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Effectiveness of Travel Demand Management Policies in Promoting Rail Transit Use and Reducing Private Vehicle Emissions: A Stated Preference Study of Bangkok, Thailand

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ABSTRACT

In this study, we focused on policies to promote reduction in the use of private vehicles that could be implemented in Bangkok during periods of severe $PM_{2.5}$ levels, including a flat charge for use of private cars, private vehicle bans, and public transport fare subsidization. The objective was to investigate how these policies can be used to help convince private car users to shift their travel modes to rail transit, and, thus, reduce vehicle emissions that contribute to air pollution. We conducted a stated preference survey of 731 private car users in Bangkok, Thailand, where stated-choice scenarios were specified with respect to all possible combinations of the proposed policies that could lead to a reduction of $PM_{2.5}$ concentration. A binomial logit model was used for the analysis. Our results suggest that the effectiveness of the travel demand management policies would vary across geographical areas of the city. Public transport fare subsidization would be effective in reducing car use among residents in the inner suburbs. A car ban would be an effective measure in outer suburbs, while the flat charge would be effective among populations in central Bangkok and the inner suburbs.

Keywords: air pollution control, travel demand management, car reduction policy, stated preference survey, Bangkok

INTRODUCTION

In recent years, the population of Thailand has become increasingly concerned about significant increases in air pollutants. The sources air pollutants in Thailand can be traced back to multiple sectors, including large-scale industrial operations, oil and coal plants, transportation, and agriculture. At the national level, air pollutants, especially $PM_{2.5}$, typically reach severe levels harmful to human health during the dry season, from December to February, due to a combination of seasonal meteorological conditions (i.e., high pressure, lower temperatures, low humidity) as reported by Chalermpong et al. (2021) and seasonal biomass burning in the agricultural sector. However, in Bangkok, a city struggling with chronic traffic congestion (TomTom, 2021), a main source of air pollutants is internal combustion engines (ICEs) in motor vehicles (Choochuay et al., 2020). While a large share of $PM_{2.5}$ comes from commercial transport emissions, the contribution from personal transportation is still substantial. Bangkok residents tend to use private vehicles rather than public transport (Thammasaroj & Jinsart, 2019), and the number of registered private vehicles has rapidly increased in recent years (Muttamara & Leong, 2000). Reducing the number of private vehicles on the road, or motivating people to change their travel mode to public transit, is an ongoing challenge for Bangkok policymakers.

A number of transport-related measures to tackle air pollution have been studied and implemented in Asia, including government campaigns, legislation, and incentives for low-emission vehicles. For example, Ho et al. (2015) studied a campaign to restrict driving aimed at improving air quality in Beijing, China. The results showed that during the period of restriction, $PM_{2.5}$ concentration was approximately 35% lower than during the unrestricted period. In 2001, Japan sought to address its $PM_{2.5}$ problem by amending the Automobile NOx-PM Law in order to establish a vehicle age limit. The law placed a limit on operation of vehicles that were 8 to 12-years-old (or older), with year-limits based on vehicle type. The results revealed that the measure effectively reduced annual $PM_{2.5}$ concentration by 5.21% (Iwata et al., 2020). In Taiwan, promoting the use of low-emission vehicles (LEV) has also been a successful measure. Taiwan's Air Pollution Control Act was enacted in 2018 with the aim of replacing old ICE vehicles with electric vehicles and banning all sales of non-electric vehicles by 2024. After one year of implementation, $PM_{2.5}$ concentration decreased by 4.58% (Environment Protection Administration, 2019). Che et al. (2011) compared the effectiveness of five measures to reduce $PM_{2.5}$ from the transport sector, i.e., upgrading vehicle emission standards, restrictions on vehicles in urban areas, phasing out of old and high emission vehicles, improvement of public transport, and promoting hybrid electric vehicles in China. The authors found that upgrading vehicle emission standards had the most impact as it led to $PM_{2.5}$ reductions of up to 46.7%. However, it was found that the combination of all measures could reduce $PM_{2.5}$ up to 57.3%.

In Bangkok, the local government has considered several measures to tackle severe air pollution during the dry season, including a daytime ban on medium-to-heavy trucks in downtown Bangkok, upgrading fuel standards, and promoting electric vehicles. However, some of these measures have yet to be implemented or are not strictly enforced.

In this study, we examine the effectiveness of measures to tackle air pollution caused by private ICE vehicles in Bangkok. Specifically, we focus on short-term travel demand management policies, including a flat charge on private vehicles entering congested areas, a private vehicle ban, and public transport fare subsidization. The objective of this study is to investigate how these policies can influence private car users to shift their travel modes to public transport, such as rail transit.

TRAVEL DEMAND MANAGEMENT

The objective of Travel Demand Management (TDM) is to promote the use of sustainable transport modes by encouraging individuals to switch from less sustainable modes of transport. Typically, prior studies have focused on 'push' and 'pull' policies (Kavta & Goswami, 2018). The aim of push policies is to change traveler behavior by discouraging the use of certain modes of travel through the application of constraints, such as increasing parking fees, implementing road-use pricing, restricting vehicle use, etc. (Dieplinger & Fürst, 2014; Dirgahayani & Sutanto, 2020; Garling & Schuitema, 2007; Goodwin, 1992). In contrast, pull policies aim to promote the use of sustainable transportation modes by improving infrastructure to reduce travel time, providing financial incentives, and offering travel feedback programs (Brög, 1998; Bueno et al., 2017; Kavta & Goswami, 2018; Wang et al., 2022).

Previous studies have demonstrated that the effectiveness and acceptance of these interventions have varied (Bueno et al., 2017; Habibian & Kermanshah, 2013; Kavta & Goswami, 2018). Research by Tertoolen et al. (1998) and Fujii and Taniguchi (2005) found that implementing either push or pull measures may result in significant changes in personal car use behavior. Guo et al. (2015) noted that implementing ‘push’ measures on car restrictions, such as banning vehicles based on their license plate numbers or limiting the use of high-emission vehicles, may help in reducing overall car use. Habibian and Kermanshah (2013) found that push policies were effective instruments to reduce car usage, while pull policies had limited impact. Still, it is important to note that push measures are not a silver bullet and are not comprehensive solutions; they should be complemented by ‘pull’ measures that improve the larger sustainable transportation system, such as improving infrastructure to reduce travel time or providing subsidies for public transportation (Guo et al., 2015). Jakobsson et al. (2002) found that two pull measures — financial incentives and travel feedback programs — could be the most effective ways of reducing the use of private cars. For instance, TDM programs that incentivize employees to use public transport have been implemented by large corporations (Rosenfield, 2018; Bueno et al., (2017). In addition, studies from New York and New Jersey in the United States found that providing employees with monthly tickets or subsidizing their public transport fares significantly increased their use of public transport (Rosenfield, 2018). In relation to effectiveness and public acceptance of policies, research from Wang et al. (2022), which was based on an analysis of stated preference surveys, suggested that the public preferred a combination of policies rather than a single measure. Nonetheless, there is also evidence in that study that a single measure can be effective in reducing private car.

In Bangkok, the local government has done a preliminary analysis on potential TDM policies related to transportation infrastructure and public communications — ‘pull’ policies. Specifically, the Office of Transport and Traffic Policy and Planning (Office of Transport and Traffic Policy and Planning, 2015) reported on the impact of developing park-and-ride facilities, modifying car tax rates, providing subsidies for rapid transit system fares, and providing travel information (i.e. applications for real-time traffic reports). In addition, a local authority tested a pilot project to reduce private car usage by improving park-and-ride facilities and discounting parking fees. The results showed a significant decrease in car usage in terms of car driving distance and an increase in ridership of the rail transit system (Chalermpong, et al. 2018).

STUDY AREA

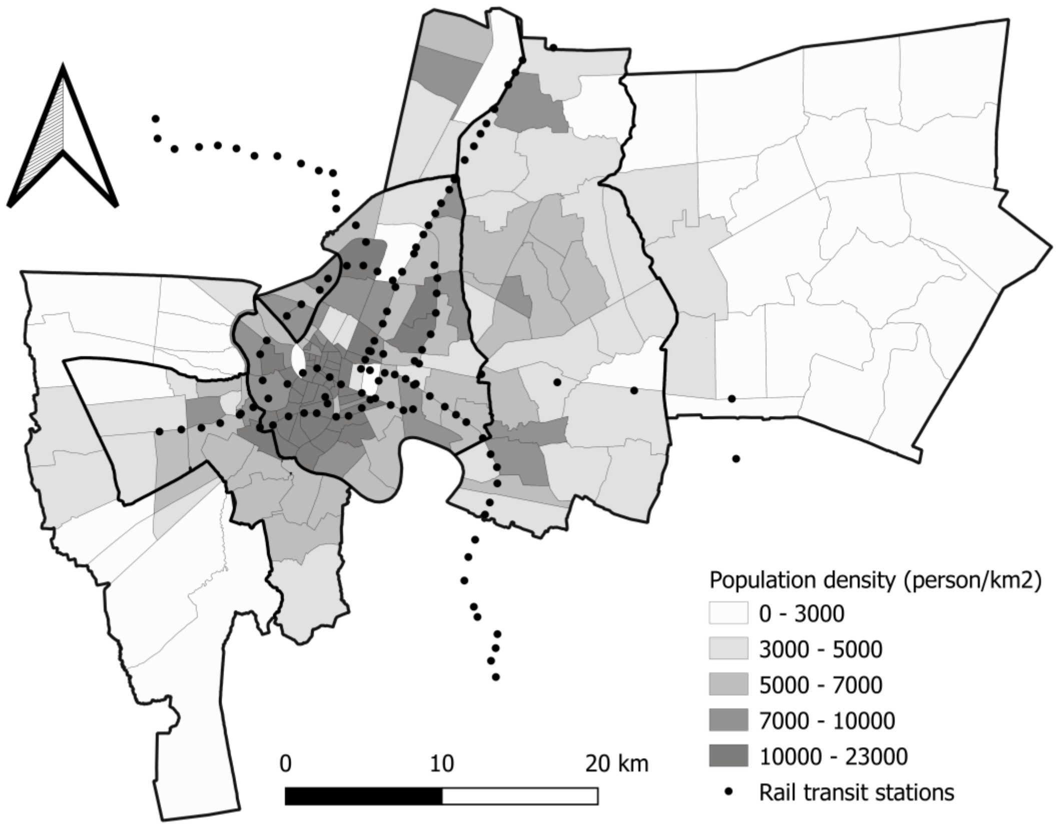
Our study focused on Bangkok, the capital of Thailand. In 2021, there were 5.5 million registered inhabitants within a total land area of 1,569 km^2 (Department of Provincial Administration, 2021). The population density in each subdistrict is shown in Figure 1 (National Statistical Office, 2019). According to the government’s Bangkok Travel Demand Survey report in 2018, the travel modes of Bangkok commuters included: car 43.2%, motorcycle 25.5%, taxi 4.2%, public transport 20.2%, shuttle bus 1.9%, and walking 5.0% (Office of Transport and Traffic Policy and Planning, 2018). Data on travel modes disaggregated by residential areas was not available.

Public transport modes in Bangkok include public buses, rail transit, taxis, and motorcycle taxis, among others. In recent years, the rail transit system has become a main form of public transport, yet its geographical coverage of the city is still limited and individuals residing in areas with low-to-middle population density have difficulty accessing the system, as shown in Figure 1. Local bus service is more comprehensive than rail transit, though bus stop density is still limited in outer suburbs areas, as depicted by Figure 2. In contrast to the rail transit system, local bus service quality is generally poor and primarily used by low-income residents. Accordingly, due to the lack of efficient, accessible, and consistently high-quality public transport services, residents often choose private cars and motorcycles over public transport (OTP, 2018).

Severe air pollution is undoubtedly one of the greatest challenges facing Bangkok residents as the city regularly ranks among the worst in the world for air quality (IQAir, 2021). In 2020, the daily average $PM_{2.5}$ concentration exceeded the Thai air quality standard for sensitive groups of people (35 μg/m^3) for 74 days, and it surpassed a more severe level of 50 μg/m^3 for 28 days (Pollution Control Department 2020). Given Bangkok's reputation as one of the world's most traffic-congested cities — reaching 11th place in TomTom's 2021 rankings — it is no surprise that one of the main sources of air pollution is the transport sector (Chalermpong et al., 2021; TomTom, 2021).

Figure 1

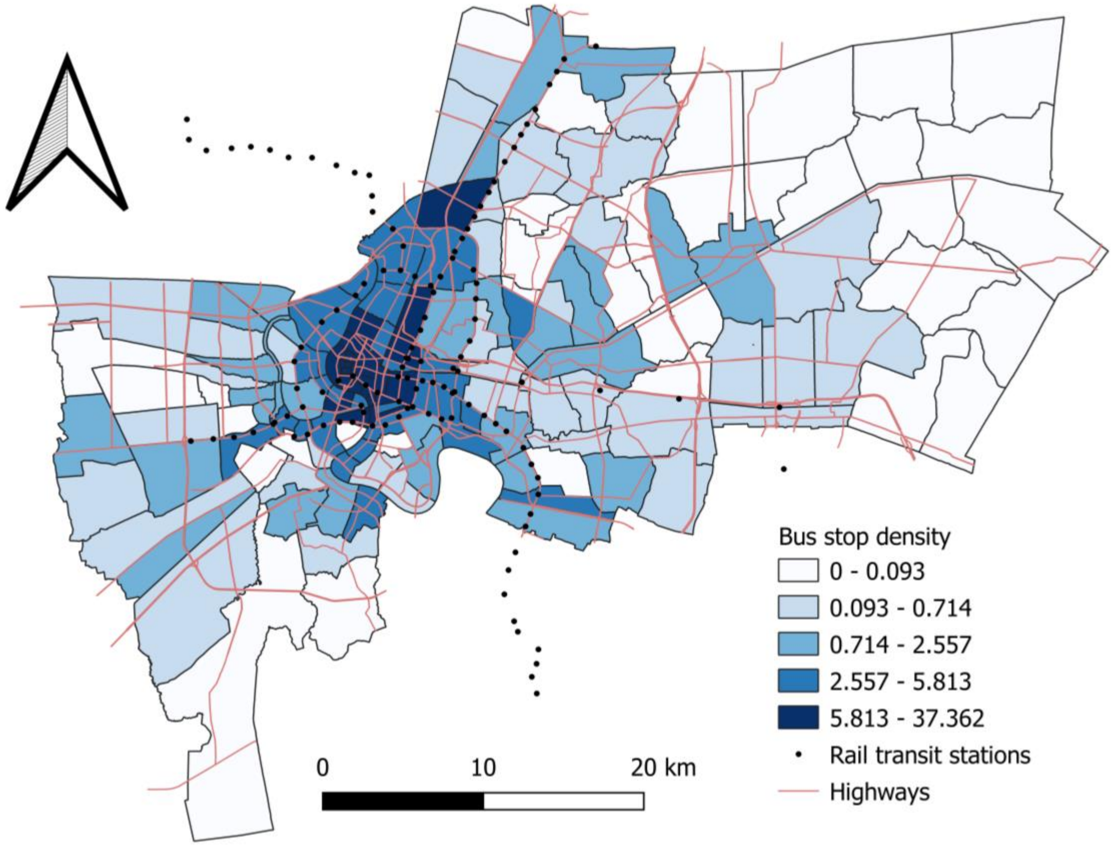
Population Density of Study Area



Note. Adapted from *Population Density*, by Bangkok Population Statistics, 2019 (http://statbbi.nso.go.th/staticreport/page/sector/th/01.aspx). Copyright 2019 by National Statistical Office.

Figure 2

Bus Stop Density and Highways in Study Area



Note. Adapted from *Bus stations and Highways*, by OpenStreetMap contributors (http://www.openstreetmap.org/copyright). Copyright 2019 by the OpenStreetMap Foundation and *Locations of rail transit stations* by Open Government Data of Thailand, 2019 (https://data.go.th/dataset?res_format=SHP&groups=logistic). Copyright 2015 by Digital Government Development Agency.

Notably, the Thai government has attempted to implement multiple transportation sector policies to mitigate air pollution in Bangkok. These include banning heavy trucks from entering inner Bangkok during the daytime on odd calendar dates, upgrading the national emission standards, measuring black smoke emitted from buses and trucks, and asking government agencies and private companies to reduce vehicle usage. However, these policies have had limited effect as they primarily focus on heavy industrial vehicles or peak congestion times. The authorities have considered imposing measures on private cars, such as a temporary car ban or congestion charge, but due to public resistance these measures have not been implemented. With this in mind, our research aims to examine empirical evidence to analyze the effectiveness of measures to tackle air pollution through limitation of personal vehicle use and corresponding reliance on public transportation in Bangkok.

METHODOLOGY

Survey Design

In this study, we investigated how transport-related measures affect an individual's choice of travel mode during periods of severe air pollution. We assumed that $PM_{2.5}$ concentration was higher than 100 μg/m^3, and that an individual had two travel mode choices: private car or rail transit. We should note that we only considered rail transit as the public transport option because private car users are more likely to use commuter rail services over public buses. Findings from the Office of Transport and Traffic Policy and Planning (2018) revealed that the value of time for private car and rail transit users was 140.7 and 120.7, respectively, while the value of time for public bus users ranged from 40.3 to 89.4. This stark difference suggests that public bus passengers represent a different group of users from private car and rail transit passengers. In addition, we assumed that during periods of severe air pollution the service quality of rail transit could be improved by subsidizing operational cost. Specifically, the frequency of rail transit service could be increased and, in turn, travel time could be reduced. To understand the effectiveness of the transport-related measures, we used a stated preference survey for each measure, specifically asking if respondents would change their travel mode from private car to rail transit when presented with specific hypothetical scenarios.

Three main measures were considered: 1) a flat charge on private vehicles entering areas with severe $PM_{2.5}$ levels, 2) a ban on private vehicles on weekdays, and 3) rail transit fare subsidization. Each measure was presented under three scenarios, with each scenario having different stated values for as shown in Table 1.

We defined three levels for each policy by using scenarios that reflect the turning points in behavior change.

First, for the flat charge scenario, since car users in Bangkok have medium-to-high incomes they would likely choose rail transit — a clean and efficient but relatively more expensive public transit mode — as their next best option when not using a private car. The flat charge in this scenario should not be lower than rail transit fare, otherwise there would be no incentive to switch travel modes. Based on the latest household survey by the Office of Transport and Traffic Policy and Planning (OTP) in 2018, the cost of rail transit ranged from 15-80 Thai Baht (THB) per trip. However, as rail transit fares have increased since the time of the survey, we adjusted to account for current pricing. We set the flat charge policy to cover the cost of a round trip on rail transit, setting the lowest charge at 50 THB and the highest charge at 100 THB.

Secondly, for the private vehicle ban scenario, we set ban levels at 20%, 50%, or 80%. Finally, in the rail transit fare subsidization policy, we defined levels of subsidization from a low of 25% to a high of 100% to ensure that these ranges cover points where respondents would choose to switch from private car to rail transit travel.

In terms of implementation of each of the above policies, the flat charge policy could be implemented through a fee for a one-day ticket. The private vehicle ban could be implemented by defining groups of license plate numbers that would be allowed to enter areas with severe $PM_{2.5}$ levels; for example, one method could rely on alternating between license plates with odd and even numbers for a 50% private vehicle ban measure. Rail transit fare subsidization could be implemented by providing a ticket discount.

Our questionnaire design separated each measure into three different forms, as seen in Table 2.

Each questionnaire form had four variables including one measure: expected $PM_{2.5}$ level after implementation, travel time reduction for private car, and travel time reduction for rail transit. There were 81 possible scenarios for each form, but in order to reduce the burden for respondents, we shortened the questionnaire by dividing it into nine sub-forms using the block decomposition technique (Eboli & Mazzulla, 2008). Therefore, we used nine different sub-questionnaires for each of the three measures, resulting in a total of 27 forms.

Table 1

Variables for Survey Design

Types	Variables	Level		
		1	2	3
Measures	Flat charge (THB/day)	50	100	200
	Private vehicle ban (%)	20	50	80
	Rail transit fare subsidization (%)	25	50	100
Other variables	$PM_{2.5}$ concentration (ug/m^3)	76-100	51-75	<=50
	In-vehicle travel time reduction for private car (%)	25	50	75
	Travel time reduction for MRT rail (%)	25	50	75

Data Collection

The target population for respondents included individuals more than 18 years of age who resided in Bangkok, regularly traveled by private car, and used rail transit as an alternative travel mode. We divided Bangkok into three zones (i.e., central Bangkok, inner suburbs, and outer suburbs) according to the 20-year Bangkok Metropolis Development Plan (Bangkok Metropolitan Administration, 2014). The sample size of each zone was determined based on population density, and participants were recruited according to their area of residence. We conducted the survey from October – December 2021, collecting 731 complete responses comprising 227, 256, and 248 responses for questionnaire 1, 2, and 3, respectively. There were at least 23 responses for each sub-questionnaire form. The Institutional Review Board of Chulalongkorn University conducted an ethical review of our methodology and approved the survey tools and sampling plan.

Analysis Method

The effects of policies and other variables on a respondent's choice of travel mode were estimated by binomial logit model. The dependent variable was the choice of travel mode -- either private car or rail transit. Independent variables included sociodemographic attributes, residential location characteristics, and trip characteristics. Travel time and travel cost were assumed to be alternative specific variables. Thus, coefficients of travel time and travel cost were assumed to be different between modes. To simplify the model for other variables, the car alternative was used as a reference, meaning the coefficients of the rest of variables for the car alternative were assumed to be zero. The utility functions of private car (V_{car}) and rail transit (V_{rail}) can be expressed as follows:

$$V_{car} = \beta_{car,T}T_{car} + \beta_{car,C}C_{car}, \qquad (1)$$

$$V_{rail} = \beta_{rail,T}T_{rail} + \beta_{rail,C}C_{rail} + \gamma_{rail}M + \beta_{rail}X \qquad (2)$$

Each alternative is denoted by a subscript. Travel time and its coefficient are denoted by $T_{alternative}$ and $\beta_{alternative,T}$, respectively. Travel cost and its coefficient are denoted by $C_{alternative}$ and $\beta_{alternative,C}$. The vector of the hypothetical variables (as shown in Table 2) is denoted as M, and its corresponding coefficient is denoted as γ. The vector of the remaining variables is denoted as X, and its corresponding coefficient is denoted as β. The model was estimated using 'mlogit' function in R (xCroissant, 2020).

RESULTS

Descriptive Statistics

The number of respondents for each zone can be found in Table 3. Most were males who lived in inner suburban areas, and the average age of respondents was 36.43-years-old. Respondents who resided in central Bangkok were older and had higher incomes than those residing in inner suburbs or outer suburbs, respectively. The survey results show that the average travel distance to access public transit system varied across areas. The lower the population density of one's residential area, the farther one had to travel to access public transit. Furthermore, while results show that each household owned at least one car, individuals residing in the outer suburbs had a higher number of private cars in their households compared to those who resided in inner suburbs and central Bangkok. This indicates that respondents who had limited access to public transport were likely to be more reliant on travelling by private car. Additionally, individuals residing in the inner suburbs owned a higher number of private motorcycles than those living in the outer suburbs or central Bangkok. A critical finding of the survey relates to cost; for individuals residing in central Bangkok or the inner suburbs, traveling by rail transit costs less than traveling by car. However, for respondents living in the outer suburbs, traveling by car costs less than traveling by rail transit.

With respect to choice of travel modes resulting from the three hypothetical scenarios of a flat charge, car ban, or public transit fare subsidization, 54%, 40%, and 72% of respondents reported that they would switch their travel mode to rail transit, respectively. In the flat charge scenario, 38% of respondents always chose private cars and 47% always chose rail transit; yet, under the car ban measure, 32% and 14% of the respondents always chose private car or rail transit, respectively. The public transit fare subsidization measure resulted in the greatest switch to rail transit — only 14% of respondents always chose private car, while 48% always chose rail transit.

Table 2

Mapping identified root causes under the conceptual framework and the problem's scale

Problem level	Institutional and legislative frameworks	Parking policies and programs	Implementation
Structure	(4.3.1) Institutional fragmentation	(4.3.4) Lack of on-street parking policy	(4.3.7) Lack of monitoring mechanisms
Stakeholder	(4.3.2) Lack of interest and commitment from both national and local (4.3.3) Limited legislative authority of the local government	(4.3.5) Lack planning and review of on-street parking programs	(4.3.6) Ineffective law and regulation enforcement (4.3.8) Perceived seriousness of infringements by driver and public officer

Table 3

Descriptive Statistics of Respondents

Variables		Central Bangkok		Inner suburb		Outer suburb		All	
Discrete variables		*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Number of observations		267	36.53	251	34.34	213	29.14	731	100.00
Gender	Male	153	57.30	175	69.72	142	66.67	470	64.30
	Female	114	42.70	76	30.28	71	33.33	261	35.70
Income	<15k THB/month	19	7.12	36	14.34	25	11.74	80	10.94
	15k-20k THB/month	73	27.34	61	24.30	51	23.94	185	25.31
	20k-30k THB/month	64	23.97	89	35.46	83	38.97	236	32.28
	>30k THB/month	111	41.57	65	25.90	54	25.35	230	31.46
Distance to transit	<0.5 km	48	17.98	30	11.95	16	7.51	94	12.86
	0.5 – 1 km	112	41.95	55	21.91	33	15.49	200	27.36
	1 – 5 km	90	33.71	102	40.64	76	35.68	268	36.66
	>5 km	17	6.37	64	25.50	88	41.31	169	23.12
Continuous variables		*Mean*	*Std*	*Mean*	*Std*	*Mean*	*Std*	*Mean*	*Std*
Age		37.43	8.77	36.31	11.06	35.31	9.61	36.43	9.87
Number of cars in household		1.5	0.72	1.57	1.03	1.61	0.93	1.56	0.90
Number of motorcycles in household		0.63	0.95	1.07	1.09	0.97	0.87	0.88	0.99
Travel frequency (Times/week)		5.87	1.17	5.3	1.36	5.42	1.33	5.51	1.30
Travel mode									
Car	Original travel time (Min)	41.93	18.81	43.85	22.22	50.47	28.01	45.08	23.21
	Travel cost (THB)	89	65.85	78.61	62.88	80.19	45.57	82.87	59.66
Rail transit	Original travel time* (Min)	18.5	12.85	22.04	17.66	25.7	18.65	21.23	16.07
	First mile travel time (Min)	12.29	7.94	15.03	10.62	14.02	8.83	13.5	9.07
	Last mile travel time (Min)	8.71	5.19	8.98	7.55	9.28	5.59	8.92	6.05
	Total travel time (Min)	39.37	16.59	45.73	23.56	49.37	23.26	43.56	20.85
	Travel cost (THB)	37.36	15.36	40.08	32.43	44.88	100.87	39.92	52.89
	Last mile travel cost (THB)	9.48	11.02	12.48	14.38	17.61	27.76	12.26	17.52
	First mile travel cost (THB)	16.78	17.96	21.44	26.42	28.73	37.74	20.95	26.66
	Total travel cost (THB)	63.41	28.02	73.73	49.57	90.1	110.56	72.66	63.46

Note. The original travel time for rail transit refers to travel time from the origin station to destination station.

Results of binomial logit model

A binomial logit model was used to analyze the effects of transport-related measures on an individual's travel mode choice. Respondents were grouped according to their residential zones, and analyzed separately, resulting in estimations for three models: central Bangkok, the inner suburbs, and the outer suburbs (Table 4). For each model, we determined the coefficient estimates, odds ratio, significant levels, and goodness-of-fit (i.e., McFadden R^2 and adjusted McFadden R^2). The adjusted McFadden R^2 values for central Bangkok, the inner suburbs, and the outer suburbs models were 0.223, 0.138, and 0.183, respectively.

Our results indicate that the effectiveness of TDM policies varies across geographical areas. All else being equal, rail transit fare subsidization was found to be more effective in reducing car use among respondents residing in the inner suburbs compared to those living in central Bangkok or the outer suburbs. The car ban was effective in reducing car use across all geographical areas, though notably its effectiveness increased the farther away a respondent lived from the center of the city. Specifically, our binomial logit model estimates were 1.258 for the outer suburbs, 1.187 for the inner suburbs, and 1.062 for central Bangkok. Finally, the flat charge was only effective in reducing car use among respondents residing in central Bangkok or the inner suburbs.

Notably, our results show that some factors affecting the utility of private car and rail transit were different across individuals' residential locations. For instance, in central Bangkok, rail transit was more preferred by low-income individuals as compared to middle-to-high income individuals. In particular, the odds ratio for low-income respondents (i.e., those with incomes of less than 15,000 THB/month) using rail transit was 3.538. Therefore, the odds that low-income respondents would prefer rail over car was 3.538 times higher than that of middle-income respondents (i.e., those with incomes between 20,001 – 30,000 THB/month). By contrast, in the outer suburbs, rail transit was more preferred by high-income individuals than by low-income individuals. Car ownership was also found to significantly decrease the utility of rail transit, but only for respondents who resided in the outer suburbs. However, motorcycle ownership significantly decreased the utility of rail transit for respondents living in inner suburbs, though it was insignificant for those who resided in other zones. This confirms that travel behavior and travel mode dependency are associated with spatial attributes of residential locations.

CONCLUSION AND DISCUSSION

Addressing the severe air quality in Bangkok has become a priority for several sectors and government bodies, especially those with the authority to design and implement air pollution related policies. In this study, we examined potential travel demand management (TDM) measures to reduce private car use for daily commuting. The result from the binomial logit model indicates that the effectiveness of measures to reduce car use differed across residential locations.

A flat charge could effectively reduce car use, yet only for respondents residing in central Bangkok or its inner suburbs. This can likely be attributed to the fact that residents in these areas generally find it cheaper to travel by rail transit than private car. Since the additional flat charge for driving a private car outweighs the car's convenience, they would switch to rail transit.

Rail transit fare subsidization was found to be more effective in reducing car use among respondents residing in the inner suburbs than among those residing in central Bangkok or its outer suburbs. This is potentially because people in the inner suburbs can enjoy more benefits from a fare reduction compared to other population groups. People in central Bangkok primarily travel short distances, meaning a rail transit fare reduction would not be a significant enough benefit to change their travel mode. For people in outer suburbs, who have difficulty accessing public transport to begin with, the benefit of the fare reduction is not large enough to absorb the cost of switching their travel mode from private car to rail transit.

Table 4

Results of Binomial Logit Model

Variables	Central Bangkok			Inner Suburb			Outer Suburb		
	Estimate	Odds Ratio	Sig.	Estimate	Odds Ratio	Sig.	Estimate	Odds Ratio	Sig.
(Intercept):rail	-0.452			-0.394			-0.165		
Stated scenarios' variables									
Flat charge:rail	0.005	1.005	***	0.004	1.004	**	0.000	1.000	
Car ban:rail	1.062	2.893	**	1.187	3.279	***	1.258	3.518	***
Rail transit fare subsidization:rail	0.999	2.717	***	1.967	7.152	***	1.050	2.857	**
$PM_{2.5}$ concentration 51-75:rail	1.048	2.851	***	0.311	1.365	.	0.391	1.478	*
$PM_{2.5}$ concentration <=50:rail	1.016	2.762	***	0.238	1.269		0.306	1.358	.
Reduced Travel time:car	0.015	1.015	**	-0.005	0.995		0.003	1.003	
Reduced Travel time:rail	-0.016	0.984		0.020	1.020	*	-0.009	0.991	
Other variables of travel modes									
Travel cost:car	0.000	1.000	***	0.000	1.000	***	0.000	1.000	*
Travel cost:rail	-0.013	0.987	*	0.007	1.007	*	0.012	1.012	**
First mile travel time:rail	0.034	1.034	*	0.014	1.014	*	-0.007	0.993	
Last mile travel time:rail	0.018	1.018		0.026	1.026	*	0.026	1.026	
First mile travel cost:rail	-0.010	0.990	*	0.000	1.000		-0.007	0.993	*
Last mile travel cost:rail	-0.008	0.992		-0.032	0.969	***	-0.013	0.987	**
Socioeconomic variables									
Age:rail	0.020	1.020	*	0.000	1.000		0.020	1.020	*
Female:rail	1.001	2.721	***	0.990	2.690	***	0.845	2.328	***
Income <15k:rail	1.264	3.538	***	0.969	2.636	***	-2.241	0.106	***
Income 15k-20k:rail	0.820	2.270	***	0.066	1.068		0.141	1.152	
Income >30k:rail	0.976	2.655	***	-0.068	0.934		-0.835	0.434	***
Number of cars in household:rail	-0.028	0.972		0.136	1.146		-0.537	0.585	***
Number of motorcycles in household:rail	-0.035	0.966		-0.292	0.746	***	-0.143	0.867	
Distance to rail transit station 5m-1km:rail	0.616	1.852	**	-0.134	0.875		1.132	3.100	**
Distance to rail transit station 1-5km:rail	-0.614	0.541	**	-1.069	0.343	***	-0.607	0.545	.
Distance to rail transit station > 5km:rail	-2.715	0.066	***	-1.906	0.149	***	-0.280	0.756	
Travel frequency (day/week):rail	-0.179	0.836	*	-0.010	0.990		-0.010	0.990	
Null Log-Likelihood	-1029.840			-834.020			-666.000		
Log-Likelihood	-775.340			-694.090			-518.970		
McFadden R^2	0.247			0.168			0.221		
Adjusted McFadden R^2	0.223			0.138			0.183		

Finally, it was found that a car ban would be effective in reducing car use across all geographical areas, though notably its effectiveness increased the farther away a respondent lived from the center of the city. These results correspond to the average number of cars per household per residential area, with car ownership being highest in outer suburbs.

Based on the results from this study, it is clear that multiple TDM policies to control severe air pollution in Bangkok have the potential to be successful, but they should be tailored according to the needs and characteristics of communities in each residential area. Creating, planning, and implementing such measures to change travel behavior will require collaboration across government bodies and stakeholders in the transportation sector in order to serve the needs of all Bangkok residents.

The limitation of this study was that the three proposed measures were analyzed separately. Therefore, the synergistic effects of the combination of these measures could not be identified in this study, and should be taken into account in future research. Additionally, there was a hypothetical bias in this study due to the stated preference approach. Future research can overcome this hypothetical bias by testing policies in a real-world setting.

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