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Potential for modal shift by passenger car and motorcycle users towards Bus Rapid Transit (BRT) in an Asian developing city

Thaned Satiennam [a,*], Sittha Jaensirisak [b], Wichuda Satiennam [a], Sumet Detdamrong [a]

[a] Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, 40002, Thailand
[b] Department of Civil Engineering, Faculty of Engineering, Ubon Ratchathani University, 34190, Thailand

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ABSTRACT

Many developing Asian cities consider a Bus Rapid Transit (BRT) system in their public transport planning because of its advantages, offering lower investment cost and flexible implementation over rail systems. The objective of this research is to assess the potential of BRT for attracting travelers from passenger cars and motorcycles. Three different BRT systems were designed for the main corridor passing through Khon Kaen City in Thailand. The study developed modal split models for predicting the choices of passenger car users and motorcycle users. The models were developed based on a Stated Preference (SP) survey. It was found that BRT could attract significantly private vehicle users to change mode choice. The proportion of motorcycle users shifting is higher than passenger car users. However, the majority of private vehicle users still prefer their own private vehicles. Both travel time and travel cost affects the mode choice, in which travel time has a highly significant effect on passenger car users' choice of BRT, but travel cost has a highly significant effect on motorcyclists' choice. Some socio-economic factors, including gender, age, driving license holding and residence location also influence the choice of BRT.

1. Introduction

Bus Rapid Transit (BRT) has become a popular worldwide transit mode, especially in Europe, South America, and particularly in Asia, due to its value for money, service capacity, affordability, relative flexibility, and network coverage [1]. Many case studies have shown that BRT can be a cost-effective way to provide a high-performance transport service [2,3]. Some developing Asian cities also consider BRT in their public transport planning because of its advantages of lower investment cost and flexible implementation over rail systems [4]. In addition, BRT is recommended to realize the low carbon society target for Asian developing cities since BRT would shift private vehicle users to a transport sector which emits lower CO_2 [5,6]. There are however several urban characteristics of Asian developing cities which are different from the successful BRT implementing cities, such as Latin American cities, which should be carefully considered to achieve a successful implementation of a BRT project, for example, urban sprawl (caused by poor city planning) and high private vehicle usage (due to poor existing public transport). Many previous studies have proposed integrated strategies with BRT systems to cope with urban sprawl in developing Asian cities. For example, the case studies of accumulating demands from urban sprawl to the BRT corridor by paratransit feeder in Bangkok [7–9] and a case study of integrating a BRT System with Rickshaw in Dhaka [10].

Due to the poor service of existing public transport and cheap motorcycle use, many developing Asian cities have a very high private vehicle share, especially for motorcycles. Hanoi and Ho Chi Minh cities in Vietnam have recorded motorcycle shares of 81%, and 90%, respectively, of all motorized trips [11,12]. The car was recorded as 40% of mode share in Malaysia [13]. In many provincial cities of Thailand, the motorcycle share accounts for approximately a half of all travel trips, e.g. 51% of all trips in Khon Kaen City [14]. Surveyed annual VKT of motorcycles in Khon Kaen city (6247 km) was higher than that in Bangkok (4015 km) [15]. Thus, it is very challenging to encourage modal shift from motorcycle to BRT. Previously, there are some studies [e.g., 16,17] that proposed policies and planning of bus systems in motorcycle-dominated communities.

It is not easy to achieve high modal shift to BRT in developing countries where an increase in wealth profile is making private vehicles a more affordable means of transport, as well as conferring elements of status causing a high passenger car (PC) and motorcycle (MC) share.

* Corresponding author.
E-mail addresses: sthaned@kku.ac.th (T. Satiennam), sittha.j@ubu.ac.th, Sittha.j@gmail.com (S. Jaensirisak), wichsa@kku.ac.th (W. Satiennam), sumet@kkumail.com (S. Detdamrong).
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Some passenger car users from high-income families prefer their existing mode because of comfort, privacy and status considerations. It is very difficult to shift them to use the public transport, even if a highly efficient public transit is provided. Motorcycle use is rather cheap and provides high accessibility, even though it is unsafe and uncomfortable. However, there is a lack of previous research studying a comparison of car users' and motorcycle users' choice behavior on BRT, as well as the effects of different BRT systems on choice behavior.

Therefore, the objective of this research is to assess potentials of BRT in shifting travelers from private vehicles (both car and motorcycle). The case study is in Khon Kaen City in Thailand, where three different BRT systems were designed and proposed to travelers. The study is based on stated preference (SP) data from which modal split models were developed for predicting the choices of passenger car users and motorcycle users to use BRT.

In this paper, the next section outlines the literature on the effectiveness of BRT. Section 3 describes the research methodology. Section 4 presents the model results and discussions. Section 5 presents the application of the developed models for BRT planning in the city, followed by the conclusions and recommendations in Section 6.

2. Experiences of modal shift to BRT

The planning of BRT is intended to increase the attractiveness of bus transport and affect modal shift from private vehicles. Some empirical data is supportive of the case that BRT has generally similar performance to light rail in the perceptions of passengers. Currie [18] examined the relative passenger attractiveness of BRT systems compared to other transit modes by using a trip attribute approach. The study examined how passengers valued trip attributes for on-street bus, BRT, and light rail and heavy rail systems in passenger behavior researches conducted in many countries. The study found that passengers valued trip attributes for BRT and rail modes in a broadly similar manner. The BRT systems should be as effective as rail in generating patronage when developed to replace on-street bus services. The lower costs for BRT systems compared to rail may be used to claim cost effectiveness advantages for BRT. In Thailand, from the attitude survey, it was also found that all aspects of BRT can compete with an on-street rail-based system and BRT systems can be effective in attracting passengers much more than the current public transport [4].

In Jakarta, Indonesia, Alvinsyah et al. [19] observed the attitude of public transport users due to the introduction of a new public transport system. The BRT systems with and without a feeder service under various fare and time savings were proposed. This study found that there are differences in peoples' perception and their probability of choosing a better service. Ernst [20] surveyed the mode shift to the Jakarta BRT in Indonesia, during the first month of operation, and found that 20% of BRT riders previously were private vehicle users (14% from private car user and 6% from motorcycle user).

Although many studies confirm that BRT is attractive to travelers, in practice the level of mode shift is uncertain. Levinson et al. [2] reviewed the BRT case studies around the world and reported that up to 72% of BRT riders in Houston were diverted from cars and 20% of BRT riders in Vancouver previously used cars. The mode shift of the Nantes BRT (BHLS, Buses with High Level of Service) in France was 29% from private cars [21]. This was rather high because the busway was deployed in a previously poorly served area and public space was reorganized to restrict car use. Only 18% of BRT (Orange Line) riders in Los Angeles were shifted from private cars [22]. In China, on the Beijing BRT Line 1, only 12.4% of riders previously were private car users [23].

The different results of modal shift are likely because of different system characteristics and performance, personal perceptions and characteristics, and local circumstances. For example, McDonnell et al. [24] analyzed the scheme of bus priority measures in Dublin, Ireland. The results indicate that respondents are willing to pay large amounts for large improvements in journey times and for improved comfort attributes. McDonnell and Zellner [25] examined the effectiveness of different BRT schemes. Various scenarios focused on the difference between the environment with and without BRT, and the ancillary policies, including exclusive bus lane, off-boarding ticket machines, express bus stops and improved bus frequency. The model results showed that all integrated measures can achieve up to 50% of bus share, while bus share was only 20% for the base case of bus with no exclusive bus lane and the ancillary measures. The modal shift is rather high; however, for this result it should be noted that bus travel time is much lower than car travel time for all scenarios tested. This leads to a question about how many travelers would switch to BRT if private vehicles (car and motorcycle) travel times were lower than or equal to BRT travel time.

In developing countries, Nurdden et al. [13] evaluated the policies encouraging public transport use in Malaysia, and found that apart from simply travel time, age, gender, car ownership, travel cost, and household income are also significant factors in influencing individual's mode choice. However, the most important policies encouraging public transport are a reduction of travel time from home to public transport stations and subsidized fare.

In summary, the proportions of modal shift from private vehicle users to BRT have a very wide range depending on various factors. Currently, in Asian developing countries, cars and motorcycles are much more convenient than other travel modes. Their support infrastructures are also well developed. It was suggested that the BRT system should be developed on high density corridors, or on corridors that are poorly served by existing buses. This system would be a high-quality bus system with rapid transit based operation (exclusive and priority lane with high frequency and reliability). Even if this infrastructure and service is developed, it is still uncertain to achieve a high modal shift to BRT, particularly in a private vehicle dominated community.

3. Case studies and methodology

3.1. Case study

Khon Kaen City in Thailand was selected as a case study of an Asian developing city because it is a private vehicle-dominated city similar to many developing cities in Asia where public transport is losing modal share. Khon Kaen City has 81% of all trips by private modes (51% by MC and 30% by PC) [14]. Less than 20% of all trips are by Song Thaew (the existing public pickup truck). The existing Song Thaew is not popular because of poorly designed service routes, delayed and unpunctual service, uncomfortable vehicles and unsafe driving. Khon Kaen city currently has a plan to operate a BRT system along its main corridor (called the Friendship Highway) passing though the middle of Khon Kaen City [26]. The BRT line on this corridor is called the Red Line, aligned from the north to the south of the city. This Red Line is the first phase among a total of five lines for the full BRT plan in Khon Kaen City. The Red Line has 17 stations along its 30 km corridor as displayed in Fig. 1.

3.2. Design of Bus Rapid Transit System

To explore various types of BRT system influencing the choice of private vehicle users, in this study, different BRT systems were designed with different efficiency levels to propose to private vehicle users. The design concept is to propose BRT systems suitable with the conditions of Asian developing cities, which have limited investment budget, urban sprawl and high private vehicle usage. The three different BRT systems are:

1) The minibus (MNB): the small air-conditioned bus is operating along a mixed traffic lane, i.e. an on-street bus. This system provides bus stops along the service route. This system is proposed for Asian

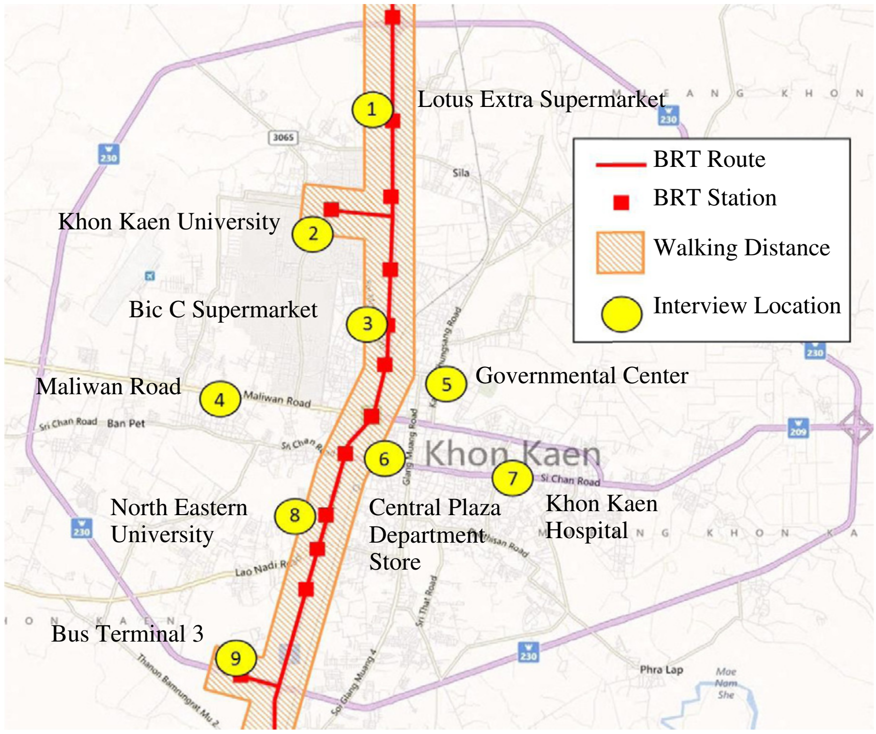
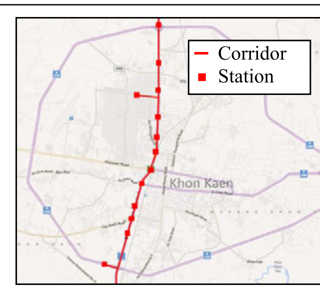
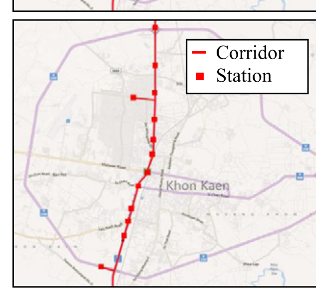
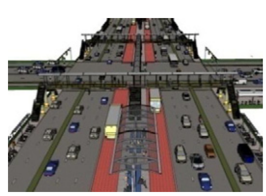
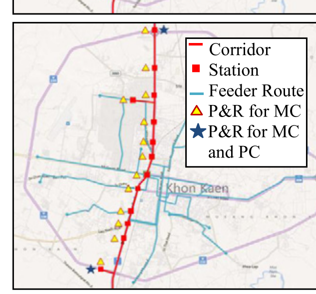


Fig. 1. Bus Rapid Transit planning corridor and interview location in Khon Kaen City.

Table 1
Summary of proposed different systems of Bus Rapid Transit.

System	Vehicle type	Busway, station & priority	Service network
MNB	 – Capacity 21–40 per. – Speed 25 kph – NGV	 – Mixed traffic lane – Bus stops	
BRT	 – Capacity 60–80 per. – Speed 40 kph – NGV	 – Exclusive bus lane – Stations with elevated platforms – Bus priority system at signalized intersection	
BRTS	 – Capacity 60–80 per. – Speed 40 kph – NGV	 – Exclusive bus lane – Stations with elevated platform – Bus priority system at signalized intersection – P&R for MC at stations – P&R for MC and PC at end-of-line stations – Song Thaew feeder routes	

developing cities that have limited investment budget. Mainly, the uncomfortable vehicles of the existing public transport are improved to attract some private vehicle users to use MNB.

2) The BRT without P&R and feeder (BRT): the BRT is operating along an exclusive bus lane. This system provides stations along its service corridor. The bus priority system is provided at signalized intersections. This system is proposed for Asian developing cities that need rapid public transport with investment cost much lower than a rail transit. The investment cost is mainly for upgrading vehicles and constructing exclusive bus lanes, stations with elevated platforms, and a bus priority system at signalized intersections.
3) The BRT with P&R and feeder (BRTS): the BRT is operating along exclusive bus lanes. A bus priority system is provided at signalized intersections. In addition, this system provides the P&R for MC at every station and P&R for PC at end-of-line stations. The Song Thaew service is re-routed as a feeder system free of charge. This system is proposed for Asian developing cities that have existing public transport routes that can be re-routed being a feeder system for BRT. A significant number of private vehicle users, whose trip origins/destinations are far away from the BRT corridor, can be shifted to use BRT by providing P&R at BRT stations. The additional investment cost is necessary for providing P&R facilities at BRT stations, as well as a good integrated system and management.

The summary of the proposals for different systems of BRT is displayed in Table 1. Illustrative images of P&R for motorcycles and Song Thaew route feeders at stations are displayed in Fig. 2. The service times of all systems are from 6:00 am to 12:00 pm.

3.3. Target group

This study explores the choice of BRT systems for private vehicle users traveling along the Friendship Highway by all trip purposes. The private vehicle users were classified into two groups, namely, a group of motorcycle users and a group of private car users. The number of interviewed samples totalled 600 in accordance with the recommended range of 200–500 samples for an analysis of a disaggregate model [27], with 300 samples in each group of private vehicle users.

3.4. Survey method

This study applied the Stated Preference (SP) Method that assumes that the BRT is operating along the Red Line along Friendship Highway in Khon Kaen City. The SP questionnaire survey was conducted. The interview survey was conducted at many trip generating locations, including universities, bus terminals, department stores, and supermarkets, along the BRT corridor. The nine survey locations are shown in Fig. 1. The samples were interviewed individually. To avoid confusion of samples, one sample was presented only four SP questions about different assumed service conditions of one system of BRT. The 200 samples were interviewed for one proposed system of BRT, divided into 100 passenger car users and 100 motorcycle users. In conclusion, 600 samples were interviewed for the 3 different systems of BRT.

3.5. Development of the SP experiment

This study determined the service attributes of the BRT that influence the choice decision of travelers. An SP experiment was developed based on service attributes, influencing BRT mode choice behavior. These attributes were selected from previous studies [17,19,28], including:

1) Access time between residential location and BRT station:
   - When a motorcycle user reaches a station, he/she can park the motorcycle at the P&R area near the station. This access time is 1 min for the traveler whose residential location is within 400 m of the station. The access time is 2 min for travelers whose residential location is further than 400 m (The access times are estimated based on the surveyed average speed of motorcycle, 45 km/h).
   - For a passenger car user to reach a station, since there is no P&R for PC at stations inside the city, a traveler whose residential location is within 400 m from the station has to walk to the station for 6 min (The walking speed is 4 km/h). Travelers whose residential location is further than 400 m can access the station by Song Thaew feeder in 9 min, estimated based on the surveyed average speed of Song Thaew, 25 km/h. For travelers staying outside the city, they can park their passenger cars at the P&R area of the station.

The access time and access cost are summarized by BRT system in Table 2.

2) Waiting time at station: this study decided the waiting time at a station should be similar to the frequency of existing Song Thaew services, every 10 min. To study a variation of waiting time influencing BRT choice, the SP exercise set three levels of waiting time: 2, 6, and 10 min.
3) In-vehicle travel time of BRT: it depends on the operating speed of different proposed systems. The average speed of a minibus (MNB) was determined at 25 km/h similar to the surveyed average speed of Song Thaew currently operating along the same corridor. The average speed of BRT was determined as 40 km/h according to the average speed of BRT systems in many cities [29]. These average speeds were further applied to calculating the in-vehicle travel time of BRT.
4) Egress time between BRT station and destination: a traveler whose destination is about 150 m from the station has to walk to the destination for 2 min, estimated based on the average walking speed, 4 km/h.
5) Total travel time: the total travel time was the combination of all travel times between travelers' residential locations and their destinations, including access time, waiting time, in-vehicle travel time, and egress time.

Fig. 2. P&R for motorcycle and Song Thaew route feeder at Bus Rapid Transit Station.

Table 2
Summary of access time and access cost by BRT system.

System	Private vehicle users	Residential location	Access mode	Travel time (min)	Travel cost (Baht)
MNB	PC users	≤400 m	Walk	6	–
		>400 m	Song Thaew	9	10
	MC users	≤400 m	Walk	6	–
		>400 m	Song Thaew	9	10
BRT	PC users	≤400 m	Walk	6	–
		>400 m	Song Thaew	9	10
	MC users	≤400 m	Walk	6	–
		>400 m	Song Thaew	9	10
BRTS	PC users	≤400 m	Walk	6	–
		>400 m	Song Thaew	9	–
	MC users	≤400 m	MC + P&R	1	0.5
		>400 m	MC + P&R	2	1

6) Ticket fare of BRT: this study decided the ticket fare of BRT should be close to the existing ticket fare of Song Thaew (9 Baht/trip). To study a variation of travel cost influencing BRT choice, the SP exercise set three levels of ticket fare: 5, 10 and 15 Baht/trip.

3.6. Survey of service conditions of private vehicles

This study determined the service attributes of private vehicles that included travel time and travel cost. Based on the current situation, travel times of motorcycle (TTMC) and passenger car (TTPC) were surveyed by driving motorcycles and passenger cars along the designed BRT corridor, simultaneously recording travel time, including running time and stopping time, by stopwatch. The average operating and running speeds of motorcycles were 40 and 45 km/h, respectively. The average operating and running speeds of passenger cars were 50 and 60 km/h, respectively. It should be noted that the surveyed speeds were rather high; this is because this designed BRT corridor is along the highway. The travel costs of motorcycle (CMC) and passenger car (CPC) were the gasoline cost that could be calculated from questionnaire data. The gasoline cost could be calculated by multiplying the existing gasoline (Baht/L) price with the fuel consumption factor (km/L).

3.7. Mode choice model development

The surveyed data from questionnaire (N) was separated into 2 groups. 80% of them were former used to develop the mode choice model by applying the Random Utility Theory. 20% of them were later used to forecast the mode choice through the developed mode choice model in a process of model validation [17]. This study developed the mode choice model by applying the Random Utility Theory. The Binary Logit model was applied to analyze the mode choice data from the SP exercise. The Binary Logit function is displayed as Eq. (1) [30].

$$P_n(i) = \frac{e^{V_{in}}}{e^{V_{in}} + e^{V_{jn}}} \tag{1}$$

where

$P_n(i)$ Probability of traveler n choosing mode i
V_{in} Systematic components of utility of traveler n choosing mode i
i, j Travel mode i and j.

This study considered many service attributes, listed in Table 3, which may influence mode choice. Besides the service attributes, this study also considered socio-economic characteristics of travelers, such as gender, age, income, as well as residential location of travelers, in the utility function.

The Coefficients of Correlation between independent variables of motorcycle and passenger car users are presented in Tables 4 and 5. There is no high correlation between independent variables since the Coefficients of Correlation between variables are less than 0.5.

3.8. Model validation and selection

3.8.1. Internal validation

This study conducted the internal validation by checking the 2 following points.

1) Sign of coefficients of independent variables: for example, a coefficient with negative sign means that the utility to travel by that mode decreases if the variable has a higher value.
2) t-Value: If the t-value of an independent variable is higher than 1.96, it means that the variable influence mode choice has a 95% confidence level.

Table 3
Independent variables in utility function.

Variable	Meaning
SEX	Dummy variable of gender of travelers (0: Male and 1: Female)
AGE	Dummy variable of age of traveler (0: ≤ 30 year old and 1: > 30 years old)
AREA	Residential location (0: within 400 m radius from BRT station, 1: outside 400 m radius from BRT station)
INC	Income of traveler (0: ≤ 20,000 Baht/month[a] and 1: > 20,000 Baht/month)
LICENSE	Dummy variable of holding of driving license (0: no driving license and 1: holding of driving license)
CONSTANT	Constant term of BRT utility
TTBRT	Total travel time of BRT (min)
CBRT	Total travel cost of BRT (Baht)
TTMC, TTPC	Total travel time of MC and PC (min)
CMC, CPC	Total travel cost of MC and PC (Baht)

[a] 1 USD ≈ 30 Baht in 2012.

Table 4
Coefficients of Correlation among independent variables of motorcycle users.

	SEX	AGE	AREA	INC	LICENSE
SEX	1				
AGE	0.13	1			
AREA	−0.15	−0.13	1		
INC	−0.06	0.12	−0.10	1	
LICENSE	−0.23	−0.02	0.16	−0.06	1

Table 5
Coefficients of Correlation among independent variables of passenger car users.

	SEX	AGE	AREA	INC	LICENSE
SEX	1				
AGE	−0.07	1			
AREA	−0.15	−0.07	1		
INC	−0.13	0.36	0.00	1	
LICENSE	−0.13	0.23	−0.06	0.19	1

3.8.2. External validation

This study selected the method of Percent Correctly Estimated for external validation. Its equation is displayed as Eq. (2).

$$\%\,\text{Correct} = \frac{\sum_{n=1}^{N} W_n}{N} \tag{2}$$

where

$$W_n = \begin{cases} 1 \text{ if traveler n chooses i once modeling result is } P_n(i) > 0.5 \\ 0 \text{ otherwise} \end{cases}.$$

The principle of Percent Correctly Estimated is to calculate the percentage accuracy of mode choice forecasting. The remaining questionnaire data (20% of all data from questionnaire) was used to forecast the mode choice through the developed mode choice model. The mode choice resulting from the developed model was compared with the existing mode choice from the questionnaire. For example, the traveler n chose i from questionnaire while the developed model results that traveler n has a probability more than 50% to choose mode i ($P_n(i) > 0.5$), thus $W_n = 1$; if it is not, $W_n = 0$. If the % Correct is approaching 100%, it means that the developed model yields the forecasting mode choice close to the existing mode choice from the questionnaire.

3.9. Model selection

The two steps of model selection procedure are shown below.

1) Comparison among the developed models that have the same number of independent variables with the Likelihood Ratio Index (ρ^2). Likelihood Ratio Index, ρ^2 interprets how accurately the model can forecast the mode choice behavior. It checks if ρ^2 approaches 1 and the developed model provides a high correlation among dependent and independent variables [30]. The Likelihood Ratio Index, ρ^2, can be calculated by Eq. (3). Subsequently, the model with higher Likelihood Ratio Index, ρ^2, is more appropriate.

$$\rho^2 = 1 - \frac{L(\beta)}{L(0)} \tag{3}$$

where

ρ^2 Rho-Square
$L(\beta)$ Maximum Log Likelihood Function
$L(0)$ Log Likelihood Function when all parameters equal 0.

2) Comparison among the developed models that have a different number of independent variables with the LL Ratio-test Method [31]. Its equation is displayed as Eq. (4).

Table 6
Socioeconomic characteristics of the sample.

Socioeconomic characteristic		Passenger car users	Motorcycle users
Sex	Male	59%	47%
	Female	41%	53%
Age	Average (year)	34	26
Income	Average (Baht/month)	20,200	8400
Driving license	Yes	89%	79%
	No	11%	21%
Residential location	≤400 m	33%	38%
	>400 m	67%	62%
Occupation	Student	18%	57%
	Private business owner	21%	9%
	Officer	23%	16%
	Governmental officer	30%	7%
	Others	8%	11%
Trip purpose	Study	5%	11%
	Work/business	65%	34%
	Shopping/others	30%	55%

$$2(LL_{\text{base model}} - LL_{\text{estimates model}}) \sim \chi^2_{(\text{number of new parameters estimated in estimated model})} \tag{4}$$

where

$LL_{\text{base model}}$ Likelihood Function of base model
$LL_{\text{estimates model}}$ Likelihood Function of estimates model
$\chi^2_{(\text{number of new parameters estimated in estimated model})}$ Chi-Square of difference of independent variables between 2 models.

4. Results

4.1. Socioeconomic characteristics

A summary of the sample characteristics, including socioeconomic conditions, residential location and trip purpose is displayed in Table 6. It is noticed that the average income of passenger car users (20,200 Baht/month) is much higher than that of motorcycle users (8400 Baht/month). In addition, more than a half of motorcycle users are students (as expected).

4.2. Results of model development

Binary Logit models for both private vehicle (MC and PC) users were developed. The summarized results of the model development are presented in Table 7. They reveal that the developed models provide high values of Likelihood Ratio Index (ρ^2) and Percent Correctly Estimated (% Correct). The ρ^2 value ranges from 0.2 to 0.4, indicating acceptable model fit [32].

Remark: figures in parentheses are t-values. Note that all of absolute t-values are more than 1.96, it implies that all of coefficients presented in the model are significant at the 95% confident level.

Mode choice models for motorcycle and car users are presented in Table 7. The models show that:

1) The signs of coefficients of travel time and travel cost of BRT and both types of private vehicles are negative, as expected. The preference of travelers would be decreased while the travel time and cost increases.
2) The sign of the coefficient of motorcycle user's age is positive. This means that older motorcycle users are more likely to switch to BRT than younger motorcycle users.
3) The sign of the coefficient of motorcycle user's gender is positive. This means that female motorcycle users are more likely to switch to BRT than male motorcycle users.

Table 7
Results of model development.

Users	Binary Logit models	ρ^2	Value of time (Baht/h)
Motorcycle users (MC)	$U_{BRT} = 2.16_{(8.81)} - 0.14TTBRT_{(-9.62)} - 0.18CBRT_{(-11.90)} + 0.56SEX_{(3.16)} + 0.70AGE_{(3.16)} - 0.43AREA_{(-2.40)}$ $U_{MC} = -0.14TTMC_{(-9.62)} - 0.18CMC_{(-11.90)}$	0.358	47
Passenger car users (PC)	$U_{BRT} = 4.17_{(9.30)} - 0.22TTBRT_{(-9.74)} - 0.09CBRT_{(-10.14)} - 0.91AREA_{(-5.07)} - 1.24LICENSE_{(-4.66)}$ $U_{PC} = -0.22TTPC_{(-9.74)} - 0.09CPC_{(-10.14)}$	0.346	147

4) The sign of the coefficient of passenger vehicle user's driving license holding has a negative sign. This means that the passenger vehicle users without a driving license are more likely to switch to BRT than the passenger vehicle users with driving license (In Thailand, some drivers do not hold a driving license).
5) The signs of the coefficients of private vehicle user's residential location are negative. This means that the private users whose residential location is within 400 m from the station are more likely to switch to BRT than those whose residential location is further than 400 m
6) The value of the travel time for motorcycle users is much lower than for car users.

In summary, the model presents factors affecting mode shift. This model can be used to test different BRT characteristics, which are presented in the next section. However, the study compared different BRT systems (minibus, BRT without P&R and feeder, and BRT with P&R and feeder, as presented in Section 3.2), the analysis showed that travel time and travel cost of BRT significantly influence mode shift, but the different systems are not significantly different in attracting mode shift. This is likely because travelers see all BRT systems are similar (much better service quality compared to the current public transport), or it may be because the SP design cannot distinguish the three systems. Therefore this issue should be further studied in more details in the BRT system design.

5. Application of developed models for BRT planning

The developed models were applied to evaluate if the current public transport was changed to BRT with fare and travel time being set the same as the existing bus, 25% of car users and 30% of motorcycle users would switch to BRT. It should be noted that the mode shift to BRT is rather high; this is because the respondents live along the designed BRT route.

The developed models were further applied to test the different levels of BRT service on the different levels of modal shift for both motorcycle and car users. The tests included (1) decreasing total bus travel time, (2) different BRT fare levels, (3) increasing travel costs of private vehicles, (4) increasing travel time of private vehicles, and (5) the integration of decreasing bus travel time and increasing private vehicle cost. The results of these scenarios tested are shown in Sections 5.1–5.4.

5.1. Effect of decreasing travel time of Bus Rapid Transit

Service improvement can be effected by decreasing total travel time by BRT. This is tested by reducing the existing public transport total travel time (the base case) by 5%, 10%, 15%, and 20%. The results are displayed in Fig. 3. It is found that once total travel time is decreased, the percentage of BRT choice by both private vehicle user types increases. When travel time decreases by 20% of the existing public transport total travel time, the proportions of motorcycle and car users switching to use BRT are 48% and 40%, respectively. This finding can suggest a strategy to decrease BRT travel time by improving access and egress service, BRT priority at intersections, and increasing service frequency.

5.2. Effect of changing fare of Bus Rapid Transit

Service improvement can also be done by reducing BRT fare. This is tested by setting the fare at 0, 5, 10 and 15 Baht. For the base case, the BRT fare is set as the existing bus cost, which is on average 12 Baht per trip. The results are displayed in Fig. 4. It was found that 74% of motorcycle users would switch to BRT if it is free, but this proportion reduces to 33% if the fare is 15 Baht. For the base case, the BRT fare is set as the average current public transport level, which is about 12 Baht/trip. For car uses, if BRT is free 42% would switch to BRT, while 23% would switch if the fare is 15 Baht. This indicates that (1) motorcycle users are rather sensitive to the change of fare levels (more than car users), and (2) not only travel fare, other service attributes and factors significantly affect the modal shift; even if BRT is free, not all travelers would switch to BRT.

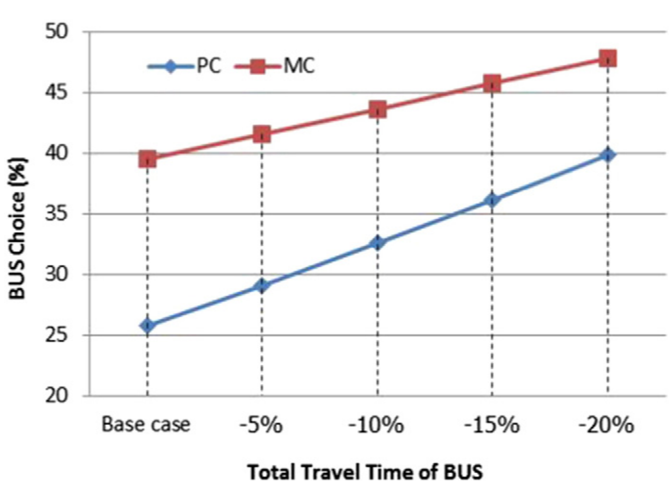


Fig. 3. Percentage of BRT choice by private vehicle users when decreasing bus total travel time.

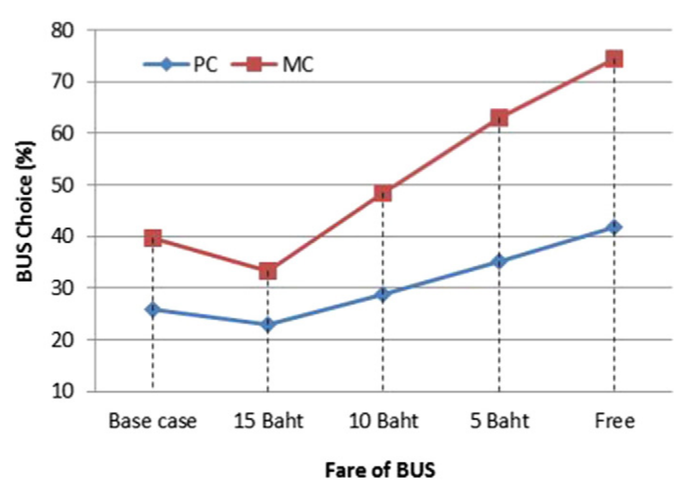


Fig. 4. Percentage of BRT choice by private vehicle users when changing fare levels.

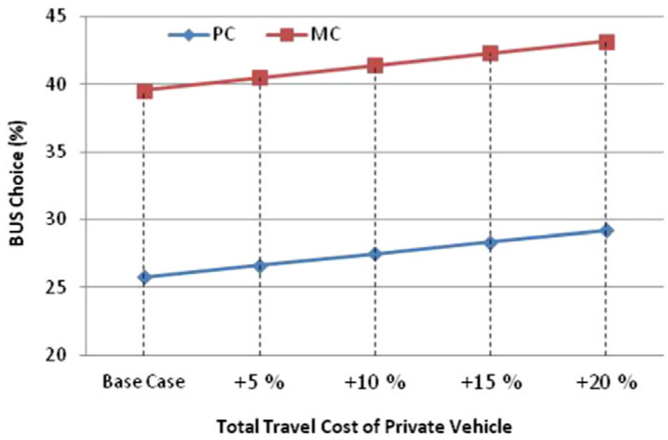


Fig. 5. Percentage of BRT choice by private vehicle users when increasing total travel cost of private vehicles.

5.3. Effect of increasing travel cost of private vehicles

Decreasing the utility of using private vehicles (MC and PC) can be done by increasing the travel cost to private vehicle users. If the private vehicle users have to pay +5%, +10%, +15% and +20% more from their existing travel costs (the base case), the results are presented in Fig. 5. We found that when the travel costs of private cars are increased, it results in an increasing number of motorcycle and car users switching to use BRT. This strategy could be implemented through direct road pricing or parking charges (currently no public and private parking charge exist in the city). However, this charging would be opposed by the public, particularly motorcycle and car users who are the majority (about 80%).

5.4. Effect of increasing travel time of private vehicles

Decreasing the utility of using private vehicles (MC and PC) can be also done by increasing the travel time for private vehicle users from their existing travel time, the base case. The results are presented in Fig. 6. The effect of increasing the travel time is similar to increasing the travel cost for the private vehicle users. It could increase the proportion of BRT users. This strategy could be implemented through reducing travel speed by reducing road capacity for private vehicles. This is automatically implemented together with BRT development, since some road space would be converted to be BRT lane. This should be less opposed by the public than directly increasing travel cost. However, it cannot generate revenue to support the BRT system.

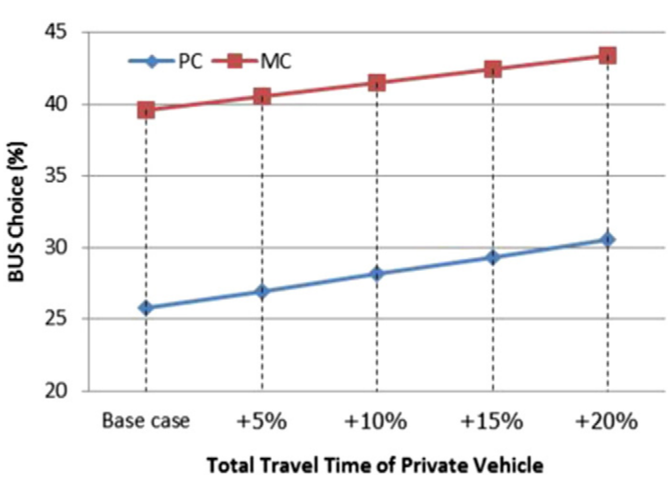


Fig. 6. Percentage of BRT choice by private vehicle users when increasing total travel time of private vehicles.

Table 8
Percentage of BRT choice by private car users when increasing travel cost of private cars and decreasing bus total travel time.

Decreasing total travel time of BRT	Increasing travel cost of private cars			
	0%	+5%	+10%	+15%
0	22%	23%	24%	25%
−5%	26%	27%	28%	29%
−10%	30%	31%	32%	33%
−15%	34%	35%	36%	37%

5.5. Effect of integrated changes

An integrated strategy is tested by decreasing bus travel time and increasing private vehicle cost. This is seen when BRT is integrated with road pricing (either direct charge or parking charge). This test sets the BRT fare level at 15 Baht per trip (which is the proposed fare level in the BRT master plan for the city and higher than the existing bus fare, average 12 Baht per trip). The results are shown in Tables 8 and 9. Without decreasing bus travel time and increasing private vehicle cost, 22% of car users and 34% of motorcycle users would switch to BRT. These BRT shifts are different from the results of previous condition setting the fare and travel time as same as the existing bus (25% of car users and 30% of motorcycle users would switch to BRT) because the setting fare is higher but the BRT travel time is faster.

With decreasing bus travel time and increasing private vehicle cost, the decrease of BRT total travel time (compared to the current public transport) can significantly increase the mode share of BRT. The increase in travel cost of cars and motorcycles has less effect in influencing mode shift. This is because currently the travel costs of private vehicles are rather low, so increasing travel cost by 15% is not a big issue for them.

6. Conclusions

This paper has assessed the potential of BRT for shifting travelers from passenger cars and motorcycles. It was found that the BRT could attract significantly private vehicle users to change mode choice. The shift proportion of motorcycle users is higher than that for passenger car users to change mode choice. When the BRT is operated with the same travel speed as the existing bus, some private vehicle users would change to the BRT system because the new buses with air-condition are much more comfortable that the existing buses (no air-condition).

Travel time and cost significantly affect the mode shift to BRT. Travel time has a highly significant effect on the choice of BRT, particularly for car users. Currently, traveling by the existing bus takes much longer than cars and motorcycles. The BRT system with priority lanes would make public transport more competitive for private vehicle users. Moreover, to reduce total travel time, the system design should also be concerned with improving access and egress services, BRT priority at intersections, and increasing service frequency.

Table 9
Percentage of BRT choice by motorcycle users when increasing travel cost of motorcycles and decreasing bus total travel time.

Decreasing total travel time of BRT	Increasing travel cost of private motorcycles			
	0%	+5%	+10%	+15%
0	34%	35%	36%	37%
−5%	36%	37%	38%	39%
−10%	38%	40%	41%	42%
−15%	41%	42%	44%	45%

The fare of the BRT has a highly significant effect on mode choice, particularly motorcycle users. However, even if BRT is free, some motorcycle users and more than a half of car users would not switch to the BRT. They are still tied to their own private vehicles.

In addition to improving bus travel time and service and setting appropriate fare levels, private vehicle could be restrained, in order to increase mode shift and generate revenue to support the BRT. This could be implemented through direct road pricing or parking charges (currently there are no public and private parking charges in the city). However, this charging would be opposed by the public, particularly motorcycle and car users who are the majority (about 80%). Thus, the public participation process and educational programs on sustainable transport development should be implemented together with the transport planning process [33].

These findings would be useful for BRT planning in developing Asian cities, which encounter a high percentage of private vehicle share, especially motorcycle usage. The BRT system has high potential in attracting private vehicle users. In short, the main concerns in planning a BRT are that the system should provide a significant decrease in travel time, a reasonable fare level for low and medium income groups (subsidy may be needed), well designed P&R stations, and free feeder systems, together with effective restraint private vehicle policies and public participation and educational programs.

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