EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Impact on fuel consumption reduction of introducing hybrid cars in Bangkok using probe information and mobile fuel measurement

Atsushi Fukuda*, Napon Srisakda, Tetsuhiro Ishizaka and Sathita Malaitham

Department of Transportation Systems Engineering, College of Science and Technology, Nihon University, Funabashi, Chiba, 274-8501, Japan

Received April 2016
Accepted June 2016

Abstract

Since a hybrid vehicle consumes less gasoline, especially in traffic congestion, it is expected to reduce fuel consumption from vehicles in a city like Bangkok. Thus, the reduction in fuel consumption after introducing hybrid car should be estimated to understand its impacts. However, fuel consumption is dependent on driving situations, which fluctuate locally and are unstable. Therefore, an estimation method using probe data reflecting local traffic conditions should be applied. In this study, a method to estimate fuel consumption of gasoline and hybrid vehicles was proposed based on probe information obtained from around 10,000 taxis and mobile fuel consumption measurement in actual test runs. To represent the local traffic situation, five different driving modes (stopping/idling, crawling, accelerating, cruising, and decelerating) were identified. Under the assumption that all probe vehicles be replaced by hybrids, fuel reduction impacts are clearly observed in congested traffic.

Keywords: Fuel consumption, Hybrid car, Probe data, Driving modes

1. Introduction

Traffic congestion results in low average speeds and non-smooth traffic flow. It involves long times of stopping/idling, increased fuel consumption and CO_2 emissions [1] because each vehicle is basically kept in idle and is still burning fuel. Thus, the auto industry introduced a new generation of fuel saving and environmentally friendly vehicles, or so-called "hybrid car/vehicles (HV)". However, it is still questionable how much fuel the owners can save in different driving modes and traffic conditions. This paper aims to estimate the fuel wasted by gasoline and hybrid vehicles in various traffic conditions in the Bangkok Metropolitan Region. The method to estimate fuel consumption of gasoline and hybrid vehicle cases was proposed based on probe information from around 10,000 taxis and mobile fuel consumption measured by actual test runs.

2. Literature review

Previous studies indicated that probe data can be used as an alternative method for fuel consumption estimation depending on driving modes. For example, probe data and road detectors to estimate fuel consumption and greenhouse gas (GHG) emissions [2]. Furthermore, the impacts of using alternative energy, i.e., diesel and a 5% biodiesel (B5) were found based on probe data [3]. Also, there are some literatures of the impacts of using hybrid vehicles under different traffic conditions and road categories over varying periods of time [4]. On the other hand, the research of Wang et al. [5] considered the impacts of hybrid car in downtown and suburban areas. Additionally, Pitanuwat and Sripakakorn [6] investigated fuel mitigation using hybrid vehicles in actual driving tests in Bangkok. These results indicated that introducing hybrid vehicles achieved the greatest reduction in fuel consumption on downtown arterials during periods of traffic congestion. However, these studies used only hybrid vehicles to test the impacts on fuel consumption, although they used data from road detectors (probe data) to define traffic conditions.

3. Methodology

The methodology of this study is shown in Figure 1.

Fractional duration is defined as "Time Sharing of Driving Modes" to use probe data in the current study. Thus, mobile fuel consumption from two cars in actual driving tests considering their fractional duration of driving modes from probe data can be used to estimate total fuel consumption. This is expressed by Equation (1) for hybrid systems and Equation (2) for non-hybrid systems.

$$\boldsymbol{FC_{without} = FC_{vspeed} \times TS} \quad (1)$$

$$\boldsymbol{FC_{withHV} = FC_{vspeed,on} \times TS \times \frac{Freq_{on}}{Freq_{on}+Freq_{off}}} \quad (2)$$

where FC_{WithHV} = Total fuel consumption for "With HV"

*Corresponding author. Tel: +81-47-469-5355
Email address: fukuda.atsushi@nihon-u.ac.jp
doi: 10.14456/easr.2017.34

$FC_{WithoutHV}$	=	Total fuel consumption for "Without HV"
$FC_{Vspeed,on}$	=	Mobile fuel consumption for each speed range when the engine is "ON"
TS	=	Time sharing for each driving modes from probe data
$Freq_{on,or\ off}$	=	Frequency of gasoline engine operation

4. Data collection

The Bangkok Metropolitan Region (BMR) was selected as a case study. One hybrid and gasoline cars, which are the same model year of release, car, and brand, were used to measure mobile fuel consumption in actual driving tests. These tests were done during June 11st to 14th, 2016. Various conditions were identified as the days of week (weekdays or weekends), periods (morning peak (7:00-9:00), off-peak (9:00-16:00), and evening peak (16:00-19:00)), and road categories (highways, arterials, and minor roads).

5. Results

5.1 Time sharing of driving modes estimation

Time sharing diagrams of five driving modes, including stopping/idling, crawling, accelerating, cruising, and decelerating in the inner areas are estimated. Figure 2 shows examples of time sharing diagrams estimation of arterials during the weekdays and weekends.

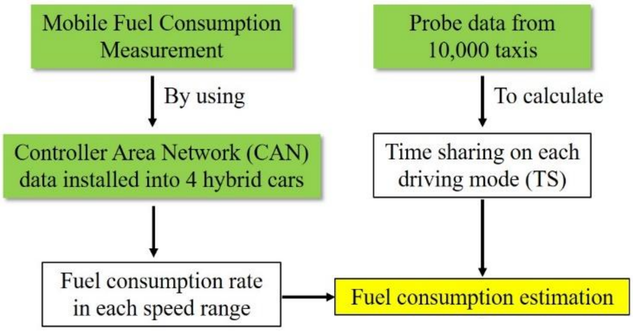


Figure 1 Methodology

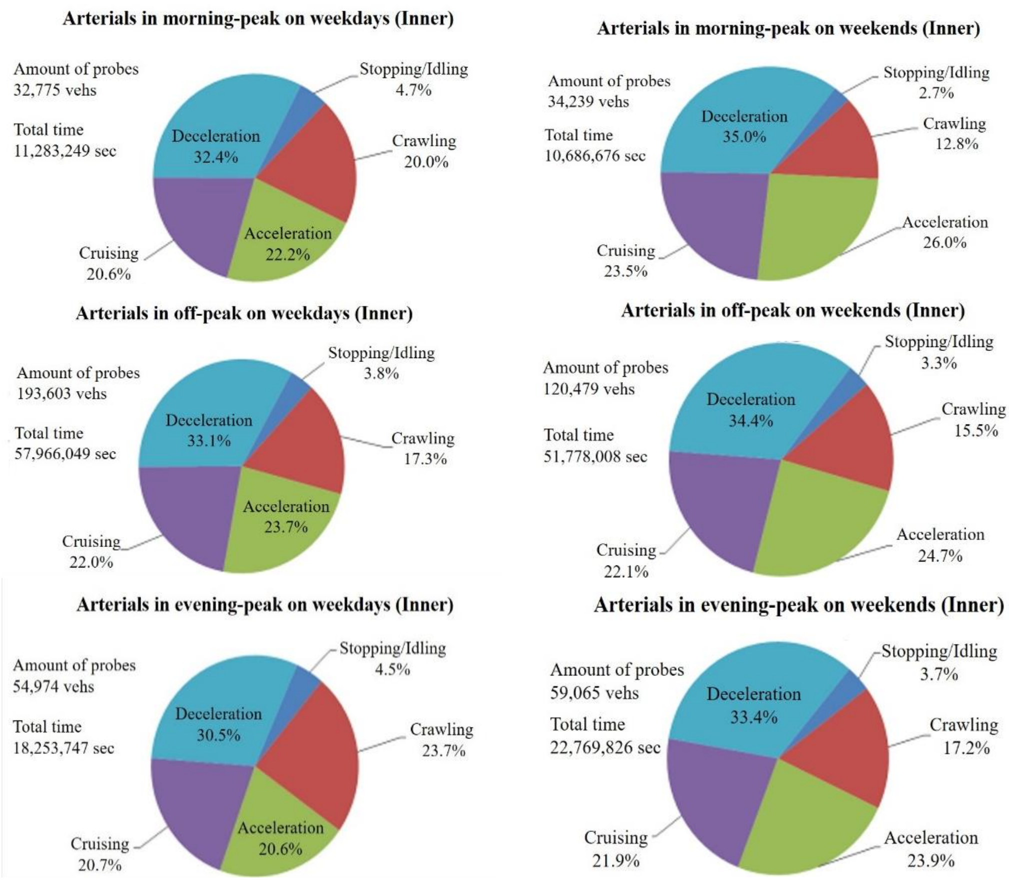


Figure 2 Time sharing diagrams in inner areas on arterials

From Figure 2, it can be seen that the crawling mode accounts for almost 30% of fuel consumption on arterials. When only stopping/idling are considered, a few impacts of congestion are only seen if congestion percentages are less than 10%.

The distribution (percentages) of driving modes among the road categories and days were compared, as shown in Figure 3. It is clearly seen that the percentages of stopping and crawling are greater in inner areas than outer areas in all cases. Traffic congestion is indicated by this figure.

6. Fuel consumption estimation and reduction by the impacts of using hybrid cars

6.1 Fuel estimation

In the actual driving test, mobile fuel consumption (CC/sec) of hybrid and gasoline cars was determined for various days of the week, and periods in each driving mode, speed range, and indicated time frequency (sec) in case of the hybrid system (the gasoline system is inoperative OFF) or operative (the gasoline system is ON).

Tables 1 and 2 summarize the weekday mobile fuel consumption by hybrid and gasoline cars during peak hours on arterials.

6.2 Fuel consumption results

By equations (1) and (2), fuel consumption rates (total fuel consumption divided by vehicle kilometers traveled, VKT) and reduction percentages (difference percentages between without HV and with HV rates) are summarized. They are presented according to three considerations (area and day of the week, road category, and driving mode) in Figure 4.

From the area/days of week results, the highest consumption rate was in the inner areas on weekdays by vehicles without HV technology. When road category was considered, the highest consumption rate was on arterials and minor roads on weekdays. Fuel reduction impacts were clearly observed in the inner areas of BMR on weekdays, and on arterials on weekdays. Since high consumption corresponds to high stopping and crawling percentages in the results of time sharing, the fuel consumption increases when traffic is congested as measured by time sharing of driving modes as found in previous study [1].

The most effective driving mode is acceleration. However, in terms of fuel reduction, stopping and crawling modes were effectively reduced by 87%.

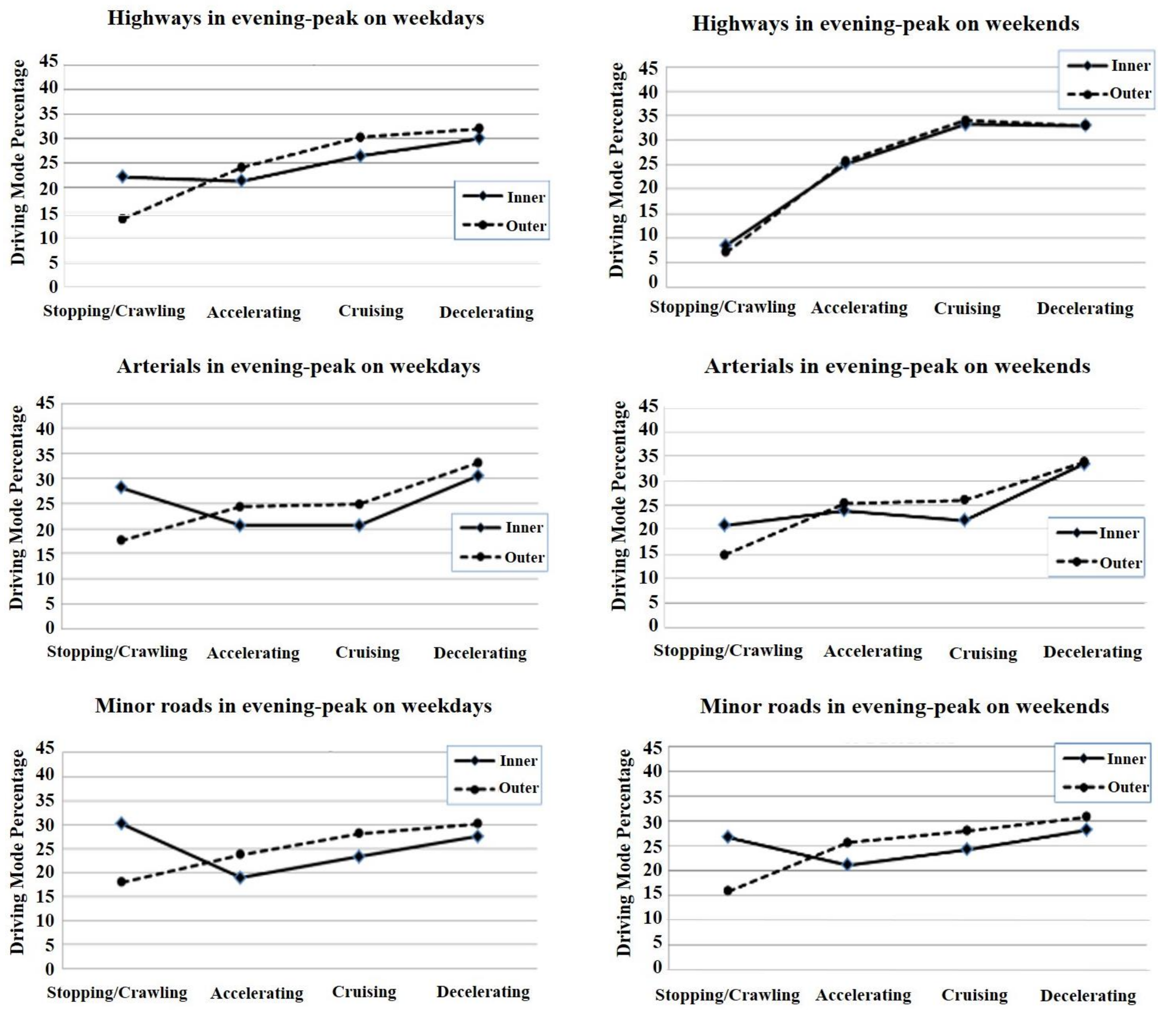
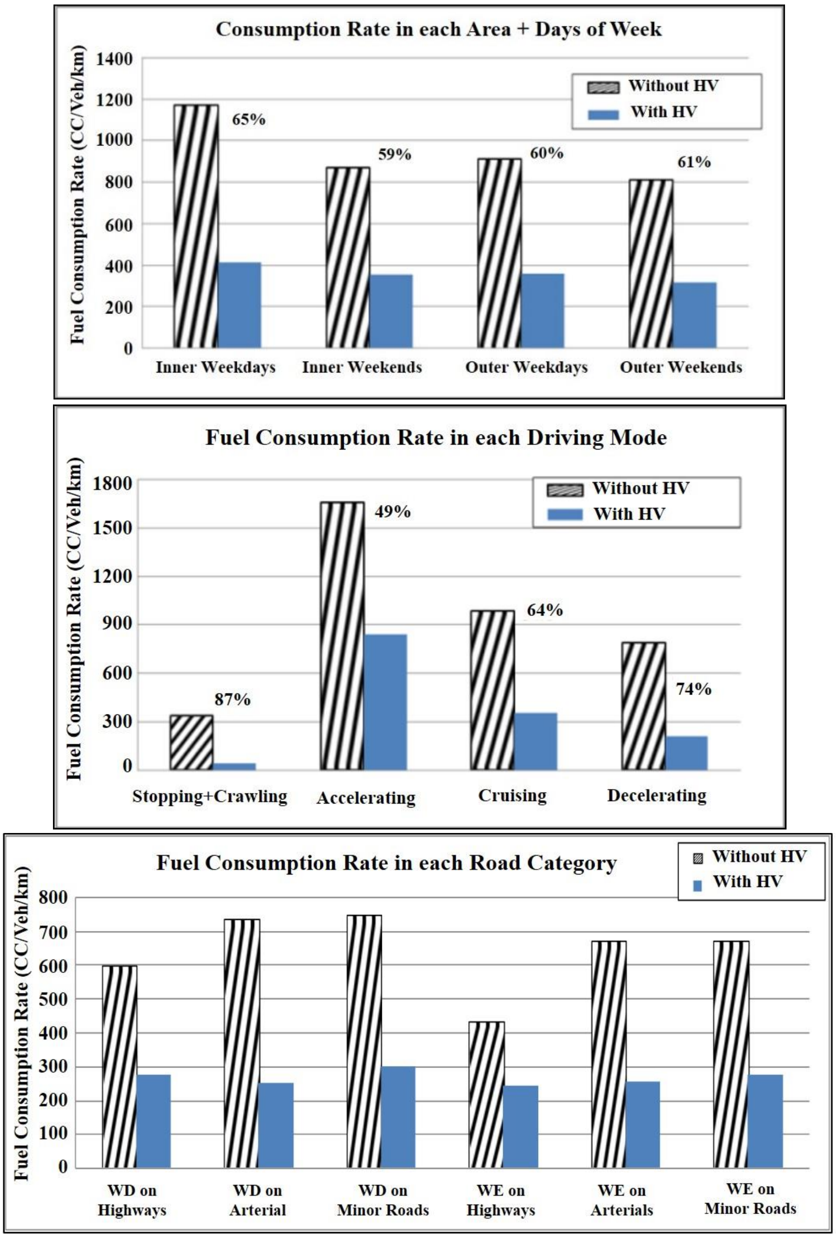


Figure 3 Percentages of driving modes on each road category and days in the evening peak



Note: WD = weekdays, WE = weekends

Figure 4 Results of fuel consumption rate and percentages of reduction under each consideration

Table 1 Mobile fuel consumption results of the hybrid car

Driving Mode	Stopping/Idling				Crawling				Accelerating				Cruising				Decelerating			
Speed Range (km/h)	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec
0	0.25	18	0	286	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-10	-	-	-	-	0.44	283	0	269	1.09	82	0	70	0.39	63	0	88	0.21	76	0	88
11-20	-	-	-	-	-	-	-	-	0.82	101	0	74	0.51	64	0	116	0.30	98	0	116
21-30	-	-	-	-	-	-	-	-	1.12	86	0	39	0.48	57	0	109	0.30	63	0	109
31-40	-	-	-	-	-	-	-	-	1.16	70	0	35	0.52	45	0	79	0.45	59	0	79
41-50	-	-	-		-	-	-	-	1.16	49	0	32	0.61	42	0	63	0.29	53	0	63
51-60	-	-	-	-	-	-	-	-	1.33	33	0	33	0.55	37	0	58	0.29	47	0	58
>61		-	-	-	-	-	-	-	1.11	25	0	0	0.51	10	0	0	0.21	21	0	0
Total (sec)	-	18	-	286	-	283	-	269	-	446	-	283	-	318	-	513	-	417	-	513
Average (CC/sec)	0.25	-	-	-	0.44	-	-	-	1.11	-	-	-	0.51	-	-	-	0.29	-	-	-

Table 2 Mobile fuel consumption results of the gasoline car

Driving Mode	Stopping/Idling				Crawling				Accelerating				Cruising				Decelerating			
Speed Range (km/h)	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec	ON	sec	OFF	sec
0	0.25	298	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-10	-	-	-	-	0.53	283	0	0	1.95	155	0	0	0.40	126	0	0	0.35	169	0	0
11-20	-	-	-	-					1.24	169	0	0	0.68	122	0	0	0.46	211	0	0
21-30	-	-	-	-	-	-	-	-	1.39	123	0	0	0.73	108	0	0	0.51	178	0	0
31-40	-	-	-	-	-	-	-	-	1.65	95	0	0	1.23	87	0	0	0.49	142	0	0
41-50	-	-	-		-	-	-	-	1.96	78	0	0	1.26	84	0	0	0.62	119	0	0
51-60	-	-	-	-	-	-	-	-	1.58	64	0	0	0.89	73	0	0	0.63	104	0	0
>61		-	-	-	-	-	-	-	1.27	21	0	0	0.54	13	0	0	0.59	24	0	0
Total (sec)	-	298	-	0	-	283	-	0	-	705	-	0	-	613	-	0	-	947	-	0
Average (CC/sec)	0.25	-	-	-	0.53	-	-	-	1.58	-	-	-	0.82	-	-	-	0.52	-	-	-

7. Conclusions

This study aims to determine time sharing of driving modes from probe data under a variety of traffic conditions to estimate fuel consumption and to study the impacts of using hybrid vehicles in BMR. The methodology is considered from both Business As Usual (BAU) and replacing hybrid vehicles cases in all probe vehicles to determine the fuel reduction impacts.

As a result, the highest fuel consumption rate is in the inner area of the BMR on weekdays for non-hybrid systems. Driving on arterials and minor roads consumes the most fuel on weekdays. This corresponds to long stopping and crawling times seen in time sharing calculations in the initial analysis. If hybrid vehicles replaced all probe vehicles, fuel reduction impacts are clearly observed in the inner areas on weekdays, on arterials and minor roads, and in stopping/crawling modes.

8. References

[1] Barth M, Boriboonsomsin K. Real-world CO2 impacts of traffic congestion. Transport Res Rec. 2008;2058:163-71.

[2] Chang XM, Chen BY, Li Q, Cui X, Tang L, Liu C. Estimating real-time traffic carbon dioxide emissions based on intelligent transportation system technologies. IEEE Trans Intell Transport Syst. 2013;14(1):469-79.

[3] Ropkins K, Quinn R, Beebe J, Li H, Daham B, Tate J, et al. Real-world comparison of probe vehicle emissions and fuel consumption using diesel and 5% biodiesel (B5) blend. Sci Total Environ. 2007; 376:276-84.

[4] Raykin L, Roorda MJ, MacLean HL. Impacts of driving patterns on tank-to-wheel energy use of plug-in hybrid electric vehicles. Transport Res Transport Environ 2012;17(3):243-50.

[5] Wang H, Zhang X, Ouyang M. Energy consumption of electric vehicles based on real-world driving patterns: a case study of Beijing. Appl Energ. 2015;157: 710-9.

[6] Pitanuwat S, Sripakagorn A. An investigation of fuel economy potential of hybrid vehicles under real-world driving conditions in Bangkok. Energ Procedia. 2015;79:1046-53.