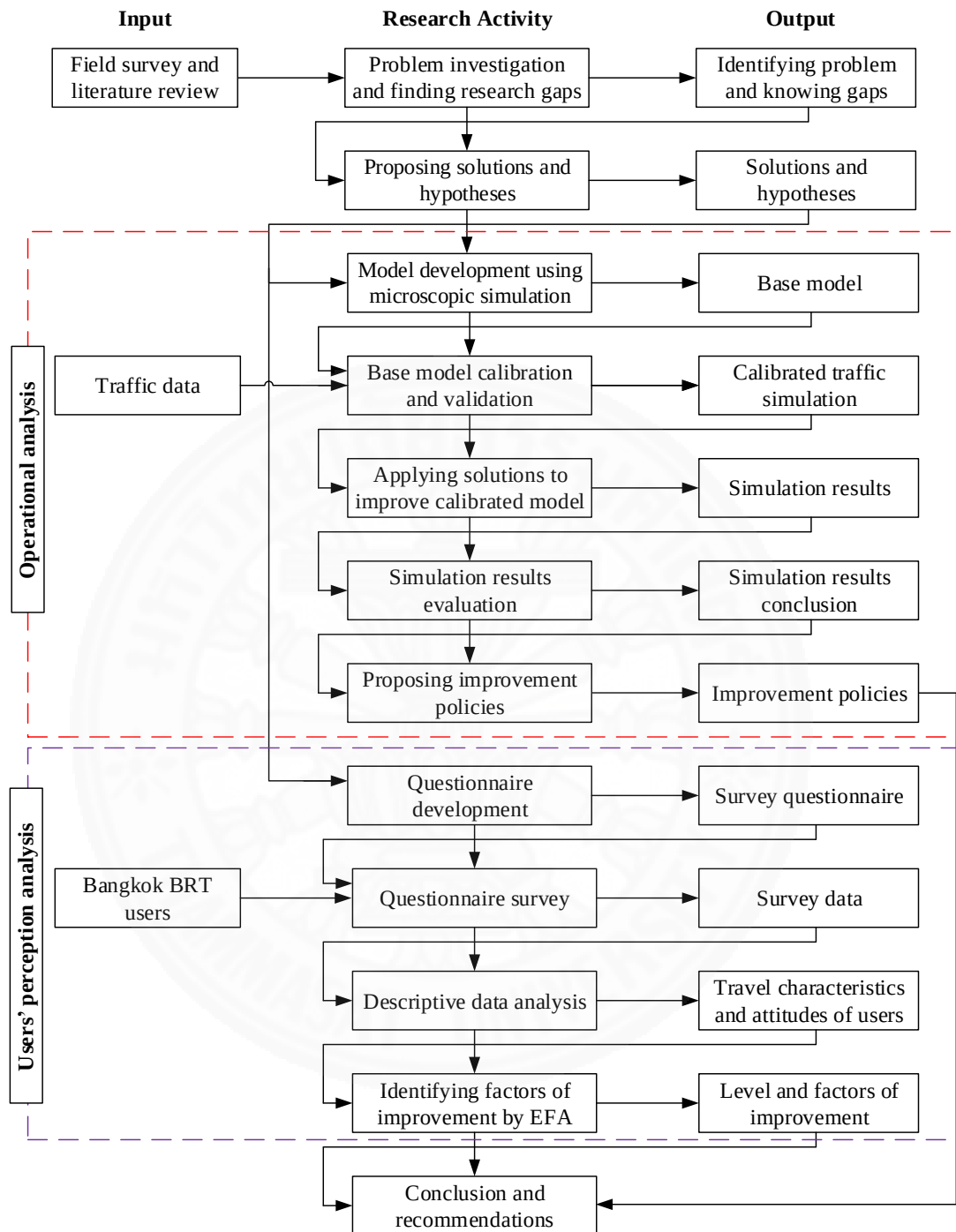


Figure 3.1 Schematic Diagram of Research Design

3.2 Study Area Description

The selected area of this present study was along the BRT trunk line in Bangkok as shown in Figure 3.2. Bangkok BRT operates from Naradhiwat road to Ratchapruek road with a total travel distance of 15.9 km. Bangkok BRT is commonly known as

Sathon-Ratchapruek corridor/trunk line. The corridor is located in the south-west of Bangkok which is surrounded by offices, schools, universities, people houses, department stores, temples, and other important places. There are 12 stations in total with only two terminal stations – start from Sathon station to Ratchapruek station. Along the BRT truck line, there are total 13 intersections which are Ratchapruek-Ratchadaphsek intersection, Mahai Sawan intersection, Charoen Nakhon (Bukhalo) intersection, Charoen Krung (Thanon Tok) intersection, Charoen Rat intersection, Rama III-Ratchadaphisek intersection, Sathupradit intersection, Rama III-Yanawa intersection, Rama III-Industrial Ring road intersection, Rama III-Narathiwat intersection, Narathiwat-Ratchadaphisek intersection, Narathiwat-Thanon Chan intersection, and Narathiwat-Sathorn. In the total of 13 intersections, there are 4 signalized intersections without flyovers and 7 flyovers above the BRT trunk line.



Figure 3.2 Map of Selected Area (Sathon Terminal Station-Ratchapruek Terminal Station)

Bangkok BRT has 6 elements of the standard principle elements of being a Bus Rapid Transit including (1) pre-board fare collection, (2) enhanced station, (3) advanced vehicle, (4) waiting area for passenger, (5) exclusive lane, and (6) road barriers as shown in Figure 3.3.



Figure 3.3 Bangkok BRT Elements

3.3 Data Collection of the Study

Data collection is a crucial part that needs to collect at the almost first after identifying and understanding the problem to be researched. It has a strong impact to result if there are some errors appeared in the collected data. In this study, there were 2 majors of data to be employed – primary data and secondary data. In which, the field survey data used as primary data and some of the traffic data used as secondary data. Primary data consists of the data from field investigation problems, required data for simulation such as traffic signal duration, queue length, travel time, and questionnaire survey data. Besides, secondary data was provided by the Bangkok Metropolitan Administration (BMA). It includes geometric data BRT corridor and traffic demand data.

3.3.1 Primary Data Collection

Primary data collection consists of three main data that needs to be gathered for this study. They are problem investigation data, required data for the simulation (traffic signal duration, queue length, saturation headways, travel times of car and BRT), and questionnaire survey data. All of the primary data were collected from the field survey. The data was commenced with the problem investigation data; this data was collected on 16th – 20th October 2017. The required data for simulation were collected on 20th June 2018 to 3rd July 2018. And, the questionnaire survey data were collected on 13th – 26th February 2019. The details of the data collection's method were explained below.

For problem investigation data, field survey observation technique was used in order to summarize the problems occur as the obstacles for operating BRT shown in Figure 3.4. The main purpose of this data collection is to collect the current situation problem regarding BRT operation obstacles.



Figure 3.4 Observation of Problem Investigation

Another important data regards to the data applied in the microscopic simulation model. The required data for the simulation model includes road capacity, traffic signal

durations, queue length, and travel time of BRT buses and cars. These data were important to make the created model truly represents the local condition prior to conducting the proposed simulation's scenarios. Besides, the required data is crucial for the process of model calibration, so that they are necessary to collect in the proper and suitable way. Figure 3.5 showed the collected locations of saturation headway and queue length data. In which the data was collected from one approaching link that had the outstanding headway and length of queue from overall 10 intersections.

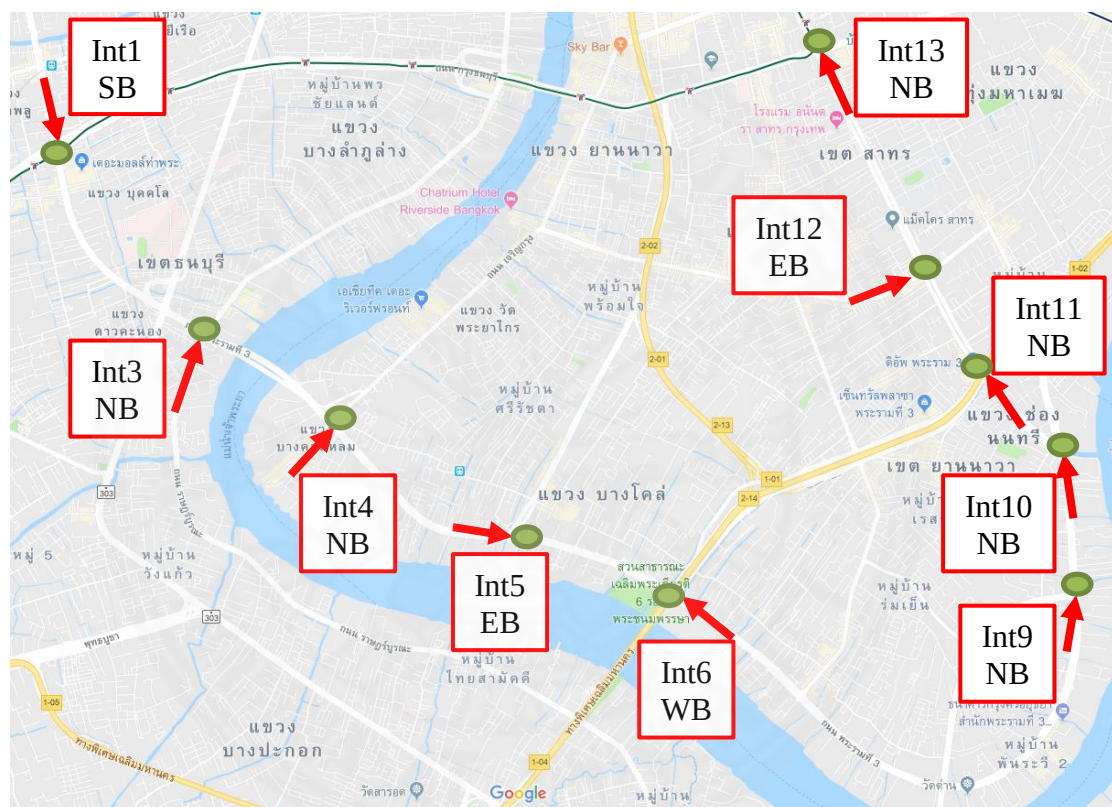


Figure 3.5 Locations of Collecting Approach Saturation Headway and Queue Length

The road capacity was collected by adopting the vehicular saturation headway at the a-grade intersections along the BRT corridor in the peak hours. According to the guideline of HCM (2000), the saturation headway is the average headway between the successive vehicles (in front vehicles) that stopped in the queue and attempt to pass the signalized intersection. The saturation headway can be collected from a point along the lane. It is started to count after the fourth vehicles leaving from the intersection when the traffic light is changed to green from red, and continue counting to the last vehicle.

The saturation headway was collected in the unit of second. The headway data were further used in the process of calibration and validation of this study as the input values.

The traffic signal durations data were collected by recording the time of each phase in each intersection along the BRT trunk line (13 intersections) see more in Appendix B. The data were collected in the peak hours to be the control traffic data of the microsimulation model.

Queue length data were collected at the intersections which had the outstanding or the longest queue length. According to NAASRA (1988), a vehicle is in a queue when it is controlled in its actions by the vehicle in front of it, or has been stopped by the component of the traffic stream. Queues can occur in traffic moving along the open road as well as at constrictions in the traffic system. The queue length was measured when the vehicles arriving at the signalized intersection during the red phase halted and not be able to leave during the red phase. The vehicles stopped at the intersection when the light turn green represented the maximum stationary queue length in this present study. The queue length in this study was collected in the vehicle unit (veh). The queue length data were collected by measuring at the 10 intersections along the BRT corridor. These maximum queue lengths were to be later used for the purpose of model calibration and validation.

Travel time was another data collected in the study. The travel time is the average time of any vehicles traversing in the road section (HCM, 2000). Travel time can be used to determine several values such as space speeds and delays (NAASRA, 1988). Hence, travel time in traffic systems should be approached carefully. This present study was adopted the basic and well-known approach to observe the travel time namely, floating car method. Floating car method is normally applied in the long road segments, in which it is appropriate for the study. Floating car method measures the mean travel time along a test section. The method works in the following way. The test vehicle attempts to simulate an average vehicle in the traffic stream, by noting the number of vehicles that overtake the test car, and the number of vehicles that the test car overtakes. The driver tries to equate these two numbers of overtaking. NAASRA (1988) suggested that a sample size of 20 round trips is required to achieve accurate results in order to against the biases occur. However, this way is considered costly and timely. Therefore, five round trips have been found adequate for most urban roads. In

this study, the floating car data were collected in five days to obtain the average data of travel times both BRT and car in the network. The travel time data were later applied in the microscopic simulation model calibration, validation and evaluation of level of service (LOS) of the BRT.

Last primary data was the BRT customers' perceptions and attitude data. It is crucial to collect from the field survey by using questionnaires. In the first step of conducting the survey, the questionnaire was developed in the appropriate form and proper words to make the respondents get the feeling of the objective of our survey is. Then, a set of questionnaires were pre-tested with some respondents to ensure whether the developed questionnaire was understandable and easy to answer. Subsequent to the pre-test or pilot test, there were some wordings to adjust in order to come up with the ready-use questionnaire. The ready-use questionnaires were later interviewed the BRT users in the stations and buses with the amount of desired sample size.

3.3.2 Secondary Data Collection

The secondary data were provided by BMA for the use of model development. The provided data contained geometric data and demand data along BRT corridor. The geometric data consisted of road configurations, type of lanes (mixed-traffic and BRT-only), number of lanes per direction, lane's width, and turning permissions at intersections as an example shown in Figure 3.6 (see Appendix A). The geometric data provided by BMA were in the CAD form. In which, it consists of all the information data regarding the width, length of the BRT corridor. But the sub-street geometry data was not included.

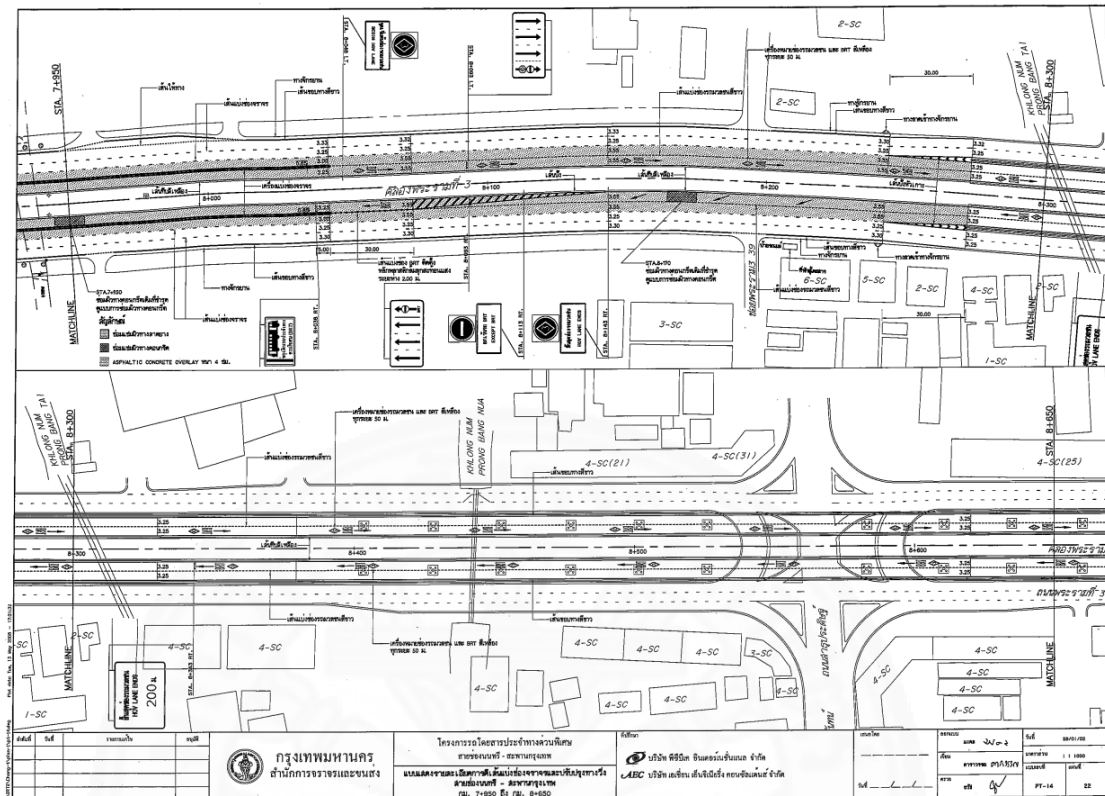


Figure 3.6 Geometric Data Collected by Bangkok Traffic and Transportation Department

Hence, the sub-street data and some physical surroundings along the Bangkok BRT Sathorn-Ratchaphruek corridor were collected. Firstly, the surroundings were identified and recorded using Google Earth as shown in Figure 3.7. Secondly, any other components that had not been clearly shown in the online source were later collected by conducting on-site visual surveys to ensure that the developed model was closed to the real situation such as the location of bottlenecks. The fundamental physical surrounding is one of the key factors that affect extremely to the result from the simulation modeling due to the width, the length, and the location of each BRT station. Thus, all fundamental information was required to collect carefully by observation several times and collecting some surroundings.

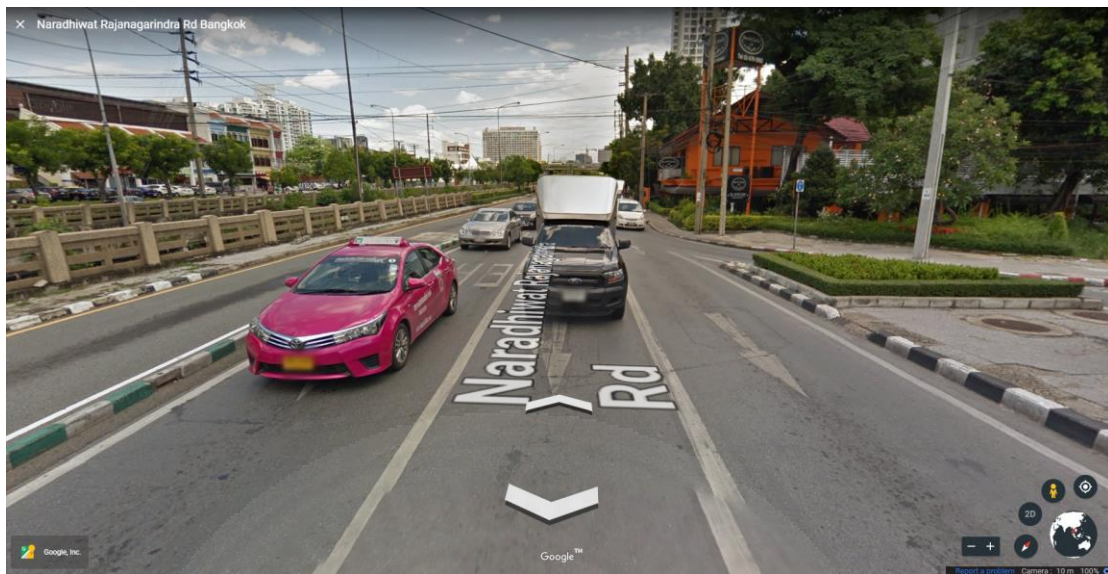


Figure 3.7 Google Earth's Geometric Data

Besides the geometric data, traffic data collected by Bangkok Traffic and Transportation Department was mainly used. It contained data such as daily traffic-flow rates in passenger cars per hour, average flow, and turning movement proportions at intersections as shown in Figure 3.8 (See Appendix B). The demand data included traffic volumes (in PCU unit) at each intersection and turning movements in an hour per hour from 6 am to 6 pm, totaling 12 hours. However, this study used the data only in peak hours 7:00-9:00 (morning peak hour) and 16:00-18:00 (evening peak hour). Since these two peak periods are the interesting times for all road users to commute for their origin to their destination. While the provided data was collected in the normal condition meaning that there were no accidents or incidents occurred which caused the unusual event.

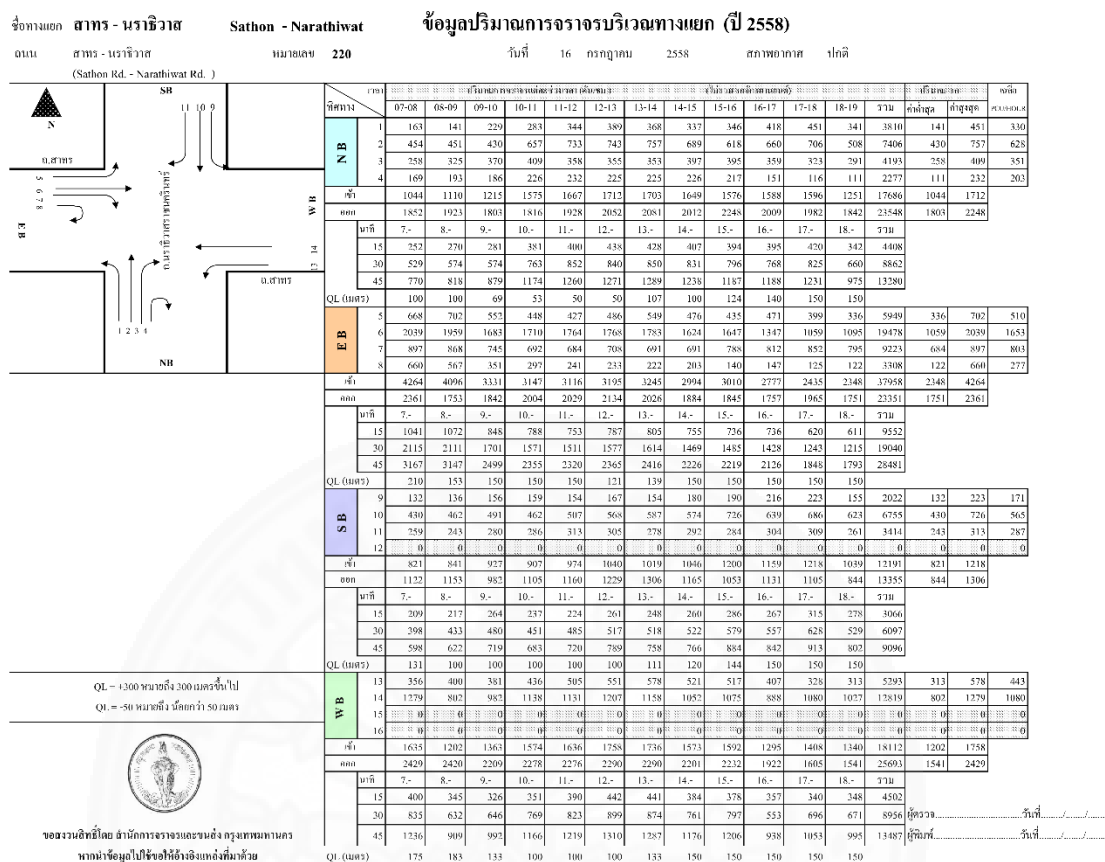


Figure 3.8 Traffic Data Provided by Bangkok Traffic and Transportation Department

3.4 Problem Investigation of BRT Operation

Bangkok BRT has encountered several issues causing the unreliability to BRT operation especially to the travel time due to being stuck in the congestion for a long time. Therefore, it is necessary to be observed the problems happening along the Bangkok BRT. It affects the operation of BRT as the obstacles of public transportation in Bangkok. Thus, the effective way to collect the current condition of Bangkok BRT was to conduct the field observation by taking the videos, pictures, taking some interview notes to draw the conclusion of the actual problem happening along the Bangkok BRT corridor.

The procedure of the problem investigation study was commenced with field data collection by on-site visual surveys involving at the station and being ridden on the BRT buses for several times to identify and categorize the appeared problems while BRT is providing service to customers as shown in Figure 3.9. From the problem

investigation result, it helped this study proposing the application via simulation scenarios to evaluate the impacts after the implementation of the proposed strategies.



Figure 3.9 On-Site Visual Survey by Ridden on BRT Buses

3.5 Operational Analysis: Traffic Simulation

The purposes of the simulation part were to develop the microscopic simulation model and to calibrate the model as closed as the real traffic condition. Another purpose was to propose the solution for improving the BRT operation by the proposed scenarios. Therefore, the simulation part was considered as the major part that conducted in this present study. Therefore, the simulation model was very carefully developed and calibrated in order to get the model that closed to the real situation under AIMSUN software. The procedures of the simulation part were detailed with the 12 typical steps under the recommendation of Daamen, Buisson, and Hoogendoorn (2014) as following.

- Determined the study objectives and the alternative scenarios to be compared;
- Set the performance indicators (delay, stop times, travel times) used in the result comparison stage;
- Created the network models to simulate by respecting to the link characteristics (number of lanes, lane's width, length of road segments,

desired speed) and node characteristics (traffic flows, turning movements, signalized control plans, traffic priorities);

- Input the demand data into the model;
- Started running the simulation model and verify the model whether the model could perform as expected or not;
- Defined the number of replications to be simulated (at least 6 replications with the 90% of confidence level, suggested by Dowling, Skabardonis, and Alexiadis (2004));
- Calibrated the simulation model with respects to road capacity, queue length, traffic flow, and travel time of car and BRT with a set of data (morning-peak-hour data) to achieve the base model;
- Validated the simulation model under the similar aspects in the calibration step with another set of data (evening-peak-hour data);
- Simulated the base model and alternatives;
- Collected the result data from the base model and alternative models;
- Analyzed the impacts on the chosen performance indicators from each scenario by comparing with the base model result; and
- Summarized the results and provided the recommendations.

In short, the procedures in traffic simulation development from the above-mentioned steps were combined and explained into three major phases. The first phase was to construct the model by inputting relevant traffic data such as geometric data, traffic volume, turning movements, traffic signal control plan, etc. The second phase, traffic simulation model was necessary to calibrate and validate in order to obtain the base model of this study. And the third phase, the alternative scenarios which aim to improve BRT operation were adopted and evaluated to draw the conclusion of the results.

3.5.1 Microscopic Simulation Model Construction

The microscopic simulation model of this present study was developed by using the traffic simulation software, AIMSUN, to build the road network with detailed roadway configurations and geometries as shown in Figure 3.10. The network was

constructed from Ratchadaphisek-Ratchaphruek intersection, continued along Ratchadaphisek road, crosses Rama III Bridge, and followed the BRT corridor until it stretched to Narathiwat-Sathorn intersection. In the developed model, there were solely 13 considered intersections in this model, in which the side-streets were eliminated due to the unavailability of data in the study area.

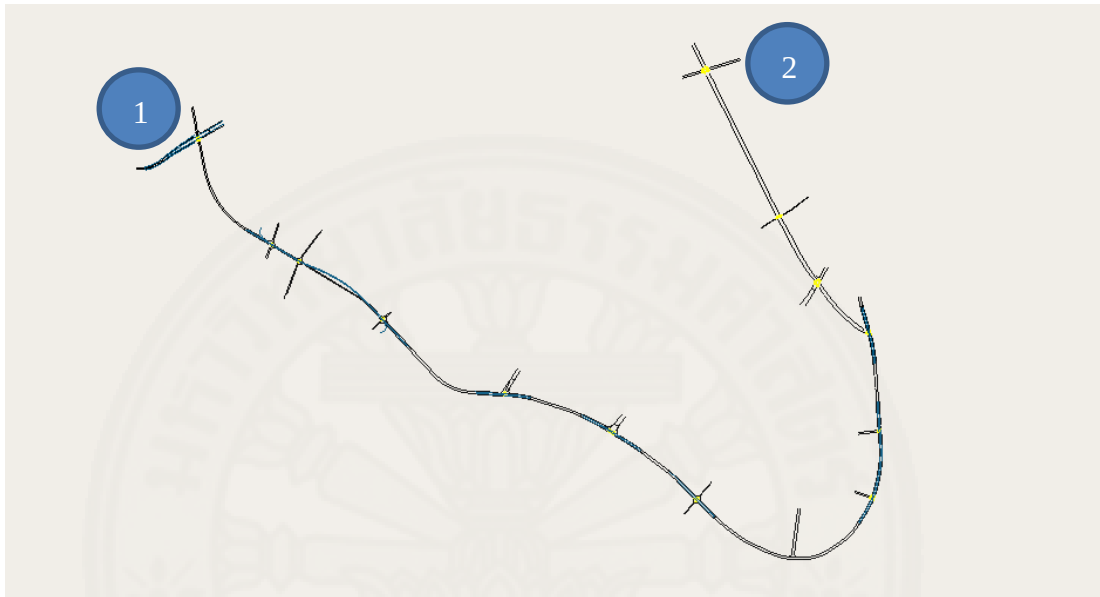


Figure 3.10 Overall Road Network Model Constructed from Ratchpruek-Ratchadapisek Intersection (1) to Narathiwat-Sathorn Intersection (2)

AIMSUN software is one of the well performed software in building the large-scale model in a quick and easy way. Since the software allows the users to create the model from the opened street map (OSM) which links with the satellite. The intimal model created by the AIMSUN based on OSM data was partially similar to the real case. But the length and the width of the road sections were adjusted with the real data to get more closed model as shown in Figure 3.11. Through the window of section editor, the relevant aspects to adjust the road section are available such as road speed, road capacity, road type, road's slope, lane types, etc.

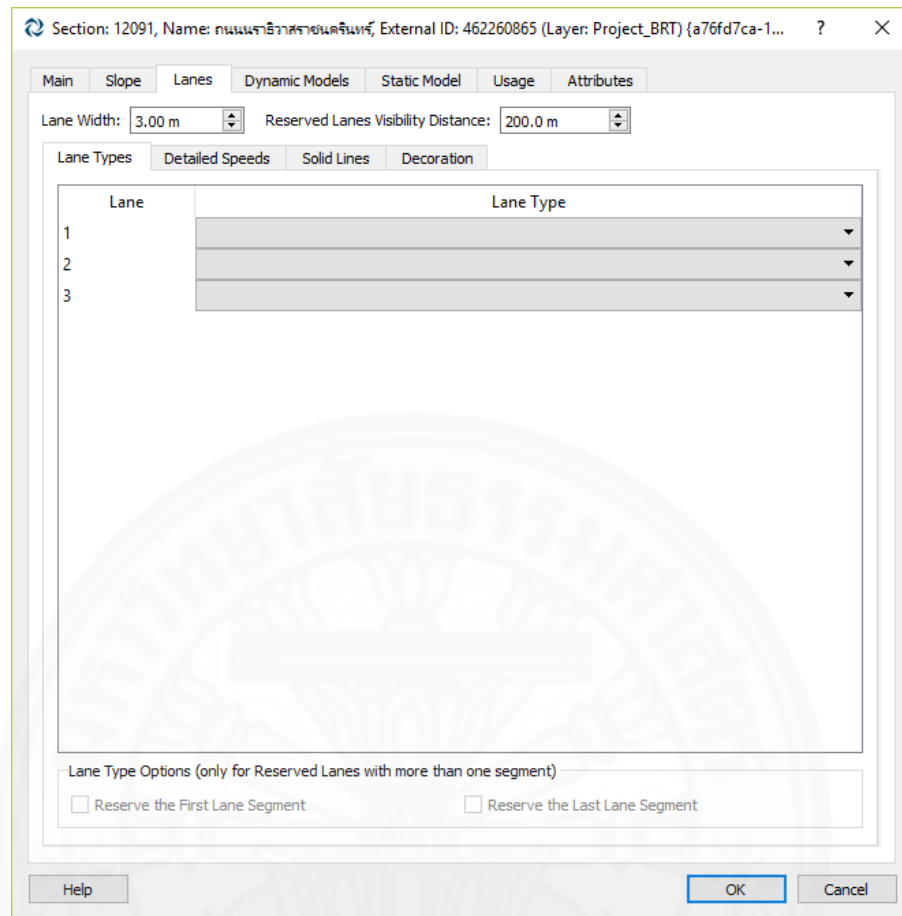


Figure 3.11 An Example of Setting Road Section

After the model was constructed properly, two sets of traffic demand and control plans were created to represent traffic conditions during the morning (7am-9am) and evening (4pm-6pm) periods. Traffic-flow rates (input flow) and turning movements (turn info) were used in creating the two two-hourly traffic states. The traffic volumes used in the model were input in the unit of PCU. In the traffic state window as shown in Figure 3.12, the vehicle types and starting-ending time of the traffic flow were needed to set.

Traffic State: 43180, Name: Traffic 07:00-08:00 Revision_Use {e1105e42-082f-4eba-ad4c-465b73c20a4b}

Main **Parameters**

Name: Traffic 07:00-08:00 Revision_Use External ID:

Vehicle Type: 53: Car Trip Purpose: None

Headers: ID: Name (External ID) From: 7:00:00 Duration: 01:00:00

Input Flow **Turn Info**

☐ Highlight incorrect definitions

☐ Show All Sections

Turn Sections	Turn Percentage	Turn Flow (veh/h)
496: ถนนสาทรใต้ (24829068) to 12063: ถนนสาทรใต้ (462071019)	78.2263	1279
496: ถนนสาทรใต้ (24829068) to 12090: ถนนราวิวาสราชนครินทร์ (462260865)	21.7737	356
822: ถนนมไหสวรรย์ (30045723) to 824: ถนนมไหสวรรย์ (30045723)	38.4152	446
822: ถนนมไหสวรรย์ (30045723) to 3285 (140491702)	61.5848	715
824: ถนนมไหสวรรย์ (30045723) to 8114: ถนนรัชดาภิเษก (199487480)	65.9193	294
824: ถนนมไหสวรรย์ (30045723) to 3355: ถนนสมเด็จพระเจ้าตากสิน (150283742)	32.7354	146
824: ถนนมไหสวรรย์ (30045723) to 8109: ถนนมไหสวรรย์ (199487477)	1.34529	6
1325: ถนนราวิวาสราชนครินทร์ (39727796) to 34886: ถนนรัชดาภิเษก (154774074)	29.0801	588
1325: ถนนราวิวาสราชนครินทร์ (39727796) to 47453: ถนนราวิวาสราชนครินทร์ (39727796)	48.7141	985
1325: ถนนราวิวาสราชนครินทร์ (39727796) to 38963: ถนนรัชดาภิเษก (154774068)	22.2057	449
1330: ถนนราวิวาสราชนครินทร์ (39727796) to 1334: ถนนราวิวาสราชนครินทร์ (39727796)	58.8818	1011
1330: ถนนราวิวาสราชนครินทร์ (39727796) to 8447: ถนนจันทน์ (236051659)	41.1182	706
1348: ถนนราวิวาสราชนครินทร์ (39727796) to 7213: ถนนสาทรเหนือ (177961596)	29.4857	258
1348: ถนนราวิวาสราชนครินทร์ (39727796) to 12054: ถนนราวิวาสราชนครินทร์ (462071018)	51.8857	454
1348: ถนนราวิวาสราชนครินทร์ (39727796) to 12063: ถนนสาทรใต้ (462071019)	18.6286	163
2136: ถนนราชพฤกษ์ (96322875) to 3202 (139501182)	42.5666	1549
2136: ถนนราชพฤกษ์ (96322875) to 2137: ถนนราชพฤกษ์ (96322875)	57.4334	2090
3202 (139501182) to 8155 (199907624)	76.6946	1188
3202 (139501182) to 3203 (139501182)	23.3054	361
3237: ถนนรัชดาภิเษก (140487201) to 3209 (139502694)	18.0169	427
3237: ถนนรัชดาภิเษก (140487201) to 3239: ถนนรัชดาภิเษก (140487201)	81.9831	1943
3239: ถนนรัชดาภิเษก (140487201) to 45081: ถนนรัชดาภิเษก (199388250)	61.0911	1187

Figure 3.12 An Example of Setting Traffic States

While traffic signal durations were used in creating the traffic signal control plans. In which, each intersection has different signalized timing. To set the control plan, the type of control plan was needed to define in which this present study was used fixed control plan with a yellow time of 3 seconds as shown in Figure 3.13. Also, the cycle length of the control plan was another important value to input in the setting. Through the control plan window, the signalized priorities were able to set to provide the priority to the specific vehicles under the ‘pre-emption’. The priority plans in this present study were given to the buses (BRT) when passing through four at-grade intersections which were Naradhiwat-Thanon Chan intersection, Naradhiwat-

Ratchadaphisek intersection, Naradhiwat-Rama III intersection, and Ratchadaphisek-Ratchapruerk intersection.

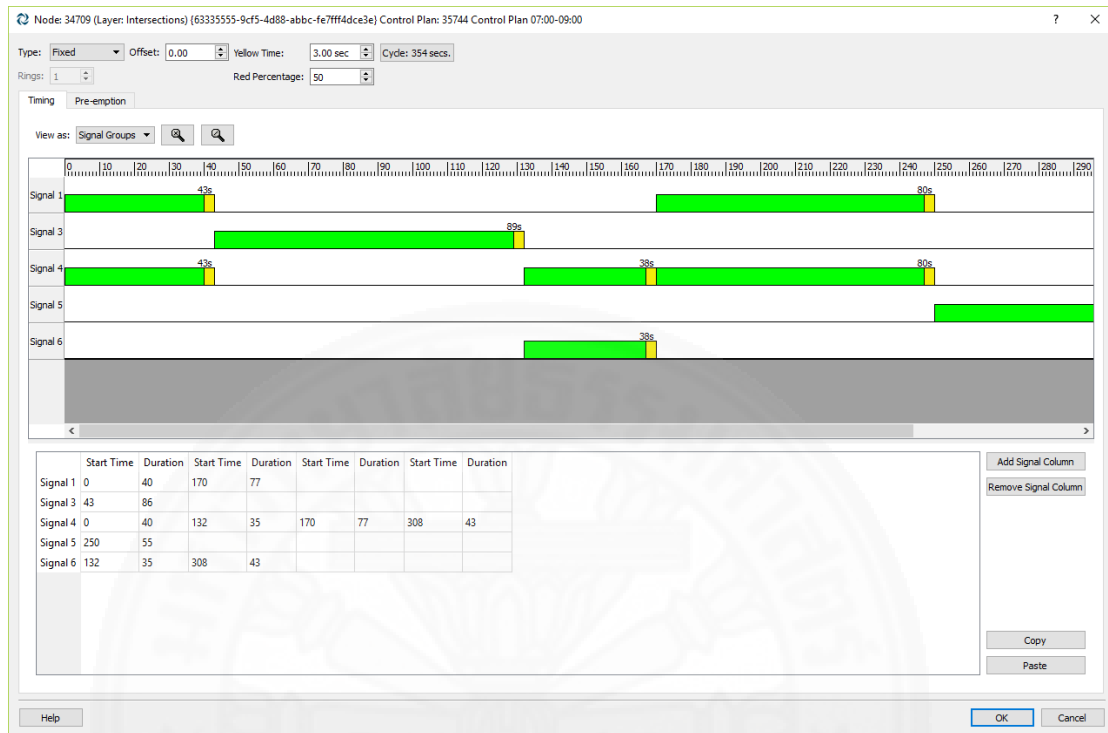


Figure 3.13 An Example of Setting Signalized Control Plan

After the demand and control plans were input, the dynamic scenario was created in order to be able to run the simulation model. In which, the created traffic demand, control plan and transportation plan were needed to defined correctly and carefully to be matched with the created one as shown in Figure 3.14.

Dynamic Scenario: 36564, Name: Base Dynamic Scenario 36564 {e7a423f7-1ea8-46da-ae58-8943fc628f3d}

Main | Outputs to Generate | Aimsun API | Variables | Strategies and Conditions | Parameters | Attributes

Name: Base Dynamic Scenario 36564 External ID:

Times

Simulated Date: 12/12/2018

Simulated Initial Time: 7:00:00 Duration: 02:00:00

Detection Cycle:

☒ Same as Simulation Step ☐ 1 seconds

Traffic

Traffic Demand: Traffic Demand 07-09 Public Transport Plan: 43890: BRT PLAN

Path Assignment: None

Master Control Plan

Master Control Plan 07-09

Detection Pattern

None

Real Data Set for Validation

RDS Real Data Set 45009

Geometry Configurations

☐ Select All Nothing Selected Filter

Help OK Cancel

Figure 3.14 An Example of Creating Dynamic Scenario

When creating alternative models, similar procedures were followed. But, when creating the dynamic scenarios as well as the simulation replications, the seed number should be same as the base model in order to against the biases occurred between the base model and alternative models. Also, the database to store the simulation results should also use the same database. In this present study, 10 replications were chosen to create the average results for each model to obtain 95-percent of confidence level according to the suggestion of (Dowling, Skabardonis, & Alexiadis, 2004) as shown in Figure 3.15.

Average: 45148, Name: Average 45148-B (ffc9df88-1c47-4ccd-b51b-927f03d4e5b5)

Main Validation Attributes

Name: Average 45148-B External ID:

ID in Database: 45148

Status: Calculated

Retrieve Settings
☐ Use Objects' External ID instead of Objects' ID

Replications

Replications	Status
☒ SEED1-B	Simulated
☒ SEED2-B	Simulated
☒ SEED3-B	Simulated
☒ SEED4-B	Simulated
☒ SEED5-B	Simulated
☒ SEED6-B	Simulated
☒ SEED7-B	Simulated
☒ SEED8-B	Simulated
☒ SEED9-B	Simulated
☒ SEED10-B	Simulated

Number of Replications Included: 10

All None

Reset All

OK Cancel

Figure 3.15 An Example of Creating Average Replication

3.5.2 Microscopic Simulation Model's Calibration

The process of model calibration in this research was according to the calibration's recommendations of Dowling, Skabardonis, and Alexiadis (2004)'s Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software.

In the calibration stage using AIMSUN, there were two major groups to be taken into account, which were global parameters and local parameters (Rajasakran, 2008; TSS, 2014). In which, global parameters influence whole network model while running on the microscopic simulation model such as reaction time, reaction time at stop, reaction time at traffic light, queue exit speed, queue entry speed, lane changing parameters, two lane car-following. On the other hand, local parameters affect the

particular section of the network, since the local parameters are speed limits, turn speeds, visibility distance or distance lane changing.

The calibration process conducted in this study was commenced with the process of flow calibration. This step had to be conducted first because the available secondary traffic data was considerably inconsistent in terms of the periods of collection. The periods of data collection ranged from July 2014 to July 2017 as shown in Table 3.1. The objective of this calibration was to calibrate the turning proportion of each intersection to obtain the goodness of fit of the developed model. Following this stage, the road capacity calibration and system performance calibration were later conducted. The morning data was used to calibrate the simulation model.

Table 3.1 Traffic Data Sets and the Periods of Data Collection

Intersection	Data Collection Period
Rama III-Industrial Ring Rd.	July 2014
Bukkhalo	February 2015
Narathiwat-Sathorn	July 2015
Narathiwat-Chan Rd.	August 2015
Rama III-Ratchadaphisek	August 2015
Rama III-Yannawa	October 2015
Narathiwat -Ratchadaphisek	July 2016
Rama III-Narathiwat	August 2016
Thanon Tok	April 2017
Charoen Rat	May 2017
Sathupradit	June 2017
Ratchadaphisek-Ratchaphruek	June 2017
Mahai Sawan	July 2017

3.5.2.1 Traffic Flow Calibration

In order to maintain the base model's ability to reproduce the current traffic conditions, data normalization process was undertaken by adopting the approaching flows from all intersections. Out of the 13 available data sets (one set per intersection), traffic-flow rates of two most recent sets (at Ratchadaphisek-Ratchaphruek and Mahai

Sawan intersections) were taken as a base because these two sets of data were the first entry volume of vehicles into the main road (Ratchadaphisek- Ratchaphruek intersection) and first entry volume of vehicles into the flyovers (Mahai Sawan intersection), and the flow rates at other intersections were adjusted to be compatible accordingly. By multiplying the traffic-flow rates within an individual intersection equally using a multiplication factor, adjusted flow rates could be obtained. Hence, the data from the year of 2014 to the year of 2017 were normalized accordingly, in which the normalization process was calculated by each intersection continuously. See the following example as shown in Figure 3.16 for multiplication factor calculation:

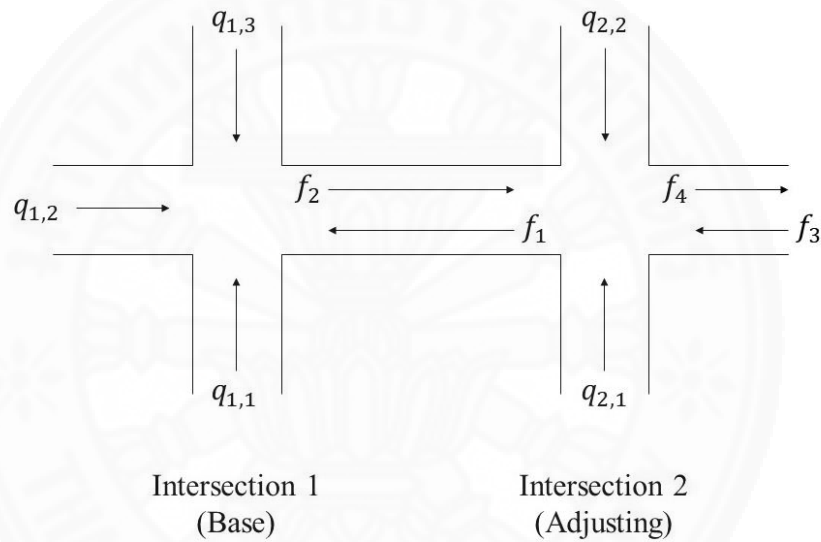


Figure 3.16 The Example of Multiplication Factor Model

Equations are defined as:

$$\text{Adjusted Flow} = \text{Initial Flow} \times c \quad (3.1)$$

$$c = \frac{f_1}{t_{2,1,l}q_{2,1} + t_{2,2,r}q_{2,2} + t_{2,3,t}f_3} \quad (3.2)$$

Where c is multiplication factor for flows at Intersection 2, f_1 is flow-rate into Intersection 1 from Intersection 2, or Target Flow (in veh/hr), $q_{2,j}$ is flow-rates into Intersection 2 from direction j , or *Adjusting Flows* (in veh/hr), f_3 is flow-rate into Intersection 2 from Intersection 3, or *Adjusting Flow* (in veh/hr), and $t_{2,j,k}$ is turning

movement ratios (in decimal) at Intersection 2 from direction j that contribute to the *Target Flow*

After every traffic flow moving into Intersection 2 was adjusted, f_3 was later used as the Target Flow in order to calculate the multiplication factor for the next intersection to the right of Intersection 2. The process was carried out until all flows at all 11 adjusting intersections were adjusted. The total squared error of modeled traffic-flow rates was checked at a total of 56 locations. The GEH statistic was used to determine if the developed model was a good representative of the flow of traffic situations.

The GEH statistic was computed as followed:

$$GEH = \sqrt{\frac{(M_i - C_i)^2}{(M_i + C_i)/2}} \quad (3.3)$$

Where M_i is modelled flow rate (in veh/hr) at location i, and C_i is input flow rate (in veh/hr) at location i

As a criterion of using the GEH statistic suggests that for 85% of the cases, the GEH statistic must be less than 5 (Dowling, Skabardonis, & Alexiadis, 2004).

3.5.2.2 Capacity Calibration

For calibration of capacity, the simple two-parameter search algorithm was performed to minimize the error of the base model's road capacity. The error indicator used in this study was the mean absolute percentage error (MAPE) by adjusting two parameters together: reaction time at stop (in sec) and queue exit speed (in m/s). These two parameters were adjusted together in each experiment which meant that they were parallelly calibrated. Since these two parameters have a strong effect on the change of the model's road capacity. The default values in AIMSUN are shown in Table 3.2.

This study modified the simple two-parameter search algorithm known as one of the fine-tuning algorithms. This present study was divided the searching step into two main phases. The first phase was to set the possible values to cover the boundary of the selected parameters and simulated it gradually with the specific intervals set by the researcher. Hence, the adjustment of reaction time at stop was chosen from the value

of 1.0 sec to 2.4 sec with 0.2 sec intervals and the queue exit speed was chosen from the value of 4.0 m/s to 9.0 m/s under 1.0 intervals in each time of the simulation. Each pair of reaction time at stop and queue exit speed was run by 10 replications. The average capacity indicator used in this study, saturation headway, was later calculated. Subsequently, the headway of 10 intersections was later compared with the field-collected headway data under the use of MAPE to minimize the error. To obtain the error of each pair of reaction time and queue exit speed, the average MAPE from each intersection was also calculated. The next step is to plot the MAPE in a contour map to visualize the obtained MAPE values. This way, the result of the search algorithm returned the optimal saturation headway from the whole set of the simulations, which this study called initial optimal value.

Once obtained the initial value of saturation headway, the second phase was then refined the parameters into a smaller interval with the objective function of minimizing the errors of saturation headway using MAPE as similar as the first phase. The interval of the second phase of calibrating the saturation headway under the reaction time parameter and queue exit speed parameter was set from 1.9 sec to 2.1 sec and 5.5 m/s to 7 m/s with 0.5 m/s interval, respectively. The average MAPE of each pair of parameters was also calculated to obtain the refined/optimal saturation headway value of the second phase calibration.

Table 3.2 Default Value of Calibration Parameters Using AIMSUN Version 8.1

Parameters	Default value
Reaction time at stop (in sec)	1.2
Reaction time at traffic light (in sec)	1.6
Queue entry speed (in m/s)	1
Queue exit speed (in m/s)	4

The objective function of this calibration stage was adopted the mean absolute percent error (MAPE) to minimize the errors from the difference between the observed saturation headway and the simulated saturation headway, which defined as:

$$\min MAPE = 100\% \times \frac{1}{n} \sum_{i=1}^n \left| \frac{M_{hi} - O_{hi}}{O_{hi}} \right| \quad (3.4)$$

Where $MAPE$ is mean absolute percentage error, M_{hi} is modeled saturation headway at intersection i (in sec), O_{hi} is observed saturation headway at intersection i (in sec), and n is number of intersections

Calibration parameters of capacity (saturation headway) were adjusted repetitively under certain limits to minimize an error. In the first phase, there were 480 simulation replications to uncover the initial pair of parameters, and 200 simulation replications to obtain the more refined parameters in the second phase from the simple two-parameter search algorithm.

3.5.2.3 System Performance Calibration

The purpose of the system performance calibration was to fine-tune the model in order to perform the well base model. In this stage, the queue length was adopted to determine whether the model could represent the field condition or not. The parameters used in this stage involving queue entry speed (in m/s) and reaction time at traffic light. These two parameters have an effect to the length of queue in the traffic microscopic simulation. Also, the algorithm used in this calibration of system performance was applied the simple two-parameter search algorithm. The steps of adopting this search algorithm were similar and followed the same procedure of dividing the calibration step into two phases. The first phase was to find the initial pair of parameters that performed the minimum $MAPE$ of the queue length, and the second phase was refined pair of parameters to get closer value of queue length from the observed queue length and simulated queue length. The pair of parameters was considered with calibration objective function, which defined as:

$$\min MAPE = 100\% \times \frac{1}{n} \sum_{i=1}^n \left| \frac{M_{qi} - O_{qi}}{O_{qi}} \right| \quad (3.5)$$

Where $MAPE$ is mean absolute percentage error, M_{qi} is modelled queue length at intersection i (veh), O_{qi} is observed queue length at intersection i (veh), and n is number of intersections

For the system performance calibration using the MAPE of queue length as the indicator, the initial interval was set to be 1.0 interval from 0 m/s to 5.0 m/s for queue entry speed parameter, also 1.0 sec interval from 1.0 sec to 5.0 sec for reaction time at traffic light. Once obtained the initial pair of the parameters (queue entry speed and reaction time at traffic light) that had the minimum MAPE among other pairs, the second phase of calibrating queue length was continued to find more refined value of the pair of parameters. In the second phase of system performance calibration in this study, the queue entry speed was set from 0.5 m/s to 1.5 m/s with 0.5 m/s interval, and the reaction time at traffic light was set from 1.5 sec to 2.5 sec with 0.5 interval.

The system performance's calibration parameters were adjusted repetitively under certain limits to minimize an error. In the first phase, there were 250 simulation replications to uncover the initial pair of parameters, and 90 simulation replications to obtain the more refined parameters in the second phase from the simple two-parameter search algorithm.

3.5.2.4 Travel Time Calibration

Once the capacity and system performance calibration were done, the travel time of BRT and car running in the corridor network had to be calibrated. The BRT's and car's observed travel time from the Sathorn station (B1) to Akharn Songkhlo station (B2) was used to compare with the simulated travel time of the BRT and car. Mean speed of vehicle parameter was calibrated. The initial speed value of BRT and car was determined by the division of distance over the vehicle travel time. Therefore, the bus speed parameter was chosen to adjust from 21.0 km/h to 31.0 km/h with 2.0 km/h interval. Also, the car speed parameter was adjusted from 40.0 km/h to 54.0 km/h with 2.0 km/h interval. In travel time calibration, the MAPE was adopted to minimize the error, which defined as:

$$\min MAPE = 100\% \times \left| \frac{M_{ti} - O_{ti}}{O_{ti}} \right| \quad (3.6)$$

Where *MAPE* is mean absolute percentage error, *M_{ti}* is modelled average travel time of vehicle *i* (sec), and *O_{ti}* is observed average travel time of vehicle *i* (sec)

The average of the travel time the BRT and car were collected from 10 simulation seeds, and was then compared with the observed travel time both vehicles.

3.5.3 Microscopic Simulation Model's Validation

Once the simulation model had been calibrated, the step of model validation had to be carried out. This study validated the simulation model by adopting evening data. The validation was commenced with validating the saturation headway, validating the queue length, and validating the travel time of BRT and car. The mean absolute percent error (MAPE) was employed to examine how much error would produce from the calibrated parameters' value. Another indicator that adopted in this study was checked by the normality distribution. The normality distribution is a tool to check the shape of data whether it distributes in the normal shape or not. By checking the normality distribution, the shape of peakedness and flatness were measured by the value of kurtosis and the balance of the distribution was measured by the value of skewness. When the value of absolute of kurtosis exceeds the specified critical value, it means that the distributions are more peaked than the normal distribution. In the same way, when the data distribute unbalanced meaning that it shifts to one side (left or right), it is considered as an unnormal distribution. Generally, the distribution value both kurtosis and skewness should not greater than ± 2.58 for 0.01 significance level and ± 1.96 for 0.05 error level (Hair et al., 2010). This study examined the distribution of the error by adopted the percentage error (PE) value, which defined as:

$$PE = 100\% \times \frac{1}{n} \sum_{i=1}^n \left| \frac{M_i - O_i}{O_i} \right| \quad (3.7)$$

Where P is percentage error, M_{ti} is modelled value i , O_{ti} is observed value i , and n is number of values

3.5.4 Enhancing BRT Operation: Case Studies

There are several ways to improve the BRT operation aiming to capture more attractiveness and reliability in term of travel time from users. In this present study, the decision to solve the current problem was made by proposing three solutions. Each of

the solutions was prepared as a scenario and tested in the simulation. To increase the reliability of the results, each scenario was tested for 10 times (seeds), and the average traffic statistical data was used in the evaluation phase.

First, providing an additional dedicated BRT lane in the reversed direction on the Rama III bridge according to the traffic conditions (RL). This solution benefited a fact that traffic congestion normally occurred in either of the traveling direction, in other words, outbound lanes would be less congested in the morning comparing to inbound lanes, and thus an outbound lane could be reversed to specially accommodate inbound buses as shown in Figure 3.17 and Figure 3.18. While the outbound lanes were more congested than the inbound lanes, so the inbound lanes could be reversed. This scenario was adopted to both in morning peak hours and evening peak hours only on the Rama III bridge section.

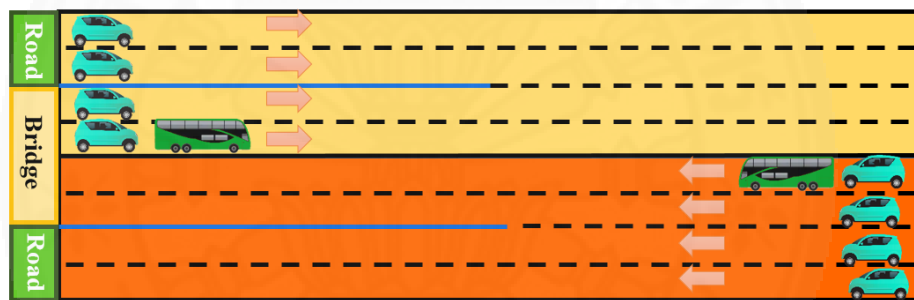


Figure 3.17 Bus Running on a Conventional Bridge in the Base Model (Eastbound Bus)

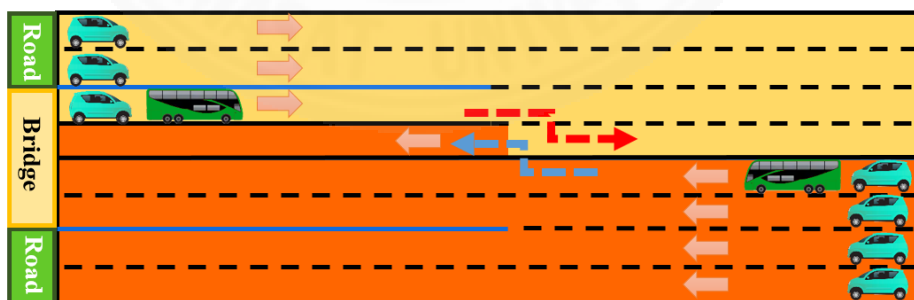


Figure 3.18 Bus Running on An Added Lane on A Bridge in the Additional Lane Solution (Eastbound Bus)

Second, enforcing fully-segregated BRT lanes throughout the corridor (FS). The current Bangkok BRT situation is that the buses are not entirely segregated from other vehicles. With this solution, the buses were fully segregated from other vehicular

traffic, and this would prohibit any other vehicles to get into the dedicated lanes and could reduce delays experienced by the buses as shown in Figure 3.19 and Figure 3.20.

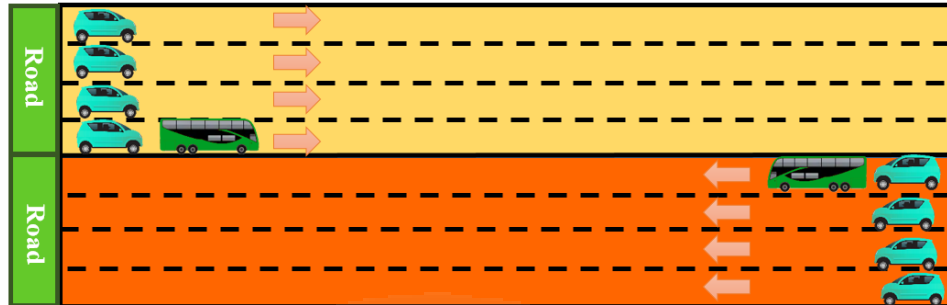


Figure 3.19 Buses Were not Segregated from Other Vehicles at this Section in the Base Model

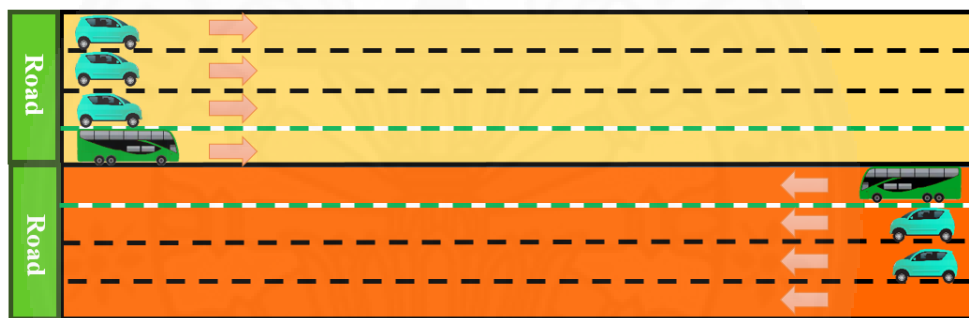


Figure 3.20 Buses Had Their Own Segregated Lanes (Dark-Grey Lane) in the Full Segregation Solution

Third, applying transit signal priority to all at-grade intersections (TSP). This would allow the buses to run through intersections without having to dwell at the intersections and could significantly reduce the buses' intersection delay and, consequently, travel time as shown in Figure 3.21 and Figure 3.22. The method was to set the detector before the bus arriving at the intersection 50 meters and after the intersection. When the detector equipped the bus approaching the intersection, the detector will force the traffic light to turn green for the BRT. After the bus passed the intersection, the traffic light will back to the normal control.

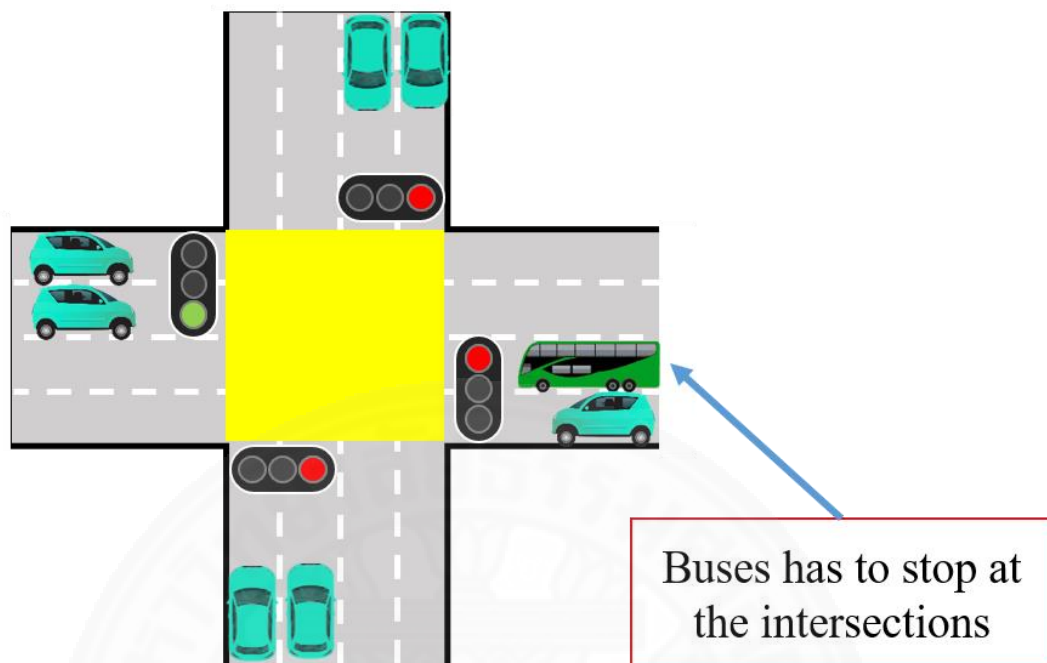


Figure 3.21 A Bus Waiting for a Green Light at an Intersection in the Base Model

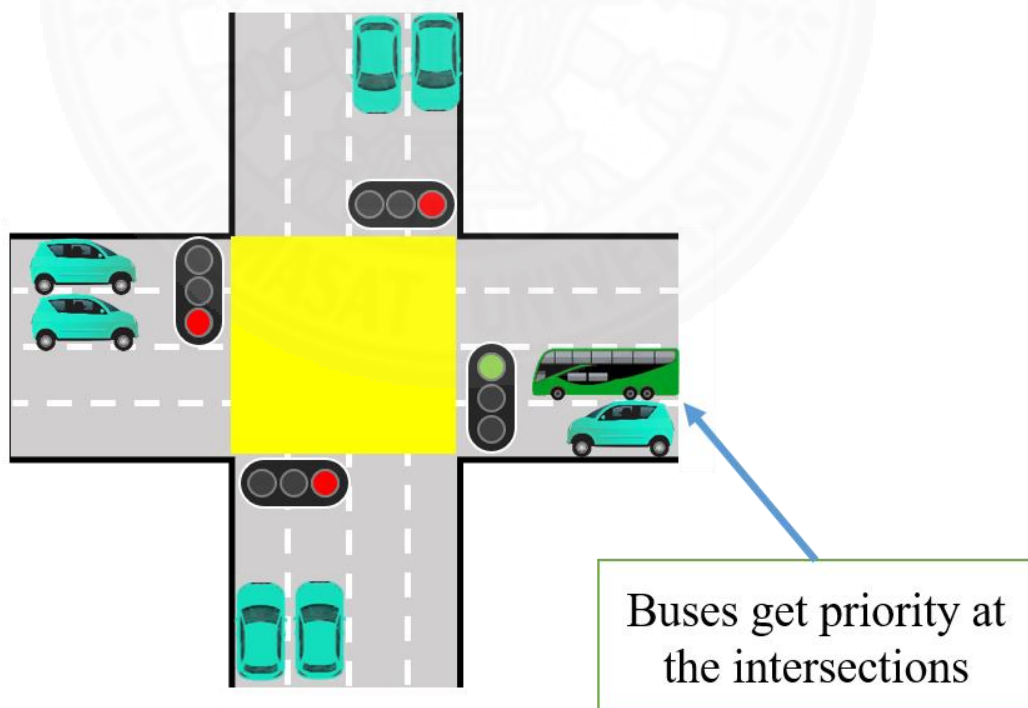


Figure 3.22 A Bus Advancing Pass an Intersection in the Transit Signal Priority Solution

3.5.5 Measure of Effectiveness Evaluation of Case Studies

Performances of each solution were evaluated based on impacts on both the buses as well as the network. Trade-offs were made in order to suggest the most suitable solution to improve the operation of Bangkok BRT. Since negative impacts on other traffic were also needed to consider in establishing any potential policies or strategies. Evaluation of the impacts of the solutions was based on how well it improved traffic conditions of the base model.

Indicators of the traffic performances to be evaluated obtained from simulation software, AIMSUN, and their definition are listed in Table 3.3.

Table 3.3 List of Indicators to Be Evaluated and Definition¹

Indicator	Unit	Definition
Delay time	sec	The average additional travel time experienced by a vehicle, <i>greater</i> delay time indicates <i>heavier</i> congestion
Stop time	sec	The average portion when a vehicle is at a complete stop, <i>greater</i> stop time indicates <i>heavier</i> congestion
Travel time	sec	The average time spent by a vehicle traversing a road segment expressed as unit of time per distance, <i>greater</i> travel time indicates <i>heavier</i> congestion

¹ As defined in Highway Capacity Manual 2000 by TRB (2000)

3.6 Users' Perception Analysis

The understanding the perception of the BRT users as the second part of this study was described with three major parts. The objectives of this part, attitude part, were to evaluate the quality of BRT service under the perception of the BRT users, and to identify the factors that should be improved together in order to improve the BRT services that desired from the users. By conducting this part, the questionnaire was developed to interview BRT users. Preparing questionnaires based on the determinants of quality of service such as reliability on the service, the comfort of the provided service, security, etc, conducting a pilot test to examine whether the created questionnaire was in practical use to inquire respondents' perception. After the questionnaires being revised, the field survey data was conducted in the BRT stations and buses. Afterward, exploratory factor analysis (EFA) was adopted to analyze the

obtained data in order for identifying the influenced factors to improve the BRT quality under the perceptions of the BRT commuters.

3.6.1 Questionnaire Design and Research Questions

As mentioned above regarding the objective of this study, a questionnaire was developed to diagnose the travel characteristics of Bangkok BRT users. In the early stage, the questionnaire was designed in English, and translated into Thai afterwards to be facile when conducting the survey on field due to the level of understanding of the selected samples. To place this into perspectives, the questionnaire is designed to inquire a diversity of gender, age, and occupation of the respondents. In regard to the previous studies (Deng & Nelson, 2012; Limanond, Butsingkorn, & Chermkhunthod, 2011; Satiennam, Jaensirisak, Natevongin, & Kowtanapanich, 2011), the questionnaire consists of six parts. The first part of the questionnaire was the personal information of the target group such as age, gender, occupation, income, vehicle ownership, etc. The second part was to ask trips detail of the sampling groups such as the origin and destination of the trip, mode of access before and after using BRT, trip purposes, duration of commuting, etc. The second part mainly inquires the respondents on their main objective of travel and their mode choice. In the third part, the respondents were asked to provide their perspective to the BRT service. The fourth and fifth part, the respondents were asked to score the level of importance before using the BRT and the satisfaction level to the current service that being providing by considering the comfort and convenience of commuting by BRT, travel time, dwell time, accessibility of each station, density of users inside the bus, bus condition, security of BRT, reliability of providing service, and cost of traveling. The scale of scoring was used 5 scales or five-point Likert-type measurement scale, where 1 means they are satisfied with the service and 9 means they are not satisfied with the service. And the sixth part, the respondents were asked to score the improvement level that they want the BRT to be improved in the future (see Appendix C)

To address the gaps to be found and answered by this study, three research questions were formulated:

- 1) Does the BRT service quality perform well when comparing to the users' perception?

- 2) How much do the users satisfy with the current service?
- 3) What are the potential factors that should be improved in order for upgrading the BRT service?

To answer the above-mentioned questions, the statistical analysis was conducted. The results were described in chapter 5.

3.6.2 Samples Selection

Questionnaires were distributed and carried out to inquire the BRT passengers during 13-28 February 2019. During the time of survey, there were no negative or substantial impacted events occurred, such as national events or festivals, road accidents, etc. This is to ensure that the data validity is reliable to be analyzed. The respondents were asked at BRT stations and on the buses randomly. Prior to conducting survey, all surveyors were trained to be able to provide a prompt explanation to respondents if required. During the period of conducting field survey, the surveyors randomly and individually asked respondents and fill out the questionnaires to make the process of asking them effectively.

The sample size of this study was calculated based on the below formula (Deb & Ali Ahmed, 2018):

$$n \geq N \left[1 + \frac{N-1}{P(1-P)} \left(\frac{d}{Z_{\alpha/2}} \right)^2 \right]^{-1} \quad (3.8)$$

Where n is minimum sample size, N is number of populations, P is quality characteristics which are to be measured, d is margin of error which take as 5%, and $Z_{\alpha/2}$ is 1.96 for 95% confidence interval

In this study, a number of population was taken as the average number of passengers per month $N=460,105$ passengers (KT, 2017), p equal to 0.7 according to the number of passengers, $d=0.05$, and $z=1.96$. After calculated, the target number of respondents as the sample size to collect was approximately 300 samples in order to comprise the research population. This sample size target is sufficient to conduct the multivariate statistical analysis, in which the recommended sample size is should be 100 or larger (Hair et al., 2010).

3.6.3 Data Validity

Obtained data from field interview survey was compiled into SPSS software version 23.0 to conduct the further statistical analysis. For the multivariate analysis like EFA, there is a necessity to check the reliability of the survey data in order to eliminate the unusable data before adopting those data (Tabachnick & Fidell, 2007). According to the recommendation of Hair et al. (2010), the collected data have to check the missing data, data normality, and outlier detection. Another indicator which plays a crucial role in the process of data validity is the Cronbach's alpha coefficient. Whereas in case of the value of α is more than 0.9, it indicates that the set of data has high reliability. This step is very important that the researchers should not be abandon before conducting any further analysis.

3.6.4 Attitude Data Analysis

In the study of attitude part, there were three parts to analyze. The first part was to assess the BRT's quality of service by comparing the actual provided service and the perception of the users. For the quality of service, this present study adopted the level of service (LOS) standard which recommended by HCM (2000), TCQSM (2003) and Deb and Ali Ahmed (2018). There were LOS of transit/auto travel time, LOS of scheduled transit service, LOS of BRT hours of service, and LOS of expectation and satisfaction employed in this present study. The details of how to measure each LOS were described in the seventh sub-chapter of chapter 2 (literature review chapter). The second part was to describe the demographic profiles of respondents in parallel with the travel characteristic of the users. Through this part, the descriptive statistic technique was used to depict some facts regarding their travel behaviors. The third part was to assess the users' perspectives and to explore and group the factors to upgrade the BRT service. This part was analyzed by using the multivariate statistical technique namely exploratory factor analysis (EFA). This technique was appropriate to this study since it could uncover the latent factors from the complicated data (Tabachnick & Fidell, 2007). The result from the EFA could provide the essential information and lead to the recommendation of improving Bangkok BRT. The detail steps of conducting EFA and the results of each part were presented in chapter 5.

CHAPTER 4

TRAFFIC MODEL ASSESSMENT USING MICROSCOPIC SIMULATION

This chapter presents the details and results of the traffic simulation by using AIMSUN software. Section 4.1 summarizes the problems occurring along the BRT corridor that being the obstacles to the operation of BRT in Bangkok. Section 4.2 details the results of model calibration and validation. Section 4.3 evaluates the impacts of the proposed solution both in the morning peak periods and evening peak periods. This section also evaluates the impacts in the economic term. Section 4.4 provides the recommendation of each solutions for the city planners and decision makers.

4.1 Problem Summarization to Bangkok BRT Operation

As BRT in Bangkok has been operated since 2010, it has not been able to provide great performance and service as it should be to the users. This happens because there are several operational problems being occurred since then until present as shown in Figure 4.1. This makes the BRT lessen the reliability from the public owing to more travel time in the congested traffic compared to private cars or other modes like a taxi. From the on-site and on-board survey, it could be concluded that the operational performances of the BRT are encountered with three major problems: 1) the BRT lane is being used by other vehicles, 2) the lane of BRT is not dedicated right of way, and 3) poor management at at-grade intersections.

As being operated in the mixed traffic, the buses are forced to move following the other automobiles for 12.4 kilometers meaning that there is not much difference from the existing buses. Another obstacle comes from the non-continuously reserved lane, this caused a serious problem directly to the BRT operational performances because there is an interruption from other vehicles coming inside BRT lanes and block buses to reach stations. The problem happens at Narathiwat-Rama III intersection and before reaching Sathorn terminal station. The last obstacle regards to the poor management at four at-grade intersections that BRT running through. The problem happens at Narathiwat-Thanon Chan Intersection, Narathiwat-Ratchdaphisek

Intersection, Narathiwat-Rama III Intersection and Ratchadaphisek-Ratchapruerk Intersection. The obstacles come from the reason that there is no use of Intelligent Transportation System (ITS) to facilitate BRT at the intersections. As a matter of fact, ITS of Bangkok BRT was at first intended to be implemented but it was not used after it started providing service to the public. Thus, the buses are forced to wait there for a while to have permission to pass. Moreover, there are two unsuitable U-turns at the intersections which caused the buses to be stuck in traffic. According to the aforementioned obstacles, they affect the BRT to spend a lot of time to reach each station and worsen reliability of users due to the long travel time.

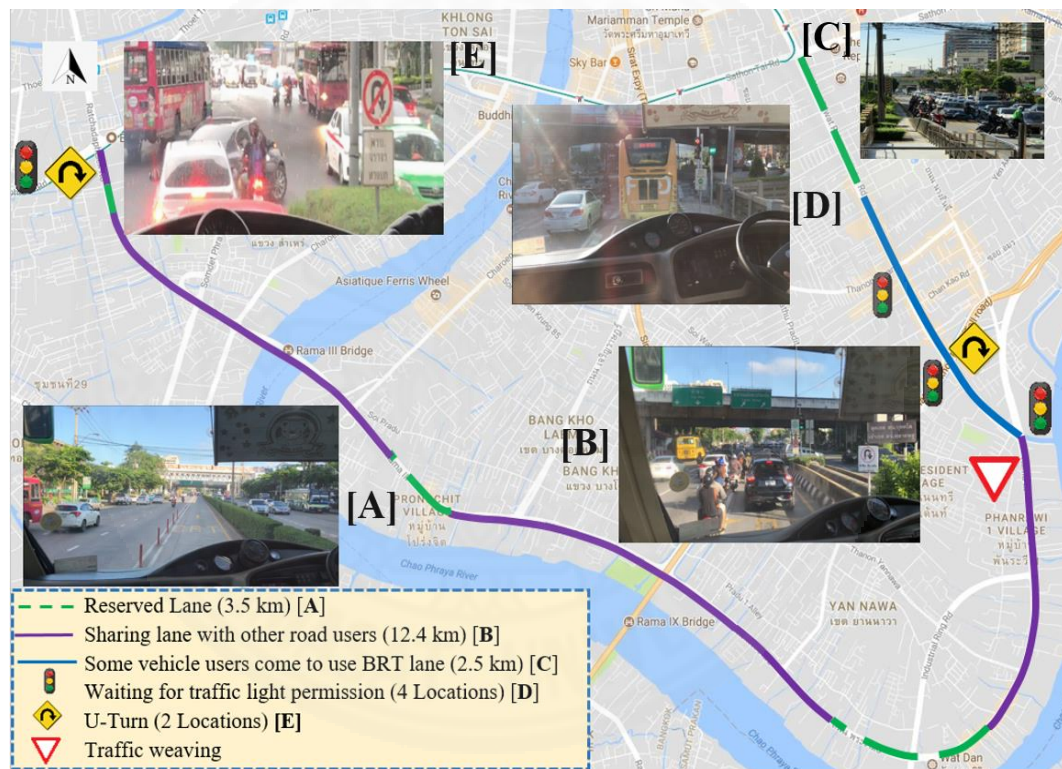


Figure 4.1 A Summary of Bangkok BRT's Operational Problems

In order to deal with the found problem on site, this study proposed three solution to handle of the aforementioned operation obstacles, which are applying transit signal priority, enforcing fully segregate lane and providing an additional lane in the reversed direction. The TSP solution was proposed to deal with the problem that the BRT stuck with the traffic light at the at-grade intersection and the traffic weaving time for the BRT. The fully segregated lane solution was proposed to solve the problem of sharing lane with other road users and to eliminate the interruption from the outside

vehicles used in the segregated lane. The reversed lane solution was proposed to reduce the congestion in the serious road section and to utilize the lane that did not have the serious congestion in the effective way. However, the illegal U-turn problem was recommended to ask the relevant authority to stop this action.

Therefore, the possible way to deal with the current happening problems were studied in detail by the microscopic simulation study and the perception study. The results of the aforementioned studies were explained in the sub-chapter with regard to providing the recommendations when improving the BRT operation in an effective and efficient way.

4.2 Microscopic Simulation Model Calibration and Validation Results

The calibration results of the microscopic simulation model were commenced with the traffic flow calibration result, followed by the capacity calibration, system performance calibration and travel time calibration. While the validation results were also examined under the same aspects as in the calibration process. However, the calibration results were tested and based on the morning data, whereas the validation results were checked by the evening data. The details of calibration and validation results were delineated in the following sub-sections.

4.2.1 Model Calibration Result

4.2.1.1 Traffic Flow Calibration Result

The traffic flow calibration was conducted in the 56 locations in the morning from 7:00 am to 9:00 am (2 hours for simulation). The result of traffic flow was presented below with regards to the input flow and simulated flow for two hours and measured by adopting GEH statistic value as shown in Table 4.1.

Table 4.1 Summary of Model Traffic Flow Calibration of Morning Peak Hours (7:00 Am to 9:00 Am) Using GEH Statistic

Intersection	Direction	Input (PCU/hr)	Output (PCU/hr)	GEH Stat
1. Ratchada-Ratchaphruek	NB	3,046	2,880	3.0
	EB	3,598	3,633	0.6
	SB	2,408	2,414	0.1

Intersection	Direction	Input (PCU/hr)	Output (PCU/hr)	GEH Stat
	WB	591	581	0.4
2. Mahai Sawan	NB	1,436	1,484	1.3
	EB(F)	1,936	2,050	2.6
	EB (G)	878	884	0.2
	SB	748	734	0.5
	WB	715	713	0.1
3. Bukkhalo	NB	2,683	2,445	4.7
	EB	862	995	4.3
	SB	1,373	1,377	0.1
	WB	1,421	1,349	1.9
4. Thanon Tok	NB	369	381	0.6
	EB	2,643	2,381	5.2
	SB	932	940	0.3
	WB (F)	1,925	1,841	1.9
	WB (G)	1,796	1,740	1.3
5. Charoen Rat	EB(G)	1,483	1,562	2.0
	EB(F)	3,301	3,134	2.9
	SB	2,062	2,077	0.3
	WB(G)	1,406	1,349	1.5
	WB(F)	2,191	2,054	3.0
6. Rama III-Ratchada	EB(G)	2,651	2,566	1.7
	EB(F)	2,447	2,424	0.5
	SB	3,217	3,232	0.3
	WB(G)	1,187	1,087	3.0
	WB(F)	1,836	1,666	4.1
7. Sathupradit	NB	65	67	0.2
	EB(G)	1,056	1,007	1.5
	EB(F)	2,587	2,579	0.2
	WB(G)	1,124	1,063	1.8
	WB(F)	2,458	2,219	4.9
8. Yannawa	NB(G)	1,609	1,604	0.1
	NB(F)	1,697	1,656	1.0
	EB	603	620	0.7
	SB(G)	2,081	2,133	1.1
9. Rama III-Industrial Ring Rd.	NB	1,922	2,162	5.3
	EB	4,928	4,829	1.4
	SB(F)	1,641	1,519	3.1
	SB (G)	2,917	2,687	4.3
10. Rama III-Narathiwat	NB	6,206	6,224	0.2
	EB	1,317	1,097	6.3

Intersection	Direction	Input (PCU/hr)	Output (PCU/hr)	GEH Stat
	SB	3,853	3,912	0.9
11. Narathiwat-Ratchada	NB	3,879	3,749	2.1
	EB	2,200	1,912	6.3
	SB	1,694	1,698	0.1
	WB	2,386	2,178	4.3
12. Narathiwat-Chan	NB	1,878	2,003	2.8
	EB	1,376	1,275	2.8
	SB	1,932	1,908	0.5
	WB	532	520	0.5
13. Narathiwat-Sathorn	NB	1,347	1,409	1.7
	EB	4,181	4,132	0.8
	SB	831	809	0.8
	WB	1,422	1,439	0.4

According to the criterion of using GEH statistic, 85% of traffic flow cases should consist of the below-5 GEH statistic. Hence, this study could obtain the GEH statistics that less than 5 for 52 cases over 56 cases in the morning peak hours. This was proved a satisfying where 52 flows (approximately 92.9%) gave the below-5 GEH statistic. When plotting the modelled flows and input flows, it revealed that the distribution patten was lay closed to the base line as shown in Figure 4.2.

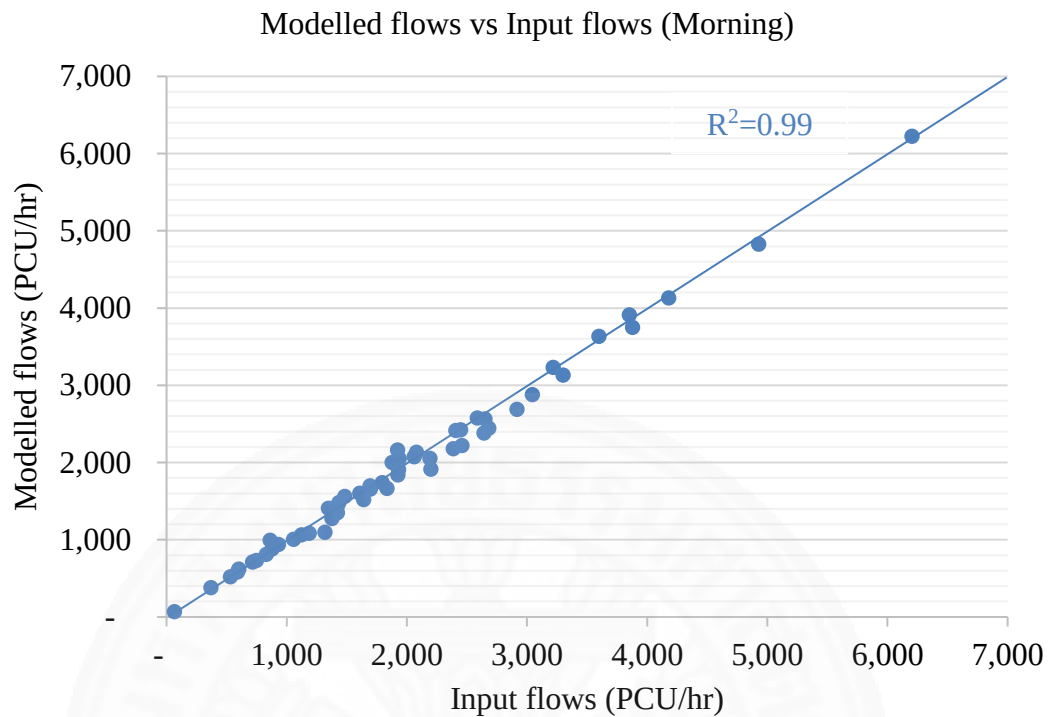


Figure 4.2 Plot of Modelled Traffic-Flow Rates Versus Input Traffic Flow-Rates for Morning Peak Hour

4.2.1.2 Capacity Calibration Result

The capacity calibration was adjusted by two parameters which were reaction time at stop and queue exit speed. The two parameters were measured by minimizing the saturation headway. Each pair of parameters error (MAPE) from the calibration was plotted in the contour map. In the first stage, the reaction time at stop was set from 1.0 sec to 2.4 sec with the interval of 0.2 sec, while the queue exit speed was set from 4 m/s to 9 m/s with the interval of 1.0 m/s. After calibrating the two parameters in the initial phase, it resulted that the value of reaction time at stop was 2.0 sec and the queue exit speed was 6.0 m/s under the MAPE approximately 1.3% as shown in Figure 4.3 (see Appendix D).

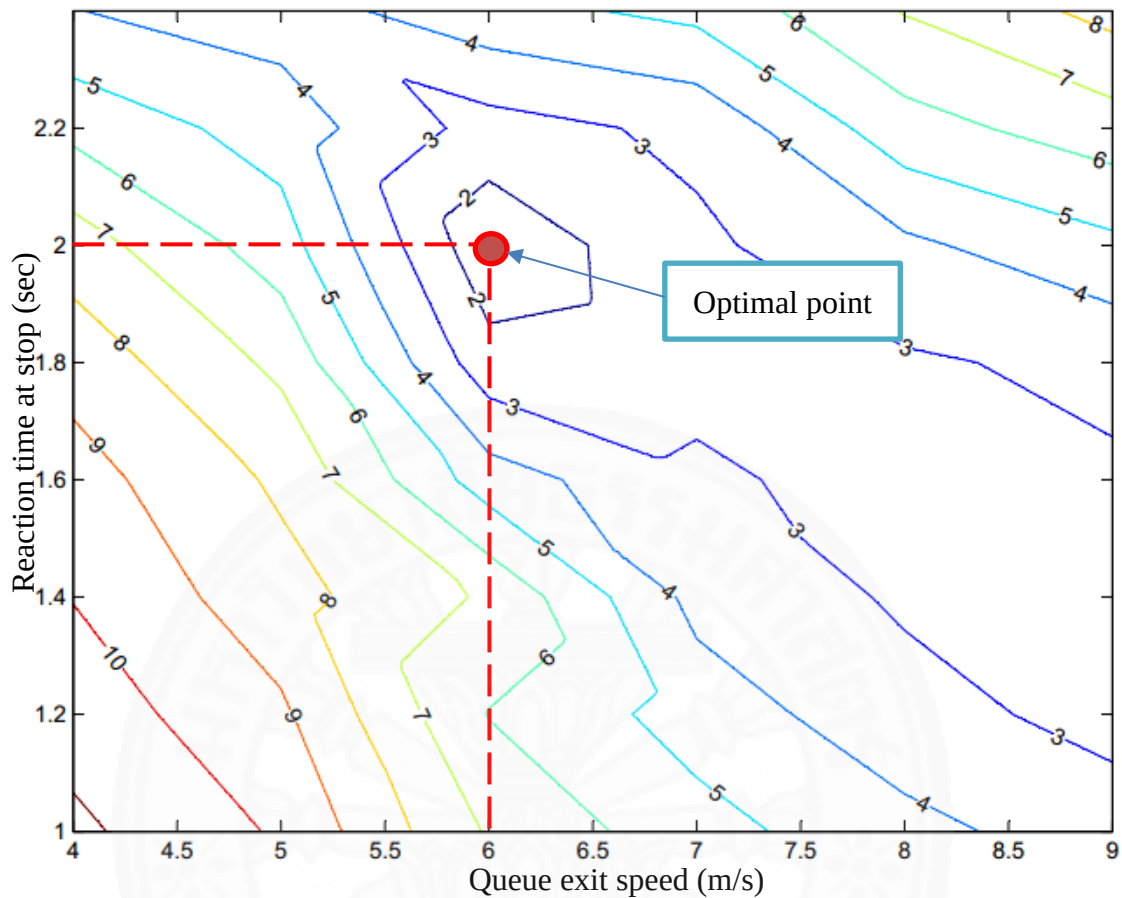


Figure 4.3 Contour Map of Initial Phase of Capacity Calibration for Morning Peak

Once the initial value of the two parameters were identified, the next phase was conducted to discover more refined values of each pair of parameters. In the second phase, the reaction time at stop and the queue exit speed were narrowed down closed to the values that uncovered in the first phase. Thus, the reaction time was refined from 1.9 sec to 2.1 sec with the interval of 0.05 sec and the queue exit speed was refined from 5.5 m/s to 7 m/s with the interval of 0.5 m/s. The result of the second phase found that the reaction time at stop of 2.0 sec and queue exit speed of 6.5 m/s were the minimum MAPE of the more refined phase. The MAPE of the second phase was reduced to approximately 1.1% as shown in Figure 4.4.

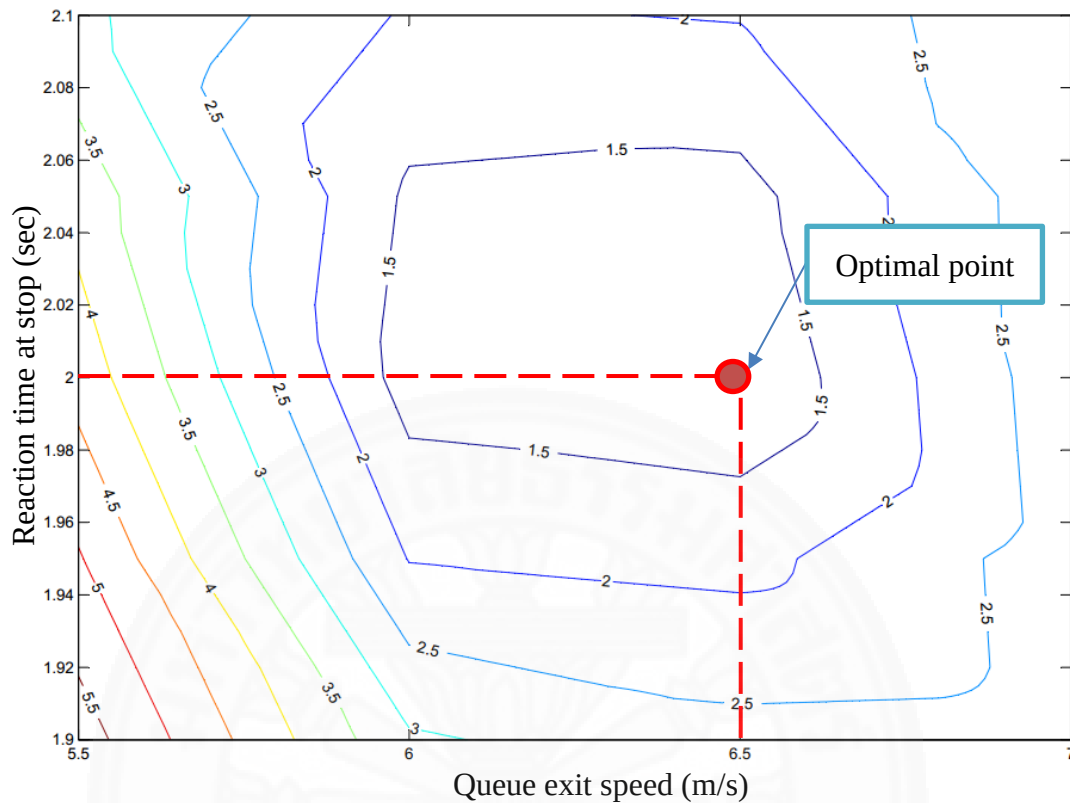


Figure 4.4 Contour Map of Second Phase of Capacity Calibration for Morning Peak

4.2.1.3 System Performance Calibration Result

Two parameters, queue entry speed and reaction time at traffic light, were adjusted to find the initial optimal values under the condition of minimum MAPE of queue length. Thus, the queue entry speed was set from 0 m/s to 5.0 m/s with the interval of 1.0 m/s. Whereas the reaction time at traffic light was adjusted from 1.0 sec to 5.0 sec with the interval of 1.0 sec. The result from the initial stage of queue length calibration revealed that the optimal queue entry speed was 1.0 sec, while the reaction time at traffic light was 2.0 sec under the MAPE of 4.9% as shown in Figure 4.5 (see Appendix D).

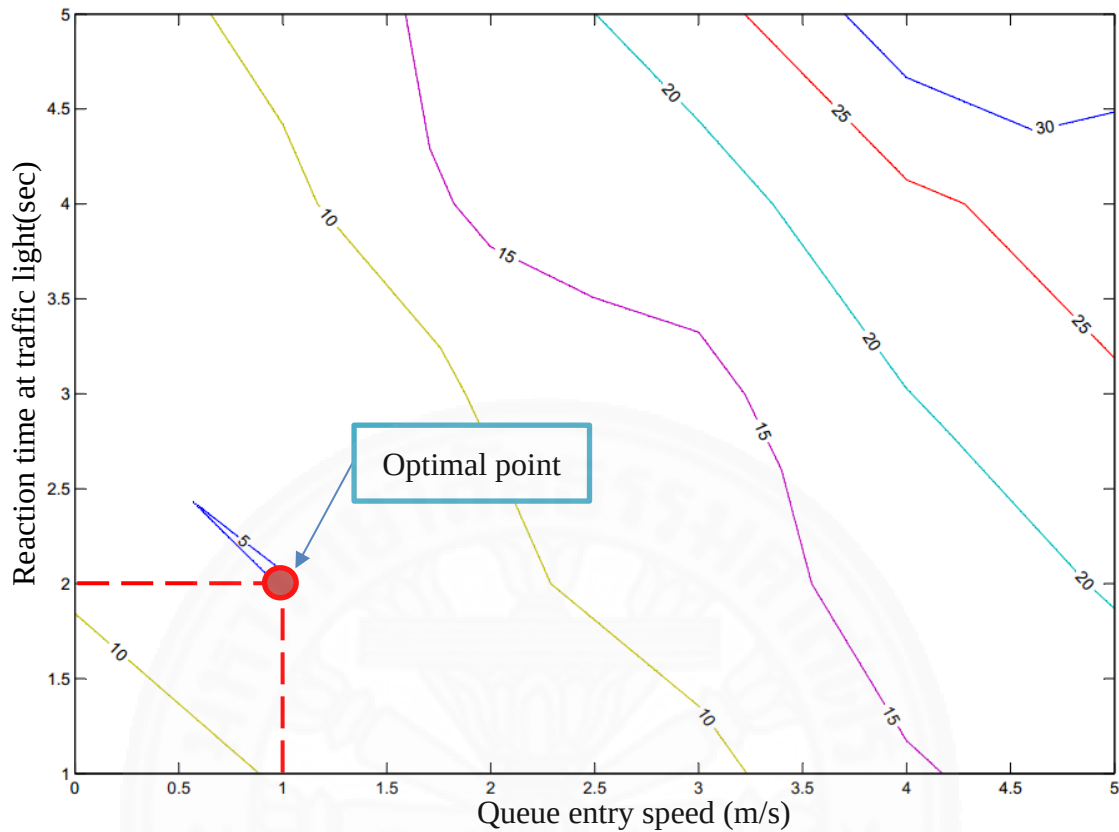


Figure 4.5 Contour Map of Initial Phase of System Performance Calibration for Morning Peak Hours

After the initial pair of parameters were discovered in the first stage of system performance calibration, the second phase to continue calibrating the queue length in the system performance calibration was conducted. The pair of parameters to calibrate queue length was more refined to the closed values of the initial obtained values. Therefore, the queue entry speed was refined from 0.5 m/s to 1.5 m/s with the interval of 0.5 m/s and the reaction time at traffic light was set from 1.5 sec to 2.5 sec with the interval of 0.5 sec. The result revealed that there was no value that could perform the lower MAPE than the previous found value. Thus, the appropriate set of queue entry speed and reaction time at traffic light was 1.0 m/s and 2.0 sec, respectively. The MAPE remained as 4.86 as shown in Figure 4.6 .

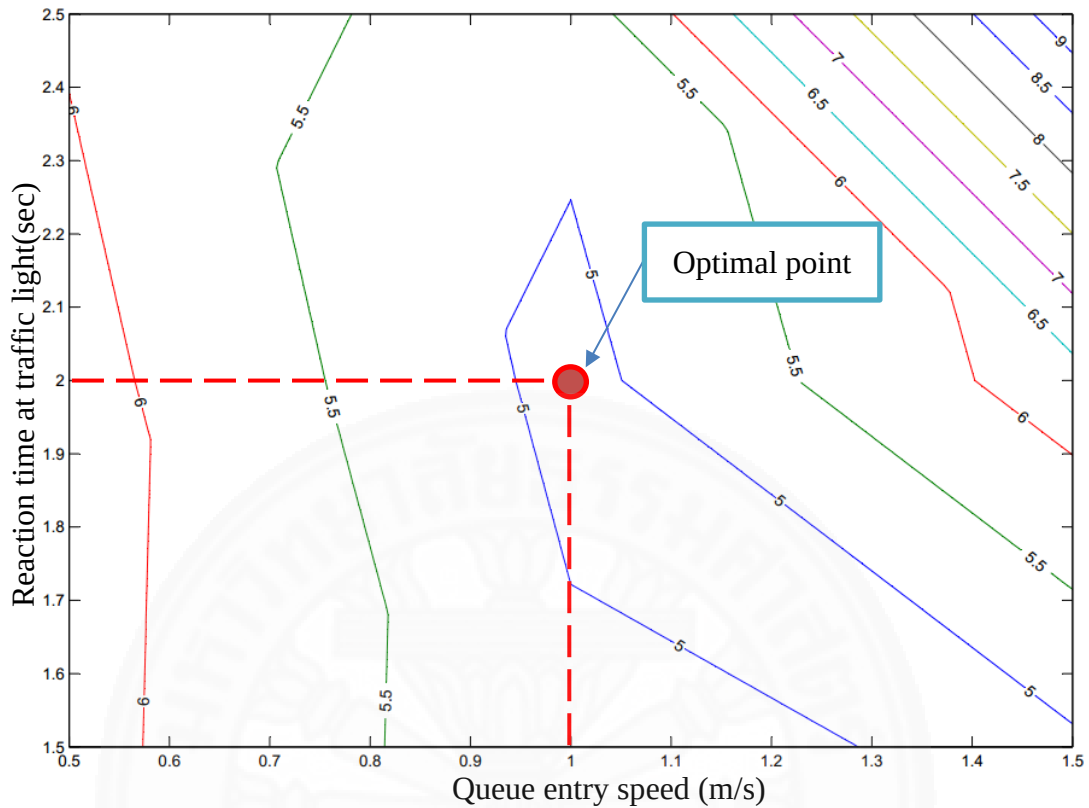


Figure 4.6 Contour Map of the Second Phase of System Performance Calibration for Morning Peak Hours

4.2.1.4 Travel Time Calibration Result

Travel times of the BRT and car were calibrated in this study. The travel time of both vehicles was adjusted by the speed value in the model. The speed of the BRT was set from 21.0 km/h to 31.0 km/h with the interval of 2.0 km/h. The result of the BRT's travel time calibration found that the mean speed to be input in the simulation was 25 km/h with the MAPE of 1.3% as shown in Figure 4.7 (see Appendix D).

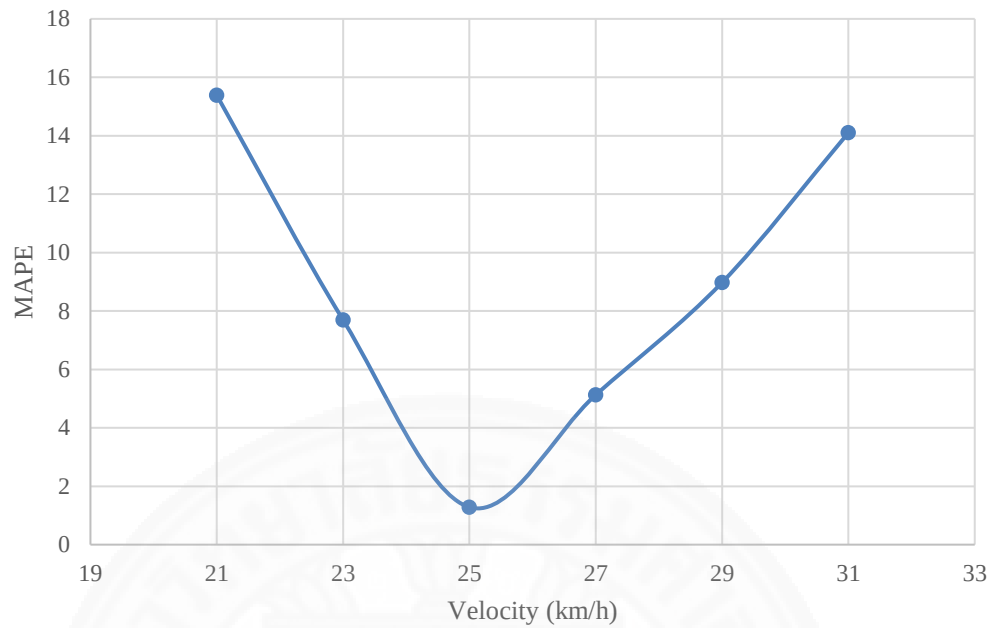


Figure 4.7 BRT's Travel Time Calibration Results

While travel time of car was also calibrated, which the mean speed of car was adjusted from 40.0 km/h to 54.0 km/h with the interval of 2.0 km/h. The result found that the optimal mean speed of car that fit to the car's travel time was 48.0 km/h by the MAPE of 2.50% as shown in Figure 4.8 (see Appendix D).

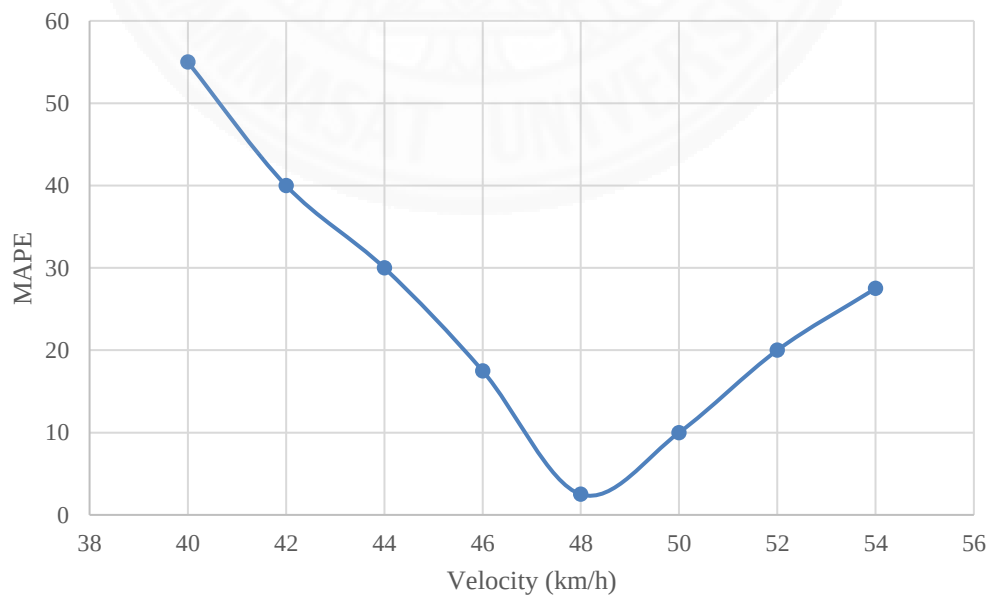


Figure 4.8 Car's Travel Time Calibration Result

4.2.2 Model Validation

4.2.2.1 Traffic Flow Validation Result

To validate the traffic flow of the simulation model in this present study, 56 locations in the evening peak hour from 16:00 pm to 18:00 pm (2 hours for simulation) was examined. The result of traffic flow calibration was measured by the GEH statistic as shown in Table 4.2.

Table 4.2 Summary of Model Traffic Flow Calibration of Evening Peak Hours (16:00 Pm to 18:00 Pm) Using GEH Statistic

Intersection	Direction	Input (PCU/hr)	Output (PCU/hr)	GEH Stat
1. Ratchada-Ratchaphruek	NB	2,792	2,675	2.2
	EB	4,332	4,233	1.5
	SB	2,829	2,893	1.2
	WB	793	790	0.1
2. Mahai Sawan	NB	1,350	1,244	2.9
	EB(F)	2,121	2,185	1.4
	EB (G)	1,478	1,430	1.3
	SB	765	761	0.2
	WB	1,145	1,193	1.4
3. Bukkhalo	NB	2,301	2,292	0.2
	EB	818	714	3.8
	SB	1,771	1,762	0.2
	WB	1,432	1,292	3.8
4. Thanon Tok	NB	356	365	0.5
	EB	2,059	1,821	5.4
	SB	906	895	0.4
	WB (F)	1,475	1,438	1.0
	WB (G)	1,631	1,650	0.5
5. Charoen Rat	EB(G)	1,219	1,162	1.6
	EB(F)	1,622	1,553	1.7
	SB	1,604	1,649	1.1
	WB(G)	1,219	1,200	0.6
	WB(F)	1,622	1,616	0.2
6. Rama III-Ratchada	EB(G)	3,352	3,327	0.4
	EB(F)	2,218	2,119	2.1
	SB	2,726	2,661	1.3
	WB(G)	915	918	0.1
	WB(F)	1,304	1,311	0.2
7. Sathupradit	NB	43	50	1.0

Intersection	Direction	Input (PCU/hr)	Output (PCU/hr)	GEH Stat
	EB(G)	2,501	2,444	1.1
	EB(F)	2,905	2,961	1.0
	WB(G)	867	864	0.1
	WB(F)	1,634	1,417	5.5
8. Yannawa	NB(G)	1,820	1,832	0.3
	NB(F)	1,086	1,128	1.3
	EB	367	385	0.9
	SB(G)	1,640	1,593	1.2
9. Rama III-Industrial Ring Rd.	NB	1,762	1,556	5.1
	EB	3,829	3,884	0.9
	SB(F)	933	1,001	2.2
	SB (G)	2,660	2,763	2.0
10. Rama III-Narathiwat	NB	4,035	4,378	5.3
	EB	1,456	1,434	0.6
	SB	3,080	3,110	0.5
11. Narathiwat-Ratchada	NB	4,699	4,694	0.1
	EB	2,565	2,618	1.0
	SB	2,536	2,673	2.7
	WB	1,812	1,578	5.7
12. Narathiwat-Chan	NB	2,539	2,612	1.4
	EB	826	714	4.0
	SB	2,372	2,412	0.8
	WB	354	356	0.1
13. Narathiwat-Sathorn	NB	2,419	2,469	1.0
	EB	2,996	2,906	1.7
	SB	1,397	1,386	0.3
	WB	1,595	1,572	0.6

The result found that 51 cases of traffic flow were lower than 5. It resulted that approximately 91.1% of 56 cases could perform satisfied with the criterion requirement of 85%. When plotting the modelled flows and input flows, it revealed that the distribution patten was lay closed to the base line as shown in Figure 4.9.

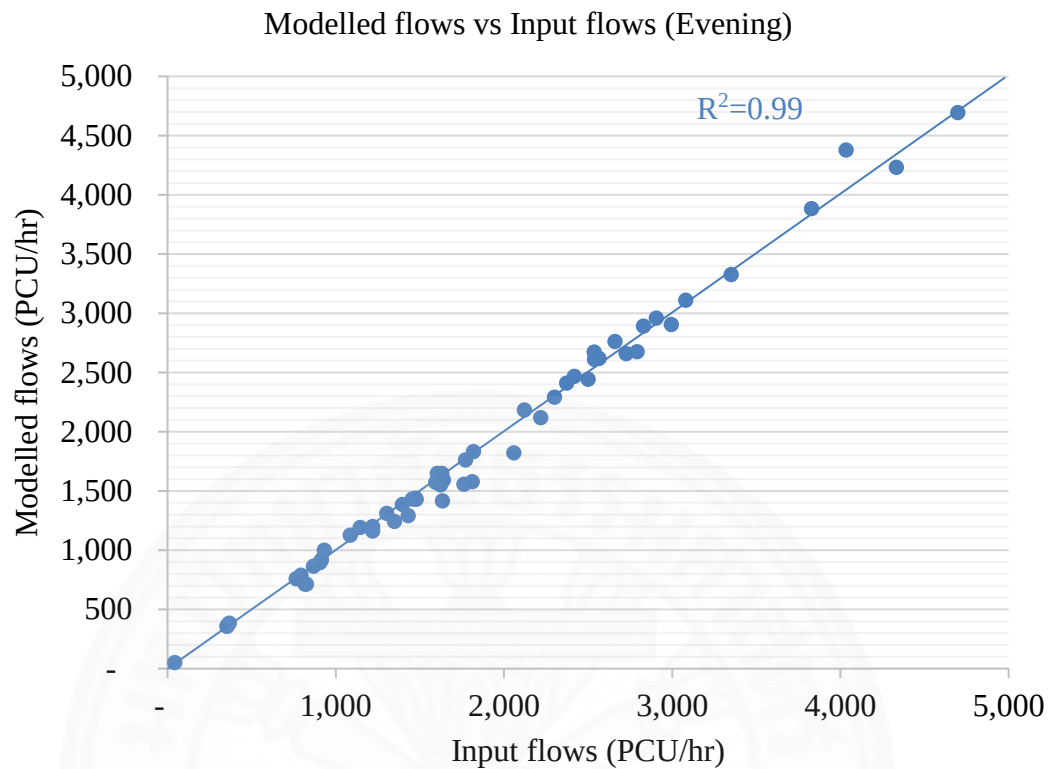


Figure 4.9 Plot of Modelled Traffic-Flow Rates Versus Input Traffic Flow-Rates for Evening Peak Hour

4.2.2.2 Capacity Validation Result

The capacity of the simulation model was validated with the evening data. This was to check the saturation headway of the observed value and simulated value. In the validation stage, 10 replications were run to obtain 95% of confidence level. The result revealed that the queue exit speed of 6.5 m/s and reaction time at stop of 2.0 sec could well perform in the evening data by the MAPE 1.5% (See Appendix D).

The result of normality distribution was lay to the value of kurtosis and skewness. The value of kurtosis was 0.36 and the skewness was 0.12, which both of the value did not exceed the critical value. Therefore, the queue exit speed of 6.5 m/s and reaction time at stop of 2.0 sec could be further used in the simulation scenarios to evaluate the results.

4.2.2.3 System Performance Validation Result

In the validation process of system performance, there were two adjusted parameters which were queue entry speed and reaction time at traffic light. These two parameters were measured by examining the MAPE of the evening queue length data. There were 10 simulation seeds performed. When the calibrated value of queue entry speed (1.0 m/s) and reaction time at traffic light (2.0 sec) were input into the simulation model with the evening data, it resulted that the MAPE performed by 7.1%, which was considered in the acceptable error range.

The normality distribution of error was measured by the value of kurtosis and skewness. In which, the kurtosis of queue length validation was -0.66 and the skewness was 0.21. Hence, both kurtosis and skewness were below the critical value. This implied that the queue entry speed of 1.0 m/s and reaction time at traffic light of 2.0 sec were able to use in the further simulation scenarios.

4.2.2.4 Travel Time Validation

The BRT's and car's travel time was validated with the evening data set. By using the mean speed value of BRT from the calibration stage (25.0 km/h), the result showed that the MAPE of the BRT's travel time in the evening data set was 3.8% and the kurtosis was -0.36 and skewness was 0.33 (see Appendix D).

While the calibrated mean speed of car (48.0 km/h) was simulated with the evening data set. This was conducted to validate the usability of the calibrated parameter. After the simulation was run for 10 replications, the result found that the MAPE of car's travel time was 6.3%, the distribution of the error was considered as normal since the kurtosis turned -0.86 and skewness turned -0.14, which they were in the acceptable range of not exceeding critical value.

4.3 Simulation Evaluation Results

This present study proposed three possible solutions to improve the BRT operation, which included using transit signal priority (TSP), enforcing fully segregated lane and providing reversed lane in the uncongested direction. The indicators to measure the effectiveness of the proposed scenarios were delay time, stop time and

travel time. Both the network level and specific section/intersection were evaluated in morning peak hours (7:00 am to 9:00) am and evening peak hours (16:00 pm to 18:00 pm). The evaluation results were reported in the unit of minute per passenger car unit (min/PCU) for the car and minute per vehicle for BRT. In which, the composition of the vehicles in the morning peak hours and evening peak hours that used as PCU in this study was shown in Table 4.3. Moreover, the economic aspect was also evaluated in the term of the cost of saving. Also, operational improvement's recommendations were provided for the decision-makers and city planners. The details of each scenario were elaborated in the following sections.

Table 4.3 Vehicle Composition in the Peak Hours

Vehicle type	Percentage at 7am-9am	Percentage at 4pm-7pm
Car	72.03	68.65
Van & Pick-up car	24.79	27.36
Bus	1.25	1.26
Mini-bus	0.24	0.29
Truck	1.14	1.84
Three-wheel vehicle	0.55	0.60

4.3.1 Whole Network Results

In the total network results, all scenarios were evaluated in the direction of inbound and outbound with regards to delay, stop time and travel time. Also, the results were discussed with two aspects of benefit: the first aspect was per vehicle (BRT and car), whereas the second aspect was for the total benefit of all users. Therefore, the results of evaluating the benefit for all users were calculated from the assumption of vehicle occupancy. Since one car could carry the passenger approximately 1.5 people (OTP, 2015a), and one BRT bus could carry 20 seats and 60 standing (Kodukula, 2010). When taking the number of passengers into account, the result could provide how beneficial of each solution to establish.

The results of this study were evaluated with regards to the delay time, stop time and travel time in the corridor and non-corridor. Corridor referred to the vehicles travel in the same road way of the BRT, while non-corridor was the results from the vehicles

that traveled in the different road way of the BRT but parallelly traveled with the BRT's trunk line including the roads under the flyovers and the sub-street of the non-corridor intersections.

Hence, the outbound and inbound result revealed that the delay time, stop time and travel time of the BRT were dramatically reduced from the base case. Since all solutions were aimed to improve the time spent of BRT on the corridor to provide the faster service to the users. Besides, some solutions could also provide benefit of decreasing delay time, stop time and travel time to the car users such as the TSP solution and the reversed lane solution. Nonetheless, the solution of enforcing fully segregated lane adversely affected the car users either who travelled in the corridor or non-corridor.

This present study showed the results of three proposed solutions both in the morning peak hours and evening peak hours. For the TSP solution and FS solution, there were no difference in conducting the strategy. While conducting the RL solution in the morning differed from the RL solution in the evening. Since the lane section was reversed in the outbound direction for the morning peak hours due to the fact that there was a huge congestion occurred in the inbound direction. In the opposite way, the reversed lane section was conducted in the inbound direction for the evening peak hours according to the packed-traffic in the outbound direction.

The details of each solution in both morning peak period and evening peak period were elaborated below.

4.3.1.1 Whole Network Results: Morning Peak Periods

According to the result of outbound direction shown in Table 4.4, the delay time and stop time could describe how each solution impacted to the network. it revealed that the delay time and stop time of a car in the corridor was reduced 3.0 min (25.1%) and 2.5 min (21.8%) for the solution of TSP, respectively. This was due to the fact that the cars that travel in the corridor also got the benefit from the use of TSP which was not only the BRT. But the delay time and stop time of a car in the non-corridor was slightly increased 3.5 min (7.1%) and 2.1 min (4.5%), respectively. while the delay and stop time of the BRT was decreased 6.3 min (37.9%) and 6.6 min (42.0%), respectively. Taken enforcing fully segregated lane into account, the result found that the BRT delay

time and stop time was reduced 8.6 min (83.2%) and 9.8 min (62.3%), respectively. While a car's delay time and stop time in the corridor was also increased 10.7 min (88.8%) and 10.4 min (91.3%), respectively. This affected much to the car users who travelled in the corridor because the one lane of the corridor was dedicated to be the only lane for the BRT. Not only a car on corridor that affected but also a car travelled in the non-corridor. The delay time of the car in the non-corridor was increased to 13.9 min (27.8%) and stop time was raised to 9.1 min (19.5%). When the reversed lane scenario was evaluated, the delay time and stop time of a car in the corridor was increased 2.0 min (16.6%) and 2.0 min (17.4%). Similar to the BRT in the corridor, the delay time and stop time of the BRT was also increased 3.4 min (20.7%) and 2.9 min (18.6%). The delay time and stop time of car and BRT increased because one lane of the bridge section in the outbound direction was reserved for the BRT, which caused more delay time and stop time to a car and the BRT in the outbound corridor. Not only a car in the corridor got the increased in delay time and stop time, but a car in the non-corridor was also received the effect of increasing the delay time and stop time by 3.2 min (6.5%) and 2.9 min (6.3%), respectively. By considering travel time changes of each solution, the result revealed that travel time of a car and the BRT in corridor was decreased 4.0 min (12.9%) and 6.1 min (16.0%) for applying TSP. But the travel time of a car in the non-corridor sections was risen up 4.4 min (6.1%). This could imply that the BRT and a car which run in the corridor line could directly receive the benefit from the use of TSP, particularly the BRT. But the use of TSP caused the impact of increasing travel time to a car in the non-corridor. When applying the FS scenario, the result returned that the travel time of a car both in corridor and non-corridor were dramatically increased by 11.5 min (36.8%) and 9.1 min (12.7%), respectively. But the BRT travel time for FS solution was decreased 13.1 min (34.5%). From the result of the travel time of FS solution, the increased travel time of a car and the BRT in the corridor was not that much different due to the fact that the congestion in the outbound direction in the morning peak was not serious, unlike the inbound direction. Whereas the travel time of a car in corridor and non-corridor and the BRT was increased by 2.0 min (6.4%), 1.8 min (2.5%) and 2.7 min (7.0%), respectively. This happened because a lane of a bridge section in the outbound direction was reduced. So, it caused directly to the travel time of the outbound travel time.

The result shown the Table 4.5 revealed the delay time, stop time and travel time of a car travelled in the corridor and non-corridor and the BRT travelled in the trunk line of the inbound direction. According to the data in the result, it obviously showed that all the measurement indicators (delay time, stop time and travel time) had the higher value than the outbound direction indicators. This was in accordance with the real traffic situation that the traffic in the inbound direction in the morning peak periods was more congested than the traffic in the outbound direction. Delay time and stop time were evaluated to identify the impacts that could occur when establishing the scenario in the real traffic. However, when applying the TSP solution, it obviously seen that the delay time of the car travelled in the corridor was relieved by 3.6 min (10.6%) and the stop time was also decreased 2.3 min (7.0%). Also, the delay time and stop time of the BRT was decreased 7.8 min (35.1%) and 7.4 min (34.7%), respectively. However, the delay time and stop time of a car in the non-corridor were increased 5.1 min (7.7%) and 3.4 min (5.8%), respectively. The delay time and stop time of a car and BRT travelled in the corridor decreased because when the TSP detected the BRT at the at-grade intersection, the car users and the BRT received more green light timing at the intersection. While the car in the non-corridor especially the sub-street received more red timing at the intersection which caused more delay time and stop time. Taking the use of FS solution into consideration, the result indicated that the delay time of a car both in the corridor and non-corridor were increased 40.5 min (118%) and 28.3 min (42.6%), respectively. Similar to the stop time of a car in both corridor and non-corridor, a car's stop time was raised by 41.0 min (127.2%) and 29.1 min (50.0%). It obviously implied that a car travelled in the corridor suffered with the increasing delay time and stop time more than a car travelled in the non-corridor. The fact behind this was that the lane of the corridor was dedicated to be the only lane for the BRT, so that the delay time and stop time adversely affected particularly to a car in the corridor and partially to the sub-street or non-corridor. Whereas the delay time and stop time of the BRT was dramatically decreased by 13.5 min (60.6%) and 14.0 min (65.6%), respectively. Another solution was the applying RL solution in the simulation model. The result found that the delay time and stop time of a car both travelled in the corridor and non-corridor and obviously the BRT were reduced with the different portion. The delay time of a car in the corridor and non-corridor were decreased 4.6 min (13.4%)

and 0.8 min (1.3%), respectively. The delay time of the BRT was hugely improved by the delay time reduction of 6.0 min (27.0%). While the stop time of a car in corridor, a car in non-corridor and the BRT were reduced by 3.1 min (9.7%), 0.6 min (1.0%) and 5.3 min (24.9%), respectively. When taking the travel time of a car and the BRT into account, the result showed that the travel time of a car in the corridor and the BRT was decreased 5.3 min (7.7%) and 6.3 min (13.1%) when applying TSP, respectively. Also, the travel time of a car travelled in the non-corridor was slightly increased 5.1 min (5.5%). But when applying the solution of FS, the travel time of a car both in the corridor and non-corridor section was worsen by 39.9 min (58.5%) and 28.0 min (30.3%) due to the lane reduction. However, the FS obviously helped the BRT reducing the travel time by 15.1 min (31.4%). Another solution to evaluate was the solution of RL, it revealed that the travel time of all vehicles both travelled in the corridor and non-corridor were reduced. The travel time of a car in the corridor was decreased 2.1 min (3.1%), the travel time of a car in the non-corridor was also decreased 1.5 min (1.6%) and the travel time of the BRT was decreased 8.3 min (17.2%).

According to the result in Table 4.6, the outbound impacts of each solution were assessed. Taking the TSP as the first solution, the result revealed that the delay time, stop time and travel time of the cars in the corridor were obviously decreased by 9,319.6 min (23.9%), 6,568.4 min (23.4%) and 19,343.5 min (13.1%), respectively. All the indicators of the cars in the corridor decreased were due to the fact that the cars received more green time at the intersection together with the BRT at the at-grade intersections. Obviously, the delay time, stop time and travel time of the BRT were decreased by 5,998.9 min (38.9%), 5,779.4 min (41.8%) and 10,137.1 min (16.5%), respectively. However, the cars travelled in the non-corridor were adversely affected. Since the delay time, stop time and travel time were increased 11,625.4 min (7.7%), 7,262.7 min (5.3%) and 16,135.7 min (6.3%), respectively. The cars travelled in the non-corridor encountered with more timing when having a trip because they received more red timing at the intersections. With regards to the employing the solution of FS, the results indicated that all indicators of the cars travelled in the corridor and non-corridor were directly affected. The delay time, stop time and travel time of the car in the corridor were affected the most due to the lane reduction by the increasing of 34,739.7 min (89.0%), 26,572.3 min (94.9%) and 56,395.7 min (38.1%), respectively. Followed by

the cars travelled in the non-corridor also affected, the delay time was increased 23,827.9 min (15.8%), stop time was increased 21,071.4 min (15.4%) and travel time was also increased 33,427.2 min (13.0%). In the opposite way, the delay time, stop time and travel time of the BRT were decreased by 8,293.5 min (53.7%), 8,934.8 min (64.7%) and 21,381.5 min (34.9%). This implied that the FS was only beneficial for the BRT rather than for car users. For the solution of RL, it obviously seen that all the indicators were increased when compared with the base value. The delay time, stop time and travel time of the cars in the corridor section were increased 6,849.4 min (17.5%), 4,833.8 min (17.3%) and 9,259.0 min (6.3%), respectively. While the cars in the non-corridor was also affected due to the reduction on lane in the reversed section. The delay time, stop time and travel time of the cars in the corridor were increased 10,905.3 min (7.2%), 10,215.0 min (7.5%) and 7,555.7 min (2.9%), respectively. Whereas the delay time, stop time and travel time of the BRT were increased 2,975.4 min (19.3%), 2,418.2 min (17.5%) and 4,056.7 min (6.6%), respectively. The reason why all indicators of the BRT was increased was due to the lane reduction on the outbound direction for the inbound BRT traveled as the reversed lane.

Regarding the result of the inbound impacts of the proposed scenarios as shown in Table 4.7, it revealed that when applying the TSP solution the delay time, stop time and travel time of the cars in the corridor were decreased 18,369.3 min (12.6%), 8,980.8 min (8.6%) and 27,021.0 min (7.3%), respectively. Similar to the BRT, all the indicators were reduced 6,364.9 min (36.4%) for delay time, 4,471.5 min (32.4%) for stop time and 11,050.3 min (13.9%) for travel time. While the cars in the non-corridor were affected with the increasing of delay time, stop time and travel time by 28,116.1 min (7.8%), 15,518.9 min (5.1%) and 26,780.2 min (5.2%), respectively. The huge amount of decreasing and increasing of all indicators caused by the huge amount of congestion in the inbound direction in the morning. The solution of FS affected adversely especially to the cars both in the corridor and non-corridor because this solution was beneficial only for the BRT. The delay time, stop time and travel time of the cars in the corridor was hugely raised by 220,115.9 min (150.5%), 166,081.3 min (159.7%) and 218,964.4 min (59.1%), respectively. Parallel with the result of delay time, stop time and travel time of the cars in the non-corridor by the increased proportion of 163,397.1 min (45.5%), 159,008.3 min (52.4%) and 161,460.6 min

(31.5%), respectively. Nevertheless, this solution improved the delay time, stop time and travel time of the BRT by the decreasing proportion of 10,517.0 min (60.1%), 9,409.4 min (68.3%) and 25,532.5 min (32.1%), respectively. This highlighted that the FS positively impacted only for the BRT users rather than other road users. The last solution to taken into consideration was the solution of RL. RL solution resulted that all vehicles travelled in the inbound direction could positively get the benefit from this solution. Since the delay time, stop time and travel time of the cars in the corridor were decreased 21,919.3 min (15.0%), 8,671.7 min (8.3%) and 11,876.2 min (3.2%), respectively. Also, the cars travelled in the non-corridor were also positively affected by the reduction of delay time of 3,600.1 min (1.0%), reduction of stop time of 3,828.2 min (1.3%) and reduction of travel time of 9,570.1 min (1.9%). Obviously, this solution was proposed to help the BRT to travel faster in the reversed lane from the outbound direction. So, the delay time, stop time and travel time of the BRT were dramatically decreased 4,611.5 min (26.3%), 3,443.5 min (25.0%) and 14,532.2 min (18.3%), respectively.

Table 4.4 Summary of Whole Network Travel Time Impacts Per Vehicle in the Morning Peak Periods for Outbound Direction

Outbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay	Corridor	Car	12.0	9.0	22.7	14.0	-3.0	10.7	2.0
		BRT	16.6	10.3	8.0	13.4	-6.3	-8.6	-3.2
	Non-corridor	Car	49.9	53.4	63.8	53.1	3.5	13.9	3.2
Stop time	Corridor	Car	11.4	8.9	21.8	13.4	-2.5	10.4	2.0
		BRT	15.7	9.1	5.9	13.0	-6.6	-9.8	-2.7
	Non-corridor	Car	46.8	48.9	55.9	49.7	2.1	9.1	2.9
Travel time	Corridor	Car	31.2	27.2	42.7	33.2	-4.0	11.5	2.0
		BRT	37.9	31.9	24.8	40.6	-6.1	-13.1	2.7
	Non-corridor	Car	72.2	76.6	81.4	74.0	4.4	9.1	1.8

Note: Unit of car's indicators are in minute per passenger car unit (min/PCU) and unit of BRT's indicator is in minute per vehicle

Table 4.5 Summary of Whole Network Travel Time Impacts Per Vehicle in the Morning Peak Periods for Inbound Direction

Inbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay	Corridor	Car	34.3	30.7	74.9	29.7	-3.6	40.5	-4.6
		BRT	22.3	14.4	8.8	16.3	-7.8	-13.5	-6.0
	Non-corridor	Car	66.3	71.4	94.6	65.5	5.1	28.3	-0.8
Stop time	Corridor	Car	32.2	30.0	73.2	29.1	-2.3	41.0	-3.1
		BRT	21.4	14.0	7.4	16.0	-7.4	-14.0	-5.3
	Non-corridor	Car	58.1	61.5	87.2	57.5	3.4	29.1	-0.6
Travel time	Corridor	Car	68.3	63.0	108.2	66.2	-5.3	39.9	-2.1
		BRT	48.0	41.7	32.9	39.7	-6.3	-15.1	-8.3
	Non-corridor	Car	92.5	97.6	120.6	91.0	5.1	28.0	-1.5

Note: Unit of car's indicators are in minute per passenger car unit (min/PCU) and unit of BRT's indicator is in minute per vehicle

Table 4.6 Summary of Whole Network Impacts Travel Time Impacts Per All Users in the Morning Peak Periods for Outbound Direction

Outbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay (pax-min)	Corridor	Car	39,052.5	29,732.9	73,792.2	45,901.9	-9,319.6	34,739.7	6,849.4
		BRT	15,432.4	9,433.6	7,138.9	18,407.8	-5,998.9	-8,293.5	2,975.4
	Non-corridor	Car	150,892.8	162,518.2	174,720.7	161,798.1	11,625.4	23,827.9	10,905.3
Stop time (pax-min)	Corridor	Car	28,011.0	21,442.6	54,583.3	32,844.8	-6,568.4	26,572.3	4,833.8
		BRT	13,816.2	8,036.8	4,881.4	16,234.4	-5,779.4	-8,934.8	2,418.2
	Non-corridor	Car	136,642.9	143,905.7	157,714.3	146,857.9	7,262.7	21,071.4	10,215.0
Travel time (pax-min)	Corridor	Car	147,874.9	128,531.3	204,270.6	157,133.9	-19,343.5	56,395.7	9,259.0
		BRT	61,252.6	51,115.4	39,871.1	65,309.3	-10,137.1	-21,381.5	4,056.7
	Non-corridor	Car	258,055.6	274,191.3	291,482.8	265,611.3	16,135.7	33,427.2	7,555.7

Table 4.7 Summary of Whole Network Impacts Travel Time Impacts Per All Users in the Morning Peak Periods for Inbound Direction

Inbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay (pax-min)	Corridor	Car	146,297.5	127,928.3	366,413.5	124,378.2	-18,369.3	220,115.9	-21,919.3
		BRT	17,505.3	11,140.4	6,988.4	12,893.8	-6,364.9	-10,517.0	-4,611.5
	Non-corridor	Car	359,186.0	387,302.1	522,583.1	355,586.0	28,116.1	163,397.1	-3,600.1
Stop time (pax-min)	Corridor	Car	103,996.6	95,015.9	270,077.9	95,325.0	-8,980.8	166,081.3	-8,671.7
		BRT	13,781.4	9,309.9	4,372.0	10,337.8	-4,471.5	-9,409.4	-3,443.5
	Non-corridor	Car	303,480.4	318,999.3	462,488.7	299,652.1	15,518.9	159,008.3	-3,828.2
Travel time (pax-min)	Corridor	Car	370,658.0	343,637.0	589,622.5	358,781.8	-27,021.0	218,964.4	-11,876.2
		BRT	79,508.6	68,458.4	53,976.1	64,976.4	-11,050.3	-25,532.5	-14,532.2
	Non-corridor	Car	512,375.0	539,155.2	673,835.7	502,804.9	26,780.2	161,460.6	-9,570.1

4.3.1.2 Whole Network Results: Evening Peak Periods

The result shown in Table 4.8 indicated the outbound impact with regards to delay time, stop time and travel time per vehicle. According to the fact that outbound direction had the higher packed-traffic than the inbound direction in the evening. When applying the TSP solution, the delay time, stop time and travel time of the BRT were reduced 5.9 min (34.3%), 6.8 min (41.2%) and 6.5 min (15.8%), respectively. The reason behind of decreasing of all indicators was because the BRT did not have to wait at the at-grade intersections. Also, a car travelled in the same corridor of the BRT was also positively affected by decreasing the delay time, stop time and travel time of 2.3 min (17.3%), 1.8 min (14.8%) and 4.0 min (12.1%), respectively. Nonetheless, the TSP returned the negative impact to a car travelled in the non-corridor by increasing the delay time, stop time and travel time of 2.9 min (5.9%), 3.1 min (6.6%) and 4.9 min (6.8%), respectively. Taken the solution of FS into consideration, the result revealed that only the BRT could receive the positive impact from the solution. The delay time, stop time and travel time of the BRT was decreased dramatically 9.5 min (55.2%), 10.0 min (60.8%) and 16.0 min (38.6%), respectively. This happened because the lane was reserved for the BRT solely. While the delay time, stop time and travel time of a car travelled in corridor was affected dramatically with the increasing of 13.7 min (103.1%), 11.9 min (97.4%) and 18.0 min (54.1%), respectively. Similar to a car travelled in the non-corridor, the delay time was raised 15.0 min (30.6%), the stop time was increased 12.2 min (25.8%) and the travel time was worsened 16.4 min (22.8%). With regard to the result of the RL solution, it indicated that all the indicators were obviously reduced especially the BRT. Since the delay time of the BRT was reduced 4.7 min (27.5%), the stop time was reduced 4.8 min (29.2%) and the travel time was also decreased 7.8 min (18.8%). Not only the BRT that having the positive impact, but a car travelled in the corridor was able to decrease the delay time, stop time and travel time by 1.4 min (10.5%), 1.0 min (8.0%) and 1.9 min (5.8%), respectively. Similar to a car travelled in the non-corridor, the delay time, stop time and travelled time were decreased 5.4 min (11.0%), 4.9 min (10.3%) and 1.5 min (2.1%), respectively.

According to the result shown in Table 4.9, it revealed the impacts of conducting each scenario in the inbound direction. By applying TSP solution, the delay of the BRT

was decreased 5.2 min (44.9%), the stop time was reduced 5.1 min (47.5%) and the travel time was affected positively with the reduction of 6.3 min (18.3%). Also, a car travelled in the corridor was also positively affected by the decreasing of delay time 3.8 min (36.8%), stop time 3.2 min (33.4%) and travel time 3.3 min (10.6%). This could imply that the TSP solution had the positive effect not only to the BRT but also the cars travelled in the corridor. While the TSP also created the negative impact to a car that travelled in the non-corridor by increasing the delay time, stop time and travel time by 2.2 min (5.6%), 2.1 min (6.0%) and 3.2 min (4.9%), respectively. Another solution to be taken in consideration was the FS solution. The FS solution could improve all indicators of the BRT but worsened the traffic both car in the corridor and non-corridor. The delay time, stop time and travel time of a car in the corridor were increased 8.6 min (82.8%), 8.8 min (90.2%) and 10.2 min (33.0%), respectively. Similar to a car travelled in the non-corridor also received the negative impacts, in which the delay time, stop time and travel time were increased 9.0 min (23.3%), 5.6 min (16.2%) and 7.3 min (11.4%), respectively. While the BRT's delay time, stop time and travel time were decreased by 6.3 min (54.4%), 6.5 min (60.2%) and 13.2 min (38.0%), respectively. Besides, the RL solution in the inbound direction also created the negative impacts to the network. The delay time, stop time and travel time of a car in the corridor were increased 1.0 min (9.5%), 1.4 min (14.7%), 1.7 min (5.5%), respectively. While a car travelled in the non-corridor was negatively affected by the increasing of delay time 1.3 min (3.4%), stop time 1.6 min (4.5%) and travel time 1.5 min (2.3%). Also, the BRT's delay time, stop time and travel time were also increased by 1.8 min (15.2%), 2.0 min (18.2%) and 2.3 min (6.5%), respectively.

To evaluate into more details, the evaluation of the all users' impact was conducted under the proposed scenario. The result shown in Table 4.10 revealed the impacts when establishing each solution. The solution TSP was obviously reduced the delay time of the BRT by 5,695.3 min (56.2%), stop time 6,147.7 min (38.6%) and travel time 11,180.9 min (15.4%). Not only the BRT's indicators were reduced, but the cars in the corridor were also positively affected. Since the delay time, stop time and travel time of the cars in the corridor were decreased 19,590.3 min (19.4%), 13,506.1 min (14.6%) and 24,113.2 min (10.4%), respectively. while the delay time, stop time and travel time of the cars in the non-corridor were increased 8,772.6 min (4.7%),

9,846.9 min (5.6%) and 21,938.7 min (7.3%), respectively. When conducting the FS solution, there were huge negative impact affected to the cars in the corridor and non-corridor, but not the BRT. Since the delay time, stop time and travel time of the cars travelled in the corridor were increased 106,327.9 min (105.3%), 88,300.8 min (95.7%) and 129,448.1 min (55.7%), respectively. Similar to the cars travelled in the non-corridor was also affected, the delay time, stop time and travel time were raised by 59,671.1 min (32.1%), 47,202.8 min (26.8%) and 70,355.5 min (23.3%), respectively. While the BRT was directly and only received the positive impacts from the FS solution. Since the delay time, stop time and travel time were dramatically decreased by 9,458.4 min (56.2%), 9,764.1 min (61.3%) and 20,039.8 min (40.1%), respectively. Another propose strategy was the RL solution. The result indicated that all indicators were reduced dramatically. Since the delay time, stop time and travel time of the cars in the corridor were reduced 11,068.0 min (11.0%), 7,631.3 min (8.3%) and 10,395.9 min (4.5%), respectively. While the cars in the non-corridor were also got the positive effect from the RL solution. The delay time was decreased 22,779.6 min (12.3%), the stop time was reduced 22,523.5 min (12.8%) and the travel time was also received the positive effect by 7,614.8 min (2.5%) reduction. Besides, the BRT's delay time, stop time and travel time were decreased 4,619.5 min (27.4%), 4,644.6 min (29.2%) and 13,918.2 min (19.2%), respectively.

According to the result of the inbound direction for the evening peak period shown in Table 4.11, the results revealed that there were advantage and disadvantage among the proposed solutions. The TSP solution could always reduce the delay time, stop time and travel time of the BRT and the cars travelled in the corridor. Since the delay time, stop time and travel time of the BRT were reduced by 5,550.5 min (47.6%), 5,068.6 min (47.1%) and 10,398.3 min (18.8%), respectively. While the cars in the corridor was able to reduce the delay time, stop time and travel time by 10,762.2 min (36.9%), 6,691.3 min (30.0%) and 15,337.1 min (13.1%), respectively. But the cars travelled in the non-corridor received the increasing of delay time, stop time and travel time by 10,909.6 min (8.3%), 8,238.8 min (6.9%) and 12,469.6 min (5.2%), respectively. The reason behind this was that the BRT and the cars in the corridor were received more green timing at the intersections which affected to the cars in the non-corridor that had to spend more red timing at the intersections. Taken FS solution into

account, the result revealed that FS solution could provide the positive impact to the BRT but not the other road users. The delay time of the BRT was reduced 6,323.3 min (54.2%), the stop time was reduced 6,453.4 min (59.9%), and the travel time was decreased 21,221.3 min (38.4%). While the cars in the corridor were suffered from the increasing of delay time, stop time and travel time by 24,757.5 min (85%), 19,451.6 min (87.2%) and 38,034.8 min (32.4%), respectively. Similar to the cars travelled in the non-corridor, the delay time was increased 29,521.3 min (22.5%), stop time was raised 18,687.9 min (15.7%) and travel time was affected with increasing of 27,971.1 min (11.7%). The last solution was the RL strategy. The RL solution proposed in the evening had the negative impact to all indicators of both the BRT and cars in corridor and non-corridor. This occurred due to the lane reduction to be the additional lane for the outbound direction. As the delay time, stop time and travel time of the BRT were increased 1,828.9 min (15.7%), 1,972.4 min (18.3%) and 3,971.0 min (7.2%), respectively. While the cars travelled in the corridor were also received the negative impact by the increasing of delay time 2,774.9 min (9.5%), stop time 3,336.0 (15.0%) and travel time 6,923.2 min (5.9%). The cars travelled in the non-corridor were encountered with the increasing of delay time, stop time and travel time by 5,529.9 min (4.2%), 6,285.6 min (5.3%) and 6,918.7 min (2.9%), respectively.

In short, all proposed solutions had the advantages and disadvantages. By applying TSP solution, the BRT and cars in the corridor could receive the positive impacts. While the cars in the non-corridor were encountered with slightly effect from the TSP solution meaning that the cars had to spend more time to wait at the at-grade intersect. Whereas the FS solution created the positive impact for only the BRT, in which the travel time of the BRT was improved. While, it also produced the huge impact to both corridor and non-corridor. This was due to the fact that there was a lane reduction in both outbound direction and inbound direction. Besides, the RL solution decreased the delay time, stop time and travel time at the reversed lane section and also the non-corridor. But it also had the negative impact to the opposite direction both at the corridor and non-corridor.

Table 4.8 Summary of Whole Network Travel Time Impacts Per Vehicle in the Evening Peak Periods for Outbound Direction

Outbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay	Corridor	Car	13.2	10.9	26.9	11.8	-2.3	13.7	-1.4
		BRT	17.1	11.3	7.7	12.4	-5.9	-9.5	-4.7
	Non-corridor	Car	49.1	52.0	64.1	43.7	2.9	15.0	-5.4
Stop time	Corridor	Car	12.2	10.4	24.2	11.3	-1.8	11.9	-1.0
		BRT	16.5	9.7	6.5	11.7	-6.8	-10.0	-4.8
	Non-corridor	Car	47.2	50.3	59.4	42.3	3.1	12.2	-4.9
Travel time	Corridor	Car	33.3	29.2	51.2	31.3	-4.0	18.0	-1.9
		BRT	41.3	34.8	25.4	33.6	-6.5	-16.0	-7.8
	Non-corridor	Car	71.8	76.7	88.2	70.3	4.9	16.4	-1.5

Note: Unit of car's indicators are in minute per passenger car unit (min/PCU) and unit BRT's indicator is in minute per vehicle

Table 4.9 Summary of Whole Network Travel Time Impacts Per Vehicle in the Evening Peak Periods for Inbound Direction

Inbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay (min/PCU)	Corridor	Car	10.4	6.6	19.1	11.4	-3.8	8.6	1.0
		BRT	11.7	6.4	5.3	13.4	-5.2	-6.3	1.8
	Non-corridor	Car	38.6	40.7	47.6	39.9	2.2	9.0	1.3
Stop time (min/PCU)	Corridor	Car	9.7	6.5	18.5	11.1	-3.2	8.8	1.4
		BRT	10.8	5.7	4.3	12.8	-5.1	-6.5	2.0
	Non-corridor	Car	34.7	36.7	40.3	36.2	2.1	5.6	1.6
Travel time (min/PCU)	Corridor	Car	30.8	27.5	41.0	32.5	-3.3	10.2	1.7
		BRT	34.7	28.3	21.5	36.9	-6.3	-13.2	2.3
	Non-corridor	Car	64.5	67.6	71.8	66.0	3.2	7.3	1.5

Note: Unit of car's indicators are in minute per passenger car unit (min/PCU) and unit f BRT's indicator is in minute per vehicle

Table 4.10 Summary of Whole Network Impacts Travel Time Impacts Per All Users in the Evening Peak Periods for Outbound Direction

Outbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay (pax-min)	Corridor	Car	100,998.9	81,408.6	207,326.7	89,930.9	-19,590.3	106,327.9	-11,068.0
		BRT	16,843.1	11,147.8	7,384.7	12,223.6	-5,695.3	-9,458.4	-4,619.5
	Non-corridor	Car	185,686.8	194,459.4	245,358.0	162,907.2	8,772.6	59,671.1	-22,779.6
Stop time (pax-min)	Corridor	Car	92,221.3	78,715.2	180,522.1	84,590.0	-13,506.1	88,300.8	-7,631.3
		BRT	15,917.2	9,769.5	6,153.1	11,272.6	-6,147.7	-9,764.1	-4,644.6
	Non-corridor	Car	175,962.4	185,809.3	223,165.2	153,438.9	9,846.9	47,202.8	-22,523.5
Travel time (pax-min)	Corridor	Car	232,436.5	208,323.3	361,884.6	222,040.6	-24,113.2	129,448.1	-10,395.9
		BRT	72,380.5	61,199.7	43,340.7	58,462.4	-11,180.9	-29,039.8	-13,918.2
	Non-corridor	Car	301,736.1	323,674.8	372,091.6	294,121.3	21,938.7	70,355.5	-7,614.8

Table 4.11 Summary of Whole Network Impacts Travel Time Impacts Per All Users in the Evening Peak Periods for Inbound Direction

Inbound direction		veh	Base	TSP	FS	RL	Δ TSP	Δ FS	Δ RL
Delay (pax-min)	Corridor	Car	29,135.0	18,372.8	53,892.6	31,909.9	-10,762.2	24,757.5	2,774.9
		BRT	11,670.1	6,119.5	5,346.8	13,499.0	-5,550.5	-6,323.3	1,828.9
	Non-corridor	Car	131,410.9	142,320.5	160,932.2	136,940.8	10,909.6	29,521.3	5,529.9
Stop time (pax-min)	Corridor	Car	22,301.7	15,610.4	41,753.4	25,637.8	-6,691.3	19,451.6	3,336.0
		BRT	10,771.4	5,702.8	4,318.0	12,743.8	-5,068.6	-6,453.4	1,972.4
	Non-corridor	Car	119,220.3	127,459.1	137,908.2	125,505.9	8,238.8	18,687.9	6,285.6
Travel time (pax-min)	Corridor	Car	117,374.4	102,037.3	155,409.2	124,297.6	-15,337.1	38,034.8	6,923.2
		BRT	55,203.8	44,805.5	33,982.6	59,174.8	-10,398.3	-21,221.3	3,971.0
	Non-corridor	Car	238,330.3	250,799.9	266,301.4	245,248.9	12,469.6	27,971.1	6,918.7

4.3.2 Travel Time Evaluation

This study has taken all traffic indicators into account while giving travel time the highest priority. Travel time is one of the most concerned factors when people creating their travel. Therefore, it was essential to evaluate and reveal how much benefit could gain to the car users and the BRT users in term of time saving. Besides, the economic aspect such as the travel cost of saving was evaluated. The travel cost of saving was calculated from the value of time (VOT) of the year 2017 for a private car user and a bus user according to the study of (OTP, 2015b). In which, the travel time of private car user was 177 bath/person/hour and bus user was 88 baht/person/hour. However, the value of time could be different in each year due to the changing of economic growth of the country. This study selected the value of time from the year of 2017 which was the most recent and available information of Bangkok by the time of conducting this research. Regards to the availability of the information, this study evaluated the travel time saving and saving cost for all solutions and delineated in the following sub-sections.

4.3.2.1 Travel Time Evaluation of TSP Solution

By applying the TSP solution, the BRT and the cars travelled in the corridor could gain the benefit of travel time reduction while the cars in the non-corridor received more travel time as shown in Figure 4.10. This happened due to the fact that the cars had to spend time at the intersection longer to dedicate the green timing to the BRT and cars in the corridor to pass the intersection. The result revealed that the travel time reduction of the BRT users and the car users in the inbound direction was greater than the outbound direction. This was because the traffic congestion occurred seriously in the inbound direction during the morning peak hours rather than in the outbound direction. The travel time of the BRT in the outbound corridor was decreased approximately 6.1 minutes per vehicle while in the inbound corridor the travel time of the BRT was decreased 6.3 minutes per vehicle. Similar with the travel time of the car in the inbound corridor and outbound corridor were decreased 5.3 minutes per PCU and 4.0 minutes per PCU, respectively. Whereas the cars in the non-corridor were affected of the increasing of 5.1 minutes per PCU in the inbound direction and 4.4 minutes per

vehicle in the outbound direction. It implied that both the BRT and cars in the inbound direction were more affected than the outbound direction.

In the overall view, the BRT users could save the travel time 21,187.4 minutes and the cars users could save 3,448.6 minutes when applying TSP solution. Regarding the economic aspect, Bangkok could save approximately 15.1 million baht per year by establishing TSP solution.

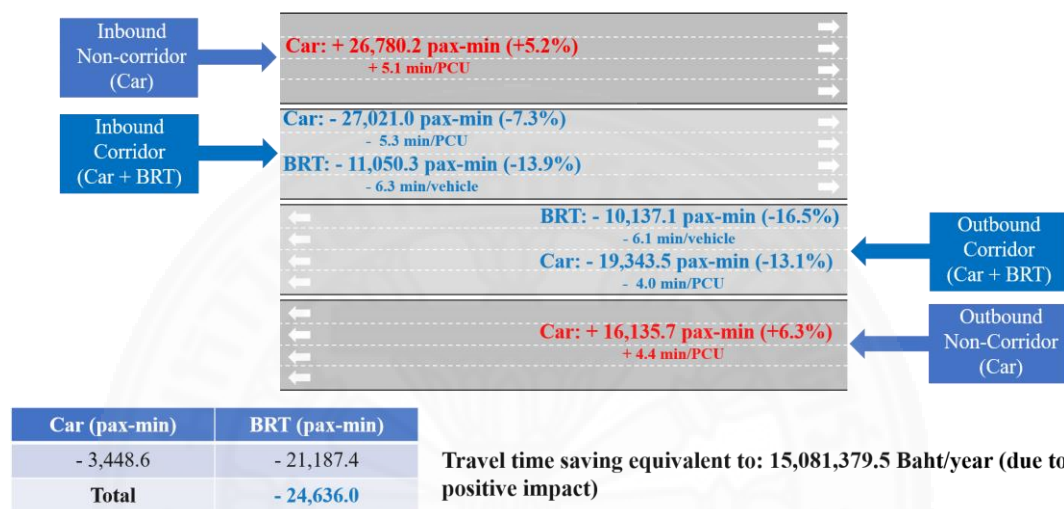


Figure 4.10 Travel Time Saving Using TSP Solution in the Morning Peak Hours (Whole Network)

By applying the TSP solution, the benefit was for the corridor users rather than for the non-corridor users. At the intersection level, the result shown in Figure 4.11 and Figure 4.12 revealed that north bound (NB) and south bound (SB) as the main corridor in the network could decrease the travel time, while the east bound (EB) and west bound (WB) increased the travel time. The reduction of travel time in the corridor was approximately 2.3 minutes per vehicle for BRT in the NB direction and 1.5 minutes per vehicle for the SB direction. While the cars in the corridor could reduce the travel time by 1.5 minutes in the NB direction and 1.3 minutes per PCU for the SB direction. This implied that the BRT could gain the benefit directly from the solution of FS, while the cars could gain the benefit as the by-product benefit. However, the travel time of the cars in the non-corridor were slightly increased by 0.7 minute per PCU and 0.6 minute per PCU in the EB direction and WB direction.

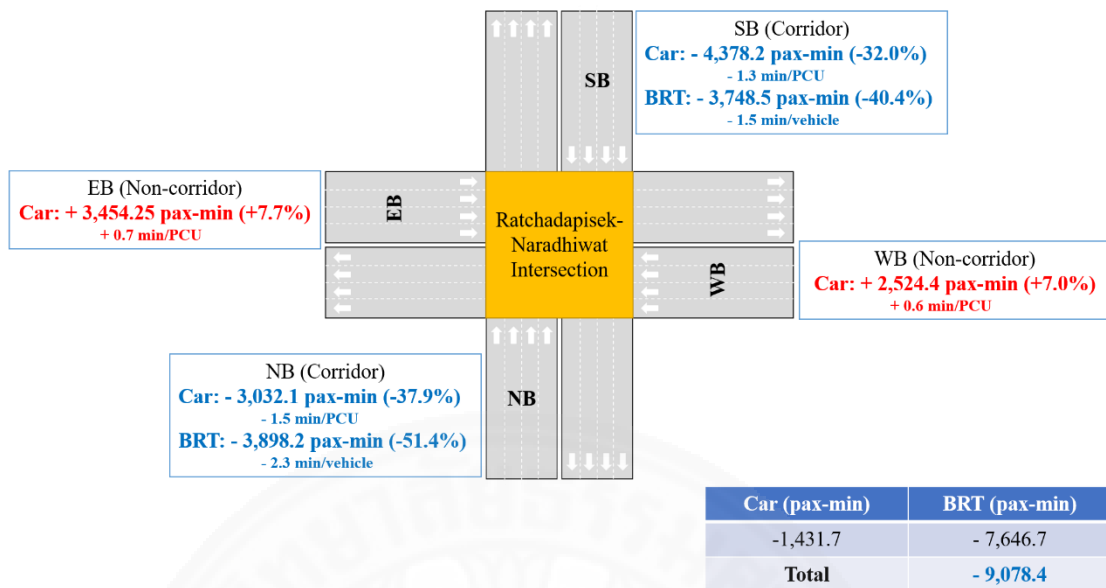


Figure 4.11 Travel Time Saving Using TSP Solution for in the Morning Peak Hours at Narathiwat-Ratchadaphisek Intersection



Figure 4.12 Traffic Simulation by Applying TSP Solution in the Morning Peak Hours at Narathiwat-Ratchadaphisek Intersection

When comparing the total benefit from all directions, it obviously seen that using TSP could produce the positive impact at the intersection by 9,078.4 minutes of travel time reduction. In which, the travel time of the BRT users could reduce 7,646.7 minutes while the car users gained the reduction of travel time of 1,431.7 minutes from both corridor and non-corridor sections.

The result of the evening condition was evaluated shown in Figure 4.13. It obviously seen that the outbound direction was could gain more travel time saving rather than the inbound direction. This was based on the fact that the traffic condition of the outbound direction in the evening was more congested than the inbound direction unlike in the morning peak periods. According to the result, the travel time of both the BRT and cars were decreased since they travelled in the corridor. While the cars travelled in the non-corridor were negatively affected. However, the travel time of the cars in the corridor was decreased greater that the increasing of travel time in the non-corridor. As the travel time of the BRT in the inbound direction was decreased approximately 6.3 minutes per vehicle and 6.5 minutes per vehicle in the outbound direction. Similar to the cars in the inbound corridor could reduce the travel time by 3.3 minutes per PCU and 4.0 minutes per PCU for the outbound corridor. Whereas the cars in the inbound non-corridor was increased 3.2 minutes per PCU and the cars in the outbound non-corridor was increased 4.9 minutes per PCU. This obviously implied that the travel time of the BRT and cars could affected with the greater proportion in the outbound direction in the evening perk hours.

According to the result, the overall view of using TSP solution returned positive impacts. In which, the cars users could save 5,042.0 minutes and the BRT users could save 21,579.2 minutes. Taking the economic aspect into the consideration, the result revealed that Bangkok could save the cost of travelling when applying the TSP solution approximately 17 million baht per year.

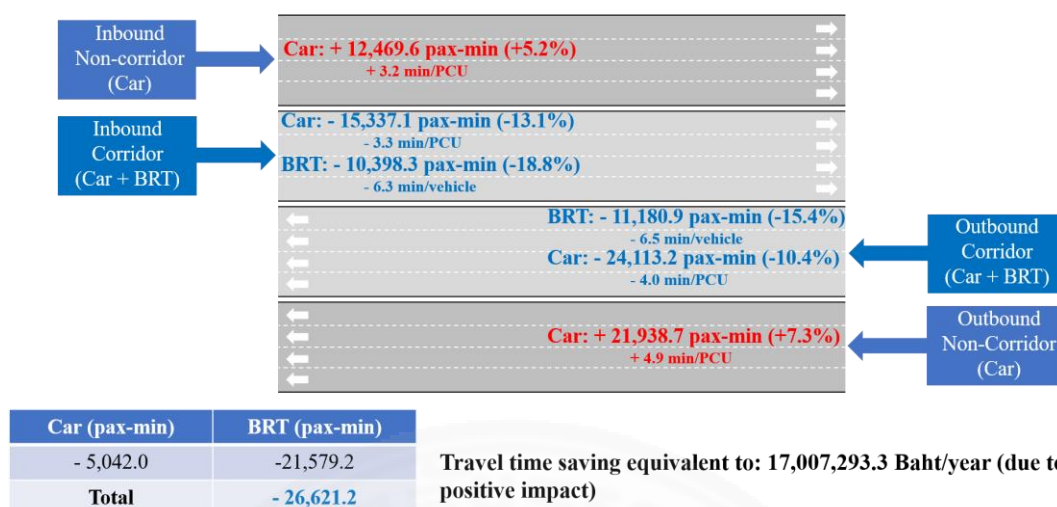


Figure 4.13 Travel Time Saving Using TSP Solution in the Evening Peak Hours
(Whole Network Evaluation)

When evaluating at the intersection level in the evening peak periods, the result shown in Figure 4.14 and Figure 4.15 revealed that the north bound direction (NS) and south bound direction (SB) served in the main corridor were able to perform the travel time reduction from both cars and the BRT when applying the TSP solution. While the cars in the non-corridor were affected with more travel time. The travel time of the BRT in the NB direction was decreased 2.0 minutes per vehicle and 1.4 minute per vehicle for the BRT in the SB direction. Together with the travel time of the car in the NB was decreased 1.5 minutes per PCU and the travel time of the cars in the SB direction was reduced 1.2 minutes per PCU. This obviously showed that the travel time reduction in the NB direction was greater than the SB direction due to the amount of the cars of the NB in the evening. While the travel time of cars in the EB and WB were slightly increased by 0.4 minute per PCU and 0.7 minute per PCU, respectively. It implied that the cars travelled in the non-corridor were slightly affected by the increasing of travel time.

However, the overall benefit returned in the positive effect, in which the travel time of the BTR could save 6,645.4 minutes for the users and the cars could save 1,134.8 minutes for the users from the corridor and non-corridor sections.

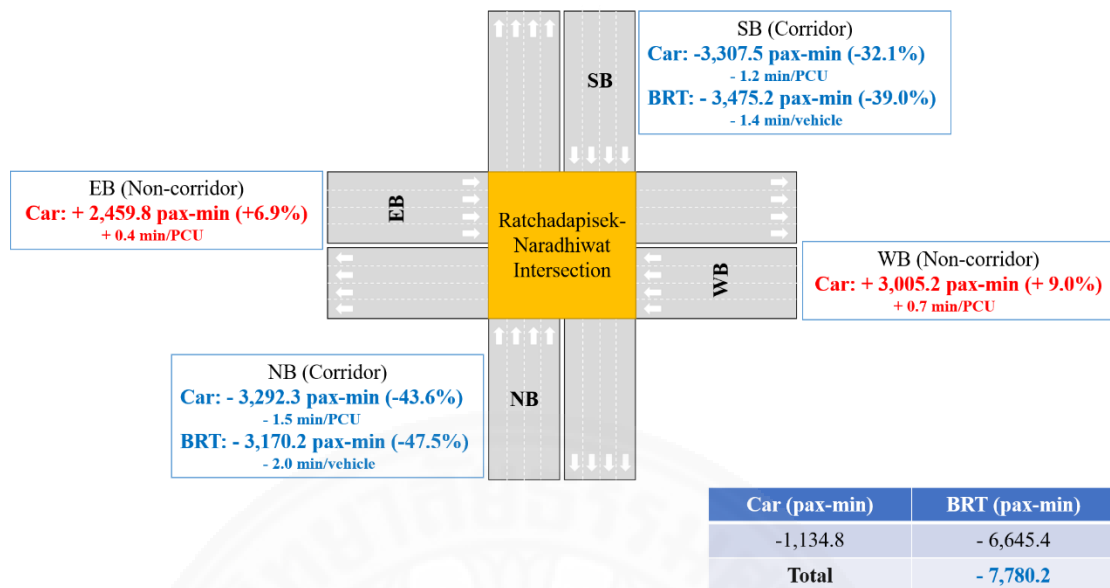


Figure 4.14 Travel Time Saving Using TSP Solution for the Evening Peak Hours at Narathiwat-Ratchadaphisek Intersection



Figure 4.15 Traffic Simulation by Applying TSP Solution in the Evening Peak Hours at Narathiwat-Ratchadaphisek Intersection

4.3.2.2 Travel Time Evaluation of FS Solution

The solution of FS was to reduce the lane of travel in both inbound corridor and outbound corridor. From this solution, the BRT could directly affect the positive impact, while the other car users were dramatically affected with the negative impacts. According to the result as shown in the Figure 4.16, the travel time of the BRT was reduced approximately 15.1 minutes per vehicle in the inbound direction and 13.1 minutes per vehicle in the outbound direction. While the increasing time of the cars in the corridor were 39.9 minutes per PCU in the inbound direction and 11.5 minutes per PCU in the outbound direction. Similar with the travel time of the cars in the non-corridor were also increased by 28.0 minutes per PCU in the inbound direction and 9.2 minutes per PCU in the outbound direction. The result could imply that the effect of using FS solution were with the inbound direction rather than in the outbound direction. This was in accordance to the real traffic condition that the inbound direction had the huge congestion in the morning while in the outbound direction was less.

The result of the overall impact revealed that the BRT could save travel time 46,914.0 minutes. While it caused the greater impact to the car users due to the lane reduction, which the travel time of the car users both travelled in the corridor and non-corridor sections was increased 470,247.9 minutes. Taking the economic aspect into account, it obviously showed that Bangkok had to spend more money for approximately 481.2 million baht per year due to the increasing amount of the congestion.

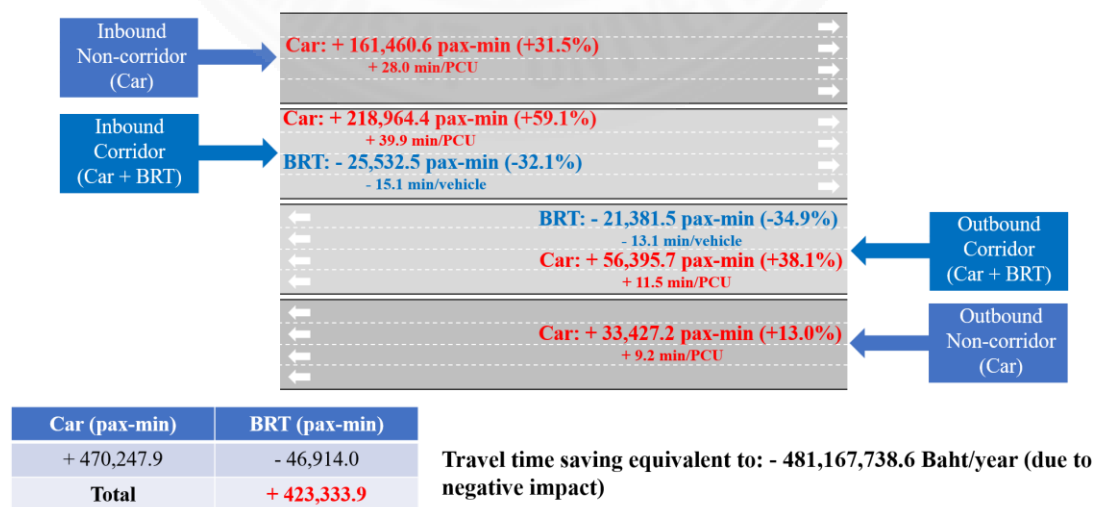


Figure 4.16 Travel Time Saving Using FS Solution in the Morning Peak Hours
(Whole Network Evaluation)

When considering only the segregated lane section, the result shown in the Figure 4.17 and Figure 4.18 indicated that the BRT in the inbound direction was increased by 14.4 minutes per vehicle, which was greater than the travel time reduction of the BRT in the outbound direction of 12.0 minutes per vehicle. However, the travel time of the cars in the inbound direction of both at the corridor and non-corridor were increased 27.6 minutes per PCU and 26.2 minutes per PCU, respectively. While the travel time of the cars in the inbound corridor and non-corridor were raised by 9.9 minute per PCU and 8.9 minutes per PCU, respectively. The reason behind of the increasing travel time of the cars in the corridor greater than the cars in the non-corridor was due to the fact that the lane in the corridor was dedicated for the BRT only.

The overall impacts of using FS was evaluated. In which, the BRT could decrease the travel time when travelling in the network in the morning by 38,866.9 minutes for the BRT users. While cars' travel time were increased by 392,819.2 in the whole considered network. When sum the benefit of the BRT and the cars together, the result revealed that the travel time of the network was increased by 353,952.3 minutes.

The result of the impacts in the evening was shown in Figure 4.19. It revealed that the travel time of the BRT in the inbound direction and outbound direction was dramatically decreased by 13.2 minutes per vehicle and 16.0 minutes per vehicle, respectively. While the travel time of the cars in the inbound corridor and non-corridor were raised by 10.2 minutes per PCU and 7.3 minutes per PCU, respectively. Also, the travel time of the cars in the outbound corridor and non-corridor were also increased by 18.0 minutes per PCU and 16.4 minutes per PCU, respectively. Regarding the result, it obviously showed that the impact of using FS solution in the evening was in the opposite way of the impacts occurred in the morning condition. In fact, the traffic condition of the outbound direction was worse than the inbound direction in the evening due to the number of vehicles in the network.

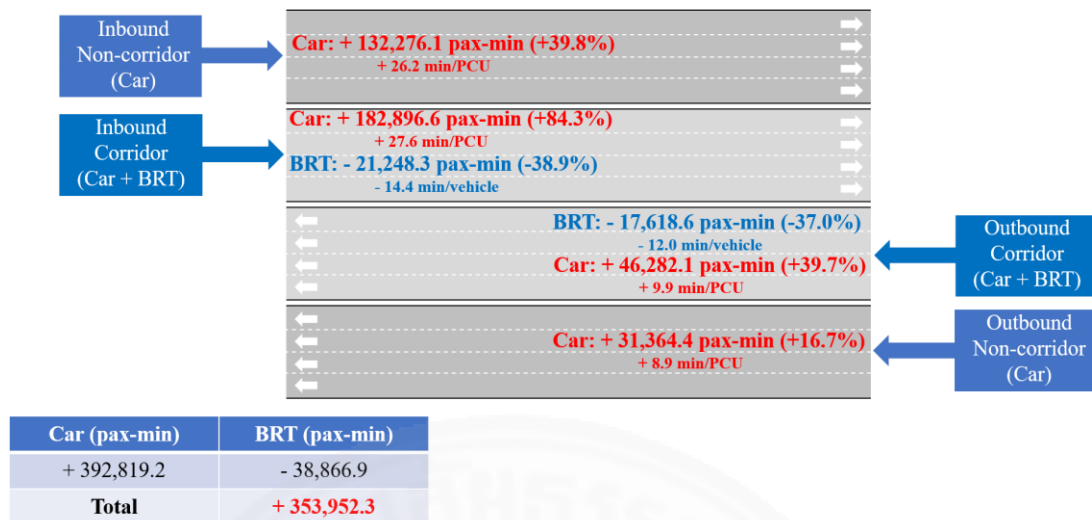


Figure 4.17 Travel Time Saving Using FS Solution for the Morning Peak Hours
(Only with the Segregated Sections)

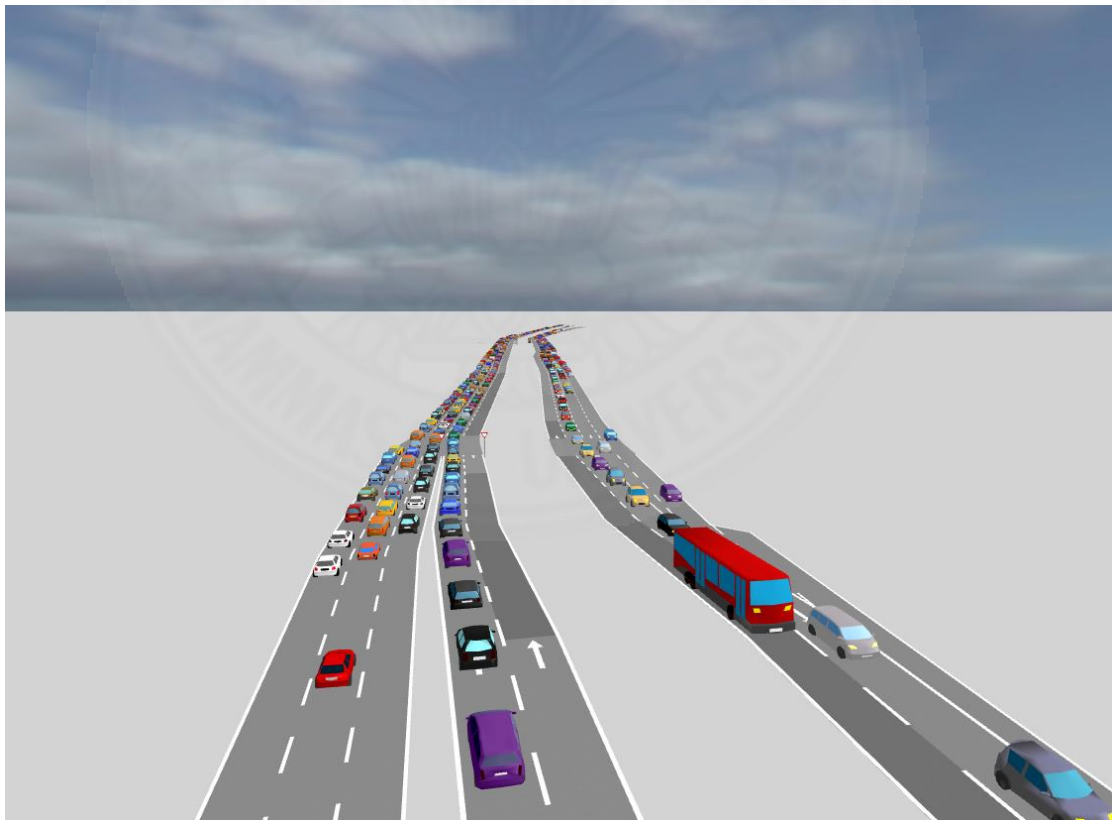


Figure 4.18 Traffic Simulation by Enforcing Fully Segregated Lane Solution in the
Morning Peak Hours at Rama III Road

When considering the total effect, the result indicated that the BRT was able to reduce travel time for the users by 50,261.1 minutes. While the travel time of the car users were increased by 265,809.5 minutes. Therefore, the total benefit of using the FS solution created more travel time to the road users rather than to the BRT users. In term of economy, the saving cost due to the travel time value was worsen and the Bangkok would lose the benefit approximately 259.2 million baht per year.

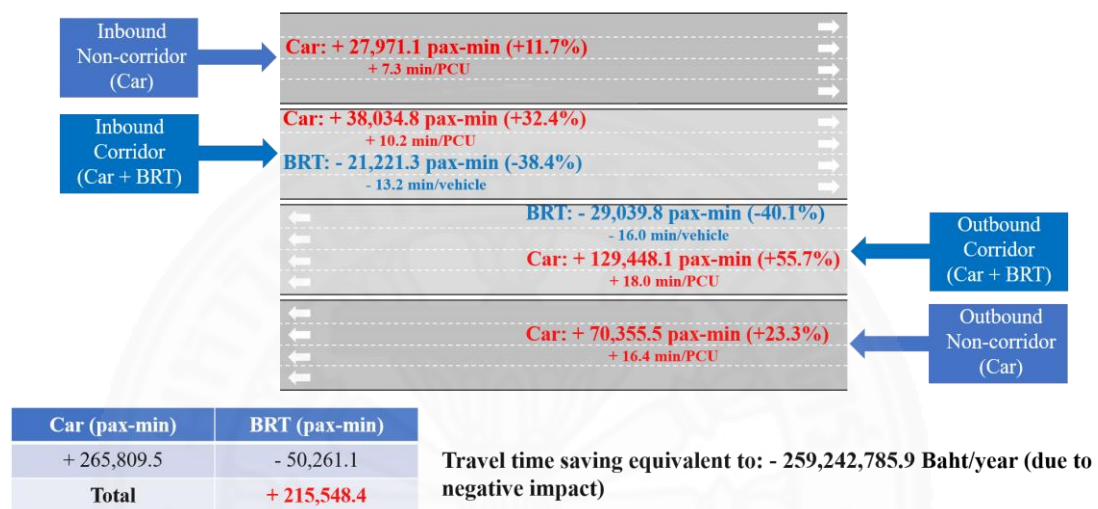


Figure 4.19 Travel Time Saving Using FS Solution in the Evening Peak Hours
(Whole Network Evaluation)

The result of the only segregated lane in the evening was evaluated and shown in Figure 4.20 and Figure 4.21. The result found that the BRT travel time in both corridor and non-corridor was decreased by 10.8 minutes per vehicle and 15.3 minutes per vehicle, respectively. While the travel time of car in the inbound corridor and non-corridor section was increased by 7.5 minutes per PCU and 6.2 minute per PCU, respectively. Similar to the travel time increasing in the outbound direction, the cars in the corridor were increased the travel time by 15.8 minutes per PCU, while the cars in the non-corridor were increased 15.3 minutes per PCU. This was obviously seen that the negative effect occurred to the cars especially the cars in the corridor. Since the cars in the corridor travelled under the condition of lane reduction. However, the use of FS solution returned the negative impact to the network. As the cars' travel time were increased 229,440.4 minutes for the car users, but only 40,555.2 minutes of the BRT

users' travel time was reduced. In which, the total network would increase the total travel time of 188,885.2 minutes.

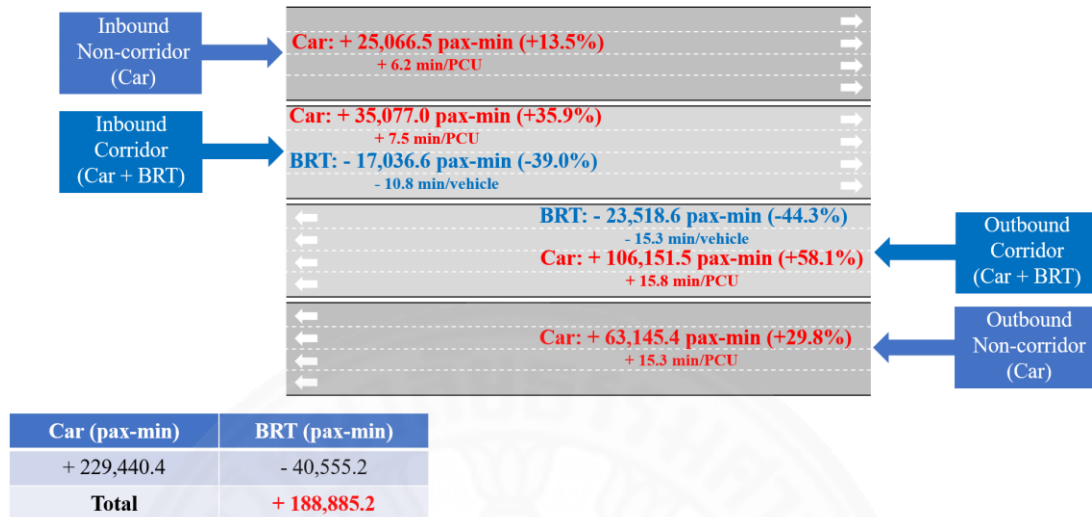


Figure 4.20 Travel Time Saving Using FS Solution for the Evening Peak Hours
(Only with the Segregated Sections)



Figure 4.21 Traffic Simulation by Enforcing Fully Segregated Lane Solution in the
Evening Peak Hours at Rama III Road

4.3.2.3 Travel Time Evaluation of RL Solution

The solution of RL was able to reduce the travel time for the specific reversed section. As the RL solution result of the morning peak hours shown in Figure 4.22, it found that the travel time of the BRT, the cars in the corridor and the cars in the non-corridor was dramatically decreased by 8.3 minutes per PCU, 2.1 minutes per PCU and 1.5 minutes per PCU, respectively. The reason that all sections got decreasing in travel time was because the BRT that used to operate in the inbound corridor shifted to use one lane in the outbound direction. This caused the increasing in travel time to the BRT, the cars in the corridor and the cars in the non-corridor by 2.7 minutes per vehicle, 2.0 minutes per vehicle and 1.8 minutes per vehicle, respectively. The increasing of travel time was occurred due to the fact that the lane of the inbound direction was dedicated to serve the BRT in the outbound direction.

Taking the whole network into account, the result revealed that the travel time of car users was decreased by 4,631.5 minutes both from the corridor and non-corridor. Whereas the travel time of the BRT users was also reduced by 10,475.5 minutes. When summing up the benefit caused to the BRT and the cars together, the result revealed that total benefit of the whole network returned in the positive impact by reducing the travel time of 15,107.0 minutes for the users. When considering the economic aspect, it revealed that the cost of saving by applying the solution of RL was approximately 10.6 million baht per year.

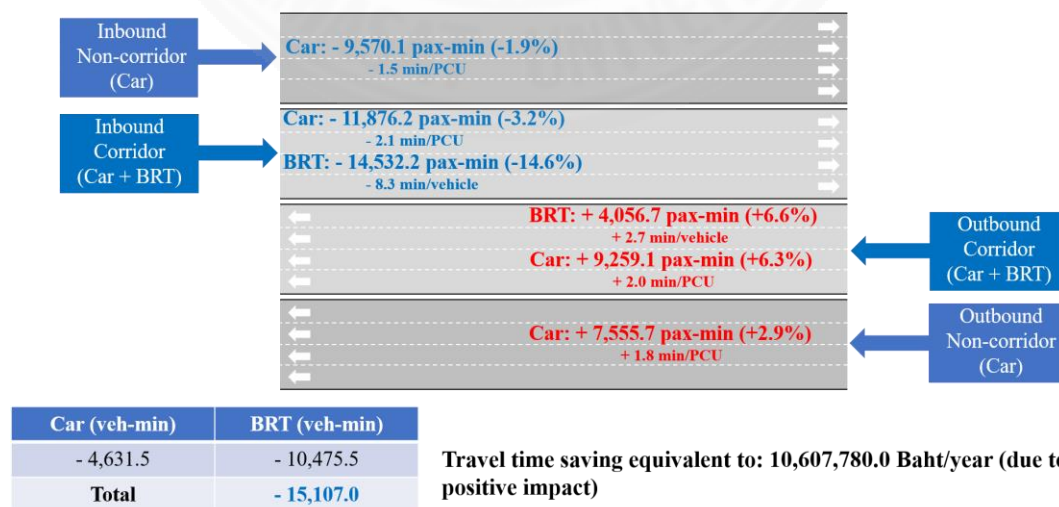


Figure 4.22 Travel Time Saving Using RL Solution in the Morning Peak Hours
(Whole Network Evaluation)

When considering only the reversed section in the morning, the result had the similar trend to the whole network evaluation as shown in Figure 4.23 and Figure 4.24. As the inbound travel time of the BRT, the cars in the corridor and the cars in the non-corridor was decreased by 7.6 minutes per vehicle, 1.7 minutes per PCU and 1.4 minutes per PCU, respectively. While the travel time of the BRT in the outbound direction was increased by 2.5 minutes per vehicle. This happened because the lane of the BRT was dedicated to be the additional lane for the inbound direction. Also, the travel time of cars in the outbound direction travelled in the corridor and non-corridor was slightly raised by 1.8 minutes per PCU and 1.6 minutes per PCU, respectively. Taking the total benefit of the only reversed section into account, the result showed that the travel time of the BRT was dramatically decreased by 5,860.2 minutes for whole users. While the car users were also able to decrease their travel time by 3,915.8 minutes. The total benefit of the RL solution in the only reversed section turned positive impact to the network.

Taking the impact of whole evening network into consideration as shown in Figure 4.25, the result revealed that the travel time of the outbound direction was decreased for both BRT and the cars in corridor and non-corridor. This was due to the fact that there was an additional lane for the outbound direction, which taken one lane from the inbound direction to be the lane served the BRT. From this fact, the inbound travel time of the BRT, the cars in the corridor and the cars in the non-corridor was increased by 2.3 minutes per vehicle, 1.7 minute per PCU and 1.5 minutes per PCU, respectively. While the outbound travel time of the BRT, the cars in the corridor and the cars in the non-corridor was decreased by 7.8 minutes per vehicle, 1.9 minutes per PCU and 1.5 minutes per PCU, respectively. This was due to having an additional lane in the outbound direction.

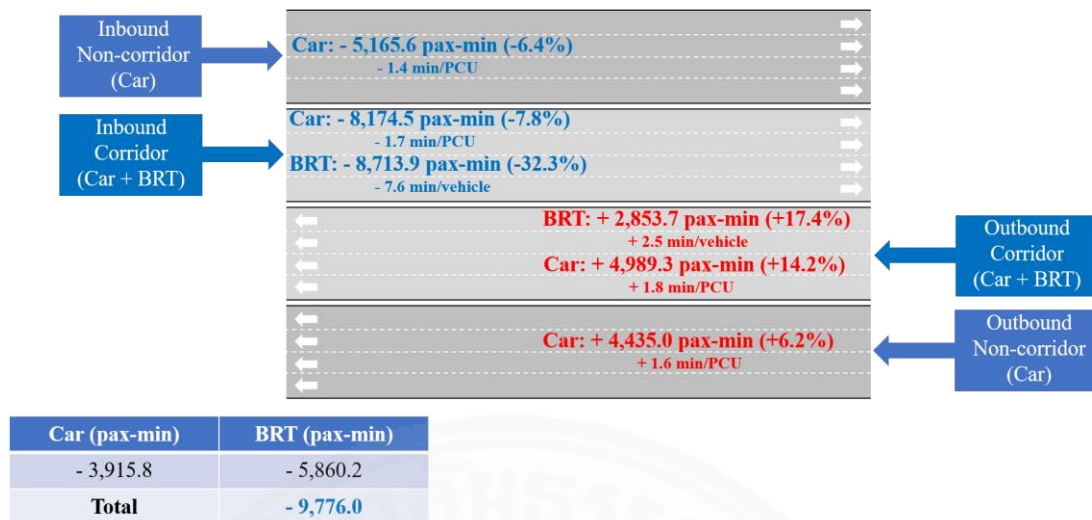


Figure 4.23 Travel Time Saving Using RL Solution for the Morning Peak Hours
(Only with the Reversed Section)



Figure 4.24 Traffic Simulation by Adopting Reversed Lane Solution in the Morning
Peak Hours at Rama III Bridge

With regards to the impact of the total network in the evening, the finding showed that the BRT could reduce the travel time of 9,947.2 minutes for the BRT users. Whereas the car users could also decrease the travel time 4,168.8 minutes. The total travel time benefit was 14,116.0 minutes for whole users. Taking the economic aspect into account, the result revealed that Bangkok could have the cost of saving approximately 9.8 million baht per year.

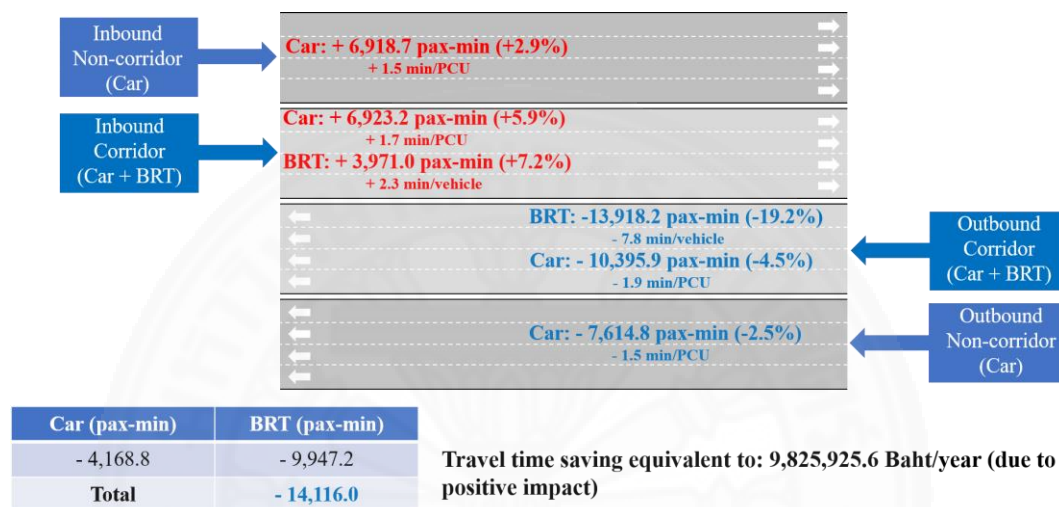


Figure 4.25 Travel Time Saving Using RL Solution in the Evening Peak Hours
(Whole Network Evaluation)

The only reversed section using the RL in the evening peak hours was evaluated as shown in Figure 4.26 and Figure 4.27. The finding indicated that the travel time of the BRT in the outbound was decreased 6.8 minutes per vehicle. While the travel time of cars in the corridor and non-corridor was reduced by 1.4 minutes per PCU. It obviously showed that the inbound travel time of the BRT and cars both travelled in the corridor and non-corridor were increased dramatically. As the travel time of the BRT in the inbound direction was increased 2.0 minutes per vehicle. The travel time of the cars in the corridor and non-corridor of the inbound direction was also increased by 1.2 minutes per PCU. When considering the total travel benefit from the inbound direction and outbound direction, the result revealed that the BRT could save the travel time by 6,433.7 minutes for the BRT users. Whereas the car users could save 6,433.7 minutes when travelling in the evening network under the RL solution. Hence, the total travel time benefit was 10,927.4 minutes for whole users in the only reserved lane.

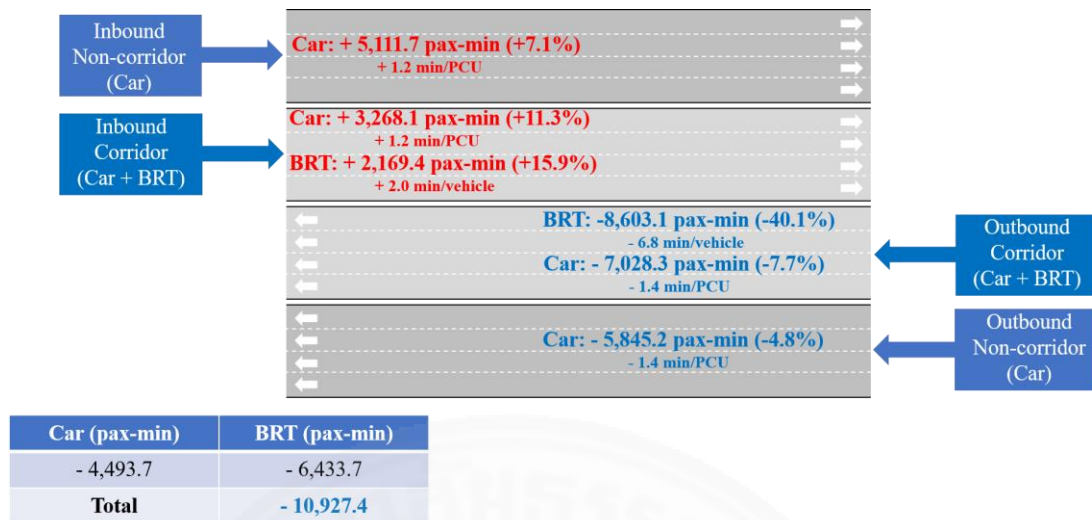


Figure 4.26 Travel Time Saving Using RL Solution for the Morning Peak Hours
(Only with the Reversed Section)



Figure 4.27 Traffic Simulation by Adopting Reversed Lane Solution in the Evening
Peak Hours at Rama III Bridge

4.4 BRT Operational Improvement's Recommendations

This present study proposed three solutions which were applying transit signal priority (TSP), enforcing fully segregate lane (FS), and providing an additional dedicated BRT lane in the reversed direction (RL). The objective of proposing the solutions was to improve the operation of the BRT in Bangkok. The impacts of each solution were evaluated with regards to the travel time saving and the economic term such as the travel cost saving. However, this study was assumed that every bus could carry 80 passengers (Kodukula, 2010) and one car could carry 1.5 passenger (OTP, 2015a), and the value of time for private car users and bus users were 177 baht/person/hour and 88 baht/person/hour, respectively (OTP, 2015b). According to the results that mentioned in the section 4.3, this study provided the advantages and disadvantages for using each solution, together with providing the recommendations based on the evaluation (see Appendix E). The recommendation was evaluated by using the result of the morning peak periods. Since the morning traffic condition was worse than the evening traffic condition.

TSP solution: The advantage of using TSP was that the car in the corridor of BRT and the bus could gain the benefit at the intersections from this solution. Since the bus will reduce the delay time and stop time at the intersection, which caused the travel time shorter than the usual case or real traffic condition. Besides the advantage, the TSP solution also had the effect slightly for the non-corridor sections, since the cars in the non-corridor section had to stay a little longer with red timing at the intersections. However, the overall use of TSP still returned positive impact to the network. In which, the travel time of the BRT users and car users were reduced. Regarding to the economic aspect, the TSP solution could save approximately 15.1 million baht per year from the value of time of the users. As mentioned earlier that this study was assumed the number of passengers of the BRT with the full capacity for every bus. But in the real operation of BRT in Bangkok, the number of passengers in the bus were not in the full capacity. However, when the assumption of the number of passengers reduced 50 percent or 480 passengers per hour, TSP still could provide the positive benefit to the network. When the demand of the users increased, the more benefit would provide to the network by

the solution of TSP. However, the cost of the TSP system and cost of equipment installation should be taken in consideration in order to establish this solution.

FS solution: This proposed solution's objective was to let the BRT operating in its lane without sharing with other road users. Thus, the benefit of using this solution was only for the BRT. Since one lane from inbound direction and outbound direction were dedicated to the BRT. The disadvantage of this solution was that the cars in the corridor and non-corridor had to stay at the traffic longer than the usual of it be. With the evaluation to make the FS solution possible in implementation, this solution would return positive impact in term of travel time saving when the demand increased to 19,320 passengers per hour. So, this solution would be appropriate to implement when the demand reached the target demand of 19,320 passengers per hour. According to the headway of the current BRT in the rush hour, the BRT headway was 5-minute headway. So, the reach the desired demand to implement this solution, the recommendation was to improve the headway or the size of the bus. In order to establish this solution, however, the cost of barrier installation and the cost of buying the buses should be considered.

RL solution: The purpose of this solution was to add one additional lane by reversing the lane in the opposite direction that was not congested as another lane. Hence, this solution affected the direction that the lane reversed. But the direction that received the additional lane could decrease the travel time effectively. This solution could be more beneficial when there was more demand according to the evaluation. Although the number of the passengers were reduced 50% or 480 passengers per hour, the network still received positive impacts in term of travel time and economic aspect. However, to establish this solution, the cost of implementation of reversing lane such as razing cost, pavement cost and sign installation cost should be considered.

From the empirical analysis, this present study found that the TSP solution was the most recommended solution to improve the operation of the BRT in Bangkok. Since this solution had the most positive impact to the network in term of travel time saving. However, this solution needed some operational costs such as the cost of TSP system and the cost of detector installation in the buses. While the solution RL was also recommended to implement. Since this solution positively affected the network. But this solution had to consider the cost of razing the existing median strip or central

reservation, the cost of pavement and the cost of installing signs. So that this solution was consider costly and timely to implement. However, the FS solution was not recommended to implement if the capacity of the BRT could not reach the desired demand of users of 19,320 passengers per hour. This solution was considered as the costliest solution. Since the decision makers had to consider more buses to serve in the system. The number of buses served in the operation are 25 buses which are sufficient only for the 5-minute headway. When the headway is changed, more buses should be put into the operation system.



CHAPTER 5

BRT SERVICE ASSESSMENT

This chapter presents details of the service assessment on the basis of the perception of the BRT users. This chapter commences with section 5.1, which compares the service quality of the BRT with the standard level of service (LOS). Section 5.2 assesses the travel characteristics of the BRT users in Bangkok by analyzing the data collected from the questionnaire survey. This section details the demographic profile of the collected respondent as the BRT users, travel information such as the users' origin and destination, travel purpose, trip generation, frequency of using the BRT, travel mode, travel time and travel cost that the users spent. Section 5.3 elaborates the user perspective on the BRT service, the difference between the expectation and the satisfaction of the users, and using EFA to analyze the improvement factors that the BRT should improve to gain more users.

5.1 Assessment of BRT's Quality of Service

Quality of service is an indicator to measure how effective the transit could operate. It regards to the availability of the transit, accessibility to the transit, and reliability of the service and system performance. According to the international transit guideline, HCM (2000) and TCQSM (2003) recommend with a six-scale measure of transit service quality namely "Level of Service (LOS)". The LOS is ranged from LOS A to LOS F, which each LOS represents the characteristics of the service under the particular value as the thresholds. In this study, LOS was applied to examine how well the BRT in Bangkok could perform. The details of the service quality of the BRT was detailed in the following sub-sections.

5.1.1 BRT Service's Availability

The accessibility of BRT service is considered as an important factor under the hours of providing service. This could affect directly to the decision of using public transit such as BRT. With this regard, Bangkok BRT's service hour was examined in this study. According to the data from BMA's report (KT, 2017), it revealed that

Bangkok BRT operates 18 hours per day both weekdays and weekends from 6:00 to 24:00. There were 9 periods of time on weekdays and 2 periods of time on weekends which providing service at different frequencies as shown in Table 5.1.

Table 5.1 Time Period and Frequency of BRT Service on Weekdays and Weekends

Weekdays			Weekends		
Time	Frequency	LOS	Time	Frequency	LOS
06:00-07:00	10 minutes	B	06:00-21:00	15 minutes	C
07:00-09:00	5 minutes	A	21:00-24:00	20 minutes	C
09:00-09:30	10 minutes	B			
09:30-16:00	15 minutes	C			
16:00-17:00	10 minutes	B			
17:00-20:00	5 minutes	A			
20:00-21:00	10 minutes	B			
21:00-22:00	15 minutes	C			
22:00-24:00	20 minutes	C			

This made Bangkok BRT in accordance with the threshold of “LOS B” which the hour of service was under or equal to 18 hours a day according to the HCM (2000). It implied that Bangkok BRT could provide the service to passengers from early morning to late evening sufficiently.

With regards to the frequencies of BRT service provided to passengers, the results in Table 5.1 indicated that the BRT’s service frequencies were set to provide the service from “LOS A” to “LOS C”. However, the “LOS A” is provided in only the peak hours both morning peaks (07:00-09:00) and evening peaks (17:00-20:00). This means that schedules are not needed for passengers during the rush hours by receiving “LOS A”. While “LOS B” is provided prior to the peak hours from 06:00-07:00 and 16:00-17:00 in the morning and evening; after the peak hours from 09:00-09:30 and 20:00-21:00 in the morning and evening. This can make the passengers think and consult about the schedules of the service’s frequency. Whereas the rest of periods of time rely on the “LOS C” which are from 09:30-16:00, 21:00-22:00, and 22:00-24:00. When considering the duration of providing service by BRT, we could see that passengers can receive “LOS A” 5 hours/day, “LOS B” 3.5 hours/day and “LOS C” 9.5 hours/day. It obviously shows that most period of times that Bangkok BRT provides service to passengers are under the “LOS C”. With the “LOS C”, it reveals that the maximum

time of waiting for the BRT and still be in the range of considering to have a risk to be unattractive for users especially among the choice riders.

5.1.2 Bangkok BRT Travel Time

BRT's travel time was examined and revealed that Bangkok BRT spent longer time than those of automobiles in the traffic for most of the time. This was resulted from the comparison of average travel time between BRT and car in the morning and evening rush hours as shown in Figure 5.1. The result of outbound (from Sathorn to Ratchapruet terminal station) in the morning shows that BRT spends longer time than automobile by approximately 33.1% or around 12 minutes. Yet, the result of inbound (from Ratchapruet to Sathorn terminal station) in morning shows that BRT spends shorter time than car approximately 44.4% or equivalent to 22 minutes. From the morning results, it obviously indicates that BRT can travel faster than the car for the inbound direction. This happens because the lane of BRT is reserved to be only bus lane at the most congested road sections so that BRT can move faster there. But BRT still spends almost similar or slightly longer travel time at the non-reserved lane to cars.

Thus, the evening results show that BRT spends longer time in both outbound and inbound direction by approximately 29.2% or 12 minutes and 7.7% or 3 minutes, respectively. As a matter of fact, BRT spends longer time where it shares its lane in the congested traffic. And, the congestion happens along the outbound corridor rather than inbound direction. If compared the inbound direction case between BRT and car, it implies that BRT in the evening can travel 0.7% faster than BRT in the morning and car in the evening can travel 2.2 times faster than the car in the morning. In short, BRT seems to spend longer time for most of the time due to the operational constraints.

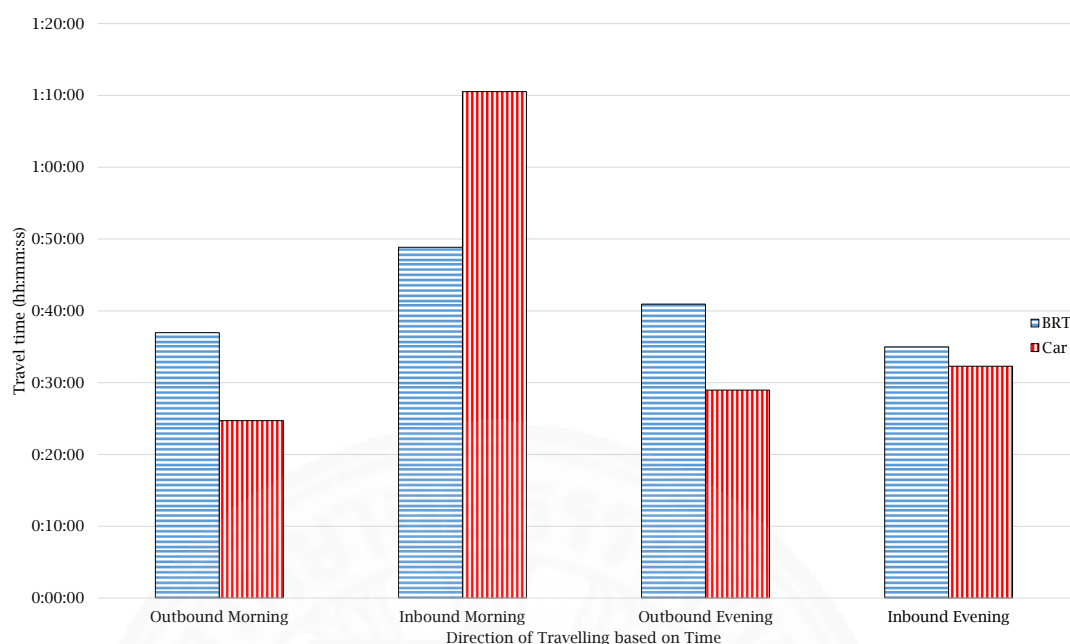


Figure 5.1 A Comparison of Average Travel Time between BRT and Car

When comparing the results of Bangkok BRT travel time to the transit quality of service guideline of TCQSM (2003), most of the cases were under the “LOS B” as shown in Table 5.2. From the results, BRT could gain “LOS A” solely in one case that BRT traveled back from Ratchapruuek terminal station to Sathorn terminal station. Therefore, the travel times between BRT and automobiles were considered to be comparable, but the BRT spent slightly longer time than automobiles. This occurred because BRT operated in the mix traffic condition and some loss times from traffic lights causing the BRT could not operate at its desired speed.

Table 5.2 Level of Service of Bangkok BRT/Automobile Travel Time

	Mode	Average time	Difference of time (mm:ss)	LOS
Travel time in morning of outbound direction	BRT	0:36:57	- 12:14	B
	Auto	0:24:43		
Travel time in morning of inbound direction	BRT	0:48:51	+ 21:41	A
	Auto	1:10:32		
Travel time in evening of outbound direction	BRT	0:40:57	- 11:59	B
	Auto	0:28:58		
Travel time in evening of inbound direction	BRT	0:34:59	- 02:41	B
	Auto	0:32:18		

5.2 Assessment of Travel Characteristics of Bangkok Bus BRT's Users

Characteristics and attitude of the BRT users in Bangkok are important to explore and examine the insights of the users on how they feel, satisfy and expect with the service. Thus, the characteristics and attitudes in this study were analyzed by the data collected from survey questionnaires. With regards to the results analyzed from the collected questionnaires, demographic profiles were first examined to the overview aspects of the samples. Secondly, the travel characteristics of BRT users were assessed to identify the travel patterns, purposes, cost and time. Lastly, the attitudes of BRT users regarding the service of BRT were evaluated on the expectation level, satisfaction level, level of service and improvement level.

5.2.1 Questionnaire Survey Description

The questionnaire survey was conducted in Bangkok from 13th to 28th February 2019. In this survey process, the respondents both in BRT stations and in buses was randomly chosen to complete the questionnaire survey. Of these questionnaires asked, the total number of respondents from the data collection process was 311, of which 350 respondents. As the total number of usable sample, it was in accordance with the recommended ranged of 200-500 samples for conducting disaggregate model analysis (Richards & Ben-Akiva, 1975). According to the recommendation as the rule of thumb by Hair et al. (2010), it suggests that the sample size to be analyzed for factor analysis should not be fewer than 50 observations or 100 observations are considered as the preferable size of sample. Another addressing in the rule of thumb is that the number of observations should be at least five times of the number of variables. Hence, the valid 88.8% set of data was considered satisfactory and used for the further analysis. The high rate of usability of received questionnaires came from two major facts. Firstly, all surveyors were trained before asking respondents on site. Secondly, the participation from the users were very active and ready to provide their information (Ayutthaya, 2011; Roaj-assawachai, 2013; Yongyat, 2013). The details of the respondents' demographic profiles are discussed in the following sections.

5.2.2 Demographic Profile of the Respondents

The information provided by the respondents was examined to determine the adequacy of the sample in order to be a representative of the whole population of the BRT users. This study comprehensively classified the respondents' profile into seven categories including gender, age, occupation, income, education background, and vehicle ownership. The undertaken demographic profiles were detailed in the following section.

5.2.2.1 Gender

The majority of gender among the respondents was female which the percentage of female was 61.1% as shown in Figure 5.2. While the percentage of male respondents was 38.9% which less than the female's percentage, taken as a whole. When taking the ratio of female to male (F/M) of the respondents into account, it obviously indicated that the F/M ratio was 1.57 which slightly greater than the F/M ratio of the Bangkok population of 1.12 in 2018 (BORA, 2018). This implied that female produced more travel than male by using BRT, which was in accordance with the previous studies in Thailand (Ayutthaya, 2011; Roaj-assawachai, 2013; Yongyat, 2013).

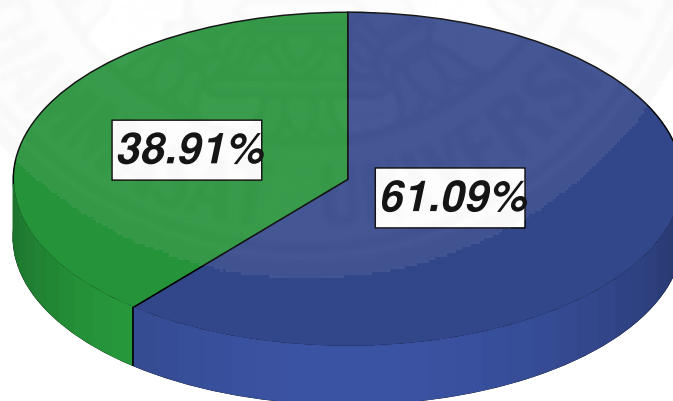


Figure 5.2 Gender of Total Respondent

5.2.2.2 Age Group

Ages of the respondents in this study were categorized into six groups including the age under 15 years, 15 to 19 years, 20 to 30 years, 31 to 40 years, 41 to 50 years, and over 50 years as shown in percentage in Figure 5.3. From the empirical analysis

results, the age between 20 and 30 years (48.87%) has the greatest proportion, followed by age between 31 and 40 years (22.51%), between 41 and 50 years (16.08%), between 15 and 19 years (7.40%), and minors groups were over 50 years (4.82%) and under 15 years (0.32%). The results obviously implied that the great majority of age range was grouped for the working age from junior working age group (20-30 years) to senior working ages (31-40 years) and (41-50 years) with 87.5% of overall percentage.

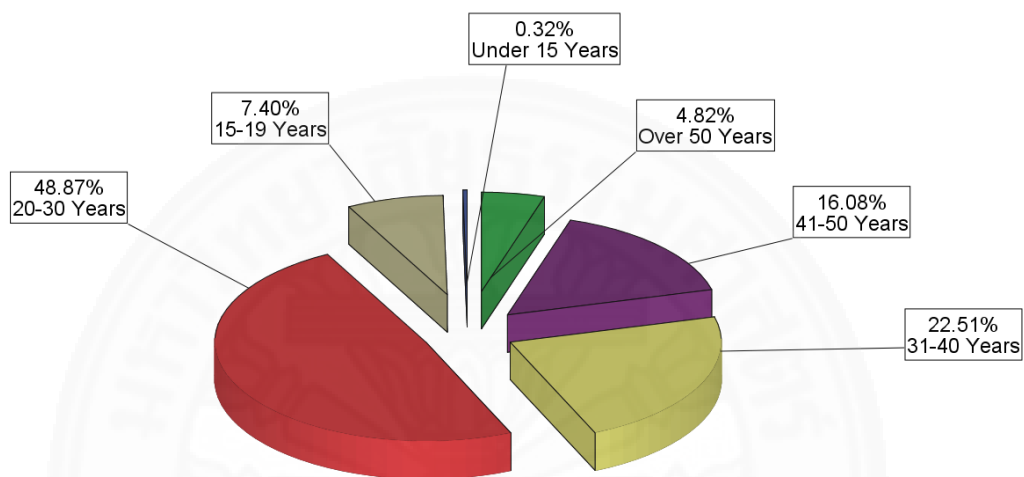


Figure 5.3 Age Range of the Respondents

5.2.2.3 Occupation

Taken as a whole, the occupation result showed that the dominant career among the respondents was private company employee (61.7%), followed by student (23.1%), and other (15.1%) including business owner, government officer, vendor and other as shown in Figure 5.4. Taking career of private company employee and students as high percentage group into consideration, it was because there are vast amount of offices and schools along the BRT trunk line.

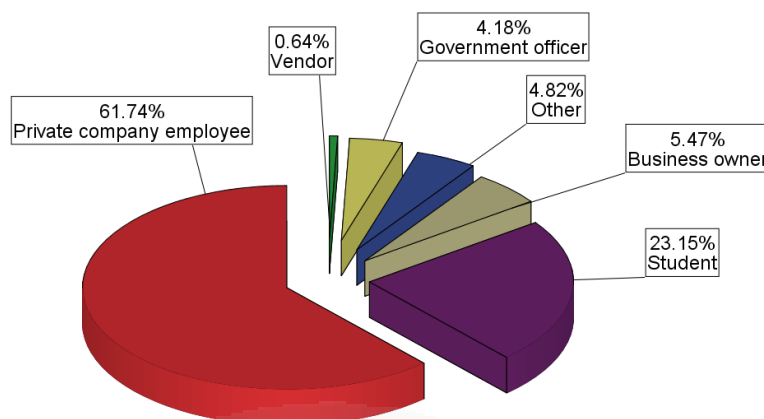


Figure 5.4 Personal Occupation of Respondents

5.2.2.4 Income

Personal income was classified into eight groups ranging from less than 10,000 Baht/month, 10,000-15,000 Baht/month, 15,000-20,000 Baht/month, 20,000-25,000 Baht/month, 25,000-30,000 Baht/month, 30,000-35,000 Baht/month, 35,000-40,000 Baht/month and more than 40,000 Baht/month as shown in Figure 5.5. The results from analysis showed that respondents who had the income under 10,000 Baht/month and over 40,000 Baht/month were the great majority among other by 20.90% and 19.29%, respectively. The result of income was assumed to be real monthly income; however, the real income may be slightly different due to bonuses, overtime working or reimbursements especially for the non-captive users.

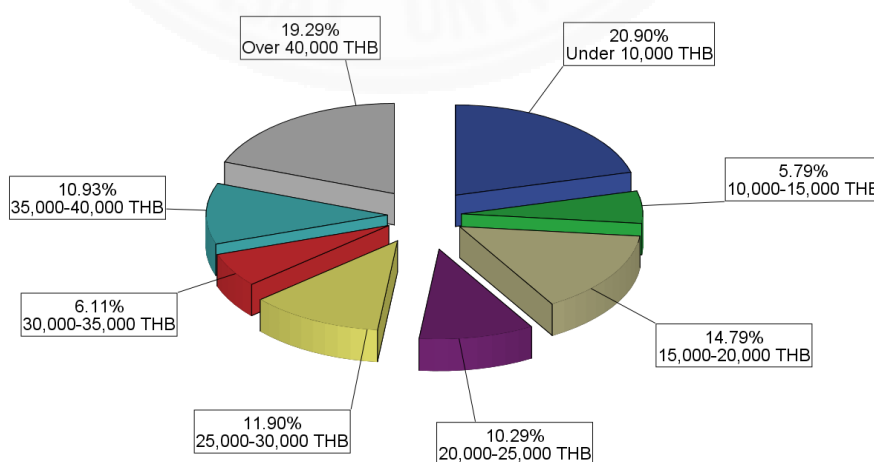


Figure 5.5 Income of Respondents

Note: THB is a currency of Thailand. 1 USD = 31.90 THB (April 2019)

5.2.2.5 Education Background

Of the total sampled BRT passengers, the education background was bachelor level, higher than bachelor level, secondary school and polytechnic level, and under secondary school level by 77.17%, 11.90%, 7.72%, and 3.22%, respectively as shown in Figure 5.6. This could imply that most of the BRT users were well educated group. This was in accordance with the fact of occupation that private company employee resulted highest among other careers.

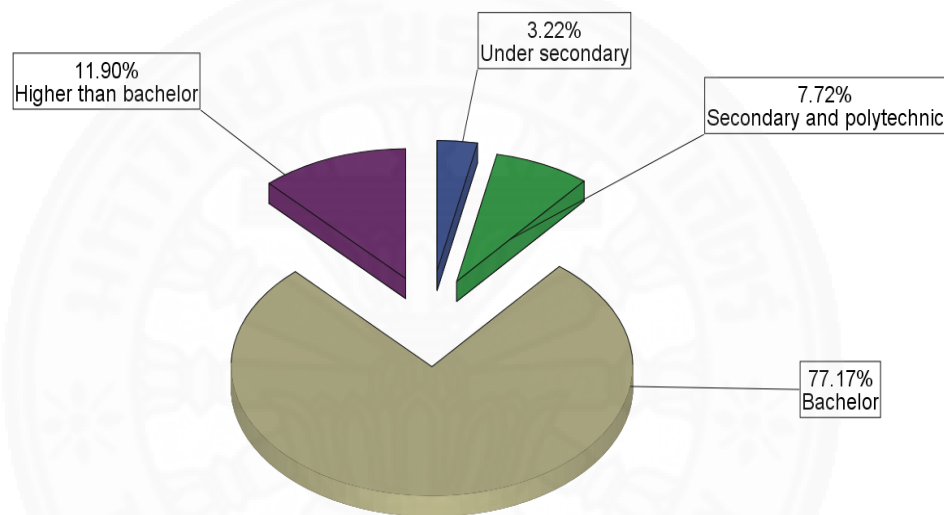


Figure 5.6 Education Background of Respondents

5.2.2.6 Vehicle Ownership

For the vehicle ownership result as shown in Figure 5.7, it indicated that most of the passengers were the captive users (those who are compulsory to use only public modes for their journey) by 48.55% and the rest were choice users (those who own their alternative private modes for their journey) including possessing car (36.33%), possessing motorcycle (9.65%), and possessing both car and motorcycle (5.47%). This result implied that the proportion of captive users and choice users were similar with a slight difference of 5.9%. However, the non-captive users had a greater proportion even they had their alternatives to ride, but they still preferred to use the BRT for their journey.

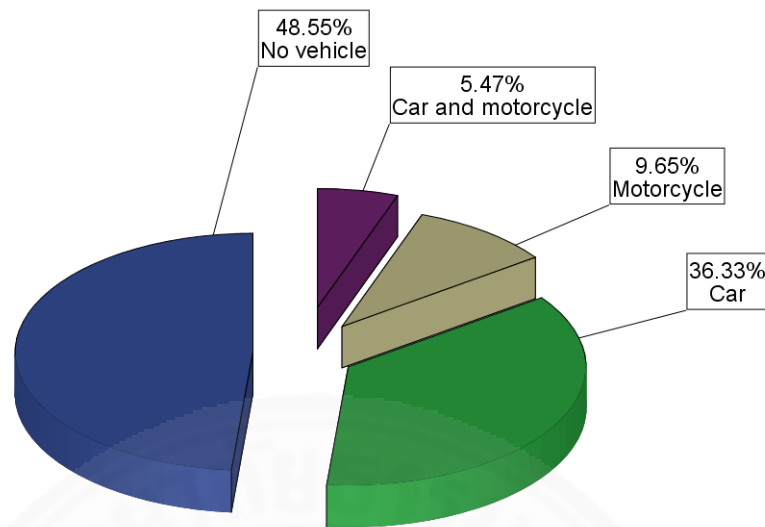


Figure 5.7 Vehicle Ownership of Respondents

In summary, the analyses of the demographic profiles returned that the samples used in this study were valid and could be as representative of the whole population. Therefore, all the collected data were ensured to be applied in the further analysis process.

5.2.3 Travel Characteristics of Bangkok Bus Rapid Transit's Users

5.2.3.1 Origin and Destination

Origin is a place where people start their trip, while destination is a place where people finish their trip. The context of origin and destination of the users was divided into two main trips which are 'ongoing trip' and 'return trip' as shown in Figure 5.8. Ongoing trip consists of the origin and destination that the BRT user first produced in their trip. The return trip consists of origin and destination that the BRT user later produced heading back to their first origin. Therefore, this study discovered where the BRT users in Bangkok start and complete their trip in both ongoing trip and return trip for the normal trip and additional trip. In addition, the departure time from origin and arrival time to destination were also examined.

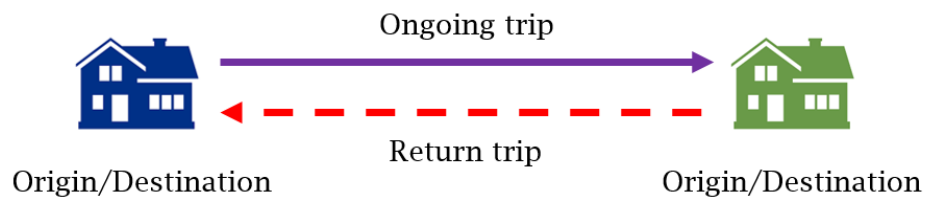


Figure 5.8 Ongoing and Return Trip

According to the findings of this study, the origin in ongoing trip of the BRT users was 97.4% generated from their home (living place) as shown in Figure 5.9. It implied that the users came to use BRT not from various places. Whereas, the BRT users trended to use BRT predominantly from 06:00 to 10:00 around 82% in the morning as shown in Figure 5.10. From the time series, it obviously showed that most of Bangkok BRT users left their origin in ongoing trip from 07:00-08:00 in the highest proportion approximately 33.1%. This time series was the time for go working or schooling. In which, it was consistent with the result of occupation of the respondents from the demographic profile which indicated that Bangkok BRT users mainly worked in the private company and being a student.

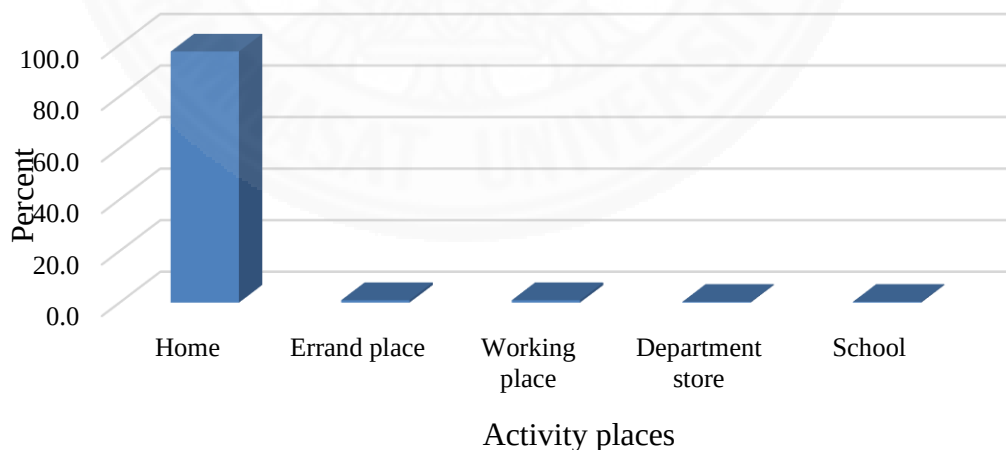


Figure 5.9 Origin in Ongoing Trip (Normal Trip)

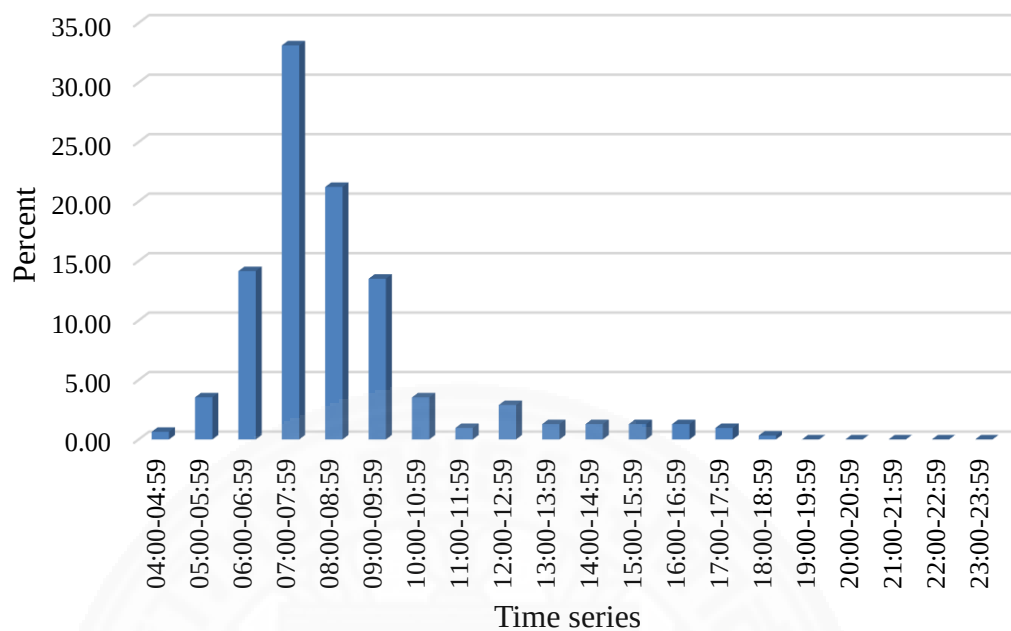


Figure 5.10 Times of Departing from Origin in Ongoing Trip (Normal Trip)

When considering the destination of the BRT users in ongoing trip, the finding as shown in Figure 5.11 resulted that their destination was relied to be working place 68.5%, followed by school 18.3%, errand place 8%, and the minor proportion of 5.2% was contributed to visiting department store, friend's or cousin's house, sport center and training place. In regard to the time series analysis, it resulted that most of the BRT users arrived at their destination from 8:00 to 09:00 as the predominant proportion of 29.9% in the morning as shown in Figure 5.12. Additionally, the BRT users arrived their destination from 07:00 to 11:00 around 81.7%. It could imply that their arrival time to destinations was considered as the time of working or schooling too.

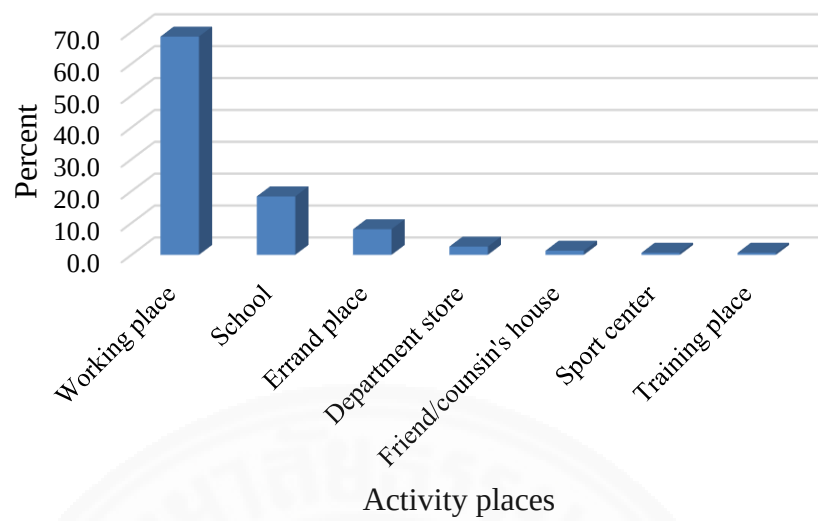


Figure 5.11 Destination in Ongoing Trip (Normal Trip)

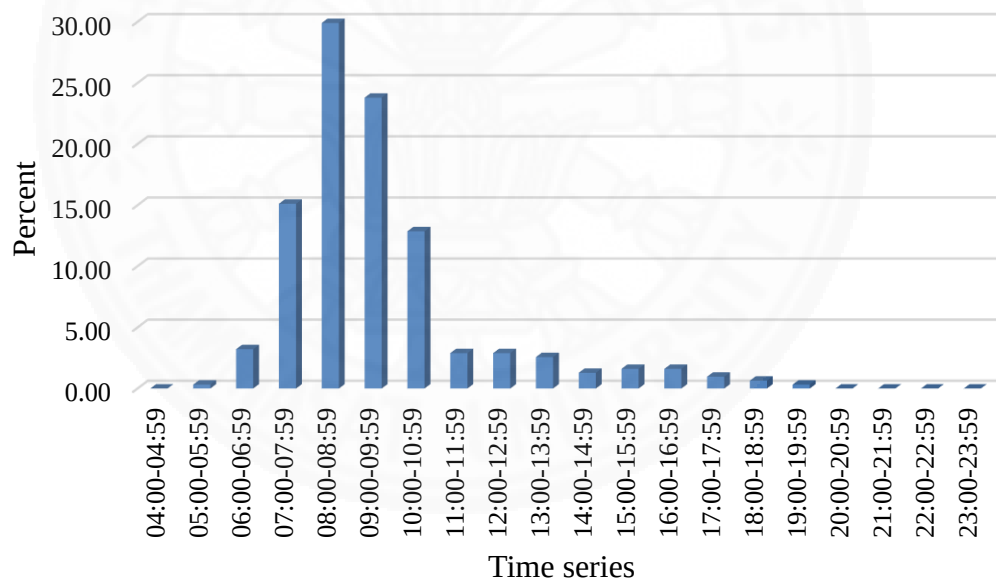


Figure 5.12 Times of Arriving Destination in Ongoing Trip (Normal Trip)

Whilst, most of the BRT users left their destination in the return trip at working place by 68.5% as shown in Figure 5.13. It followed by school, errand place, department store, friend's or cousin's house, sport center and training place by 18.3%, 8%, 2.6%, 1.3%, 0.6% and 0.6%, respectively. With the regards to the time series analysis, the

result revealed that the BRT users trended to leave from their origin in the return trip at 17:00 to 19:00 by approximately 50.2% which contributed as the huge proportion.

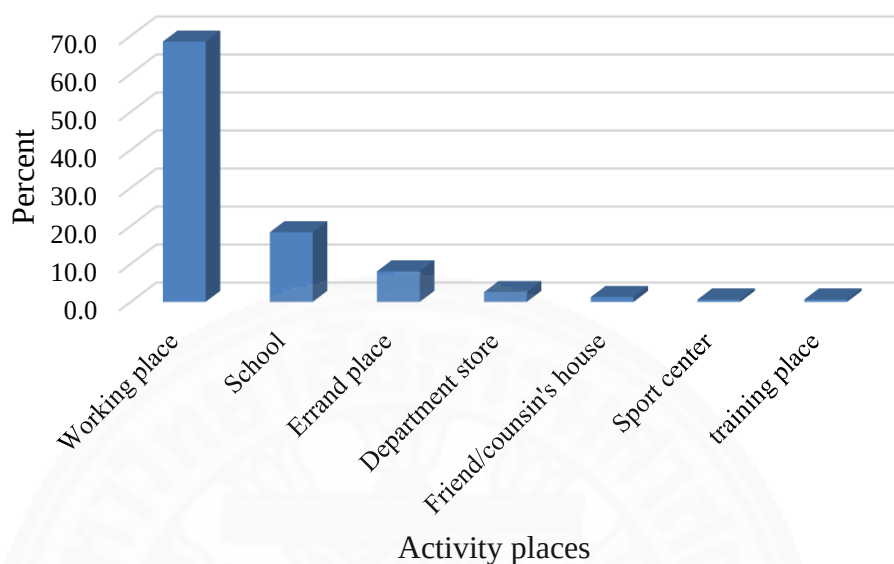


Figure 5.13 Origin in Return Trip (Normal Trip)

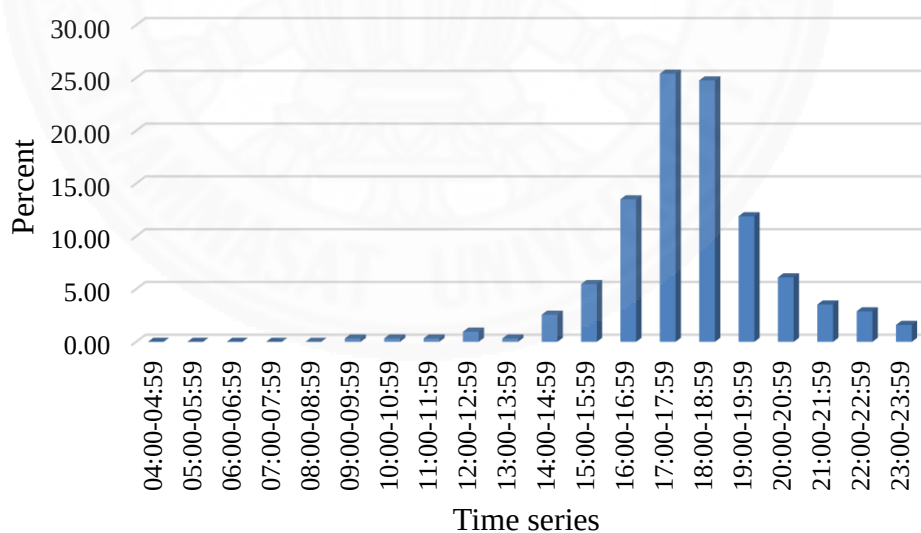


Figure 5.14 Times of Departing from Origin in Return Trip (Normal Trip)

Another result with respecting to the destination of the BRT users in return trip for normal trip was shown in Figure 5.15. It revealed that the users' destination was heading to their home with the predominant proportion of 97.7%. When considering

time of arriving destination in the return trip in normal situation, the result shown in Figure 5.16 found that 74.9% of the BRT users arrived their destination from 17:00 to 21:00 in the evening. Also, it revealed that the users dominantly arrived at their destination from 19:00-20:00 by 27.33%. This implied that the majority time of arriving destination was after working or schooling times.

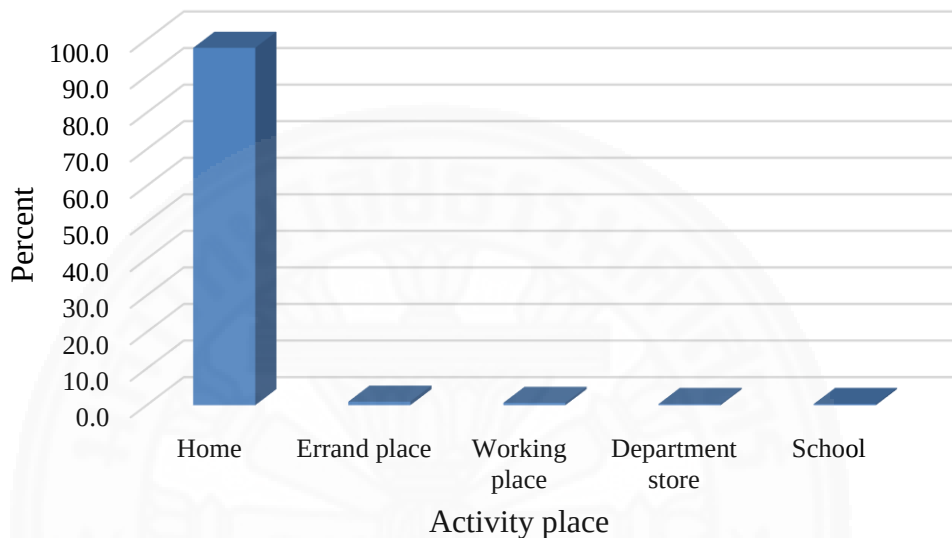


Figure 5.15 Destination in Return Trip (Normal Trip)

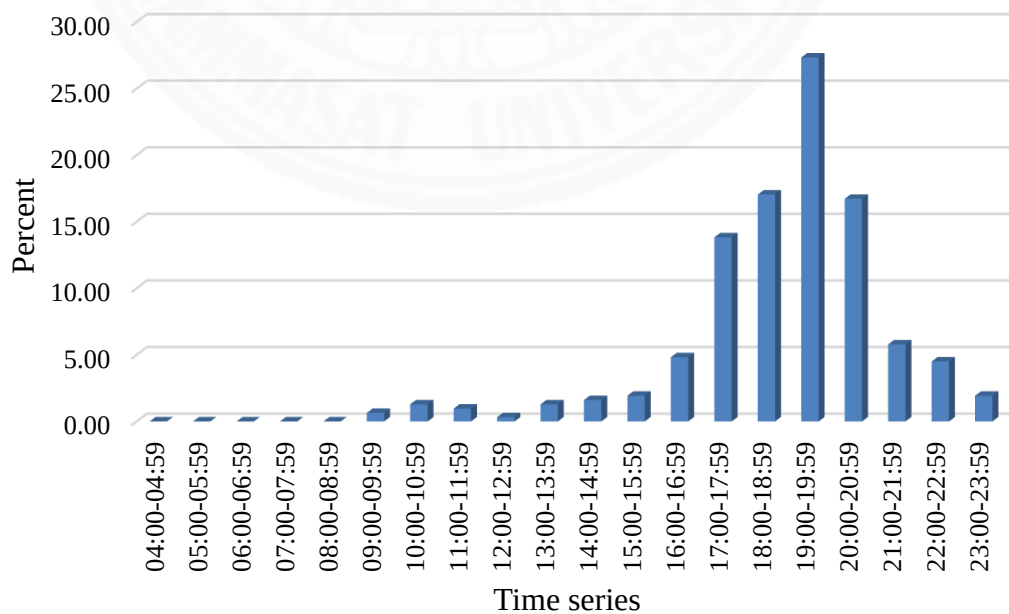


Figure 5.16 Times of Arriving Destination in Return Trip (Normal Trip)

In short, most of the BRT users started their ongoing trip from their home as their origin from 07:00-08:00 and ended their ongoing trip at working place and school from 08:00-09:00 in the morning for their normal trip. In contrast, the users left their origin as the working place in their return trip from 17:00-19:00 in the evening and arrived at their destination as their home from 19:00-20:00. From the finding both ongoing trip and return trip, it confirmed that most of the BRT users produced their journey mainly for traveling to work and school, in which the other trips were considered as a minor case.

Moreover, this study was also studied about the additional trips that the BRT users created. The result found that about 34.1% (106 respondents) of the whole respondents produced their additional trip which differed from their normal trips. According to the result as shown in Figure 5.17, it showed that the BRT users created their additional trips on weekends rather than weekdays by 81.1% and 18.9%, respectively. This meant that Bangkok BRT was attracted to their additional trips during the weekends. As a matter of fact, the background of the users were mainly the private company employees which they have to work during weekdays so that the additional trips were likely to happen on weekends.

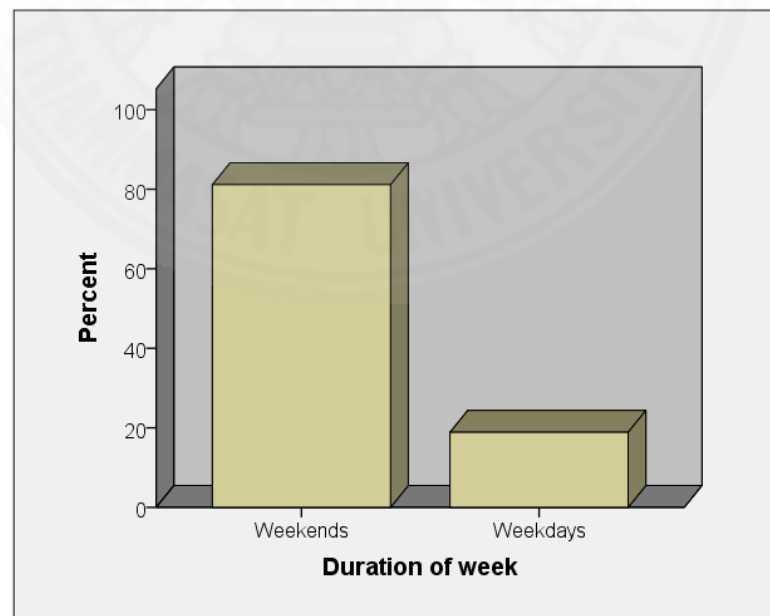


Figure 5.17 Additional Trip Duration

Whereas, the origin and destination in ongoing trip for their additional trip were also examined as shown in Figure 5.18 and Figure 5.19. The analysis results found that 93.4% of the BRT users outstandingly departed their origin from home to various destinations – 55.6% to department store, 32.1% to visit friend's/cousin's house, 6.6% to errand place, 2.8% and 1.9% to sport center and temple, respectively. This could imply that the BRT users spent their additional trip to the department store as an outstanding case. Therefore, they also made the visit to their friends or cousins as their additional trip due to the fact that they mostly produced their trips to working place rather than other trips in their normal trips.

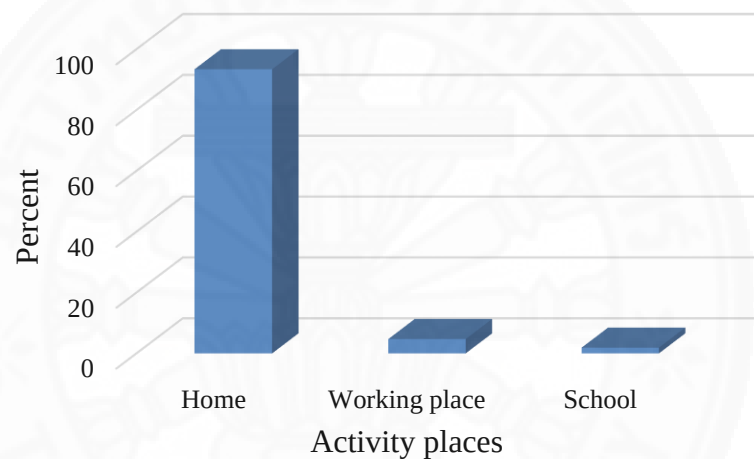


Figure 5.18 Origin in Ongoing Trip (Additional Trip)

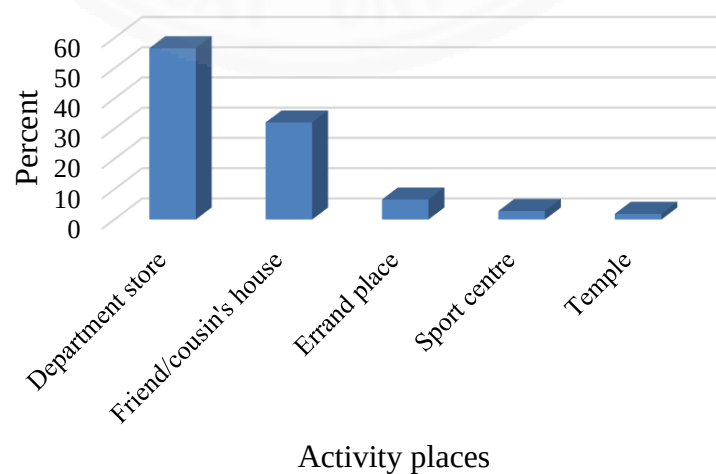


Figure 5.19 Destination in Ongoing Trip (Additional Trip)

Respecting to time of departing from origin and arriving destination in ongoing trip for the additional trip as shown in Figure 5.20 and Figure 5.21, this study found that most of the BRT users had different times of departing from their origin. The users dominantly departed from their origin from 09:00-15:00 and they arrived their destination around the same period of time from 09:00-15:00 by 78.3%. This implied that the BRT users trended to produce their trips in the late morning to afternoon time rather than travelling in the night times for the additional trips.

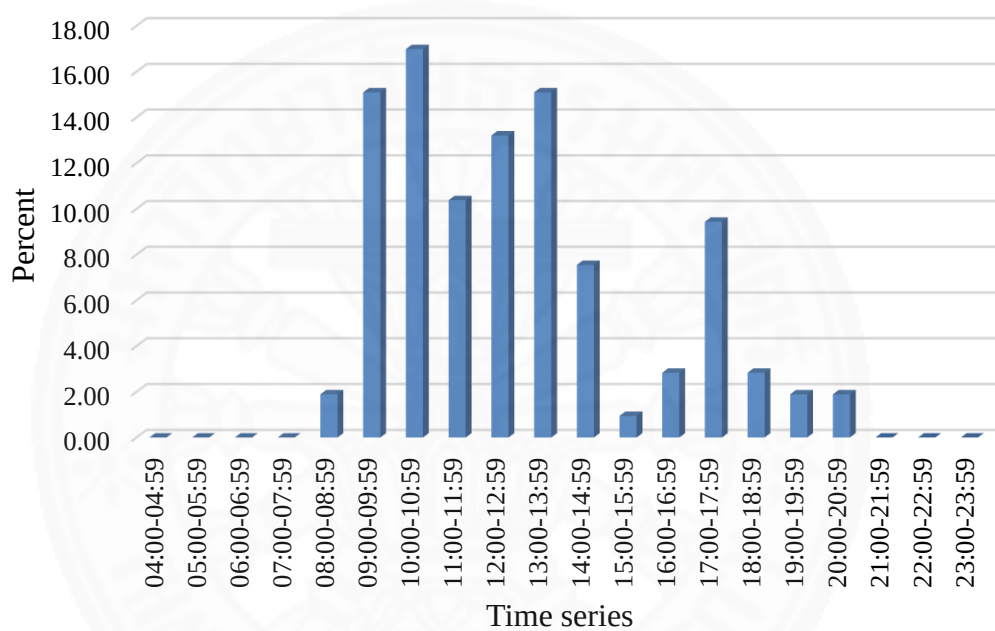


Figure 5.20 Times of Departing from Origin in Ongoing Trip (Additional Trip)

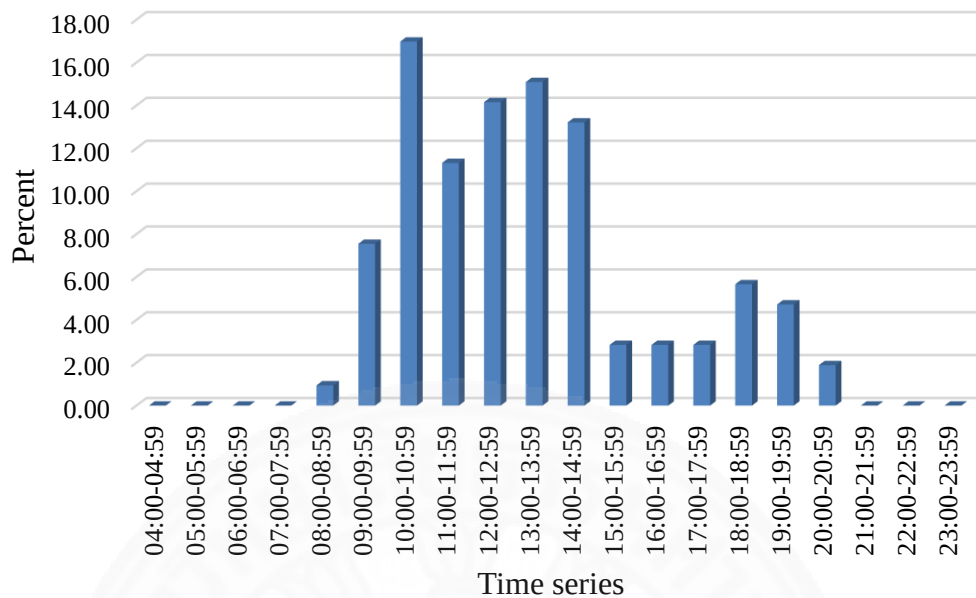


Figure 5.21 Times of Arriving Destination in Ongoing Trip (Additional Trip)

In the similar way of the trip in return of the BRT users, the results as shown in Figure 5.22 and Figure 5.23 revealed that the BRT users made their journey in contrast to the ongoing trips. In which, they predominantly left their origin in return trip at department store by 55.6% and headed back to their destination as their home by 96.2%.

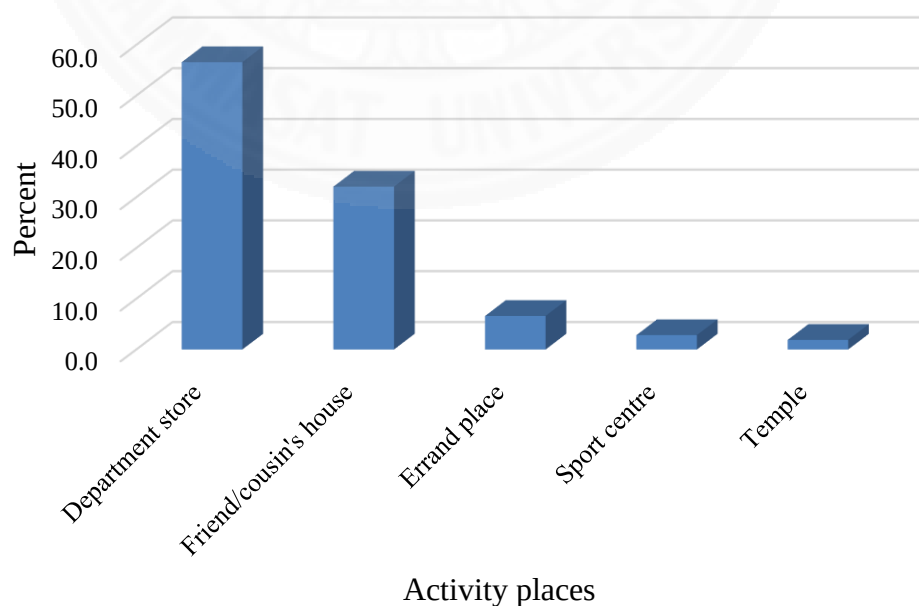


Figure 5.22 Origin in Return Trip (Additional Trip)

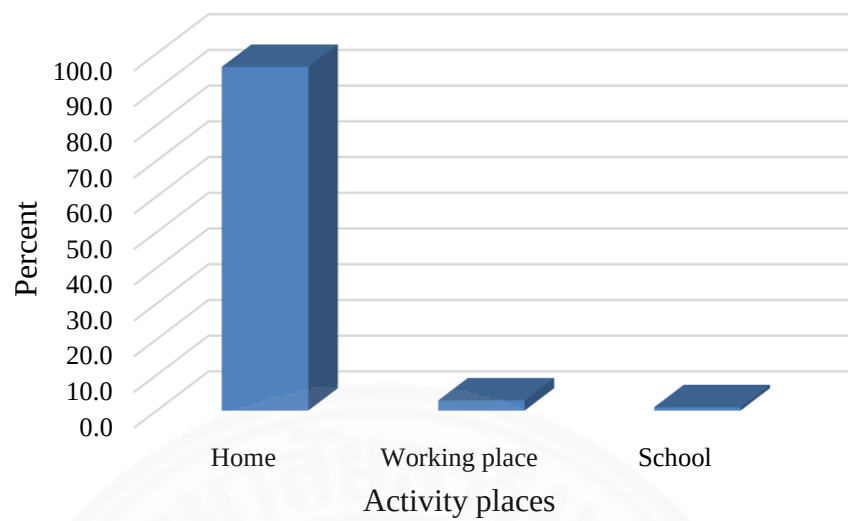


Figure 5.23 Destination in Return Trip (Additional Trip)

However, the BRT users started to leave their origin in return trip for the additional trip from 16:00-21:00 approximately 81.1% but the dominant time of departing from origin was from 19:00-20:00 by 22.6% as shown in Figure 5.24. In regards to the arrival time of the BRT users in return trip as shown in Figure 5.25, it resulted that they arrived their destination which mainly their home from 16:00-22:00 by 84.9% with the highest proportion of 28.3% for departing from 19:00-20:00. This revealed that the BRT users were likely to depart from their origin and arrive their destination in the late evening for the additional return trip.

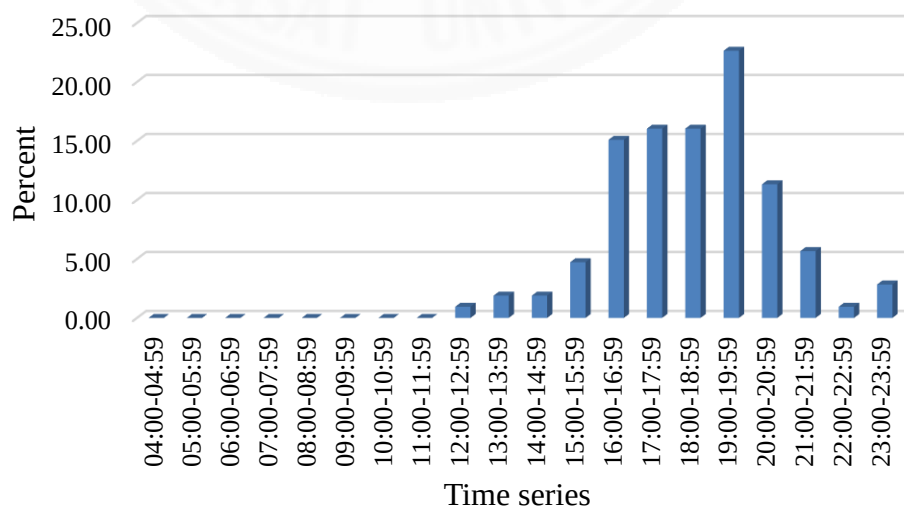


Figure 5.24 Times of Departing from Origin in Return Trip (Additional Trip)

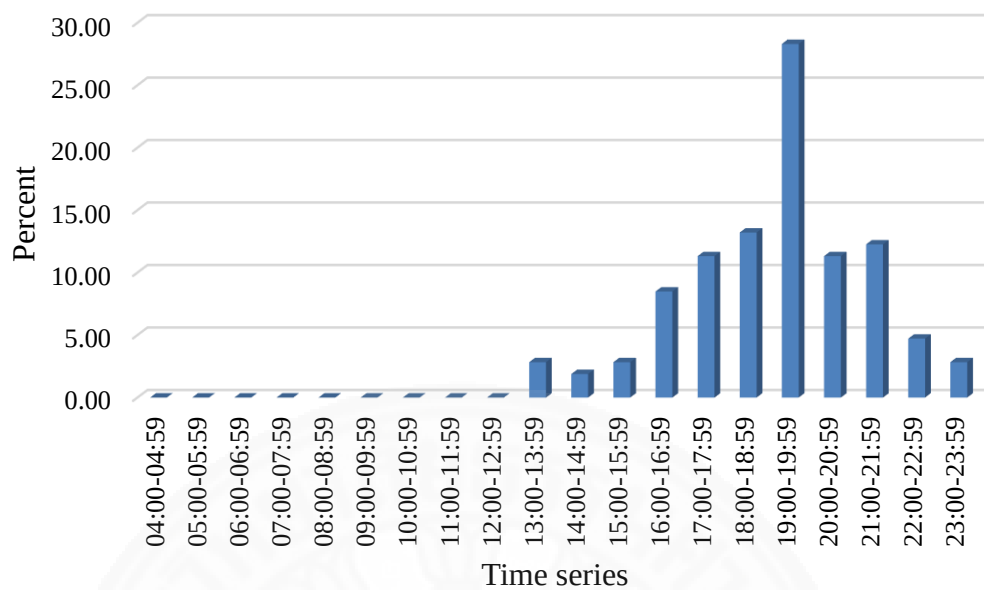


Figure 5.25 Times of Arriving Destination in Return Trip (Additional Trip)

In short, the BRT users were likely to make their additional trip on weekends. Most of them left their origin to destination by departing from their home to department store in the ongoing trip and vice versa in the return trip for their additional trip. For the ongoing trip, the users started and completed their journey outstandingly within 10:00-11:00 in the morning. However, from 19:00-20:00 was the time period that most of the BRT users traveled in their return trips.

5.2.3.2 Travel Purpose

The BRT users traveled with several of purposes as shown in Figure 5.26, including working (68.17%) as predominant purpose, school (18.33%), personal business (7.07%), shopping (2.57%), meeting friends (1.61%), and other (2.25%). From this empirical finding, it obviously confirmed that most of the BRT users' journey was for working rather than other purposes.

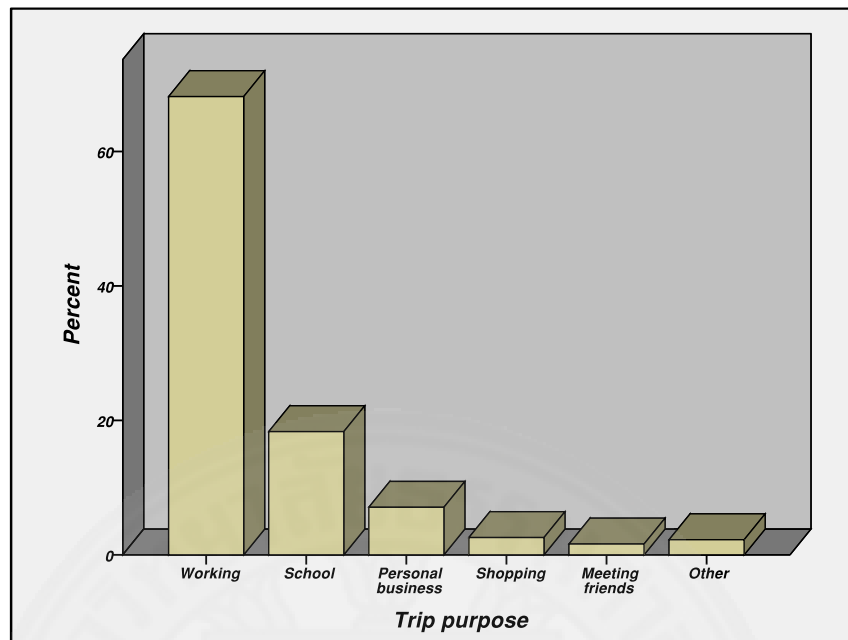


Figure 5.26 Trip Purpose of the Respondents

When taken the travel purposes of the respondents in their additional trips into account, it found that 53.8% of the BRT users (34.1% of whole respondents) created their purpose mainly to shopping as the predominant case as shown in Figure 5.27. It followed by 32.1% of meeting friends or cousins, 6.6% of personal business and other (7.5%) including going to sport center, temple and so on.

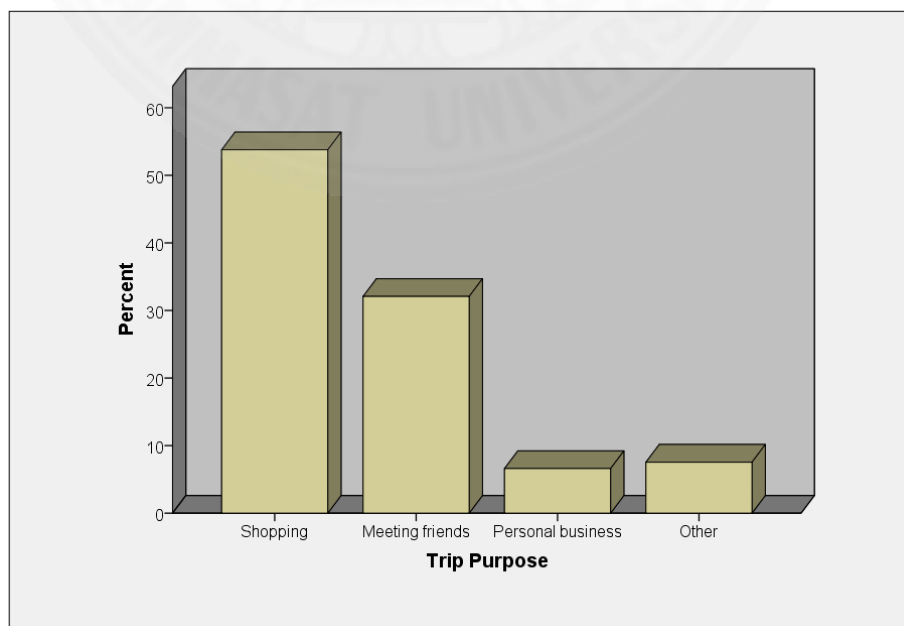


Figure 5.27 Additional Trip Purpose

5.2.3.3 Trip Generation

Another evidence was from the result of trip generation among the respondents as shown in Figure 5.28. The result affirmed that home-based work trip resulted predominantly (67.85%), followed by home-based school trip (18.33%), home-based social-recreational trip (6.43%), home-based shopping trip (2.25%), home-based other trips (1.29%), and non-home-based trip (2.25%). This implied that the BRT had a great interest to the users who traveled for working. The possible reason to explain this is that the BRT located in the serious congested area but it has its own segregated lane which makes its travel faster than the other modes in term of speed and time. Also, the BRT provides the service along the business and education zone which is only the fastest alternative way in the area to reach their destinations, especially working place, on time.

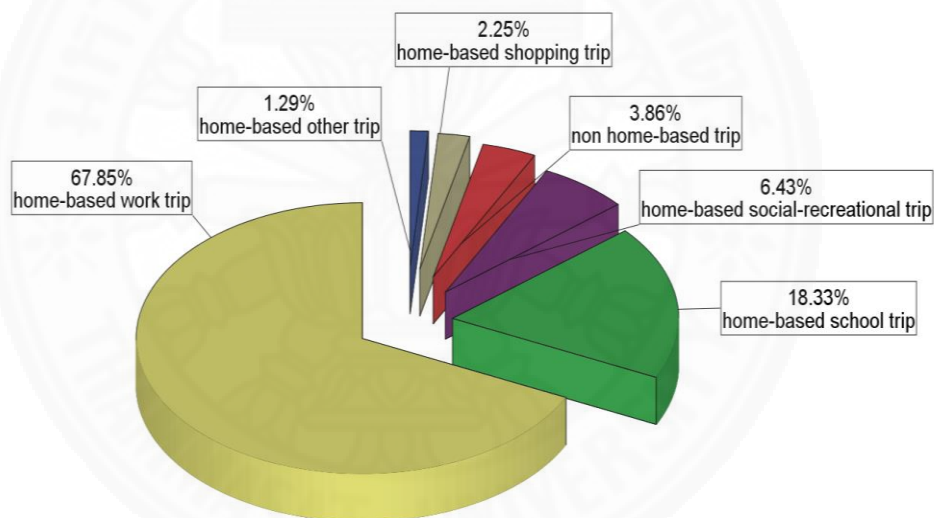


Figure 5.28 Trip Generation of the Respondents

5.2.3.4 Frequency Use of BRT

The frequency result as shown in Figure 5.29 was another indicator which implied that most of the regular BRT users traveled in the weekday or working days rather than other occasions due to the special characteristics of the nearby-station area (business and education zone). It resulted that they made their journey 6-10 times per week by 63.0%, as the greatest proportion, of which 87.78% of respondents. This strongly helped confirming that those who used BRT were for working trip. However,

there were the irregular users (12.22%) who also created their trip less than 2 times per month (42.11%), 3-5 times per month (34.21%) and 6-10 times per month (23.68%).

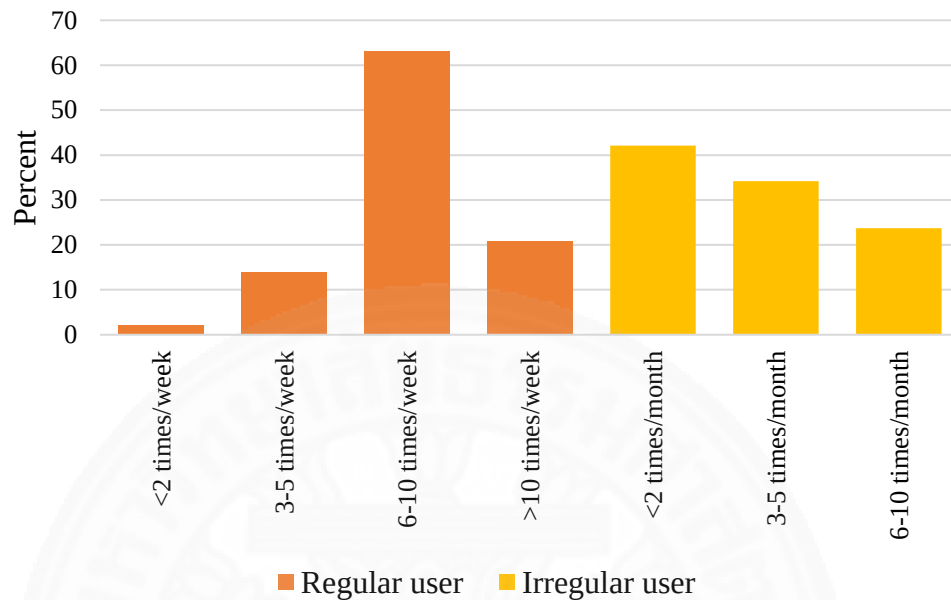


Figure 5.29 Frequency of Regular and Irregular Users Using the BRT

5.2.3.5 Travel Mode, Travel Time and Travel Cost

The access and egress in this study were defined into four attributes under the ongoing trip and return trip as shown in Figure 5.30. The access is defined to be “access in ongoing trip” which refers to trips generating from origin to terminal A; and “access in return trip” which refers to trips generating from destination to terminal B. In contrast, egress is defined to be “egress in ongoing trip” which regards to trips exiting from terminal B to destination; “egress in return trip” which respects to trips departing from terminal A to destination. The four attributes were applied to examine the travel modes of the BRT users generated during regular trips and additional trips with also regards to the times and costs of each mode.

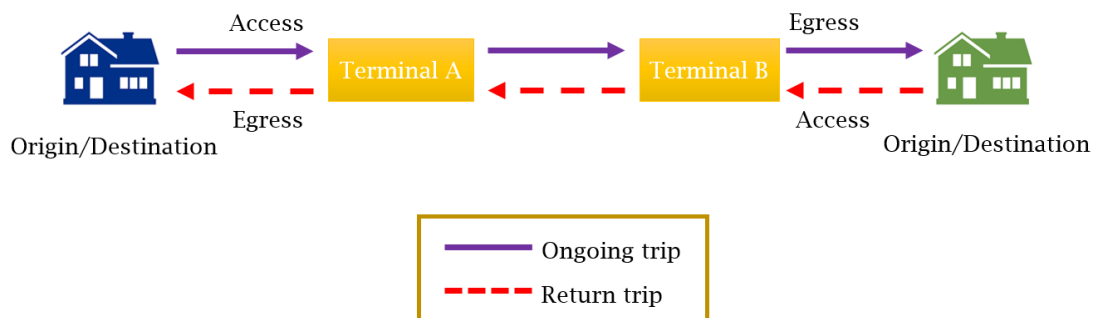


Figure 5.30 Access and Egress from/to Origin/Destination in Ongoing and Return Trip

The modes of traveling of the BRT users created were uncovered by regarding 3 aspects which were access mode, transit mode and egress mode. The results were based on the patterns of how they made their journey's modes in "ongoing trip" and "return trip". According to the analysis results as shown in Figure 5.31, it revealed that approximately 96.5% of the whole respondents made their ongoing trip by using the BRT. Hence, 60% of the BRT users access the stations by the mode of walking as the predominant mode among other modes in their ongoing trip. This could imply that the BRT stations are located in the area where the users resided around causing the users chose to walk to access the stations rather than other modes. However, the mode of motorcycle taxi (22%) and using the private car (10%) contributed in a huge proportion accounting 92% when considering as the affected modes of access for the ongoing trip. While bicycle (1%) mode to access the BRT stations were not popular among the users in Bangkok due to lack of park and ride area provided. Even though the vast amount of proportion of access mode for the ongoing trip was from the aforementioned modes (walking, motorcycle taxi, car), the results shown that some of the BRT users accessed the stations with not only one mode but they accessed with the combination mode such as a combination of walking and taxi-bus (1.3%), a combination of motorcycle taxi and boat (0.3%), a combination of taxi-bus and motorcycle taxi (0.3%), a combination of walking and boat (0.3%), and a combination of walking and motorcycle (0.3%).

In light of this corner, solely 34% of the ongoing trip users used BRT as the direct mode or only mode from their origin to their destination. In which, 66% of the ongoing users used a combination mode called "multimodal transportation mode". The

most popular multimodal transportation mode was the combination of BRT and BTS by 21.3%. This implied that the BRT was not able to serve the users to arrive their destination directly from their origin causing some users had to take one more transit mode after using BRT. As well as a combination between BTS and BRT was in the third place of interest of the BRT users by 14.3%. This revealed that the users who used this mode could not get the BRT service from their origin in order to reach their destination under that fact that they needed to take another transit mode like BTS prior to using BRT. Moreover, 10.7% of the users in the ongoing trip used a combination of three modes which they first used the bus and connected with BTS as the second mode prior to getting the BRT service. It also followed by the other multimodal transportation modes such as a combination of van, BTS and BRT (4.7%), BRT, BTS and bus (3.7%), BRT and Bus (3%), MRT, BTS and BRT (2%), BRT, BTS, and MRT (1.3%) and other minor combinations. As a matter of fact, from the result, it revealed the BRT users had the necessity to use BRT even the origin of the BRT users was not closed to get the BRT service. It also indicated that the BRT service was not yet able to get the interest by one mode of travel.

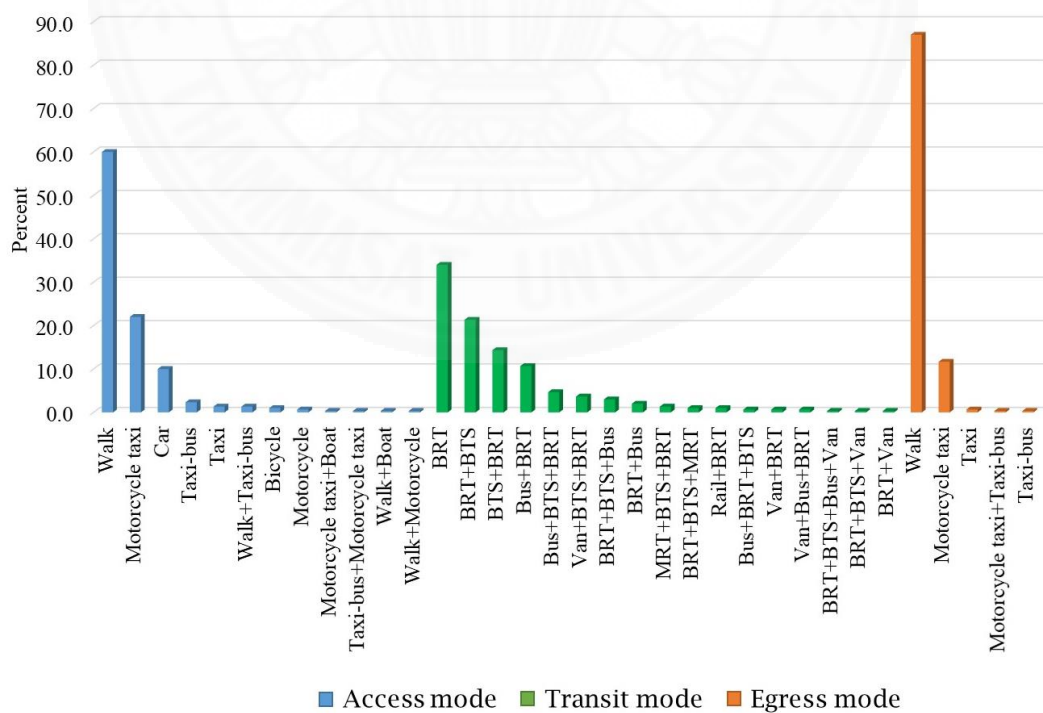


Figure 5.31 Access, Transit and Egress Mode of Ongoing Trip

Additionally, 87% of the BRT users were likely to use walking mode as their egress mode from the BRT stations to reach their destination for their ongoing trip. This could imply that their destination was closed to the stations after getting off from the transit mode or another word is that their destination was in the range of preferable distance to walk. It followed by 11.7% of the users used motorcycle taxi to get to their destination, and other modes contributed as a minor proportion of egress mode.

Table 5.3 detailed the time and cost used for each mode of travel from their origin to their destination for the ongoing trip. It showed that the major mode of access and mode of egress contributed to each mode of transit, in which walking mode was the major proportion.

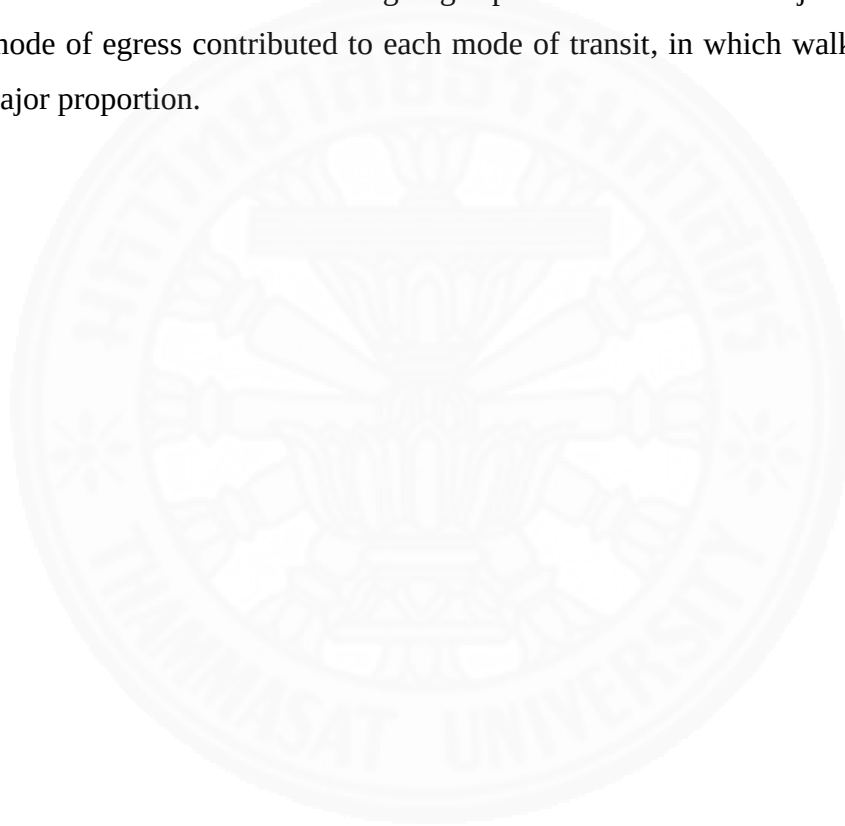


Table 5.3 Mode, Time and Cost of Ongoing Trip

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
1	BRT (32.80%)	Walk	Walk	40.54	15.00	20.26	63
		Motorcycle taxi	Walk	35.93	33.93	4.50	14
		Walk	Motorcycle taxi	43.83	34.17	1.93	6
		Motorcycle taxi	Motorcycle taxi	47.00	50.00	1.61	5
		Car	Walk	63.00	95.00	1.29	4
		Car	Motorcycle taxi	69.25	90.00	1.29	4
		Taxi	Walk	62.50	100.00	0.64	2
		Walk+Taxi-bus	Walk	23.00	23.00	0.32	1
		Taxi-bus	Motorcycle taxi	75.00	37.00	0.32	1
		Bicycle	Walk	38.00	15.00	0.32	1
		Motorcycle taxi+Boat	Walk	85.00	21.50	0.32	1
2	BRT+BTS (20.58%)	Walk	walk	52.57	58.56	11.25	35
		Motorcycle taxi	Walk	51.21	60.36	4.50	14
		Car	Walk	50.86	78.86	2.25	7
		Walk	Motorcycle taxi	77.00	87.75	1.29	4
		Motorcycle taxi	Motorcycle taxi	60.00	67.50	0.64	2
		Walk	Taxi-bus	40.00	60.00	0.32	1
		Walk	Taxi	140.00	147.00	0.32	1
3	BTS+BRT (13.83%)	Walk	Walk	56.38	43.25	5.14	16

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
3	BTS+BRT (13.83%)	Car	Walk	96.63	118.00	2.57	8
		Motorcycle taxi	Walk	75.57	72.86	2.25	7
		Motorcycle taxi	Motorcycle taxi	46.50	75.00	0.64	2
		Car	Motorcycle taxi	77.50	130.50	0.64	2
		Walk	Motorcycle taxi	50.00	46.00	0.32	1
		Walk+Taxi-bus	Walk	85.00	51.00	0.32	1
		Walk+Boat	Walk	102.00	50.00	0.32	1
		Taxi-bus	Walk	72.00	75.00	0.32	1
		Walk+Motorcycle	Walk	115.00	94.00	0.32	1
		Bicycle	Walk	67.00	60.00	0.32	1
		Motorcycle	Motorcycle taxi	70.00	70.00	0.32	1
		Taxi	Motorcycle taxi	50.00	115.00	0.32	1
4	Bus+BRT (10.29%)	Walk	Walk	76.90	24.88	6.43	20
		Taxi-bus	Walk	88.33	28.17	0.96	3
		Motorcycle taxi	Motorcycle taxi	73.67	63.50	0.96	3
		Walk+Taxi-bus	Walk	108.50	28.50	0.64	2
		Taxi-bus+Motorcycle taxi	Walk	90.00	53.50	0.32	1
		Walk	Motorcycle taxi	63.00	44.00	0.32	1
		Motorcycle taxi	Walk	80.00	47.00	0.32	1
		Car	Walk	157.00	61.50	0.32	1

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
5	Bus+BTS+BRT (4.50%)	Motorcycle taxi	Walk	107.00	66.25	1.93	6
		Walk	walk	77.80	62.50	1.61	5
		Bicycle	Walk	110.00	58.00	0.32	1
5	Bus+BTS+BRT (4.50%)	Car	Walk	60.00	49.00	0.32	1
		Car	Motorcycle taxi	110.00	114.00	0.32	1
6	Van+BTS+BRT (3.54%)	Walk	Walk	92.50	74.50	1.93	6
		Motorcycle taxi	Walk	105.00	102.00	0.96	3
		Taxi-bus	Walk	135.00	58.00	0.32	1
		Walk	Motorcycle taxi	82.00	97.00	0.32	1
7	BRT+BTS+Bus (2.89%)	Walk	Walk	82.00	46.30	1.61	5
		Motorcycle taxi	Walk	85.33	63.83	0.96	3
		Car	Walk	85.00	90.00	0.32	1
8	BRT+Bus (1.93%)	Walk	Walk	66.60	24.00	1.61	5
		Walk	Motorcycle taxi	75.00	49.00	0.32	1
9	MRT+BTS+BRT (1.29%)	Motorcycle taxi	Walk	58.50	63.50	0.64	2
		Walk	Walk	55.00	63.00	0.32	1
		Car	Walk	165.00	175.00	0.32	1
10	BRT+BTS+MRT (0.96%)	Walk	Walk	50.00	62.50	0.64	2
		Taxi	Walk	115.00	201.00	0.32	1
11	Rail+BRT (0.96%)	Walk	Walk	70.00	21.25	0.64	2
		Motorcycle taxi	Walk	102.00	35.00	0.32	1

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
12	Van+BRT (0.64%)	Taxi-bus	Walk	72.00	31.00	0.32	1
		Motorcycle taxi	Walk	53.00	85.00	0.32	1
13	Van+Bus+BRT (0.64%)	Motorcycle	Walk	105.00	67.00	0.32	1
		Walk	Walk	210.00	108.00	0.32	1
14	Bus+BRT+BTS (0.64%)	Walk	Walk	62.00	53.50	0.64	2
15	BRT+BTS+Bus+Van (0.32%)	Motorcycle taxi	Walk	137.00	180.00	0.32	1
16	BRT+BTS+Van (0.32%)	Walk	Walk	150.00	179.00	0.32	1
17	BRT+Van (0.32%)	Motorcycle taxi	Walk	100.00	115.00	0.32	1
18	Car (0.64%)	-	-	67.50	150.00	0.64	2
19	Car+Bus+BTS+Walk (0.32%)	-	-	70.00	37.50	0.32	1
20	Car+Bus+Motorcycle taxi (0.32%)	-	-	55.00	75.00	0.32	1
21	Motorcycle taxi (0.32%)	-	-	20.00	50.00	0.32	1
22	Motorcycle taxi+BTS+Motorcycle taxi (0.32%)	-	-	70.00	99.00	0.32	1
23	Motorcycle taxi+Bus+Van (0.32%)	-	-	31.00	53.00	0.32	1
24	Motorcycle taxi+Bus+Walk (0.32%)	-	-	25.00	25.00	0.32	1
25	Taxi+BTS+Walk (0.32%)	-	-	45.00	126.00	0.32	1

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
26	Walk+Bus+Van (0.32%)	-	-	100.00	44.00	0.32	1
27	Walk+Van+Bus+Walk (0.32%)	-	-	85.00	21.50	0.32	1

When considering the return trip's modes, the result as shown in Figure 5.32 revealed that the return trip's users of 97.1% out of the total respondents made their journey from their origin to destination by BRT and multimodal transportation modes. In light of this corner, the results showed that the BRT users accessed the mode of walking predominantly by 87.4%. This implied in the opposition of the mode of egress in the ongoing trip that contributed in the high percentage of egress from the modes of transit. Motorcycle taxi was followed by 10.6% and other minor modes which was also similar to the egress mode of their prior trip. Another perspective was regard to the transit modes of the users in return trip. The outstanding mode the BRT users gave an interest to was still using one mode to connect their origin and destination, which was BRT by 33.4%. However, the multimodal transportation modes still accounted higher proportion than using merely BRT. The dominant mode was relied on the combination of BTS and BRT by 23.2% which was in contrast to the transit mode that the BRT users used in their ongoing mode. The multimodal transportation modes were followed by the combination of BRT and BTS (13.9%), the combination of BRT and bus (9.3%), the combination of three modes such as BRT-BTS and bus (5.6%), BRT-BTS and van (3.6%), Bus-BTS and BRT (2.6%) and other minor modes.

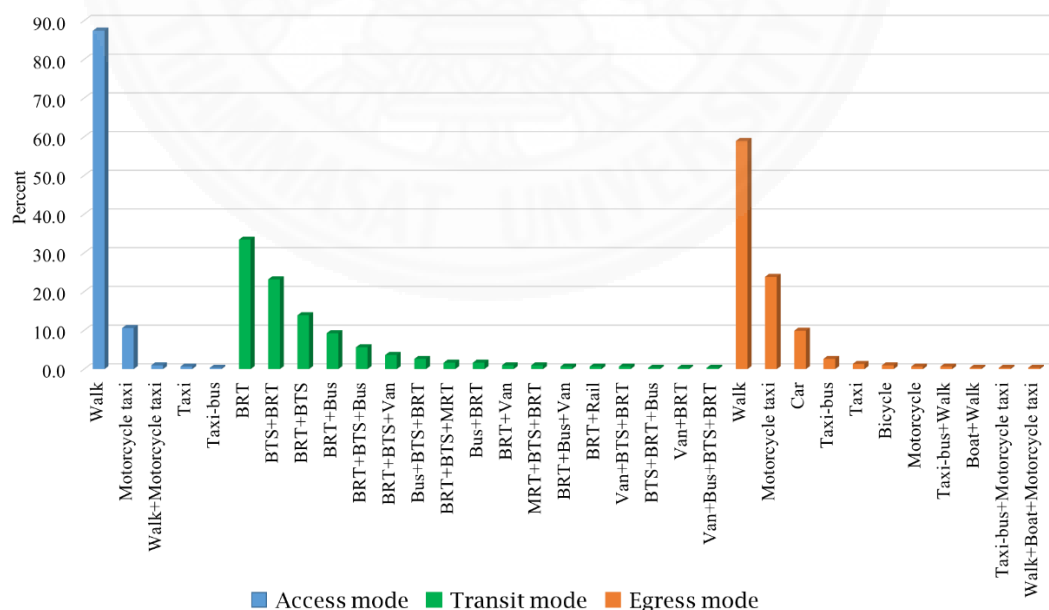


Figure 5.32 Access, Transit and Egress Mode of Return Trip

The above result also showed that most of the BRT users preferred walking mode the most as their egress mode by 58.9% in the return trip. Using motorcycle taxi and car were 23.8% and 9.9%, respectively. This implied that most of the BRT users' destination was comfortable to access by three main modes mentioned earlier.

Table 5.4 showed the details of mode cost access, mode of egress and mode of transit with respect to the cost and time. The results were associated with the previous findings from the ongoing trip that the mode of walking was the popular mode for the access mode and egress mode in any transit modes.

In summary of the ongoing trip and return trip, the aforementioned results revealed that the BRT users preferred to use only single mode for their access mode and egress mode. It obviously showed that they dominantly preferred walking as their access mode and egress mode to connect from their origin to their destination.

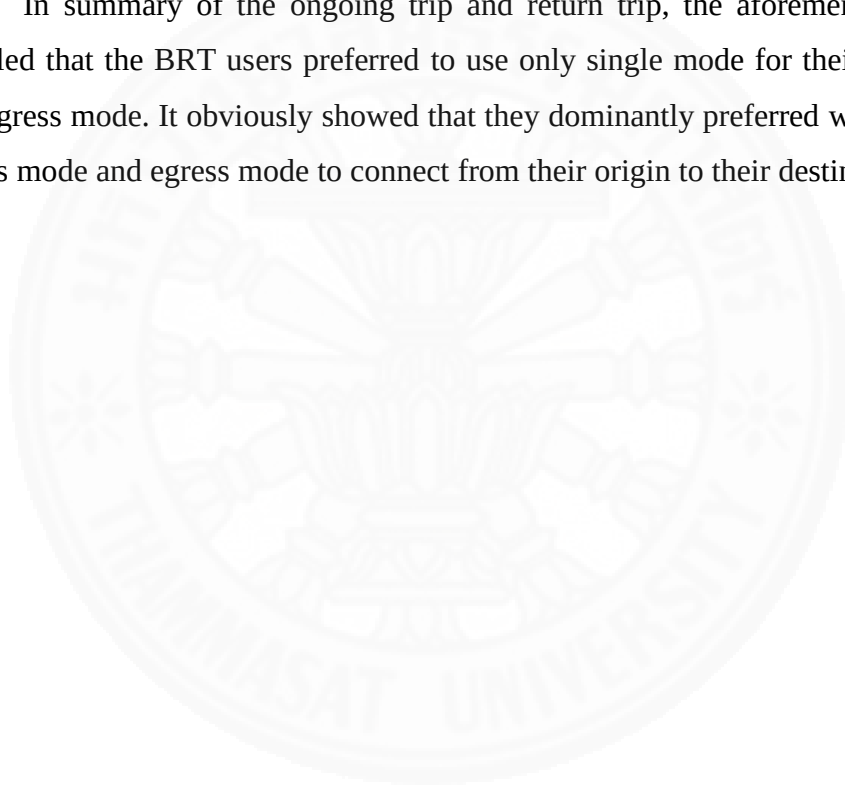


Table 5.4 Mode, Time and Cost of Return Trip

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
1	BRT (32.48%)	Walk	Walk	41.31	15.00	19.94	62
		Walk	Motorcycle taxi	56.93	31.96	4.50	14
		Walk	Car	46.50	30.00	1.29	4
		Motorcycle taxi	Walk	68.00	62.50	1.29	4
		Motorcycle taxi	Motorcycle taxi	78.75	90.00	1.29	4
		Motorcycle taxi	Car	61.75	100.00	1.29	4
		Walk+Motorcycle taxi	Walk	86.67	27.33	0.96	3
		Walk	Taxi	33.50	30.00	0.64	2
		Walk	Bicycle	23.00	25.00	0.32	1
		Motorcycle taxi	Taxi-bus	70.00	47.00	0.32	1
		Walk	Taxi-bus+Walk	70.00	80.00	0.32	1
		Walk	Walk+Boat+Motorcycle taxi	105.00	67.00	0.32	1
2	BTS+BRT (22.51%)	Walk	Walk	65.97	42.28	11.58	36
		Walk	Motorcycle taxi	53.29	40.56	5.47	17
		Walk	Car	54.50	49.38	2.57	8
		Motorcycle taxi	Walk	87.50	126.50	1.29	4
		Motorcycle taxi	Motorcycle taxi	102.50	107.50	0.64	2
		Taxi	Walk	55.00	60.00	0.32	1
		Taxi-bus	Walk	95.00	101.00	0.32	1
		Walk	Taxi-bus+Motorcycle taxi	85.00	90.00	0.32	1
3	BRT+BTS (13.5%)	Walk	Walk	74.80	72.13	4.82	15
		Walk	Motorcycle taxi	79.70	70.40	3.22	10

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
3	BRT+BTS (13.5%)	Walk	Car	55.38	57.88	2.57	8
		Motorcycle taxi	Motorcycle taxi	70.00	51.75	0.64	2
		Walk	Bicycle	60.00	56.00	0.32	1
		Motorcycle taxi	Walk	40.00	60.00	0.32	1
		Motorcycle taxi	Motorcycle	80.00	146.00	0.32	1
		Motorcycle taxi	Car	55.00	61.00	0.32	1
		Motorcycle taxi	Taxi	35.00	63.00	0.32	1
		Walk	Taxi-bus+Walk	80.00	58.00	0.32	1
		Walk	Boat+Walk	165.00	175.00	0.32	1
4	BRT+Bus (9%)	Walk	Walk	65.11	34.64	5.79	18
		Walk	Taxi-bus	95.40	93.90	1.61	5
		Walk	Car	86.50	43.00	0.64	2
		Motorcycle taxi	Motorcycle taxi	77.50	61.50	0.64	2
		Walk	Motorcycle taxi	80.00	33.00	0.32	1
5	BRT+BTS+Bus (5.47%)	Walk	Motorcycle taxi	83.88	65.00	2.57	8
		Walk	Walk	61.25	70.25	1.29	4
		Motorcycle taxi	Walk	70.00	75.50	0.64	2
		Walk	Bicycle	72.00	80.00	0.32	1
		Walk	Car	115.00	42.00	0.32	1
		Motorcycle taxi	Motorcycle taxi	123.00	73.00	0.32	1
6	BRT+BTS+Van (3.54%)	Walk	Walk	75.67	82.83	1.93	6
		Walk	Motorcycle taxi	105.00	52.33	0.96	3
		Motorcycle taxi	Walk	137.00	180.00	0.32	1

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
		Walk	Taxi-bus	115.00	201.00	0.32	1
7	Bus+BTS+BRT (2.57%)	Walk	Walk	82.00	45.25	1.29	4
		Walk	Motorcycle taxi	69.50	79.00	0.64	2
		Walk	Motorcycle taxi	30.00	100.00	0.32	1
		Walk	Car	95.00	41.50	0.32	1
8	BRT+BTS+MRT (1.61%)	Walk	Walk	93.33	59.33	0.96	3
		Walk	Motorcycle taxi	65.00	75.00	0.32	1
		Walk	Car	37.00	69.00	0.32	1
9	Bus+BRT (1.61%)	Walk	Walk	98.75	32.13	1.29	4
		Motorcycle taxi	Walk	65.00	74.00	0.32	1
10	BRT+Van (0.96%)	Walk	Motorcycle taxi	60.00	28.00	0.32	1
		Walk	Motorcycle	105.00	115.00	0.32	1
		Walk	Taxi-bus	78.00	108.00	0.32	1
11	MRT+BTS+BRT (0.96%)	Walk	Walk	70.00	57.00	0.64	2
		Walk	Taxi	112.00	150.00	0.32	1
12	BRT+Rail (0.64%)	Walk	Walk	63.00	67.00	0.32	1
		Walk	Motorcycle taxi	70.00	51.50	0.32	1
13	Van+BTS+BRT (0.64%)	Walk	Walk	72.00	57.00	0.32	1
		Taxi	Walk	70.00	49.00	0.32	1
14	BRT+Bus+Van (0.64%)	Walk	Walk	64.00	35.25	0.64	2
15	BTS+BRT+Bus (0.32%)	Walk	Walk	35.00	40.00	0.32	1
16	Van+BRT (0.32%)	Walk	Motorcycle taxi	50.00	58.00	0.32	1

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
17	Van+Bus+BTS+BRT (0.32%)	Walk	Motorcycle taxi	170.00	104.00	0.32	1
18	Taxi (0.64%)	-	-	107.50	113.00	0.64	2
19	Walk+BTS+Walk+Car (0.64%)	-	-	90.00	64.50	0.64	2
20	Bus (0.32%)	-	-	40.00	15.00	0.32	1
21	Car (0.32%)	-	-	100.00	115.00	0.32	1
22	Car+Bus+Taxi-bus (0.32%)	-	-	113.00	65.00	0.32	1
23	Motorcycle (0.32%)	-	-	20.00	40.00	0.32	1
24	Bus+Motorcycle taxi+Walk (0.32%)	-	-	53.00	85.00	0.32	1

Additionally, the additional trip was also estimated both ongoing trip and return trip. Since the BRT users made their additional trip around 34% out of whole respondents. For the result of ongoing trip for the additional trip as shown in Figure 5.33, it revealed that the access mode and egress mode of the users were walking which accounted respectively 70.8% and 98.1% as the huge proportion among other modes. When considering the transit modes, the use of BRT and the combination of BRT and BTS as the multimodal transportation mode played the similar usage proportion by 44.3% and 42.5% to connect their origin and destination, respectively.

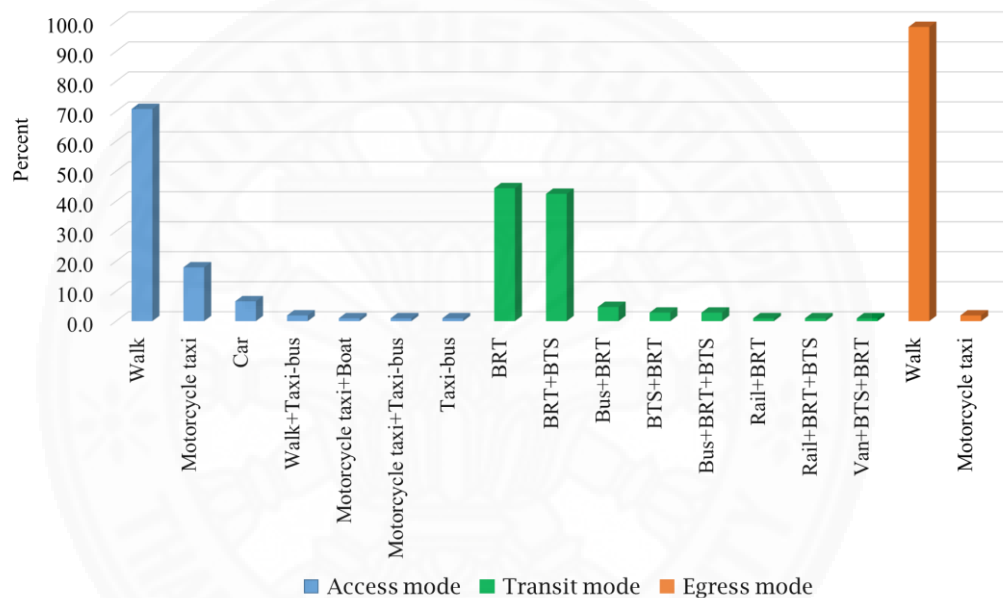


Figure 5.33 Access, Transit and Egress Mode of Ongoing Trip (Additional Trip)

The cost and time of each transit modes were evaluated in detail as shown in Table 5.5. According to the result, it obviously showed that walking was predominant mode among other modes. The possible reason of why the users used walking mode more than other modes was due to the lowest cost to pay when travelling.

Table 5.5 Mode, Time and Cost of Ongoing Trip (Additional Trip)

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
1	BRT (44.34%)	Walk	Walk	32.64	15.00	36.79	39
		Motorcycle taxi	Walk	37.75	31.25	3.77	4
		Walk	Motorcycle taxi	20.00	35.00	0.94	1
		Car	Walk	45.00	65.00	0.94	1
		Walk+Taxi-bus	Walk	45.00	23.00	0.94	1
		Motorcycle taxi+Boat	Walk	90.00	44.00	0.94	1
2	BRT+BTS (42.45%)	Walk	Walk	47.26	43.07	25.47	27
		Motorcycle taxi	Walk	46.09	53.18	10.38	11
		Car	Walk	51.00	65.20	4.72	5
		Motorcycle taxi	Motorcycle taxi	55.00	73.00	0.94	1
		Motorcycle taxi+Taxi-bus	Walk	80.00	58.00	0.94	1
3	Bus+BRT (4.72%)	Walk	Walk	91.25	24.25	3.77	4
		Car	Walk	95.00	61.50	0.94	1
4	BTS+BRT (2.83%)	Walk	Walk	55.00	31.00	1.89	2
		Motorcycle taxi	Walk	67.00	80.00	0.94	1
5	Bus+BRT+BTS (2.83%)	Motorcycle taxi	Walk	95.00	76.00	0.94	1
		Walk+Taxi-bus	Walk	110.00	52.50	0.94	1
		Taxi-bus	Walk	92.00	62.00	0.94	1
6	Rail+BRT (0.94%)	Walk	Walk	60.00	21.50	0.94	1
7	Rail+BRT+BTS (0.94%)	Motorcycle taxi	Walk	112.00	51.00	0.94	1
8	Van+BTS+BRT (0.94%)	Walk	Walk	60.00	62.00	0.94	1

The result of the mode of access and egress of the return trip for additional trip was shown in Figure 5.34. According to the result, it revealed that the BRT users were likely to use walking mode more than other modes in both their access mode and egress mode by 98.1% and 71.7%, respectively. With the similar outcome for the transit modes, 44.3% and 42.5% of the users in the additional trip preferred to use BRT and a combination mode of BTS and BRT to connect their origin and destination, respectively.

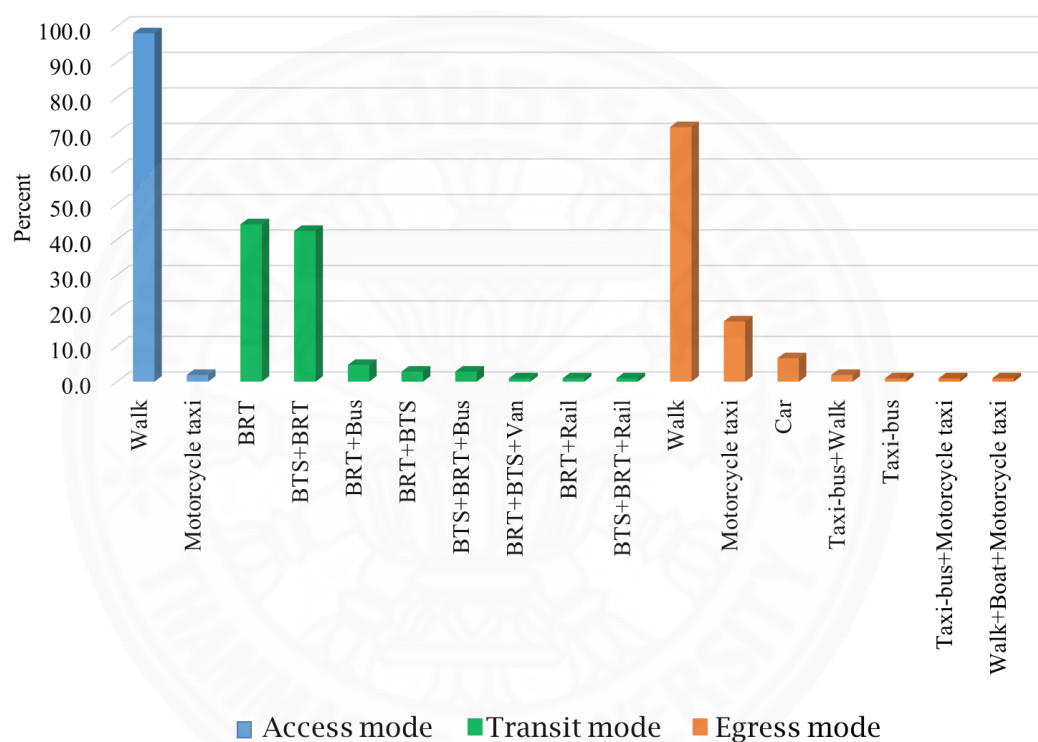


Figure 5.34 Access, Transit and Egress Mode of Return Trip (Additional Trip)

Table 5.6 showed the details of each modes with respect to time and cost of the access mode and egress mode.

Table 5.6 Mode, Time and Cost of Return Trip (Additional Trip)

No	Transit mode (Percent)	Mode of Access	Mode of Egress	Time (min)	Cost (THB)	Percent	Frequency
1	BRT (44.34%)	Walk	Walk	32.02	15.00	37.74	40
		Walk	Motorcycle taxi	41.66	33.33	2.83	3
		Walk	Car	45.00	65.00	0.943	1
		Walk	Taxi-bus+Walk	45.00	23.00	0.943	1
		Walk	Walk+Boat+Motorcycle taxi	90.00	44.00	0.943	1
		Motorcycle taxi	Walk	20.00	35.00	0.943	1
2	BTS+BRT (42.45%)	Walk	Walk	46.70	43.07	25.47	27
		Walk	Motorcycle taxi	46.09	53.18	10.38	11
		Walk	Car	51.00	65.20	4.717	5
		Motorcycle taxi	Motorcycle taxi	50.00	73.00	0.943	1
		Walk	Taxi-bus+Motorcycle taxi	80.00	58.00	0.943	1
3	BRT+Bus (4.72%)	Walk	Walk	91.25	24.25	3.774	4
		Walk	Car	95.00	61.50	0.943	1
4	BRT+BTS (2.83%)	Walk	Walk	67.50	33.50	1.887	2
		Walk	Motorcycle taxi	67.00	80.00	0.943	1
5	BTS+BRT+Bus (2.83%)	Walk	Motorcycle taxi	95.00	76.00	0.943	1
		Walk	Taxi-bus+Walk	110.00	52.50	0.943	1
		Walk	Taxi-bus	92.00	62.00	0.943	1
6	BRT+Rail (0.94%)	Walk	Walk	60.00	21.50	0.943	1
7	BRT+BTS+Van (0.94%)	Walk	Walk	60.00	62.00	0.943	1
8	BTS+BRT+Rail (0.94%)	Walk	Motorcycle taxi	112.00	51.00	0.943	1

5.3 Assessment of Attitudes of Bus Rapid Transit Users Study

The attitude of the BRT users was examined under three major parts in order to discover how the users feel to the BRT service. First part was to assess the perspectives of the users who using BRT service with respect to the availability and the travel time of BRT compared to automobile. Second part was to evaluate the level of expectation prior to using the BRT and level of satisfaction after using the BRT service. Third part was to adopt exploratory factor analysis (EFA) to identify the factors that should be improved. The details of each part were discussed in the below sub-sections.

5.3.1 The Users' Perspectives on BRT Service

The providing service of Bangkok BRT under the perspectives of the users was evaluated in order to know insights from their experiences. Hence, the late arrival of the bus at the BRT station, waiting time at the stations, and the travel time compared to automobile were evaluated.

The result of late arrival times of BRT was shown in Figure 5.35. It revealed that 77.17% of the passengers encountered the over the schedule of the BRT arrival at the stations 1 to 2 times per week. It followed by 18.33% of the BRT users found 3 to 4 times per week and 5 to 6 times per week were experienced by 3.86% of the users, and other minor. The happened late arrival of the BRT caused by the fact that there was not sufficient of the buses even there are 25 buses in service. Unfortunately, the buses were sometimes broken causing unsafety to the passengers, in which the BRT sometimes had to serve the users later than the schedule. Nonetheless, this study found that the BRT in Bangkok could not operate and provide the service as the planned schedule. Additionally, this could affect the reliability of the service to the new users when they have the first time to use the BRT.

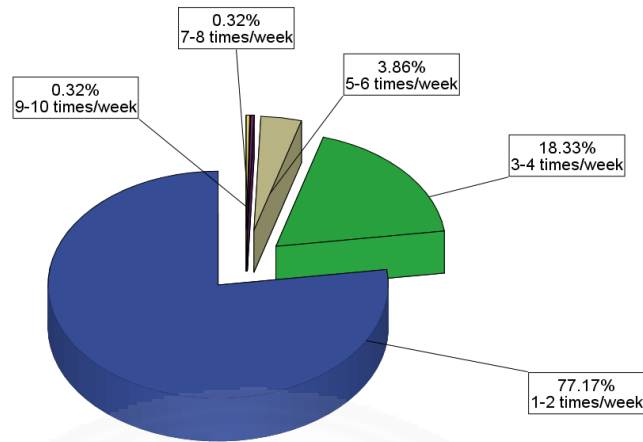


Figure 5.35 Number of Late Arrival of BRT at Stations

The waiting time of the users at the station was analyzed. It resulted as shown in Figure 5.36 that the majority of the users spent their time approximately 10 minutes at the stations by 39.87%, followed by 27.65%, 24.44% and 4.82% for the waiting time of 5 minutes, 15 minutes and 20 minutes, respectively. According to the previous finding of the origin and destination, this study found that most of the users traveled from their origin and destination in the peak hours rather than the normal time. This implied that only 27.65% of the users could receive the service with the frequency of the rush hours by 5 minutes. Due to the fact that the passengers who used the BRT in the peak hours had a huge amount compared to the capacity of the bus that could contain. This caused the long queue at the stations, in which it affected to the waiting time of the passengers.

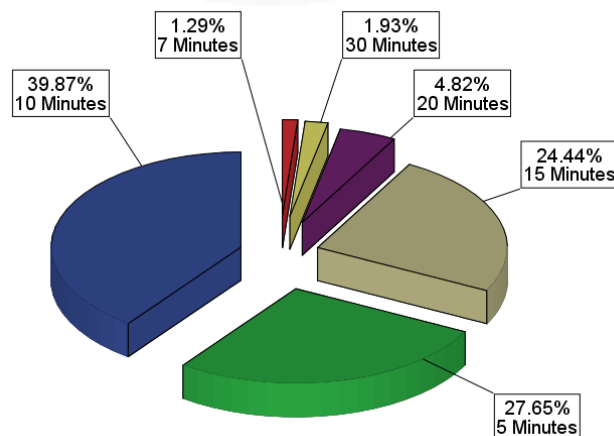


Figure 5.36 Waiting Time of The BRT Users at The Station

The level of service under the perspective of the users was assessed regarding the travel time of the BRT compared to automobile. The result shown in Table 5.7 indicated that 39.9%, 32.5% and 21.2% graded BRT in LOS B, LOS A and LOS C, respectively. The LOS D and LOS E was graded as minor proportion. This revealed that the level of service of the BRT under the perception of the users was in accordance with the previous finding of the real operating travel time of BRT. In which, both the travel time assessment from real operated and under the perception of the users were in the similar level which was LOS B as a majority. It also meant that the travel time of BRT in Bangkok is comparable to the automobile but cheaper than using automobile in the specific route of travel.

Table 5.7 Level of Service of Travel Time of BRT Compared to Automobiles

No	Frequency	Percent	Cumulative Percent	LOS
1	124	39.9	39.9	B
2	101	32.5	72.3	A
3	66	21.2	93.6	C
4	13	4.2	97.7	D
5	7	2.3	100.0	E

5.3.2 Level of Expectation and Satisfaction of BRT Users

The level of expectation and satisfaction of the BRT users were examined under nine determinants with regard to the recommendation of TCRP (1999) to measure the transit quality service. The mentioned nine determinants consist of (1) low cost of BRT, (2) using less time than auto, (3) punctuality (scheduled), (4) comfort, (5) good accessibility, (6) cleanliness, (7) not overcrowded on bus, (8) safety, and (9) reliability on BRT system.

To measure the level of expectation and satisfaction with the aforementioned nine determinants, this study applied the 5-likert scale which commences with 1 represents strongly disagree (SD), 2 represents disagree (D), 3 represents neutral (N), 4 represents agree (A), and 5 represents strongly agree (SA). The result of the expectation level was shown in Table 5.9 and result of satisfaction level was shown in Table 5.10.

As presented in Table 5.9 with respect to average expectation level, it revealed that the expectation level was ranged from 3.82 to 4.67. The BRT users were likely to

set their expectation most to the safety matter (4.67), followed by travel time which uses less than auto (4.42), the punctuality of BRT (4.41), the reliability of the BRT system (4.41), good accessibility (4.30), cleanliness of the BRT (4.30), comfort of BRT (4.26), the passengers on the BRT are not overcrowded (4.00), and cost of the BRT is low (3.82). This could imply that most of the BRT users concerned about safety when traveling and also the travel time. In line with the Table 5.10 presented the average satisfaction level of the BRT users, it uncovered that the BRT users satisfied the BRT service ranged from 3.48 to 4.08. The users were much satisfied with the cost of service that being operated (4.32), followed by safety (4.31), comfort of the BRT (4.23), good accessibility (4.21), cleanliness (4.16), reliability on BRT system (4.07), travel time of BRT less than automobile (4.02), punctuality (3.91), and the passengers on the BRT is not overcrowded (3.48). When considering the overall level between expectation level and satisfaction level, the BRT users expected BRT to serve them at the level of 4.29 but they could perceive at the level of 4.08. This implied that the BRT users perceived the service lower than what they expected to be. Nonetheless, the level of expectation's ranking order as shown in Table 5.9 and level of satisfaction's ranking order as shown in Table 5.10, the results revealed that the BRT users were expecting much to the time of travel by BRT and the punctuality of the BRT but they perceived quite further than they expected. In the similar result, the BRT users expected the passengers in the BRT should not be overcrowded and also concerned about the safety and reliability of the BRT system but these three things were slightly lower than what they expected. In contrast, the users were expecting the cost of travel and comfort traveling by BRT quite low concern but they were much satisfied when compared to other concerns. While the users were also more satisfied on the accessibility and cleanliness of the BRT provided than what they expected.

To summarize in short, the result shown in Figure 5.37 elucidated that the satisfaction matter of cleanliness, good accessibility and comfort when traveling by BRT was closed to what the users expected even it was slightly lower. The matter of punctuality, being not overcrowded on bus, safety, reliability and travel time when traveling by BRT was quite lower than what they expected. Nevertheless, the cost of travel that expected to be low was over satisfied than what they expected to be.

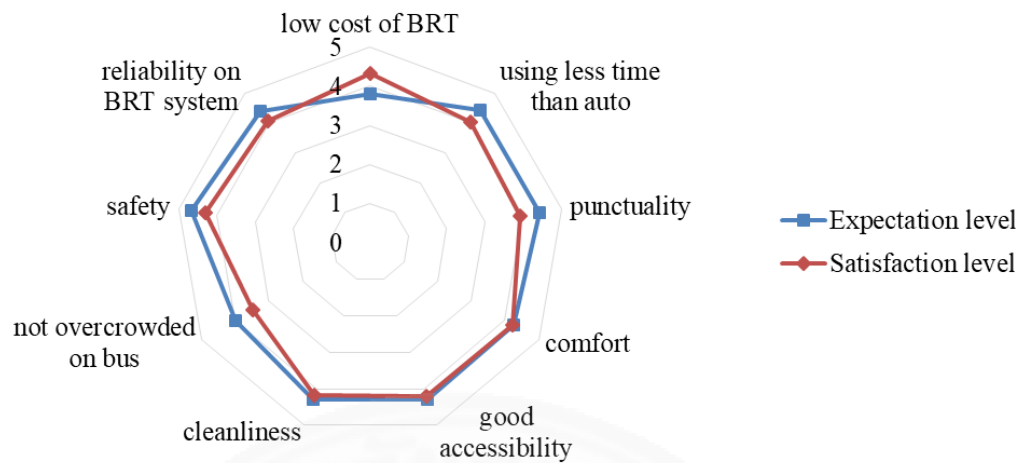


Figure 5.37 Level of Expectation Vs Level of Satisfaction of the BRT Users

When considering LOS to determine the situation of BRT users according to their attitudes between expectation level and satisfaction level, this study applied the LOS scale ranged from 1 to 5 under the percentage deviation values by the recommendation of Kittelson (2003). The result presented in Table 5.8 showed that all of the determinants of the level of service were under LOS 1 by comparing the level of expectation and level of satisfaction. This implied that the current BRT service was at the best service level. Also, all the respondents were still satisfied with all performance indicators or factors of the provided service.

Table 5.8 Level of Service Between Expectation and Satisfaction

Performance factors	Expectation level	Satisfaction level	Percentage deviation values (%)	LOS
low cost of BRT	3.82	4.32	13.31	1
using less time than auto	4.42	4.02	9.16	1
punctuality	4.41	3.91	11.51	1
comfort	4.26	4.23	0.60	1
good accessibility	4.30	4.21	2.09	1
cleanliness	4.30	4.16	3.07	1
not overcrowded on bus	4.00	3.48	13.02	1
safety	4.67	4.31	7.85	1
reliability on BRT system	4.41	4.07	7.66	1

Table 5.9 Descriptive Statistics of the Level of Expectation of BRT Users

	Low cost of BRT	Using less time than auto	Punctuality (scheduled)	Comfortable	Good accessibility	Cleanliness	Not overcrowded on bus	Safety	Reliability on BRT system
Mean	3.82 ⁹	4.42 ²	4.41 ³	4.26 ⁷	4.30 ⁵	4.30 ⁶	4.00 ⁸	4.67 ¹	4.41 ⁴
Std. Deviation	1.045	0.783	0.765	0.752	0.761	0.697	0.919	0.570	0.738
Skewness	-0.720	-1.342	-1.167	-0.646	-0.924	-0.592	-0.501	-1.654	-1.291
Kurtosis	0.277	1.768	0.940	-0.358	0.681	-0.337	-0.497	2.287	1.938

Note: Superscript number is ranking order

Table 5.10 Descriptive Statistics of the Level of Satisfaction of BRT Users

	Low cost of BRT	Using less time than auto	Punctuality (scheduled)	Comfortable	Good accessibility	Cleanliness	Not overcrowded on bus	Safety	Reliability on BRT system
Mean	4.32 ⁹	4.02 ²	3.91 ³	4.23 ⁷	4.21 ⁵	4.16 ⁶	3.48 ⁸	4.31 ¹	4.07 ⁴
Std. Deviation	0.775	0.945	0.927	0.726	0.758	0.755	0.915	0.727	0.875
Skewness	-0.928	-0.701	-0.547	-0.639	-0.644	-0.734	-.332	-.794	-0.712
Kurtosis	0.422	-0.011	-0.190	0.007	0.089	0.659	-0.051	0.186	0.108

Note: Superscript number is ranking order

5.3.3 Analysis of BRT Improvement Using EFA

The objective of using EFA technique in this study was to identify the improvement level based on the perception of the BRT respondents. Also, this was conducted to help confirm whether the proposed solutions meet the need of the BRT users or any suggestions from the perspective of the users to take into account. Hence, the improvement of the BRT was analyzed under 9 variables taking into account of the improvement of the BRT. The 9-variable includes adding more frequency in the rush hours, expanding service time in the morning, expanding service time in the evening, travelling in the segregated lane (BRT lane only), upgrading the condition of buses and stations, applying ITS system at the at-grade intersections, accessing the information easily, improving driving skill of BRT driver, and cancelling flat rate. Additionally, the 9 determinants were collected by applying five-Likert scale to measure, in which 1 refers to strongly disagree (SD), 2 refers to disagree (D), 3 refers to neutral (N), 4 refers to agree (A), and 5 refers to strongly agree (SA). The data was collected in the form of quantitative data. Thus, the data were analyzed by the multivariate statistics technique called exploratory factor analysis (EFA) using the statistical package for the social sciences (SPSS) version 23 software.

5.3.3.1 Data Screening

Beforehand of conducting the multivariate analysis, the data screening as univariate was important to check the suitability of the data. This is to ensure that the data meet all of the requirements and there would not consist of any corrupted data affecting to the use of multivariate techniques. Consequently, the data screening commenced with identifying the missing data, the normality of the item used, outlier scanning, and the examination of standard deviations and standard errors of the mean (Hair et al., 2010; Tabachnick & Fidell, 2007).

Missing data is generally known as the information given by respondents not available to apply in any multivariate analysis. Most cases of missing data occur from the respondents who fail or ignore to provide an answer to the particular questions in a survey. According to Hair et al. (2010), the practical impact of missing data affects directly to the reduction of the sample size by eliminating the observation as inadequate

data. In this present study, thirty-nine samples were eliminated due to incompleteness of the data provided by the respondents. Consequently, there were indeed 311 cases which included in the analysis of EFA. The 311 sets of answer were no missing data as shown in Table 5.12.

Assessing normality was another essential step in the multivariate technique. The normality was the most fundamental assumption in the multivariate analysis to be examined. The normality is a tool to check whether the data that the analyst used were in the normal distribution or not. The examination of the normality was investigated by statistics value of skewness and kurtosis. The skewness and kurtosis were used to compare with the benchmark value or rule of thumb of ± 2.58 (Hair et al., 2010). Since the kurtosis is statistical value that refers to the peakedness or flatness of the distribution of the data. When the data turn with the high skewness, it means that the data is too tall known as leptokurtic or too flat known as platykurtic. Whereas skewness is another statistical measure of how balance of the distribution of the data under the test of variance and covariance (Tabachnick & Fidell, 2007). In this present study, all the received data from the respondents were tested the skewness and kurtosis as shown in Table 5.12. The skewness values ranged from -1.79 to -0.20, and were thus inside the threshold, which indicated that the respondents answered these questions quite similarly. The kurtosis values ranged from -0.77 to +3.15, which 8 variables falling within the recommendation range and there was one variable (V1) was over the recommended value. The result of the data is consistent with expectations that the effect of skewness and kurtosis disappears with samples of 200 or more (Tabachnick & Fidell, 2007).

Another indicator to check the validity of the data was the outlier detection. Outlier is a measure to identify a substantial difference of the observed value and predicted value. Outlier can be detected by calculating the z-score. The cases which turn an absolute value of z-score ($|z|$) greater than 3.29 will be defined as an outlier. In this study, only one variable containing case with an absolute value of z-score ($|z|$) greater than 3.29 which had the outlier of 1.3 percent. According to the suggestion of Field (2013), the outlier among the data detected over the benchmark value should be less than one percent. In which, this study found the outlier occurred in one variable

(V1). However, the number of such outlier could consider as relatively small and not excessive when compared with the standard.

To ensure that the outlier did not perform as the bias of the population means, mean difference and 5% trimmed mean of each variable was examined (Panuwatwanich, 2008). The 5% trimmed mean refers to a statistical measure which calculated from a set of observations where there was an elimination of the upper and lower bound of the five percent score. Generally, the difference of mean is calculated by the difference between 5% trimmed mean and the mean of the data. In which, the difference of mean should not greater than 0.20 (Pallant, 2013). From the result shown in Table 5.12, it showed that the difference of mean ranging from 0.02 to 0.11. It implied that none of the variable found over the standard.

Therefore, the variable V1 was not eliminated and remained the model. So, it was guaranteed that all 311 set of the data were retained and ready for conducting the further analysis. Regarding the remained 311 samples to analyze with the multivariate technique such as EFA, Hair et al. (2010) suggested that the sample size should not less than 50 observations, but over 100 observations are preferable. Another general rule of determining the sufficiency of sample is to have minimum five times of the variables in the model, but more preferable case is around 10 times of the considered variables. Hence, the remaining samples were sufficient to conduct the multivariate analysis.

5.3.3.2 Exploratory Factor Analysis

Prior to conduct the EFA, the descriptive statistics of each variable used in the further analysis was examined as shown in Table 5.11. The result was ranged from 3.19 (improving driving skill of BRT driver) as the minimum value to 4.20 (travelling in the segregated lane) as the maximum value. The correlation of each variable was also essential to analyze to examine the relationship among the variables. A correlation matrix is generally adopted for making a decision and a diagnostic in the advance analysis. If any of the variables has a strong correlation coefficient to another variable, it means that the variable is trended to be group in the same factor. Table 5.13 showed the correlation matrix of variables used in the analysis of this study. The result found that each variable has a good relationship with each other.

Once the data were examined and confirmed to use in the EFA, another important step is to conduct the multivariate test of normality and adequacy of the variables. This stage should be conducted prior to the extracting factors (Wipulanusat et al., 2017). By employing the SPSS software V23, the normality was be able to determine by Bartlett's test of sphericity. Besides, the adequacy of the samples was examined by the Kaiser-Meyer-Olkin (KMO) through SPSS V23. According to the suggestion of Tabachnick and Fidell (2007) and Wipulanusat et al. (2017), the data is factorable when the KMO is over the standard value of 0.6. In this study, the KMO value of the variable was 0.732, which confirmed that the sampling was adequate and appropriate to conduct the factor analysis. Regarding the value obtained from the Bartlett's test of sphericity, the approximate chi-square (χ^2) was 396.51 with the degree of freedom (df) of 36. The test was highly significant where the p-value was less than 0.001 level. This could imply that the data was in the normal range of multivariate.

Table 5.11 Descriptive Statistics of Improvement Variables

Variable : Description	Mean	Std. Deviation	Analysis N
V1: Adding more frequency in the rush hours	3.57	0.853	311
V2: Expanding service time in the morning	3.74	1.144	311
V3: Expanding service time in the evening	3.45	1.201	311
V4: Travelling in the segregated lane (BRT lane only)	4.20	0.997	311
V5: Upgrading the condition of buses and stations	3.63	1.148	311
V6: Applying ITS system at the at-grade intersections	3.90	1.053	311
V7: Accessing the information easily	3.87	1.033	311
V8: Improving driving skill of BRT driver	3.19	1.108	311
V9: Cancelling flat-rate fare	3.44	1.298	311

Table 5.12 Descriptive Statistics of the Variables

Variables: Description	Missing values	Cases with $ Z >3.29$	Mean	5%trimmed Mean	Δ Mean	SD	SE	Skewness	Kurtosis
V1: Adding more frequency in the rush hours	0.0%	1.3%	4.47	4.58	0.11	0.85	0.05	-1.79	3.15
V2: Expanding service time in the morning	0.0%	0.0%	3.74	3.82	0.08	1.14	0.06	-0.58	-0.42
V3: Expanding service time in the evening	0.0%	0.0%	3.45	3.5	0.05	1.20	0.07	-0.44	-0.60
V4: Travelling in the segregated lane (BRT lane only)	0.0%	0.0%	4.2	4.31	0.11	1.00	0.06	-1.26	1.18
V5: Upgrading the condition of buses and stations	0.0%	0.0%	3.63	3.7	0.07	1.15	0.07	-0.64	-0.23
V6: Applying ITS system at the at-grade intersections	0.0%	0.0%	3.9	3.98	0.08	1.05	0.06	-0.83	0.22
V7: Accessing the information easily	0.0%	0.0%	3.87	3.94	0.07	1.03	0.06	-0.73	0.04
V8: Improving driving skill of BRT driver	0.0%	0.0%	3.19	3.21	0.02	1.11	0.06	-0.20	-0.46
V9: Cancelling flat-rate fare	0.0%	0.0%	3.44	3.49	0.05	1.30	0.07	-0.47	-0.77

Table 5.13 Correlation Matrix

Variables		V1	V2	V3	V4	V5	V6	V7	V8	V9
Correlation	V1	1.000								
	V2	0.270	1.000							
	V3	0.191	0.429	1.000						
	V4	0.271	0.145	0.204	1.000					
	V5	0.208	0.104	0.167	0.249	1.000				
	V6	0.243	0.040	0.137	0.329	0.434	1.000			
	V7	0.208	0.215	0.101	0.282	0.313	0.219	1.000		
	V8	0.187	0.098	0.073	0.207	0.394	0.243	0.264	1.000	
	V9	0.175	0.137	0.108	0.068	0.156	0.053	0.097	0.264	1.000

There are two essential steps to conduct the EFA which are factor extraction and factor rotation (Hair et al., 2010). Factor extraction is a step to identify the appropriate number of factors, while the factor rotation is a step to help interpret of the provided factors from the step of factor extraction. Thus, the factor extraction has to conduct prior to factor rotation. In the factor extraction, the most common tool used to extract the factors is principal component analysis (PCA). PCA considers the total variance and is a method to extract the maximum variance from the data set with each component. In deciding to determine factors, there are four criteria suggested by Hair et al. (2010) to achieve the appropriate number of factors to explain the relationship among the variables. The four criteria consist of latent root criterion, a priori criterion, percentage of variance criterion, and scree test criterion. The latent root criterion is applied to recommend the factors that extracted under the total variance, using the value of eigenvalue greater than one to be considered as significant factor. The priori criterion is a simple and reasonable criterion which the analyst has already known the number of factors to be extracted before conducting the factor analysis. The percentage of variance criterion is an approach taking the cumulative percentage of variance to explain the number of factors which should be extracted. The scree plot test criterion is a graphical plot of the eigen value of the factor. To determine the number of factors to be extracted, a sudden slope in the graph is considered as the maximum number of factors among all variables. The sudden slope is measured by drawing a horizontal line and vertical line into the graph with a start at each end of the curve. The cut point in the graph is considered as the maximum number of the factors to be extracted. According to the result shown in Table 5.14, it revealed that there were three extracted factors in this study in which the three factors were explained by the cumulative percentage of variance approximately 56% of total variance. And, the scree plot as shown in Figure 5.38 indicated that the point of inflection was cut at the point which there were three factors in the stage of factor extraction.

After the stage of factor extraction, the factor rotation is essential to conducted to help explain the extracted factors by using the loading values. Varimax rotation is to load variables to factor clearly or varimax can give a clearer separation of the factors. The varimax was conducted to identify the maximum variance of factor loadings and minimum number of variables that had high loadings on each other.

Table 5.14 Total Variance Explanation

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.662	29.580	29.580	2.662	29.580	29.580	2.108	23.422	23.422
2	1.305	14.499	44.079	1.305	14.499	44.079	1.615	17.939	41.361
3	1.054	11.716	55.795	1.054	11.716	55.795	1.299	14.434	55.795
4	0.828	9.201	64.997						
5	0.820	9.107	74.104						
6	0.704	7.820	81.924						
7	0.628	6.980	88.904						
8	0.513	5.702	94.606						
9	0.485	5.394	100.000						

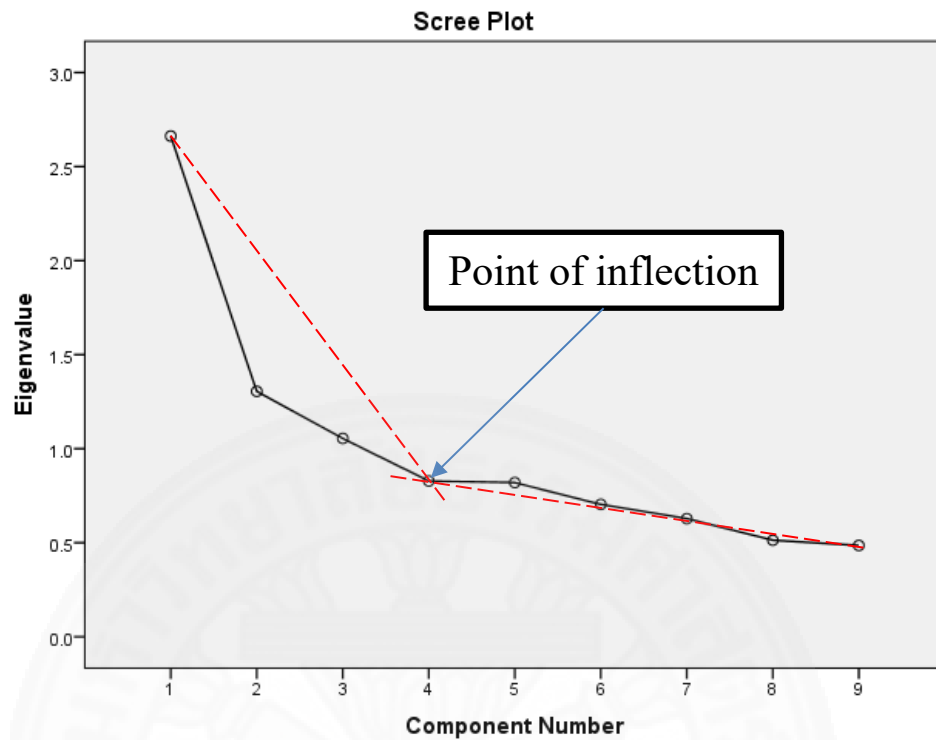


Figure 5.38 Scree Plot of Principal Component Factoring

In the stage of factor rotation, the value of 0.50 is normally considered as the cut-off point of the loading and was used to be the cutoff point of this study. However, prior to extracting factors, the value of communality estimates should be calculated. The communality index is used to assess the variance in a particular variable by the common factor. The communality is denoted by h^2 which calculated by the sum of squared factor loadings. Generally, a variable which has the communality value less than 0.2 will be eliminated.

The communality is defined as:

$$h_j^2 = a_{j1}^2 + a_{j2}^2 \dots \dots + a_{jn}^2 \quad (5.1)$$

Where a is loading for j variables

Table 5.15 EFA of BRT Improvement

Variable: Description	Component			H ²
	1	2	3	
V6: Applying ITS system at the at-grade intersections	0.770	-0.008	-0.026	0.594
V5: Upgrading the condition of buses and stations	0.688	0.011	0.306	0.567
V4: Travelling in the segregated lane (BRT lane only)	0.641	0.258	-0.103	0.488
V7: Accessing the information easily	0.532	0.187	0.166	0.346
V2: Expanding service time in the morning	0.019	0.830	0.108	0.701
V3: Expanding service time in the evening	0.119	0.774	-0.026	0.614
V1: Adding more frequency in the rush hours	0.362	0.542	0.178	0.456
V9: Cancelling flat rate	-0.065	0.168	0.848	0.752
V8: Improving driving skill of BRT driver	0.446	-0.043	0.634	0.603

Table 5.15 represents the factor loadings which contribute in each variable to the factors. From the calculation of communality, it revealed that there was no case to be eliminated since all variables turned the h^2 greater than 0.2. Therefore, there were three factors in this study according to the result of EFA. The generated factors were needed to name them with the neutral and appropriate name in order to be the name that could represent the variables contained in a factor. The name of each factor should be named by the analyst. Hence, Table 5.16 presents the factors which are the operational improvement factor, service improvement factor, and other improvement factor which consists of cost and safety. Also, the mean value of implement each factor was also evaluated under the variables contained in each factor. Based on these 9 variables, the cronbach's alpha coefficient was also calculated which yielded the value of 0.786, indicating the internal consistency of the data was considerably good.

According to the result shown in Table 5.16, the operational improvement was prioritized to improve first, followed by the service improvement factor, and cost and safety improvement factor, respectively.

Table 5.16 BRT Improvement Factors

Factor	Description	Mean Value	Percent of the variance
Operational improvement	Apply ITS system at the at-grade intersections, upgrade the condition of buses and stations, operate in the segregated lane (BRT lane only), and access the BRT information easily	3.9	23.4
Service improvement	Expand service time in the morning, expand service time in the evening, and add more frequency in the rush hours	3.6	17.9
Other improvement	Cancel flat rate, and improve driving skill of BRT driver	3.3	14.4

To place this into more detailed perspective, each factor was elucidated how each variable within each factor affects its belonged factor according to the result shown in Table 5.11. For the operational improvement factor, it consisted of four variables in which the variable 4 (travelling in the segregated lane (BRT lane only)) was the most variable with mean value of 4.20 that should be taken into account, followed by the variable 6 (applying ITS system at the at-grade intersections) with the mean value of 3.90, variable 7 (accessing the information easily) with the mean value of 3.87 and variable 5 (upgrading the condition of buses and stations) with the mean value of 3.63. From the aforementioned result, it revealed that the BRT users had the most concerned issue of facilitating their travel while using BRT. Whereas, the abovementioned variables in the operational improvement factor should be taken into account respectively when conducting the planning and making the decision of improving the BRT operation. Besides, the variables contained in the service improvement factor were

3 variables. In which, the variable 2 (expanding service time in the morning) was showed as the most variable that should be accounted under the mean value of 3.74, followed by variable 1 (adding more frequency in the rush hours) with the mean value of 3.57 and variable 3 (expanding service time in the evening) with the mean value of 3.45. This could imply that the BRT users wanted the BRT improve the service by expanding time of service in the morning (rush hours) earlier than the current provided. So, the decision makers should take this issue into consideration in order to make BRT more attractive for the users. Lastly, the last factor was consisted of two variables which were variable 8 (improving driving skill of BRT driver) and variable 9 (cancelling flat rate) with the mean value of 3.19 and 3.44, respectively. As the matter of fact, the variable 9 had the greater mean value than the variable 8, which means that the BRT users paid more concern to the cost of operation rather than the driving skill of the driving since it might be already in the acceptable performance. Therefore, this was another issue that the decision makers and the planners should take into account.

CHAPTER 6

CONCLUSION

This final chapter presents the key findings of this study. Besides, it addresses the contributions and the limitations of this study. Moreover, the future research directions are also addressed. This chapter commences with Section 6.1, which recapitulates the objectives of this study with highlighting the outcomes found in this study. Section 6.2 presents the study contributions, which the policy recommendations are provided under the findings of this study. Section 6.3 discusses the research limitations.

6.1 Research Objectives and Outcomes

The fundamental aim of this research study consisted of two parts. The first part was to conduct the traffic simulation with the proposed solutions. By conducting this part, the most appropriate and possible solution to improve the BRT operation in Bangkok was recommended for the city planners and decision makers. The second part was to assess the BRT service quality and to identify the influenced factors to improve the service of the BRT. To achieve such study's objectives, a number of research activities were carried out. The activities associated with the outcomes of it were summarized below.

6.1.1 Research Framework Development

To clearly understand the problem and the direction of conducting a study, the literature review had to be conducted at the early stage. The literature review of this study was conducted by reviewing the existing national and international publications, books, guidelines and reports as presented in chapter 2. In particular, this study reviewed the literature pertinent to the principal elements of the BRT implementation of the standard BRT and the BRT in Bangkok. From the literature, it found that the principal elements to improve the BRT system performance are to improve the travel time, reliability of the service, the image and identity, passenger safety and security, system capacity, and accessibility. Thus, these factors were examined in this study.

More specifically, the literature was critically reviewed the procedure of conducting the traffic simulation model. This included the procedure of building the network using microscopic traffic simulation software and the procedure of model calibration and validation. This resulted in the central thesis of this study. Besides the model development, the evaluation measurement was also review to identify the key indicators to assess the impacts. Thus, this study adopted three indicators to measure the impacts of the traffic simulation model, which were delay time, stop time and travel time. Further literature reviewing discovered the method to identify the influence factors from the perception of the users by developing the questionnaire and analyzing under the statistical technique. Several techniques were reviewed. Hence, this study adopted exploratory factor analysis (EFA) to identify the underlying factors to support the BRT improvement of the operation and service.

As mentioned earlier, this study aimed to evaluate the impacts of the traffic when implementing the proposed solution. Therefore, the simulation model was needed to develop and calibrate at the early stage to ensure that the model was fit to the real traffic condition prior to evaluate the impacts. Therefore, the steps of calibration were delineated in chapter 3. The impacts' evaluation of implementing the proposed solutions were elaborated in the chapter 4, associated with the recommendations. Besides the simulation study, the assessment of BRT service was also conducted to uncover the insight of the BRT users included the travel characteristics, expectation level, satisfaction level and the influence factors to improve BRT operation. This was detailed in chapter 5.

6.1.2 Assessment of BRT Operation Improvement

Prior to conducting the traffic simulation, the problem investigation along the BRT trunk line was conducted. The results of study revealed that the BRT operation was being obstructed by 3 major problems, including 1) the BRT lane is being used by other vehicles, 2) the lane of BRT is not dedicated right of way, and 3) poor management at at-grade intersections. These three problems caused BRT lose the reliability from public due to longer travel time. According to found problem, this study proposed three solution to handle of the aforementioned operation obstacles, which are

applying transit signal priority (TSP), enforcing fully segregate lane (FS) and providing an additional lane in the reversed direction (RL). The TSP solution was proposed to deal with the problem that the BRT stuck with the traffic light at the at-grade intersection and the traffic weaving time for the BRT. The fully segregated lane solution was proposed to solve the problem of sharing lane with other road users and to eliminate the interruption from the outside vehicles used in the segregated lane. The reversed lane solution was proposed to reduce the congestion in the serious road section and to utilize the lane that did not have the serious congestion in the effective way.

Therefore, to be able to evaluate the impacts of the proposed solution, this present study developed the microscopic simulation model from Ratchapruek-Ratchadaphisek intersection to Sathorn-Narathiwat intersection. Along the corridor, there were altogether 12 BRT stations, 13 signalized intersections and 7 flyovers. The model was developed by using AIMSUN software and calibrated by adopting the simple two-parameter search algorithm to find the most fit parameter to input in the model. The study was simulated under the traffic condition in the morning peak hours (7:00 am – 9:00 am) and the evening peak hours (16:00 pm – 18:00 pm). In the stage of calibration, traffic volume as flow data was calibrated for 56 cases and found that the GEH could achieve approximately 92.9% over the cases. Also, the model's capacity was calibrated by the saturation headway with the reaction time at stop and queue exit speed. The model's system performance calibration was calibrated by the queue length with the reaction time at traffic light parameter and queue entry speed parameter. Later, the travel time of car and BRT were calibrated using mean speed parameter. After the parameters were iteratively calibrated, the model could obtain the optimal value of each parameter as shown in Table 6.1.

After the model developed and calibrated, the scenarios of proposed three solution were evaluated. The result evaluation was commenced with the TSP solution, FS solution and RL solution, respectively.

According to the result of TSP solution, the study summarized that the BRT and the cars travelled in the corridor could gain the benefit of travel time reduction while the cars in the non-corridor received more travel time. This happened due to the fact that the cars had to spend time at the intersection longer to dedicate the green timing to the BRT and cars in the corridor to pass the intersection. The result also revealed that the

travel time reduction of the BRT users and the car users in the inbound direction was greater than the outbound direction in the morning peak hours, while vice versa in the evening peak periods. This was because the traffic congestion occurred seriously in the inbound direction during the morning peak hours and the traffic got worse in the outbound direction during the evening peak hours. The benefit of the travel time saving and economic aspect of using TSP solution was elaborated in the section 4.3.2.1.

Table 6.1 Default and Calibrated Parameters' Value

Calibration criteria	Parameter	Default value	Calibrated value
Capacity calibration	Reaction time at stop	1.20 sec	2.0 sec
	Queue exit speed	4.0 m/s	6.5 m/s
System performance calibration	Reaction time at traffic light	1.60 sec	2.0 sec
	Queue entry speed	1.0 m/s	1.0 m/s
Travel time calibration	Mean speed of Car	110 km/h	48 km/h
	Mean speed of BRT	90 km/h	25 km/h

The solution of FS was to reduce the lane of travel in both inbound corridor and outbound corridor. From this solution, the BRT could directly affect the positive impact, while the other car users were dramatically affected with the negative impacts. The benefit of the travel time saving and economic aspect of using TSP solution was elaborated in the section 4.3.2.2.

The solution of RL was able to reduce the travel time for the specific reversed section. Since the purpose of this solution was to add one additional lane by reversing the lane in the opposite direction that was not congested as another lane. Hence, this solution affected the direction that the lane reversed. But the direction that received the additional lane could decrease the travel time effectively. The benefit of the travel time saving and economic aspect of using TSP solution was elaborated in the section 4.3.2.3.

Therefore, this present study recommended the TSP solution as the most recommended solution to improve the operation of the BRT in Bangkok. Since this

solution had the most positive impact to the network in term of travel time saving among three solutions.

In short, each solution has its own advantages and disadvantages and some issues to take into account when implement each of the solution as described in Table 6.2.

Table 6.2 A Summary of Advantage and Disadvantage of Proposed Solutions

Solution	Advantage	Disadvantage	Travel time saving	Related cost item
Transit Signal Priority (TSP)	BRT and cars in corridor could save travel time.	The travel time of the cars in non-corridor was slightly affected.	15.1 million baht/year	The cost of TSP system, the cost of detector installation in the buses and the cost of maintenance
Fully segregated lane (FS)	Only travel time of BRT could reduce.	Cars in corridor and non-corridor were affected by the increasing of travel time.	- 481.2 million baht/year	The cost of razing the existing median strip or central reservation, the cost of pavement and the cost of installing signs

Solution	Advantage	Disadvantage	Travel time saving	Related cost item
Reversed lane (RL)	The BRT and cars that travelled in the direction that received the additional lane could decrease the travel time effectively.	Both BRT and cars travelled in the direction that the lane reversed were affected by the slightly increasing of travel time.	10.6 million baht/year	The cost of barrier and the cost of installation

6.1.3 BRT Service Assessment

From the empirical results, this study found that the availability of the BRT service was LOS B and frequency served the users was LOS A in the peak hours. While considering the operational travel time of the BRT, most of the cases were under the “LOS B”. This implied that the service of the BRT was in the good condition. This study also revealed the travel characteristics of the users. Since most of the BRT users created their trip from their home to the working place and school or from their working place and school to their home rather than other places in the weekdays. The users only used the BRT for the purpose of shopping in the weekends for most of the cases. It was obviously showed that the major travel purpose of the BRT users was working and studying and their trip generation of the users was home-based work trip and home-based school trip. This, therefore, confirmed that the BRT was served the working staff and student due to the special characteristics of the study area which surrounded by company buildings and educational places. Interestingly, the result revealed that choice users preferred to use the BRT rather than captive users on account of the fact that BRT is the only fastest and most convenient served in the congested area. And the most preferable mode that the users used to access the station and egress from the station was walking mode. This implied that the users’ origin and destination were closed to the BRT stations. Another aspect of this study revealed that the satisfaction matter of

‘cleanliness’, ‘good accessibility’ and ‘comfort when traveling by BRT’ was closed to what the users expected even it was slightly lower. The matter of ‘punctuality’, ‘being not overcrowded on bus’, ‘safety’, ‘reliability’ and ‘travel time’ when traveling by BRT was quite lower than what they expected. Nevertheless, the cost of travel that expected to be low was over satisfied than what they expected to be.

Besides, the study also identified the factors that should be improved in order to gain more attractive of using BRT, which were the operational improvement factor, service improvement factor, and other improvement factor which concerned about cost and safety issue. The operational factor was prioritized to improve. This factor consisted of applying ITS system at the at-grade intersections, upgrading the condition of buses and stations, operating in the segregated lane (BRT lane only), and accessing the BRT information easily. While the following factor was the service improvement factor, which included expanding service time in the morning, expanding service time in the evening, and adding more frequency in the rush hours. The last factor to be improved was other concerned improvement factor, which included cancelling flat rate, and improving driving skill of BRT driver.

6.2 Study Contributions

6.2.1 Academic Contribution

Undeniably, the majority of the past research in the context of simulation has provided the parameters to put in the simulation in Bangkok. However, the parameters were not able to represent the real traffic condition. Therefore, in the context of academic contribution, the empirical results of the traffic simulation could provide the calibrated parameters as shown in Table 6.1 to truly represent the traffic simulation in Bangkok especially for such a congested area. The parameters calibrated in the study could be the input value as the driving behavior parameter in the simulation model. In which, it could obviously help the researcher to save the time of calibrating the parameters in lieu of starting from the unknown value. Since the process of calibration was the time consumed process. Moreover, this study also showed the advantages and disadvantages of each solution adopted in this study. Since there were no previous studies provide the possible solution to improve the BRT operation in Bangkok

according to the critical reviews. So, this could contribute as the alternative way for improving the operational issue of the BRT in Bangkok. This could be the guideline for the city planner and decision makers to take the proposed solution in this study into account for solving the problem that is similar to the Bangkok BRT. Together with the simulation contribution, this study could also provide the factors that should take into consideration when there is a need to improve or planning BRT in the future.

6.2.2 Practical Contribution

The TSP solution was proposed to deal with the problem that the BRT stuck with the traffic light at the at-grade intersection and the traffic weaving time for the BRT. The fully segregated lane solution was proposed to solve the problem of sharing lane with other road users and to eliminate the interruption from the outside vehicles used in the segregated lane. The reversed lane solution was proposed to reduce the congestion in the serious road section and to utilize the lane that did not have the serious congestion in the effective way. However, the illegal U-turn problem was recommended to ask the relevant authority to stop this action.

The findings of this study contributed to conclude as the policies for the city planners or decision makers for the issue of improving the quality of the BRT in Bangkok. The summary of the policies related to the operation improvement were described in Table 6.3. Additionally, the summary of the non-operational policies was described in Table 6.4.

Table 6.3 Research Findings and Operational Policy Recommendations

Research findings	Policy Recommendations
1) The TSP solution is recommended to be appropriate and possible solution for improving the current operation of the BRT in Bangkok	• By applying the TSP, the city planners and decision makers have to consider the cost of TSP system and the cost of detector installation in the buses • The TSP system could also cause the delay to the network if the system is not well enough maintained. So, the

Research findings	Policy Recommendations
	cost of maintenance should also be taken into consideration • Before applying the solution, the city planners and decision makers should inform the information to the road users on how beneficial of the system be. Since there will be negative comments from the road users but the positive impact is greater. So, that it is essential to make the people clearly understand of the TSP system • When there is more demand of users than the current demand using BRT, this solution is more effective and beneficial to the whole network
2) The RL solution is also recommended to be a possible solution to help improving the BRT operation in Bangkok	• By using RL solution, the city planners and decision makers have to consider the cost of razing the existing median strip or central reservation, the cost of pavement and the cost of installing signs. So that this solution was consider costly and timely to implement • This solution will be more practical when the demand of users is increased
3) The solution of FS has great benefit to the BRT but not the road users at the current demand of using BRT	• The cost of implement this solution is not expensive as the TSP and RL solution, but it is not recommended to implement with the current demand of 960 pax/hour. This solution will cause

Research findings	Policy Recommendations
	the huge negative impact to the road users. But if the demand of the BRT users reaches approximately 19,320 passenger per hour, it is worth to implement.
4) The difference of travel time between BRT and private mode (automobile) is comparable, but BRT still perform slower than the automobile for most of the cases	• The issue of travel time of BRT should be taken in the policy makers' consideration in order to improve Bangkok BRT to be the real rapid public transportation mode. For instance, the BRT should have its own lane for whole corridor, provide the ITS system to facilitate the BRT at the intersections
5) Most of the satisfaction levels are under what the users expected especially the crowded of passengers on the BRT and punctuality of the BRT	• The policy makers should focus on these issues to make the users reach their expectation of using BRT service in Bangkok, including: - Punctuality of the BRT - Overcrowded of passengers on BRT - Safety - Reliability on BRT system - Travel time of BRT
6) There are three major factors from the empirical analysis result by EFA affecting in the improvement of BRT in Bangkok, which are: • Operational improvement • Service improvement	• The policy makers should prioritize these three factors. In which, the operational improvement should be highly prioritized, followed by the service improvement, cost and safety improvement, respectively

Research findings	Policy Recommendations
Cost and safety improvement	

Table 6.4 Research Findings and Non-operational Policy Recommendations

Research findings	Policy Recommendations
1) Working group and student group are the majority of the BRT users in the current BRT route in Bangkok.	The policy makers should focus on working group and student group to increase the use of BRT in Bangkok. For instance, provide an attractive promotion or issue a special card for these groups
2) The characteristics of the operating area affect the purpose of users' trips since the current BRT is located in the business and education area	The characteristics of BRT area should be focused by the policy makers. For example, if the BRT area is located in the education zone, the stations should be located in front of the schools or universities
3) The mode of walking and using motorcycle taxi is the major mode used to access and egress by the users in Bangkok	The mode of walking and using motorcycle taxi should be taken in account when making the policy in Bangkok in order to facilitate people in using BRT. For illustration, there should have a proper waiting area for the users or should organize the motorcycle taxi into a system
4) There are several combined modes between BRT and other public modes like train or bus When travelling from the origin to destination of the users. In which, the BRT cannot be a main mode of travel, but a feeder mode	The policy makers should more focus on the interchange's facilities like providing some information of the surrounded interchange modes. By doing so, BRT will capture the more interest from public since it becomes

Research findings	Policy Recommendations
	more convenient and be a good feeder mode
5) The frequency or headway of the current BRT is considered in the acceptable range according to the real operation and the perception of the users since the users are satisfied with “LOS B, LOS A, LOS C” more than 90% but the waiting time of the users is long especially in the peak hours.	The policy makers should focus on the waiting time of the BRT in Bangkok, which the appropriate size of bus should be considered. The policy makers also need to focus on the frequent headway of the BRT when there are more demands of using BRT. For example, provide more buses in the rush hours.

6.3 Study Limitations and Future Research Directions

This present study has taken approximately one and half year to complete the objectives. During the time of conducting this study, the process of data collection of the traffic data and the questionnaire survey consumed much time. Also, the calibration process was another time consumed. Therefore, there were some limitations which this study could not take into consideration due to the time constraint. Since this study did not have enough time and manpower to help collecting data especially the mid-block traffic volumes and the recent traffic volumes at each intersection. Also, the data used in the simulation was analyzed by using the PCU data which means that the results analyzed in this study was based on the traffic composition of the provided data. In which, it could affect the driving behavior in the calibration process if the traffic composition is changed. Therefore, the midblock data should be paid more attention for the calibration stage. Moreover, some parameters in the microscopic simulation should be calibrated such as distance zones, visibility distance, vehicle's acceleration and deceleration, guidance acceptance, etc. For the future study, LOS is also recommended to apply in order to measure the traffic condition after applying the solutions. For the attitude part, the perspective of the non-BRT users should be included. Therefore, it would reveal some interesting factors to help BRT improve in more effective way.

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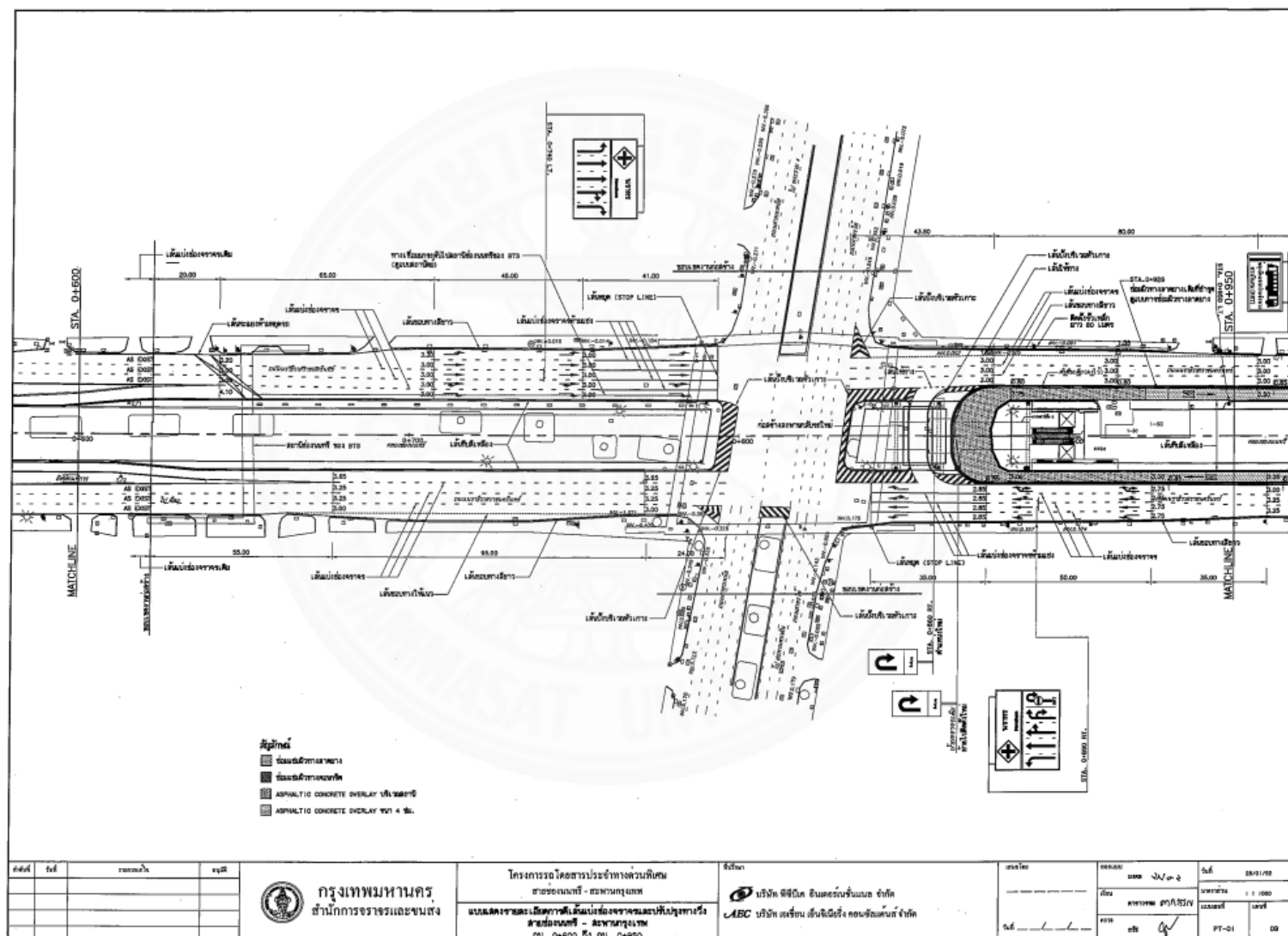
The seal of Thammasat University is a large, faint, circular watermark in the background. It features a central emblem with a crown and a lotus flower, surrounded by the university's name in Thai and English.

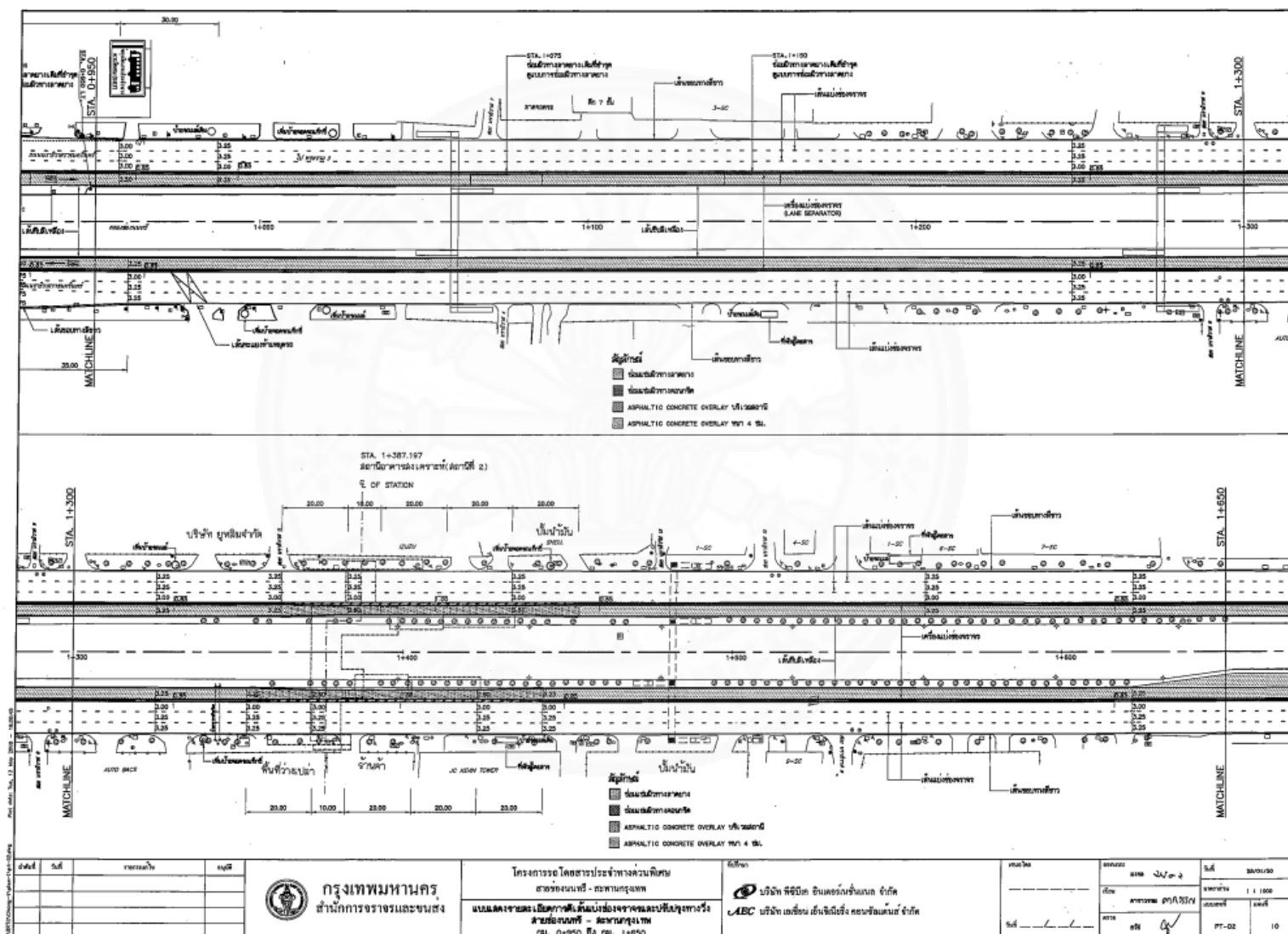
APPENDICES

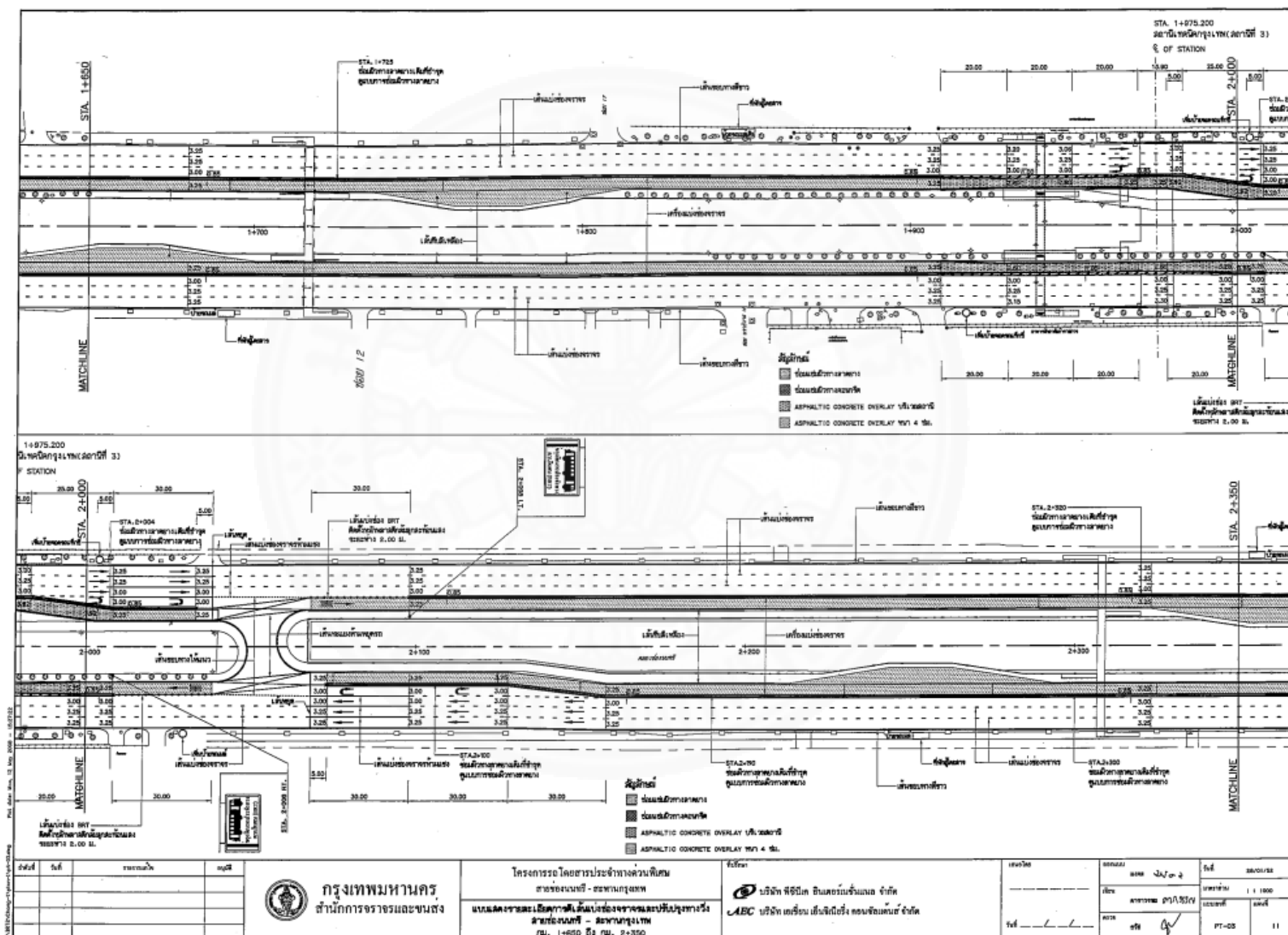
APPENDIX A

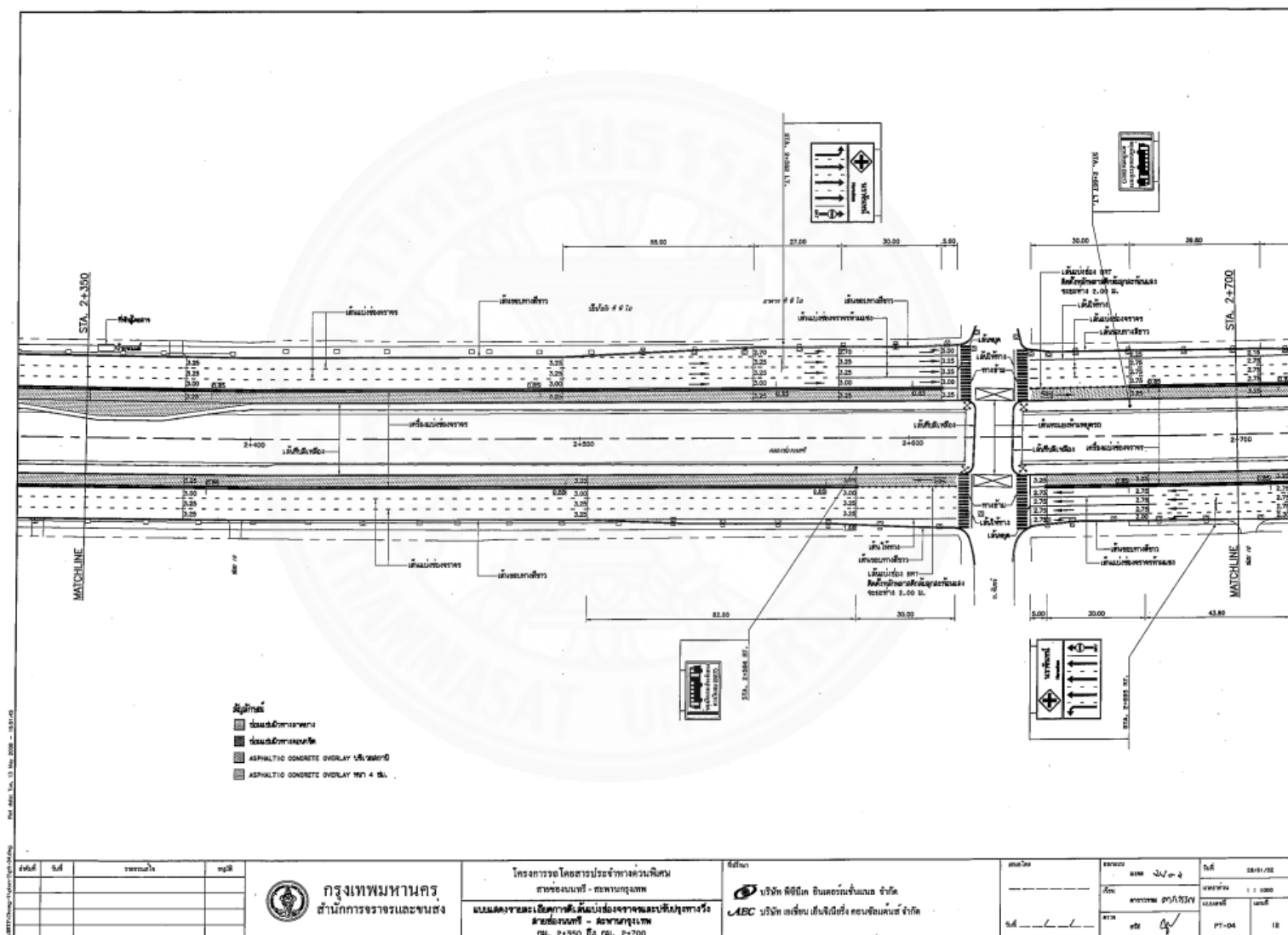
Example of Construction CAD Drawing of Bangkok BRT











APPENDIX B**Example of Traffic Volume Data and Traffic Signal Duration**

ชื่อทางแยก สาทร์ - นราธิวาส

Sathon - Narathiwat

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2558)

ถนน สาทร์ - นราธิวาส

หมายเลข 220

วันที่ 16 กรกฎาคม 2558

สภาพอากาศ ปกติ

(Sathon Rd. - Narathiwat Rd.)

ทิศทาง	เวลา	ปริมาณการจราจรรวมต่อชั่วโมง (คัน/ชม.)										(ไม่รวมรถจักรยานยนต์)										ปริมาณ รว		เฉลี่ย
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ค่าสูงสุด	ค่าต่ำสุด	รวม		ค่าสูงสุด	ค่าต่ำสุด	รวม	ค่าสูงสุด	ค่าต่ำสุด	
NB	1	163	141	229	283	344	389	368	337	346	418	451	341	3810	141	451	330							
	2	454	451	430	657	733	743	757	689	618	660	706	508	7406	430	757	628							
	3	258	325	370	409	358	355	353	397	395	359	323	291	4193	258	409	351							
	4	169	193	186	226	232	225	225	226	217	151	116	111	2277	111	232	203							
	เข้า	1044	1110	1215	1575	1667	1712	1703	1649	1576	1588	1596	1251	17686	1044	1712								
	ออก	1852	1923	1803	1816	1928	2052	2081	2012	2248	2009	1982	1842	23548	1803	2248								
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม										
	15	252	270	281	381	400	438	428	407	394	395	420	342	4408										
	30	529	574	574	763	852	840	850	831	796	768	825	660	8862										
	45	770	818	879	1174	1260	1271	1289	1238	1187	1188	1231	975	13280										
SB	QL (เมตร)	100	100	69	53	50	50	107	100	124	140	150	150											
	5	668	702	552	448	427	486	549	476	435	471	399	336	5949	336	702	510							
	6	2039	1959	1683	1710	1764	1768	1783	1624	1647	1347	1059	1095	19478	1059	2039	1653							
	7	897	868	745	692	684	708	691	691	788	812	852	795	9223	684	897	803							
	8	660	567	351	297	241	233	222	203	140	147	125	122	3308	122	660	277							
	เข้า	4264	4096	3331	3147	3116	3195	3245	2994	3010	2777	2435	2348	37958	2348	4264								
	ออก	2361	1753	1842	2004	2029	2134	2026	1884	1845	1757	1965	1751	23351	1751	2361								
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม										
	15	1041	1072	848	788	753	787	805	755	736	736	620	611	9552										
	30	2115	2111	1701	1571	1511	1577	1614	1469	1485	1428	1243	1215	19040										
WB	45	3167	3147	2499	2355	2320	2365	2416	2226	2219	2126	1848	1793	28481										
	QL (เมตร)	210	153	150	150	150	121	139	150	150	150	150	150											
	9	132	136	156	159	154	167	154	180	190	216	223	155	2022	132	223	171							
	10	430	462	491	462	507	568	587	574	726	639	686	623	6755	430	726	565							
	11	259	243	280	286	313	305	278	292	284	304	309	261	3414	243	313	287							
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
	เข้า	821	841	927	907	974	1040	1019	1046	1200	1159	1218	1039	12191	821	1218								
	ออก	1122	1153	982	1105	1160	1229	1306	1165	1053	1131	1105	844	13355	844	1306								
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม										
	15	209	217	264	237	224	261	248	260	286	267	315	278	3066										
VB	30	398	433	480	451	485	517	518	522	579	557	628	529	6097										
	45	598	622	719	683	720	789	758	766	884	842	913	802	9096										
	QL (เมตร)	131	100	100	100	100	100	111	120	144	150	150	150											
	13	356	400	381	436	505	551	578	521	517	407	328	313	5293	313	578	443							
	14	1279	802	982	1138	1131	1207	1158	1052	1075	888	1080	1027	12819	802	1279	1080							
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
	เข้า	1635	1202	1363	1574	1636	1758	1736	1573	1592	1295	1408	1340	18112	1202	1758								
	ออก	2429	2420	2209	2278	2276	2290	2201	2232	1922	1605	1541	25693	1541	2429									
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม										
	15	400	345	326	351	390	442	441	384	378	357	340	348	4502										
QL (เมตร)	30	835	632	646	769	823	899	874	761	797	553	696	671	8956										
	45	1236	909	992	1166	1219	1310	1287	1176	1206	938	1053	995	13487										

QL = +300 หมายถึง 300 เมตรขึ้นไป
QL = -50 หมายถึง น้อยกว่า 50 เมตร

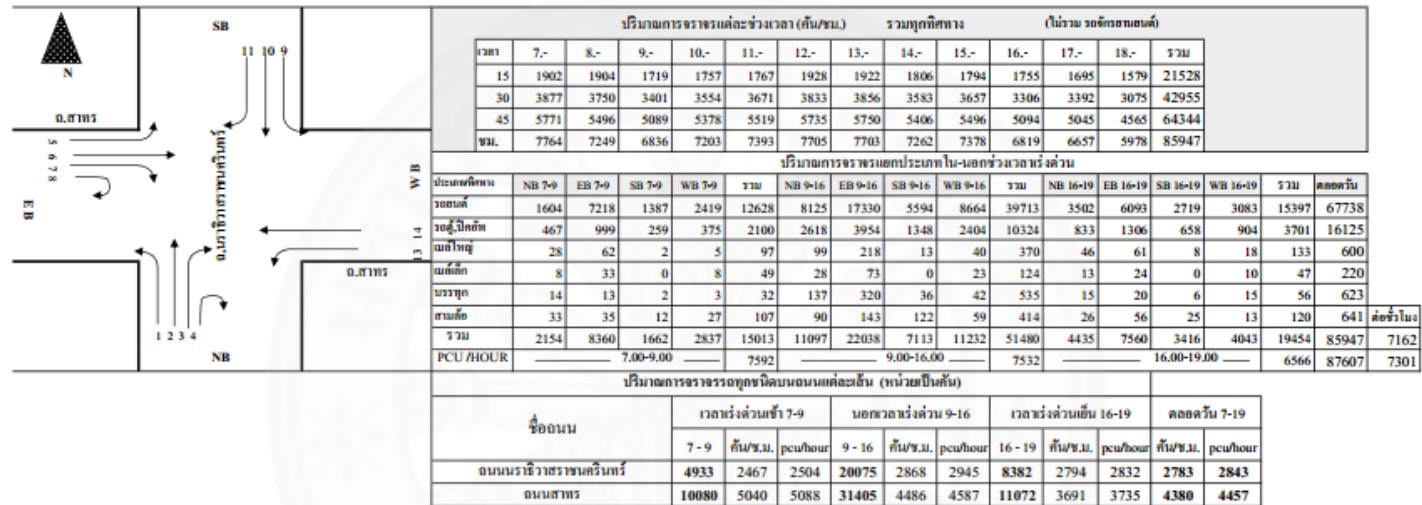


ขอสงวนสิทธิ์โดย สำนักการจราจรและขนส่ง กรุงเทพมหานคร
หากนำข้อมูลไปใช้ขอให้อ้างถึงแหล่งที่มาด้วย

ผู้ตรวจ.....วันที่...../...../.....
ผู้พิมพ์.....วันที่...../...../.....

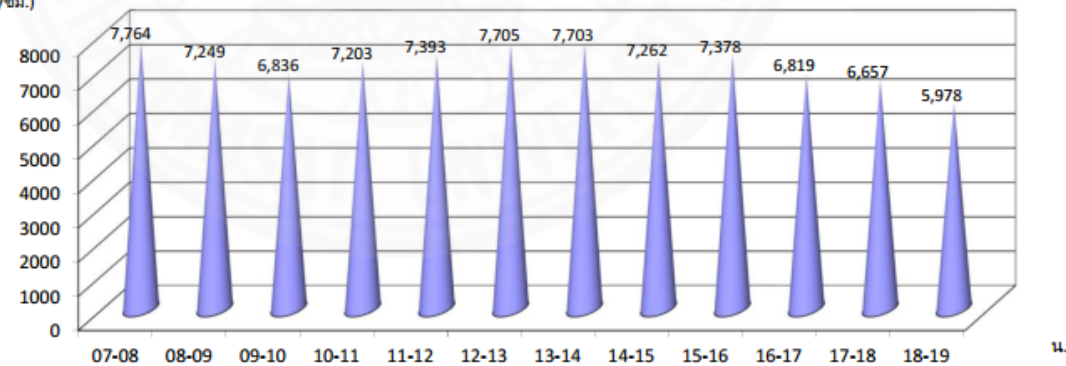
ชื่อทางแยก **สาทร - นราธิวาส****Sathon - Narathiwat****ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2558)**ถนน **สาทร - นราธิวาส**หมายเลข **220**วันที่ **16 กรกฎาคม 2558**สภาพอากาศ **ปกติ**

(Sathon Rd. - Narathiwat Rd.)



ปริมาณ(คัน/ชม.)

ปริมาณการจราจรตามช่วงเวลา



ชื่อทางแยก เจริญราษฎร์ (Charoen Rat)

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2560)

ถนน พระรามที่ 3 - เจริญราษฎร์

หมายเลข 406

วันที่ 8 พฤษภาคม 2560

สภาพอากาศ ปกติ

Rama III Rd. • Charoen Rat Rd.

 ถนนศรีวิบูลย์		SB		เวลา		ปริมาณการจราจร แต่ละช่วงเวลา (คัน/ชม.)																(ปริมาณ รถจักรยานยนต์)		ปริมาณ รด		เฉลี่ย
						ทิศทาง																รวม		ค่าสูงสุด	ค่าต่ำสุด	
EB	5	667	620	729	733	802	818	735	651	624	666	680	490	8215	490	818	731									
	6	806	778	555	558	455	509	450	360	345	301	302	303	5722	301	806	513									
	6*	3468	3299	3211	2850	2515	2449	2431	2159	2615	2565	2587	2544	32693	2159	3468	2863									
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	8	147	191	281	199	219	269	248	280	261	278	321	301	2995	147	321	265									
	เข้า	5088	4888	4776	4340	3991	4045	3864	3450	3845	3810	3890	3638	49625	3450	5088										
	ออก	3751	3689	3592	3499	3187	3266	3117	2773	2772	3125	2890	2448	38109	2448	3751										
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม												
SB	15	1322	1278	1150	1168	1029	981	965	981	981	959	992	931	12737												
	30	2600	2495	2377	2268	2033	1999	1930	1972	1927	1921	1919	1833	25274												
	45	3862	3646	3589	3320	3039	3006	2917	2535	2865	2832	2931	2727	37269												
	QL (เมตร)	150	140	120	88	70	67	50	50	50	50	50	50													
	9	923	786	589	561	628	646	674	592	544	526	472	490	7431	472	923	645									
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	10*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	11	832	922	865	848	812	778	733	614	572	770	710	574	9030	572	922	768									
WB	12	332	320	246	232	269	262	265	272	324	310	321	270	3423	232	332	293									
	เข้า	2087	2028	1700	1641	1709	1686	1672	1478	1440	1606	1503	1334	19884	1334	2087										
	ออก	1702	1596	1692	1732	1815	1781	1679	1468	1538	1531	1571	1271	19376	1271	1815										
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม												
	15	512	565	436	416	419	405	433	365	352	362	372	326	4963												
	30	1067	1078	880	800	810	846	859	719	709	782	763	685	9998												
	45	1617	1544	1292	1213	1270	1252	1276	1110	1080	1176	1142	1002	14974												
	QL (เมตร)	71	68	70	53	50	50	50	50	50	50	50	50													
QL	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	14	511	463	428	584	432	394	411	316	289	381	402	356	4967	289	584	446									
	14*	2261	2113	2018	1868	1724	1825	1725	1563	1650	1696	1457	1217	21117	1217	2261	1880									
	15	703	656	717	767	744	701	679	545	590	555	570	511	7738	511	767	662									
	16	224	249	198	222	269	269	266	226	273	244	207	193	2840	193	273	240									
	เข้า	3699	3481	3361	3441	3169	3189	3081	2650	2802	2876	2636	2277	36662	2277	3699										
	ออก	5421	5112	4553	4191	3867	3873	3821	3337	3777	3636	3568	3530	48686	3337	5421										
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม												
QL (เมตร)	15	908	959	864	885	756	811	814	630	696	674	717	545	9259												
	30	1791	1844	1698	1766	1574	1658	1564	1324	1341	1338	1413	1141	18452												
	45	2734	2661	2526	2617	2390	2417	2336	1949	2073	2083	2051	1717	27554												
	QL (เมตร)	79	60	53	50	50	50	50	50	50	50	50	50													



ขอสงวนสิทธิ์โดย สำนักการจราจรและขนส่ง กรุงเทพมหานคร
หากนำข้อมูลไปใช้ขอให้อ้างอิงแหล่งที่มาด้วย

ชื่อทางแยก **เจริญราษฎร์ (Charoen Rat)**

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2560)

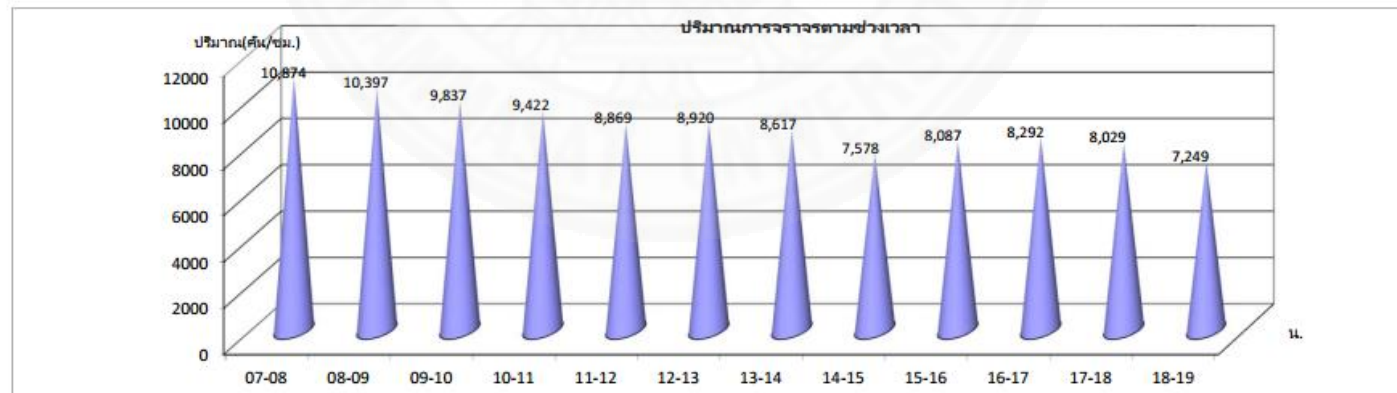
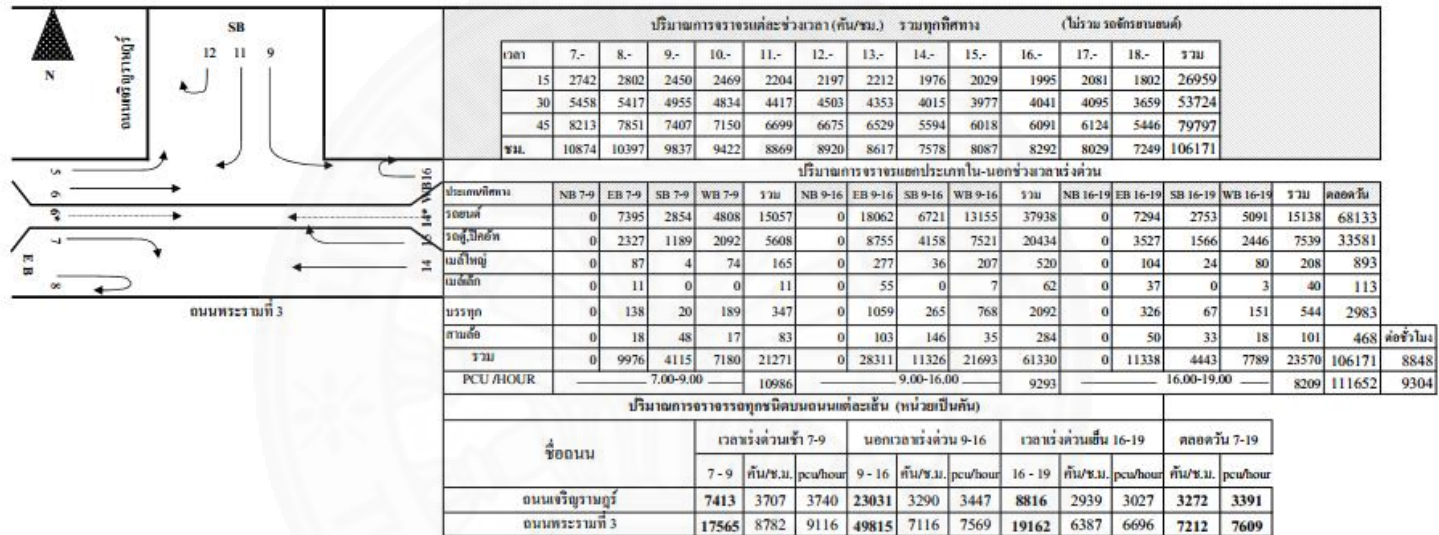
ถนน พระรามที่ 3 - เจริญราษฎร์

หมายเลข 406

วันที่ 8 พฤษภาคม 2560

สภาพอากาศ ปกติ

Rama III Rd. - Charoen Rat Rd.



ชื่อทางแยก **รัชดา - นราธิวาส**

(Ratchadaphisek - Naradhiwas Rajanagarindra)

ถนน **รัชดา - นราธิวาสราชนครินทร์**

หมายเลข **223**

วันที่ **7 กรกฎาคม 2559**

สภาพอากาศ **ปกติ**

Ratchadaphisek Rd.- Naradhiwas Rajanagarindra Rd.

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2559)

ทิศทาง	เวลา	ปริมาณการจราจรในแต่ละช่วงเวลา (คัน/ชม.)																(ไม่รวมรถจักรยานยนต์)			เฉลี่ย
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ค่าสูงสุด	ค่าสูงสุด	รวม	ค่าสูงสุด	ค่าสูงสุด	รวม	
NB	1	324	325	370	456	539	579	527	551	577	568	649	687	6152	324	687	526				
	2	1629	1532	1404	1188	1047	1079	1082	1012	1145	1148	1237	1072	14575	1012	1629	1281				
	3	172	166	190	202	163	180	178	190	204	187	160	151	2143	151	204	179				
	4	717	647	705	725	714	733	767	812	761	692	785	703	8761	647	812	736				
	เข้า	2842	2670	2669	2571	2463	2571	2554	2565	2687	2595	2831	2613	31631	2463	2842					
	ออก	2619	2724	2714	2818	2583	2643	2698	2889	2900	2719	2945	2757	33009	2583	2945					
	นท	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม							
	15	675	693	616	674	626	654	681	640	695	675	678	655	7962							
	30	1383	1356	1297	1300	1218	1270	1270	1278	1330	1330	1410	1293	15735							
	45	2070	2013	1977	1952	1838	1887	1921	1947	2005	1974	2140	1933	23657							
	QL (เมตร)	80	65	70	71	53	66	80	80	95	100	100	84								
	5	381	390	361	365	433	399	384	386	385	372	349	314	4519	314	433	381				
	6	541	494	459	463	468	447	477	565	541	569	483	438	5945	438	569	518				
	7	614	711	649	623	499	503	548	619	691	616	625	629	7327	499	711	618				
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	เข้า	1536	1595	1469	1451	1400	1349	1409	1570	1617	1557	1457	1381	17791	1349	1617					
	ออก	1558	1304	1368	1321	1436	1422	1436	1403	1531	1588	1842	1744	17953	1304	1842					
	นท	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม							
	15	415	435	344	377	360	323	360	405	415	424	341	348	4547							
	30	790	830	730	718	695	669	723	826	804	801	752	701	9039							
	45	1168	1197	1120	1088	1011	1005	1050	1190	1225	1168	1123	1034	13379							
	QL (เมตร)	68	65	50	58	58	55	50	50	73	90	85	55								
SB	9	147	165	127	158	159	165	175	140	162	138	177	127	1840	127	177	159				
	10	700	791	770	809	795	800	790	799	785	809	841	754	9443	700	841	827				
	11	249	231	260	288	321	310	343	319	327	370	485	370	3873	231	485	326				
	12	65	65	47	47	29	37	36	40	42	41	52	34	535	29	65	45				
	เข้า	1161	1252	1204	1302	1304	1312	1344	1298	1316	1358	1555	1285	15691	1161	1555					
	ออก	2524	2451	2191	2043	1929	1850	1889	1828	1951	1916	2026	1752	24350	1752	2524					
	นท	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม							
	15	267	313	309	320	325	320	346	339	322	313	414	332	3920							
	30	568	621	598	651	655	652	687	652	660	665	808	659	7876							
	45	851	948	914	974	956	978	1023	975	983	1003	1181	979	11765							
	QL (เมตร)	69	75	58	55	53	54	50	50	73	80	80	55								
	13	588	575	590	661	575	607	593	659	663	602	694	671	7478	575	694	632				
	14	985	748	738	577	576	533	566	533	627	650	708	687	7928	533	985	685				
	15	449	464	379	443	420	335	387	390	379	355	388	332	4721	332	464	396				
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	เข้า	2022	1787	1707	1681	1571	1475	1546	1582	1669	1607	1790	1690	20127	1475	2022					
	ออก	860	825	776	823	790	792	830	895	907	894	820	716	9928	716	907					
	นท	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม							
	15	507	491	453	445	416	375	390	434	451	405	428	451	5246							
	30	1034	935	854	873	852	731	767	832	869	833	877	886	10343							
	45	1518	1392	1302	1261	1218	1110	1163	1191	1234	1196	1331	1282	15198							
	QL (เมตร)	76	65	65	70	76	66	80	80	95	118	120	100								

QL - +300 หมายถึง 300 เมตรขึ้นไป
QL - -50 หมายถึง น้อยกว่า 50 เมตร



ขอสงวนสิทธิ์โดย สำนักการจราจรและขนส่ง กรุงเทพมหานคร
หากนำข้อมูลไปใช้ขอให้แจ้งแหล่งที่มาด้วย

ผู้ตรวจ.....วันที่...../...../.....
ผู้พิมพ์.....วันที่...../...../.....

Traffic Signal Duration Data

Intersection					
Sathorn-Ratchadaphisek Intersection					
No	M-Directions	T1	T2	T3	Average
1	↘↓ U	81.7	80.41	80.2	80.77
2	←↙	44.95	44.6	44.3	44.62
3	↑↓	35.56	39.17	37.6	37.44
4	↓↘ U	77.58	85.77	83.9	82.42
5	→↗	55.34	55.37	55	55.24
6	↑↓	43.49	40.01	42	41.83
Thanon Chan-Naradhiwat Intersection					
No	Directions	T1	T2	T3	Average
1	↙←	63.67	85.11	76.96	75.25
2	↑↘↓	73.77	73.28	74.45	73.83
3	↑↻↗	29	29.02	29.12	29.05
4	→↗↻	42.05	46.11	44.11	44.09
Ratchadaphisek-Naradhiwat Intersection					
No	Directions	T1	T2	T3	Average
1	↑↓	70.79	62.57	57.68	63.68
2	↑↘	38.21	44.8	57.68	46.90
3	↘↘	15.2	16.15	15.23	15.53
4	→↗	34.42	24.53	16.69	25.21
5	→←	45.95	57.65	50.49	51.36
6	←↙	35.49	36.33	38.18	36.67
Naradhiwat-Rama III Intersection					
No	Directions	T1	T2	T3	Average
1	↑↓	38.25	40.1	39.5	39.28
2	↘↓	29.5	30.73	30.5	30.24
3	↗	44.03	44.95	44	44.33
Rama III-Industrial Ring Intersection					
No	Directions	T1	T2	T3	Average
1	↙U	73.19	123.1	89.34	95.21

Intersection					
2	↑↓	40.46	29.83	35.23	35.17
3	↗	128.78		146.18	137.48
Rama III-Yan Nawa Intersection					
No	Directions	T1	T2	T3	Average
1	↑	46.58	46.63	45.36	46.19
2	↘↓	30.86	31.48	32.6	31.65
3	↘	17.97	16.86	17.3	17.38
Rama III-Sathupradit Intersection					
No	Directions	T1	T2	T3	Average
1	↑↓	28.85	28.4	29.38	28.88
2	↗↘	45.08	43.27	46.24	44.86
3	↖↑	16.4	14.965	15.12	15.50
4	→↘	16.4	14.965	15.12	15.50
Rama III-Ratchadaphisek Intersection					
No	Directions	T1	T2	T3	Average
1	↖	81.05	72.53	79.6	77.73
2	↑↓	47	42.54	40.18	43.24
3	↑↗	11.59	31.22	26.16	22.99
Rama III-Charoenrat Intersection					
No	Directions	T1	T2	T3	Average
1	↖	58.37	41.47	47.31	49.05
2	↑↗	61.94	46.4	34.82	47.72
3	↑↓	35.52	36.04	62.81	44.79
Rama III-Charoen Krung Intersection					
No	Directions	T1	T2	T3	Average
1	←↖	31.43	26.67	28.5	28.87
2	→←	38.17	36.57	35.99	36.91
3	→↘U	34.69	36.42	39.34	36.82
4	↑↗	55.68	55.02	55.63	55.44
5	↓↘	60.26	58.88	55.96	58.37

Intersection					
Rama III-Charoen Nakhon Intersection					
No	Directions	T1	T2	T3	Average
1	↖←	85.25	79.41	82.7	82.45
2	↓↘	47.32	82.15	65.5	64.99
3	→↗	61.37	59.6	60.9	60.62
4	↓↘	24.94	36.02	35.6	32.19
5	↑↗	68.57	53.96	55.6	59.38
Mahai Sawan-Somdet Prachao Taksin Intersection					
No	Directions	T1	T2	T3	Average
1	↖←	36.91	38.17	35.17	36.75
2	→↗	41.59	45.61	41.83	43.01
3	↑↓	58.25	47.39	55.4	53.68
4	↘↗	22.72	32.74	29.6	28.35
Ratchadaphisek-Ratchapruek Intersection					
No	Directions	T1	T2	T3	Average
1	↗↖↘	86.72	74.75	83.7	81.72
2	↓↘U	43.4	40.37	51.76	45.18
3	↑↗U↘	54.96	67.97	66.7	63.21
4	↑↓	24.09	47.92	45.3	39.10

APPENDIX C
Questionnaire Survey





A Interview of Bus Rapid Transit's Users of Using BRT and Influenced Factors of Choosing BRT



DD MM YY			HH MM		Station		Interview No.	
Date			Time				Direction: 1Inbound/2Outbound	

Commentary: This questionnaire was designed by the master degree student majored in Civil Engineering and Technology of Sirindhorn International Institute of Technology, Thammasat University. Please fill your answer based on your true experience. All your answers will be kept confidentially and proceeded for the statistics analysis for the use of education only. Thank you very much for your cooperation.

Please put a tick ✓ into the box ☐ or fill your information in the provided space based on your true experience

Part 1: Travel Information

1.1. Origin of trip..... Time

HH	MM

 Destination of Trip..... Time

HH	MM

Origin of return trip..... Time

HH	MM

 Destination of return trip..... Time

HH	MM

1.2. Outbound: Boarding point:..... Alighting point:.....
Inbound: Boarding point:..... Alighting point:.....

1.3. Purpose of travel ☐

1. Working 2. School 3. Personal bussiness 4. Meeting friend 5. Shopping 6. Other.....

1.4. Mode, time and cost of travel for Outbound and Inbound to/from Bus Rapid Transit station
Please choose 1-7 to fill in the boxes of each travel mode

1. walking	2. bicycle	3. motorcycle	4. motorcycle taxi	5. car	6. taxi	7. other.....
Out <u>bound</u>	Mode of travel			Time (minute)		Cost (baht)
	→		→		→	
In <u>bound</u>	Mode of travel			Time (minute)		Cost (baht)
	→		→		→	

1.5. In case of using car instead of BRT from origin to destination, you spend.....minutes; distance.....km

1.6. In case of using other public transports (.....) from origin to destination, you spend.....minutes; distance.....km

1.7. How many times have you experienced to wait over scheduling of Bus Rapid Transit?

☐ 1-2times/week ☐ 3-4times/week ☐ 5-6times/week ☐ 7-8times/week ☐ 9-10times/week

1.8. Waiting time at Bus Rapid Transit station minutes

1.9. How often do you use Bus Rapid Transit?

☐ Frequent times/week ☐ Infrequent.....times/month

Part 2: Personal Information

2.1 Gender ☐ M ☐ F 2.2 Age years old 2.4 Income

2.3 Occupation

1. Private company employee 4. Business owner 3. 15,001 – 20,000 baht 2. 10,001 – 15,000 baht

2. Government officer 5. Vendor 5. 25,001 – 30,000 baht 6. 30,001 – 35,000 baht

3. Student 6. Other..... 7. 35,001 – 40,000 baht 8. Over 40,000 baht

2.5 Education level ☐ Under secondary ☐ Secondary and polytechnic ☐ Bachelor ☐ Master or higher

2.6 Vehicle ownership ☐ No ☐ Motorcycle ☐ Car

Part 3: Users' perspective of Bus Rapid Transit's service

In your perspectives, what grade should you evaluate BRT's service? (from A-F)
A is excellent to F is poor (need an improvement)

[illegible]

Part 4: Importance level on the factors of using Bus Rapid Transit

How much do these listed factors affect to your decision of choosing to use Bus Rapid Transit?

	Importance level				
	Strongly disagree				Strongly agree
	1	2	3	4	5
1. Saving cost of travel	☐	☐	☐	☐	☐
2. Travel time is less than using car and taxi	☐	☐	☐	☐	☐
3. On time scheduling	☐	☐	☐	☐	☐
4. Travel comfort	☐	☐	☐	☐	☐
5. Accessibility comfort	☐	☐	☐	☐	☐
6. Cleanliness	☐	☐	☐	☐	☐
7. Passenger density in BRT	☐	☐	☐	☐	☐
8. Safety while using BRT	☐	☐	☐	☐	☐
9. Reliability of BRT system	☐	☐	☐	☐	☐

Part 5: Satisfaction level on the factors of using Bus Rapid Transit

How much do these listed factors affect to your satisfaction of using Bus Rapid Transit?

	Did you experience any problems?		Satisfaction level				
	Yes	No	SD				SA
			1	2	3	4	5
1. Saving cost of travel	☐	☐	☐	☐	☐	☐	☐
2. Travel time is less than using car and taxi	☐	☐	☐	☐	☐	☐	☐
3. On time scheduling	☐	☐	☐	☐	☐	☐	☐
4. Travel comfort	☐	☐	☐	☐	☐	☐	☐
5. Accessibility comfort	☐	☐	☐	☐	☐	☐	☐
6. Cleanliness	☐	☐	☐	☐	☐	☐	☐
7. Passenger density in BRT	☐	☐	☐	☐	☐	☐	☐
8. Safety while using BRT	☐	☐	☐	☐	☐	☐	☐
9. Reliability of BRT system	☐	☐	☐	☐	☐	☐	☐

Part 6: Improvement level on the factors of using Bus Rapid Transit

6.1 How much do you want these listed factors be improved?

	Improvement level				
	SD				SA
	1	2	3	4	5
1. Add frequency of BRT in rush hour	☐	☐	☐	☐	☐
2. Expand the morning service time	☐	☐	☐	☐	☐
3. Expand the evening service time	☐	☐	☐	☐	☐
4. Operate in the segregated lane only	☐	☐	☐	☐	☐
5. Improve BRT buses and stations' condition	☐	☐	☐	☐	☐
6. Facilitate BRT at intersections	☐	☐	☐	☐	☐
7. Be able to access BRT information easier	☐	☐	☐	☐	☐
8. Improve driving skill of BRT's driver	☐	☐	☐	☐	☐
9. Travel cost based on distance	☐	☐	☐	☐	☐

6.2. Are the current existing BRT stations suitable?

☐ Suitable

☐ Unsuitable

6.3. Where should the new BRT station be built?

6.4. Do you have any recommendations?

Thank you very much for your cooperation



cooperated with



APPENDIX D

Calibration and Validation Data



Capacity calibration using saturation headway

First Phase												
Intersections		Int 1	Int 3	Int 4	Int 5	Int 6	Int 9	Int 10	Int 11	Int 12	Int 13	MAPE
Field headway		2.17	2.2	2.25	2.13	2.03	2.11	2.15	2.09	2.13	2.25	
Parameters		Simulated saturation headway (sec)										
Queue Ex	rT@stop											
4	1	1.92	1.90	1.91	1.93	1.90	1.90	1.91	1.90	1.91	1.90	11.22
	1.2	1.93	1.91	1.93	1.94	1.91	1.92	1.93	1.91	1.92	1.92	10.57
	1.4	1.93	1.93	1.94	1.95	1.92	1.93	1.95	1.92	1.94	1.94	9.96
	1.6	1.95	1.95	1.95	1.95	1.93	1.93	1.97	1.93	1.95	1.96	9.41
	1.8	1.95	1.98	1.98	1.99	1.95	1.95	1.99	1.94	1.95	1.96	8.62
	2	1.98	2.00	2.01	2.02	1.99	1.97	1.97	1.97	1.99	1.98	7.50
	2.2	2.01	2.05	2.05	2.08	2.03	2.02	2.00	1.99	2.01	2.02	5.73
	2.4	2.05	2.08	2.09	2.09	2.05	2.08	2.05	2.05	2.05	2.08	4.03
5	1	1.97	1.95	1.95	1.95	1.93	1.91	1.94	1.92	1.93	1.92	9.87
	1.2	1.97	1.97	1.96	1.97	1.95	1.93	1.95	1.93	1.95	1.94	9.17
	1.4	1.98	1.99	1.97	1.98	1.97	1.94	1.98	1.95	1.96	1.97	8.38
	1.6	1.99	2.00	1.99	1.99	1.98	1.95	1.98	1.97	1.98	1.98	7.83
	1.8	2.03	2.05	2.02	2.03	1.99	1.97	1.99	1.99	1.98	1.99	6.76
	2	2.08	2.07	2.05	2.04	2.02	1.99	2.01	2.01	2.02	2.03	5.46
	2.2	2.10	2.09	2.09	2.07	2.05	2.02	2.01	2.03	2.04	2.06	4.55
	2.4	2.15	2.12	2.11	2.10	2.09	2.05	2.04	2.05	2.08	2.07	3.54
6	1	1.99	2.00	1.99	2.07	1.95	2.00	2.01	2.01	2.01	1.98	6.89
	1.2	2.00	2.03	2.00	2.09	1.97	2.03	2.04	2.02	2.03	2.00	5.96
	1.4	2.01	2.05	2.01	2.10	1.98	2.05	2.60	2.04	2.04	2.04	6.85
	1.6	2.01	2.07	2.03	2.11	1.99	2.07	2.07	2.05	2.07	2.06	4.48
	1.8	2.09	2.13	2.10	2.14	2.05	2.12	2.12	2.07	2.09	2.16	2.37
	2	2.16	2.19	2.19	2.17	2.08	2.16	2.13	2.10	2.14	2.24	1.26
	2.2	2.18	2.25	2.24	2.19	2.12	2.18	2.20	2.19	2.22	2.27	2.60
	2.4	2.23	2.29	2.28	2.24	2.18	2.23	2.25	2.24	2.27	2.29	4.66
7	1	2.00	2.04	2.02	2.09	1.97	2.03	2.06	2.05	2.03	2.05	5.36
	1.2	2.01	2.05	2.04	2.11	1.99	2.06	2.07	2.06	2.05	2.07	4.57
	1.4	2.02	2.07	2.05	2.13	2.01	2.09	2.09	2.08	2.07	2.09	3.68
	1.6	2.03	2.09	2.07	2.15	2.02	2.10	2.10	2.09	2.10	2.11	3.13
	1.8	2.08	2.11	2.09	2.19	2.08	2.13	2.15	2.13	2.14	2.17	2.75
	2	2.12	2.16	2.19	2.22	2.11	2.17	2.19	2.17	2.19	2.21	2.81
	2.2	2.17	2.19	2.26	2.25	2.18	2.20	2.22	2.22	2.21	2.27	3.23
	2.4	2.25	2.27	2.29	2.27	2.20	2.23	2.28	2.27	2.27	2.30	5.27
8	1	2.03	2.08	2.05	2.14	2.05	2.09	2.07	2.07	2.05	1.99	4.32
	1.2	2.05	2.09	2.08	2.16	2.06	2.10	2.08	2.09	2.09	2.10	3.32
	1.4	2.06	2.11	2.09	2.15	2.07	2.11	2.11	2.11	2.11	2.12	2.87
	1.6	2.07	2.13	2.11	2.17	2.09	2.13	2.14	2.13	2.14	2.15	2.71
	1.8	2.12	2.18	2.26	2.20	2.17	2.17	2.19	2.19	2.19	2.19	2.88
	2	2.15	2.22	2.29	2.22	2.20	2.22	2.25	2.24	2.23	2.25	3.79
	2.2	2.22	2.28	2.31	2.27	2.23	2.27	2.29	2.27	2.27	2.29	5.61
	2.4	2.25	2.31	2.33	2.30	2.27	2.31	2.32	2.30	2.30	2.32	7.06
9	1	2.05	2.11	2.09	2.15	2.07	2.08	2.14	2.10	2.00	2.11	3.43
	1.2	2.06	2.13	2.10	2.17	2.09	2.11	2.16	2.12	2.12	2.14	2.70
	1.4	2.07	2.15	2.11	2.18	2.10	2.13	2.17	2.14	2.14	2.16	2.76
	1.6	2.10	2.16	2.13	2.19	2.11	2.15	2.19	2.15	2.16	2.17	2.87
	1.8	2.15	2.21	2.28	2.21	2.19	2.19	2.25	2.19	2.20	2.22	3.22
	2	2.23	2.23	2.31	2.23	2.23	2.25	2.28	2.26	2.24	2.26	4.78
	2.2	2.28	2.26	2.33	2.26	2.28	2.28	2.32	2.30	2.29	2.30	6.55
	2.4	2.30	2.34	2.35	2.31	2.30	2.34	2.35	2.33	2.32	2.34	8.32

Second Phase												
Intersections	Int 1	Int 3	Int 4	Int 5	Int 6	Int 9	Int 10	Int 11	Int 12	Int 13	MAPE	
Field headway	2.17	2.2	2.25	2.13	2.03	2.11	2.15	2.09	2.13	2.25		
Parameters		Simulated saturation headway (sec)										
Queue Ex	rT@stop											
5.5	1.9	2.05	2.06	2.05	2.05	2.00	1.99	2.00	2.00	2.03	2.03	5.75
	1.95	2.06	2.07	2.06	2.07	2.01	2.01	2.01	2.02	2.05	2.05	5.05
	2	2.06	2.08	2.08	2.08	2.02	2.05	2.02	2.04	2.07	2.07	4.30
	2.05	2.07	2.09	2.09	2.09	2.04	2.06	2.03	2.05	2.09	2.09	3.79
	2.1	2.11	2.10	2.11	2.11	2.06	2.07	2.04	2.06	2.11	2.12	3.11
6	1.9	2.10	2.13	2.14	2.11	2.06	2.10	2.09	2.02	2.06	2.09	3.07
	1.95	2.13	2.15	2.16	2.13	2.07	2.13	2.11	2.06	2.09	2.17	1.98
	2	2.16	2.19	2.19	2.17	2.08	2.16	2.13	2.10	2.14	2.24	1.26
	2.05	2.16	2.20	2.22	2.18	2.09	2.17	2.14	2.11	2.17	2.27	1.41
	2.1	2.17	2.22	2.24	2.19	2.11	2.19	2.18	2.13	2.19	2.28	1.94
6.5	1.9	2.10	2.14	2.15	2.12	2.07	2.12	2.10	2.05	2.07	2.11	2.66
	1.95	2.14	2.16	2.17	2.14	2.09	2.13	2.11	2.07	2.10	2.18	1.85
	2	2.16	2.19	2.20	2.15	2.11	2.14	2.14	2.09	2.13	2.23	1.08
	2.05	2.18	2.21	2.23	2.17	2.12	2.16	2.16	2.11	2.16	2.25	1.33
	2.1	2.19	2.23	2.26	2.17	2.14	2.17	2.17	2.13	2.19	2.29	2.03
7	1.9	2.09	2.11	2.09	2.19	2.08	2.13	2.15	2.13	2.14	2.17	2.71
	1.95	2.11	2.14	2.14	2.21	2.10	2.15	2.17	2.15	2.16	2.19	2.74
	2	2.12	2.16	2.19	2.22	2.11	2.17	2.19	2.17	2.19	2.21	2.81
	2.05	2.14	2.17	2.22	2.23	2.13	2.18	2.20	2.19	2.20	2.23	2.83
	2.1	2.15	2.18	2.23	2.24	2.15	2.19	2.21	2.20	2.21	2.25	2.94

Capacity calibration using queue length

First Phase												
Intersections		Int 1	Int 3	Int 4	Int 5	Int 6	Int 9	Int 10	Int 11	Int 12	Int 13	Mean percentage error (MPE)
Field queue length		51	65	19	58	15	28	10	17	90	225	
Parameters		Simulated saturation headway (sec)										
Queue En	rT@TL											
0	1	47	41	14	42	15	29	9	16	78	190	14.70
	2	49	56	17	47	14	27	10	15	79	203	9.13
	3	51	61	18	53	14	31	10	17	81	215	5.19
	4	55	69	19	54	14	35	9	16	85	220	7.62
	5	58	72	19	55	15	35	10	16	94	229	6.68
1	1	53	62	17	51	13	25	11	20	82	220	9.39
	2	55	64	18	56	14	26	10	19	94	224	4.86
	3	59	71	18	59	14	29	10	20	98	230	7.09
	4	63	72	19	65	14	30	10	19	99	237	8.73
	5	64	75	19	67	15	31	11	20	105	239	11.76
2	1	57	75	19	58	17	26	11	19	83	220	7.94
	2	56	77	20	62	17	27	11	20	86	226	8.99
	3	60	80	20	65	17	29	10	21	87	230	10.40
	4	63	85	22	69	17	33	11	22	91	231	16.34
	5	67	90	21	71	18	32	11	20	93	235	17.25
3	1	60	81	21	61	16	32	10	17	85	229	8.62
	2	61	85	21	65	16	35	9	18	88	230	12.50
	3	65	90	22	67	15	36	10	18	90	235	13.61
	4	69	92	22	73	17	39	10	17	91	240	17.89
	5	69	93	23	79	18	40	9	18	93	246	22.70
4	1	69	84	23	67	15	33	9	19	88	231	14.56
	2	71	86	24	71	15	35	9	19	90	234	17.10
	3	75	90	24	75	15	37	10	20	92	238	19.89
	4	78	93	25	77	16	39	10	20	96	242	23.82
	5	79	97	26	81	7	40	11	21	99	249	33.10
5	1	65	89	25	79	14	33	9	17	90	235	17.11
	2	69	91	25	84	15	35	11	18	95	239	20.44
	3	73	95	26	87	16	37	10	19	97	244	24.29
	4	73	91	26	91	16	41	9	20	101	249	28.05
	5	77	98	26	95	17	42	10	21	108	251	32.08
Intersections		Int 1	Int 3	Int 4	Int 5	Int 6	Int 9	Int 10	Int 11	Int 12	Int 13	Mean percentage error (MPE)
Field queue length		51	65	19	58	15	28	10	17	90	225	
Parameters		Simulated saturation headway (sec)										
Queue En	rT@TL											
0.5	1.5	48	61	18	53	15	31	9	17	81	214	6.15
	2	49	66	19	55	14	34	9	18	86	219	6.17
	2.5	52	71	19	58	14	36	10	19	90	222	5.95
1	1.5	52	62	18	55	15	25	10	20	86	222	5.12
	2	55	64	18	56	14	26	10	19	94	224	4.86
	2.5	58	69	19	57	15	29	10	20	97	227	5.15
1.5	1.5	55	63	19	56	14	27	10	20	85	222	4.91
	2	58	69	19	60	14	29	11	20	89	226	6.28
	2.5	61	72	19	63	14	31	11	21	91	230	9.32

Capacity calibration using travel time: BRT

BRT travel time calibration			
Field travel time (sec)		78	
Mean speed (kph)	Simulated travel time (sec)	Average Simulated travel time (sec)	Mean percentage error (MPE)
21	95	91	15.38
	88		
	92		
	89		
	90		
	88		
	92		
	93		
	94		
	87		
23	85	84	7.69
	89		
	82		
	83		
	85		
	81		
	80		
	88		
	82		
	84		
25	83	79	1.28
	79		
	77		
	81		
	79		
	76		
	75		
	79		
	82		
	80		
27	76	74	5.13
	70		
	72		
	75		
	78		
	73		
	76		
	73		
	74		
	70		

29	68	71	8.97
	72		
	73		
	68		
	74		
	71		
	67		
	69		
	71		
	72		
31	70	67	14.10
	68		
	62		
	69		
	67		
	64		
	68		
	67		
	65		
	66		

Capacity calibration using travel time: Car

Car travel time calibration			
Field travel time (sec)		40	
Mean speed (kph)	Simulated travel time (sec)	Average Simulated travel time (sec)	Mean percentage error (MPE)
40	65	62	55.00
	61		
	62		
	63		
	65		
	64		
	61		
	62		
	60		
	61		
42	54	56	40.00
	57		
	53		
	57		
	55		
	56		
	56		
	57		
	54		
	56		
44	52	52	30.00
	54		
	50		
	51		
	53		
	54		
	55		
	50		
	53		
	51		
46	44	47	17.50
	47		
	45		
	46		
	45		
	47		
	48		
	46		
	48		
	49		

48	43	41	2.50
	41		
	42		
	39		
	38		
	40		
	41		
	38		
	42		
	41		
50	35	36	10.00
	38		
	36		
	35		
	37		
	36		
	34		
	35		
	36		
	37		
52	34	32	20.00
	33		
	36		
	30		
	31		
	33		
	32		
	30		
	33		
	31		
54	30	29	27.50
	29		
	27		
	28		
	30		
	29		
	27		
	28		
	30		
	29		

Capacity Validation using saturation headway

Intersections	Field headway (sec)	Simulated headway (sec)	Absolute percentage error (PE)
Int 1	2.18	2.18	0.00
		2.19	0.46
		2.21	1.38
		2.17	0.46
		2.2	0.92
		2.19	0.46
		2.19	0.46
		2.18	0.00
		2.17	0.46
		2.21	1.38
Int 3	2.18	2.16	0.92
		2.17	0.46
		2.14	1.83
		2.16	0.92
		2.15	1.38
		2.13	2.29
		2.12	2.75
		2.13	2.29
		2.14	1.83
		2.15	1.38
Int 4	2.24	2.18	2.68
		2.19	2.23
		2.18	2.68
		2.2	1.79
		2.2	1.79
		2.1	6.25
		2.18	2.68
		2.2	1.79
		2.2	1.79
		2.22	0.89
Int 5	2.14	2.16	0.93
		2.17	1.40
		2.14	0.00
		2.14	0.00
		2.17	1.40
		2.18	1.87

Intersections	Field headway (sec)	Simulated headway (sec)	Absolute percentage error (PE)
		2.18	1.87
		2.15	0.47
		2.18	1.87
		2.17	1.40
Int 6	2.09	2.17	3.83
		2.18	4.31
		2.14	2.39
		2.16	3.35
		2.15	2.87
		2.17	3.83
		2.13	1.91
		2.15	2.87
		2.15	2.87
		2.14	2.39
Int 9	2.15	2.14	0.47
		2.15	0.00
		2.15	0.00
		2.15	0.00
		2.17	0.93
		2.16	0.47
		2.16	0.47
		2.17	0.93
		2.18	1.40
		2.16	0.47
Int 10	2.13	2.13	0.00
		2.16	1.41
		2.14	0.47
		2.11	0.94
		2.1	1.41
		2.12	0.47
		2.13	0.00
		2.12	0.47
		2.11	0.94
		2.14	0.47
Int 11	2.15	2.13	0.93
		2.12	1.40
		2.14	0.47
		2.15	0.00
		2.11	1.86

Intersections	Field headway (sec)	Simulated headway (sec)	Absolute percentage error (PE)
		2.13	0.93
		2.12	1.40
		2.11	1.86
		2.12	1.40
		2.11	1.86
Int 12	2.17	2.12	2.30
		2.17	0.00
		2.16	0.46
		2.17	0.00
		2.13	1.84
		2.15	0.92
		2.16	0.46
		2.15	0.92
		2.14	1.38
		2.16	0.46
Int 13	2.26	2.18	3.54
		2.2	2.65
		2.19	3.10
		2.19	3.10
		2.22	1.77
		2.18	3.54
		2.19	3.10
		2.2	2.65
		2.21	2.21
		2.17	3.98
Mean absolute percentage error (MAPE)			1.51

Capacity Validation using queue length

Intersections	Field queue length (veh)	Simulated queue length (veh)	Absolute percentage error (PE)
Int 3	40	38	5.00
		38	5.00
		39	2.50
		40	0.00
		38	5.00
		38	5.00
		37	7.50

Intersections	Field queue length (veh)	Simulated queue length (veh)	Absolute percentage error (PE)
		38	5.00
		39	2.50
		38	5.00
Int 4	47	49	4.26
		49	4.26
		52	10.64
		50	6.38
		50	6.38
		49	4.26
		51	8.51
		50	6.38
		52	10.64
		51	8.51
Int 5	36	39	8.33
		40	11.11
		37	2.78
		39	8.33
		38	5.56
		37	2.78
		40	11.11
		39	8.33
		36	0.00
		37	2.78
Int 6	42	37	11.90
		38	9.52
		40	4.76
		39	7.14
		38	9.52
		39	7.14
		40	4.76
		41	2.38
		39	7.14
		38	9.52
Int 9	30	27	10.00
		26	13.33
		26	13.33
		25	16.67
		27	10.00
		28	6.67
		26	13.33

Intersections	Field queue length (veh)	Simulated queue length (veh)	Absolute percentage error (PE)
		26	13.33
		24	20.00
		25	16.67
Int 10	16	16	0.00
		14	12.50
		14	12.50
		13	18.75
		14	12.50
		15	6.25
		14	12.50
		15	6.25
		14	12.50
		15	6.25
Int 11	26	23	11.54
		24	7.69
		24	7.69
		25	3.85
		25	3.85
		26	0.00
		24	7.69
		25	3.85
		25	3.85
		23	11.54
Int 12	44	45	2.27
		45	2.27
		46	4.55
		45	2.27
		45	2.27
		44	0.00
		43	2.27
		46	4.55
		45	2.27
		44	0.00
Int 13	90	82	8.89
		80	11.11
		83	7.78
		84	6.67
		85	5.56
		85	5.56
		83	7.78

Intersections	Field queue length (veh)	Simulated queue length (veh)	Absolute percentage error (PE)
		84	6.67
		84	6.67
		83	7.78
Mean absolute percentage error (MAPE)			7.11

Capacity Validation using travel time: BRT

No	Simulated travel time (sec)	Absolute percentage error (PE)
1	79	5.33
2	79	5.33
3	75	0.00
4	73	2.67
5	75	0.00
6	81	8.00
7	71	5.33
8	75	0.00
9	77	2.67
10	74	1.33
11	76	1.33
12	77	2.67
13	76	1.33
14	78	4.00
15	73	2.67
16	74	1.33
17	76	1.33
18	79	5.33
19	73	2.67
20	75	0.00
21	71	5.33
22	72	4.00
23	71	5.33
24	70	6.67
25	82	9.33
26	79	5.33
27	83	10.67
28	74	1.33
29	80	6.67
30	76	1.33
31	80	6.67

No	Simulated travel time (sec)	Absolute percentage error (PE)
32	77	2.67
33	76	1.33
34	78	4.00
35	75	0.00
36	82	9.33
37	75	0.00
38	75	0.00
39	76	1.33
40	74	1.33
41	72	4.00
42	78	4.00
43	75	0.00
44	82	9.33
45	79	5.33
46	80	6.67
47	76	1.33
48	82	9.33
49	85	13.33
50	75	0.00
MAPE		3.79

Capacity Validation using travel time: Car

No	Simulated travel time (sec)	Absolute percentage error (PE)
1	35	5.41
2	37	0.00
3	38	2.70
4	39	5.41
5	35	5.41
6	39	5.41
7	36	2.70
8	34	8.11
9	33	10.81
10	38	2.70
11	39	5.41
12	40	8.11
13	41	10.81

No	Simulated travel time (sec)	Absolute percentage error (PE)
14	36	2.70
15	32	13.51
16	35	5.41
17	38	2.70
18	42	13.51
19	38	2.70
20	40	8.11
21	37	0.00
22	42	13.51
23	42	13.51
24	35	5.41
25	38	2.70
26	33	10.81
27	35	5.41
28	39	5.41
29	34	8.11
30	36	2.70
31	40	8.11
32	39	5.41
33	37	0.00
34	40	8.11
35	41	10.81
36	36	2.70
37	35	5.41
38	34	8.11
39	32	13.51
40	35	5.41
41	38	2.70
42	36	2.70
43	39	5.41
44	41	10.81
45	41	10.81
46	38	2.70
47	36	2.70
48	37	0.00
49	42	13.51
50	35	5.41
MAPE		6.27

APPENDIX E
Evaluation of Benefit from Travel Time Saving



Recommendation for establishing the proposed solution in the morning peak hours for the network

Level of demand of passenger	Benefit						
960 pax/hour (full capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-21,187.4	-24,636.1	-3,713,405.4	-11,368,093.7	-15,081,499.1
	FS	470,247.9	-46,914.1	423,333.9	506,339,472.9	-25,171,734.2	481,167,738.6
	RL	-4,631.7	-10,475.5	-15,107.2	-4,987,151.2	-5,620,628.8	-10,607,780.0
480 pax/hour (half capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-10,593.7	-14,042.4	-3,713,405.4	-5,684,046.9	-9,397,452.3
	FS	470,247.9	-23,457.0	446,790.9	506,339,472.9	-12,585,867.1	493,753,605.8
	RL	-4,631.7	-5,237.7	-9,869.4	-4,987,151.2	-2,810,314.4	-7,797,465.6
1,440 pax/hour (1.5 times of full capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-31,781.1	-35,229.8	-3,713,405.4	-17,052,140.6	-20,765,546.0
	FS	470,247.9	-70,371.1	399,876.9	506,339,472.9	-37,757,601.4	468,581,871.5
	RL	-4,631.7	-15,713.2	-20,344.9	-4,987,151.2	-8,430,943.2	-13,418,094.5
1,920 pax/hour (2 times of full capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-42,374.8	-45,823.5	-3,713,405.4	-22,736,187.5	-26,449,592.9
	FS	470,247.9	-93,828.1	376,419.8	506,339,472.9	-50,343,468.5	455,996,004.4
	RL	-4,631.7	-20,951.0	-25,582.7	-4,987,151.2	-11,241,257.6	-16,228,408.9

Level of demand of passenger	Benefit						
10,080 pax/hour (10.5 times of full capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-222,467.6	-225,916.3	-3,713,405.4	-119,364,984.3	-123,078,389.7
	FS	470,247.9	-492,597.5	-22,349.6	506,339,472.9	-264,303,209.6	242,036,263.3
	RL	-4,631.7	-109,992.7	-114,624.4	-4,987,151.2	-59,016,602.5	-64,003,753.7
19,320 pax/hour (≈20times of full capacity of BRT)	Solution	Time of saving (pax-min)			Travel time saving (baht/year)		
		Car	BRT	Total	Car	BRT	Total
	TSP	-3,448.7	-426,396.2	-429,844.9	-3,713,405.4	-228,782,886.7	-232,496,292.0
	FS	470,247.9	-944,145.3	-473,897.3	506,339,472.9	-506,581,151.6	-241,678.8
	RL	-4,631.7	-210,819.4	-215,451.1	-4,987,151.2	-113,115,154.8	-118,102,306.0

BIOGRAPHY

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