Impact of Electronic Toll Collection System on Energy Saving and CO_2 emission: A Case Study of Passenger Cars in Thailand

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Abstract- Traffic problems have been a long-standing issue for Thailand, although many measures have already been implented to solve them. Electronic Toll Collection system (ETC) is one of those measures used for reducing the traffic problems at the front of checkpoint on the expressway. However, there are no research studies on the effect of ETC on expressway transportation in Thailand. The objective of this study was to evaluate the impact of the four main factors (time, speed and acceleration, fuel consumption, and CO_2 emission) on the ETC system compared to the Manual Toll Collection (MTC). In addition, four scenarios of applying ETC were analyzed to evaluate the potential of energy saving and CO_2 emission in Thailand. In this study, Ram Inthra Toll Plaza, Bangkok was selected as a case study, and the car model Nissan March year 2010 was selected as the representative vehicle. Results found that time consumed for paying the fee at ETC was only two seconds which is faster than MTC about six times. Using ETC toll can reduce fuel consumption by up to 4 milliliter/trip and reduce CO_2 emission about 9.7% compared with MTC. It is estimated that Thailand could reduce fuel consumption up to 1,262,471 liter/year with the reduction of 2,754 ton CO_2eq/year, when ETC toll is applied to all the expressways of the country.

Keywords Fuel consumption, energy saving, CO_2 emission, passenger cars, Electronic Toll Collection.

1. Introduction

Traffic jam is a common problem in every major city in the country. In 2015, the number of passenger cars and commercial vehicles in use worldwide was estimated about 1,282,000 unit [1]. The number of passenger cars and commercial vehicles used worldwide is projected to reach the two billion marks by 2040 [2]. Spending too much time on the road will have an impact on the development of social and public health and will also lead to loss of energy and economic opportunity. There are no universal measures to get rid of the traffic problems permanently, because each city has its own problems. The problems, such as the insufficient road, the unbalanced to meet the needs of road users, and the traffic management, were claimed to be mainly clauses for traffic congestion. To solve this problem, flexible measures are required, for example, adjusting the working time of companies, encouraging working remotely from home, and diversifying route and cost of transportation.

In Thailand, due to rapid development in urban area, the usage of private automobiles and commercial vehicles has been increased as well as the problem of road congestion. During year 2012 - 2016, the number of car using expressway has been increased continuously about 3.9% in each year [3]. In 2017, Thailand topped the list on traffic scorecard with drivers spending an average of 56 hours in peak hour congestion [4]. This causes was leading to consume a lot of fuel in transportation without the necessity. Ministry of Energy of Thailand has reported that transportation sector tends to increase energy consumption in the last five years. In 2012, the energy consumption in this sector was 26,230 kiloton of oil equivalent (ktoe), while its increased to 30,190 ktoe in 2016, approximately about 15% compared to year 2012 [5]. With this situation, Thai government tries to find an appropriate technology and measures [6-9] for reducing energy consumption in this sector and also solving traffic problems [10,11].

Electronic toll collection system (ETC) is an advanced technology of the toll collection system. It applies in developed and developing country to solve the problem of the traffic jam at the front of the checkpoint. ETC system is not only reducing transaction time at the toll booth but also enhance the convenience and safety of travelers [12-14]. Many benefits have been claimed with the use of ETC system, for example, saving staff costs, minimizing air pollution and fuel consumption, and others [15-17].

With these advantages, Electronic Toll Collection system has been studies for use in many countries, especially developing countries in the ASEAN region, where traffic problems are a major problem for the country. Karsaman et al [18] compared the ETC system with manual system in different toll roads in Indonesia. They found that the ETC system was cheaper than the old system when considering long-term investment. In addition, the transaction speed of ETC was faster than the conventional system. Salleh et al [19] revealed that ETC system made the expressway companies in Malaysia reducing their duplication tasks and resources. In Philippines, Gugol et al [20] identified that there are the significant differences in Toll Plazas performance when applying ETC, especially the reduction of service times at Toll Plaza.

However, there are some studies that have different opinions. A prior study [21] investigated the factors for adopting ETC system and found that the time saved by using the ETC system was not significant role in the decision for driver to use ETC. Meanwhile, the price of electronic pass and discount for ETC tolls were determined as important factors for motivating driver to use ETC tolls [21,22]. Another study [23] revealed that drivers were less likely to use ETC toll if they perceived a high level of risk.

With such experiences in research from foreign countries, it is necessary to determine the factors that will affect the adopting of ETC toll in Thailand. This is because each country has its own problem; the objective of this study thus is to evaluate the impact of the four main factors (time, speed and acceleration, fuel consumption, and CO_2 emission) on the ETC system to the traffic in Thailand.

2. Methodology

2.1 Literature review and indicator defined

In this study, the first step will be started from literature review (as shown in Fig. 1), the lesson-learned related with ETC system from foreign countries were reviewed. Then, the indicators those affected of the ETC installation were analyzed. It should be noted that MTC is a conventional payment in which the driver used cash for paying the fee. ETC uses wireless communication between the in-vehicle device and the toll gate antenna, drivers are able to drive through toll gates without stopping [24]. ETC pay the fee by micropayments from drivers who have typically signed up in advance and loaded money into a declining-balance account which is deducted every time they pass a toll point [25].

After that, the indicators for evaluating the impacts of ETC compared to MTC were defined. From the analysis, the travel time, speed and acceleration, fuel consumption, and CO_2 emission are discussed in this study.

2.2 Experimental design

(1) Selection of representative toll plaza

To select the representative toll plaza, the specific sampling method was used in this study. The criteria of selecting the representative toll plaza was consisted of: (1) lanes with less than 2,000 cars/lanes/day; and (2) the toll booth should be direct at least 100 meters from the entrance to the collection point and from the collection point to the exit. With these criterion, Ram Inthra Toll Plaza was selected as a case study. The location of study area was shown in Fig. 2.

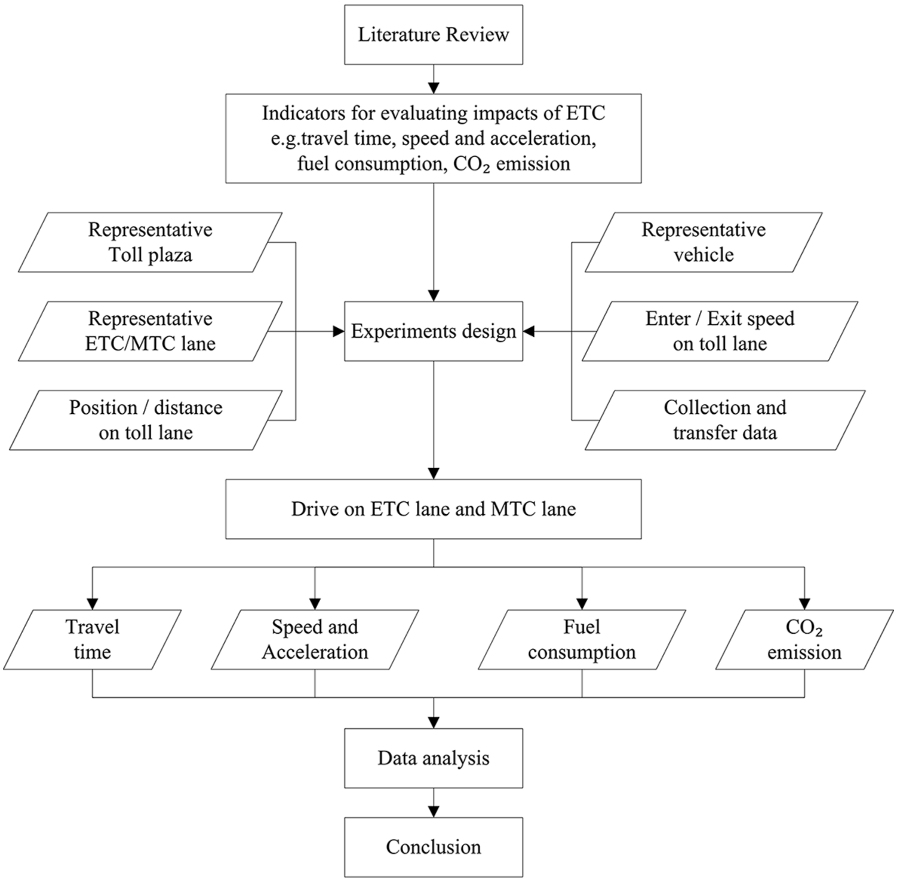


Fig. 1. Research framework of this study.

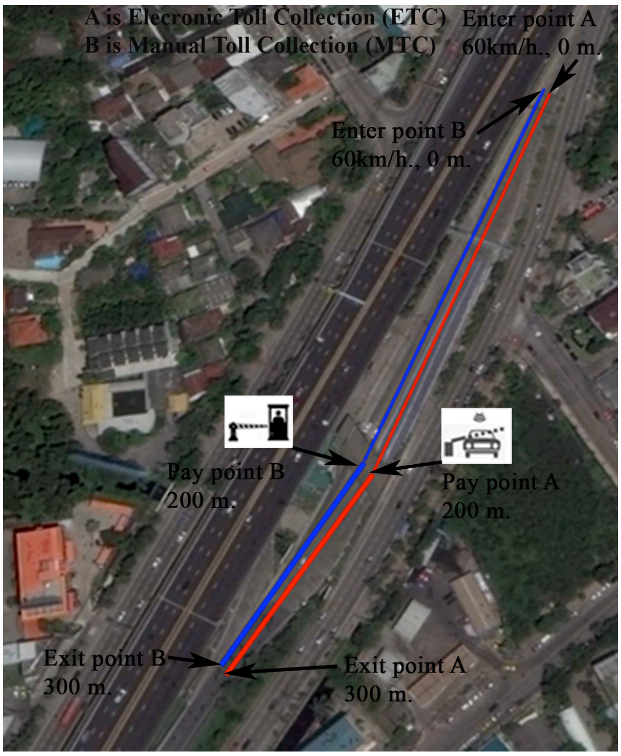


Fig. 2. The location of study area at Ram Inthra toll plaza.

In case of selected representative lanes, one of MTC and one of ETC was selected in which both of them was contiguous for controlling the most similar distance between the experiment. The second lane was selected as representative of ETC and the third lane for representative of MTC, as shown in Fig. 2.

(2) Position and distance for experiment

To collect the data, the distance between the entrances and pay points must be straight, which has the distance 200 meters to reduce the speed for paying tolls. After paying tolls, the data will collect until the exit point, which has the distance 100 meters, as shown in Fig.3. The driver will drive the car to the toll station at a speed of close to 60 km/h to the entrance; after that, the speed will be reduced depending on the situation in both the ETC and MTC tolls. When the toll is paid, drivers will drive their car out of the pay point with an acceleration to get the desired speed (60 km/h) at the exit point, as shown in Fig. 3.

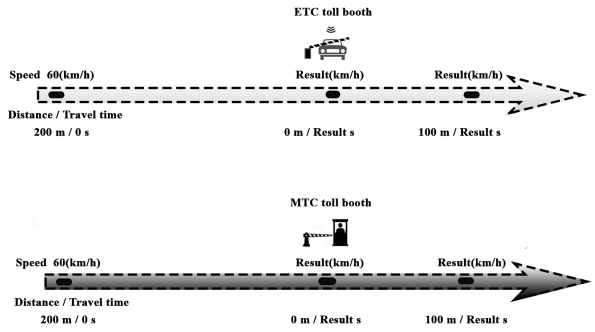


Fig. 3. Designed of collecting data experiment.

(3) Collection and transfer data

Fig. 4 shows the automotive network of this study. It illustrates that the power and torque of the internal combustion engine must be built to match with the required power and torque of the vehicle wheels as driving cycle for experiments. Driving cycle consisted of speed profile and acceleration profile. As shown in Fig. 4, the collection and transfer data system is divided into three main parts: the first part is drivetrains and vehicle dynamic section, which consisted of engine, rotary load (engine), rotary friction, rotary load, gearbox; the second part is control section; and the third part is data storage section. The collected data will be stored in engine control unit (ECU), which receives data from sensors. The data will be transferred from on-board diagnostic (OBD) port by ELM327 scanner (Bluetooth) to smart phone through Torque Pro and Realtime Charts application.

(4) Selection of vehicle groups and types of fuels for this study

In this study, the specific sampling was used, which has the criteria based on the number of registered vehicles classified by vehicle type and fuel type as of December 31, 2017 [26]. With the total number of more than 6 million vehicles in Thailand, the passenger cars using petrol is the most fraction of collecting data, as shown in Table 1. In addition, the trend of car sales in the group of passenger car was analyzed. It was realized that the most car sold in 2017 was Eco-car with 28.94%, followed by B-segment (27.43%), PPV (13.85%), C-segment (12.51%), Crossover (7.18%), SUV (5.10%), and others (4.98%) [27]. Therefore, this study selected Nissan March year 2010 as the representative vehicle, with engine size not exceeding 1200 cc, exhausted standard EURO-IV, manual transmission, and mileage 350,000 km. The reason of choosing Nissan March is because it is the ECO car and is the best-selling model in Thailand.

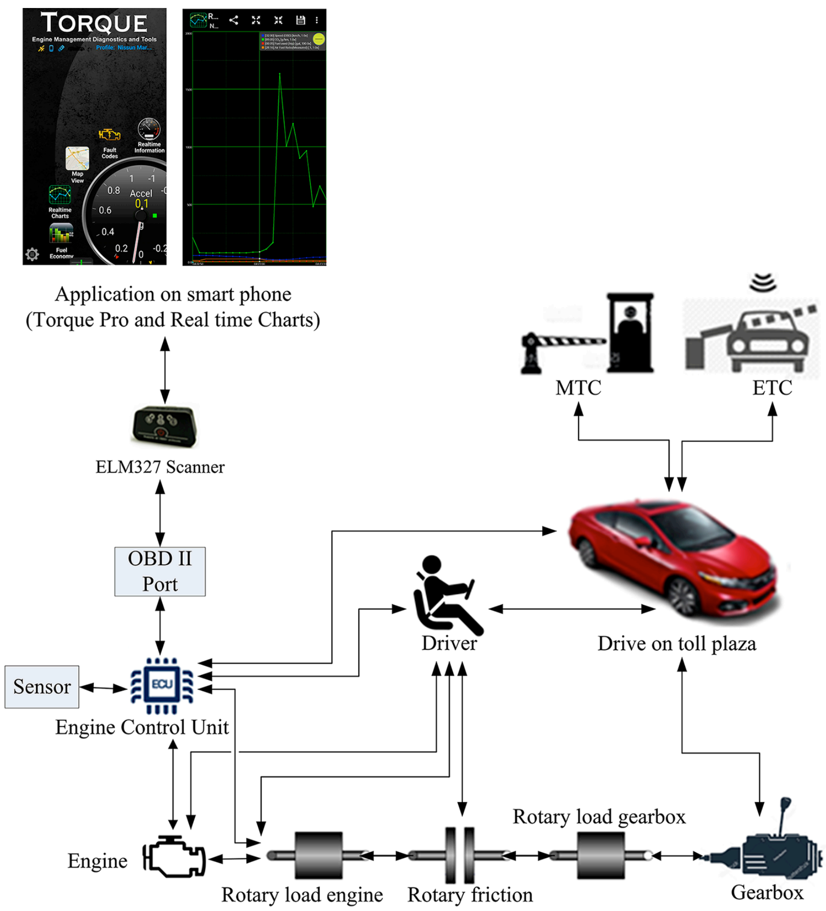


Fig. 4. Schematic diagram of collection and transfer data in this study.

Table 1. Percentage the number of registered vehicles classified by vehicle type and fuel type.

Classified by vehicle types	**Percentage**
Passenger car and taxi	72
Van and pick Up	24
Microbus and passenger van	4
Classified by fuel types	**Percentage**
Petrol	45.2
Diesel	40.1
LPG	9.8

2.3 Drive testing on toll lane

Driving a car according to the requirement stated in the previous section on ETC and MTC tolls. For each toll, the driver will drive 9 times to collect data. The collected data will be analyzed in statistical method (i.e. mean, standard deviation, and coefficient of variation).

2.4 Evaluation the effect of using ETC toll on CO_2 emission

In this section, the energy and CO_2 reduction from using ETC toll were evaluated. The total of fuel consumption was calculated by equation (1) and the total of CO_2 emission was calculated by equation (2).

$$TFC_i = P_{pc} \cdot P_i \cdot T \cdot FC_i \quad (1)$$

$$TCO_{2i} = P_{pc} \cdot P_i \cdot T \cdot FC_i \cdot EFCO_2 \quad (2)$$

Where;

TFC_i refers to total fuel consumption of the year from driving through the type of toll lane i in Bangkok and vicinity of Thailand

TCO_{2i} refers to total CO_2 emission of the year from driving through the type of toll lane i in Bangkok and vicinity of Thailand

P_{pc} refers to the percentage of passenger car in Bangkok and vicinity of Thailand of the year

P_i refers to the percentage of trip which driving through the type of toll lane i of the year

T refers tothenumber of vehicle which driving through the toll lane of the year

FC_i refers tothe fuel consumption of a passenger car driving through the type of toll lane i

$EFCO_2$ refers to the emission factor of CO_2 emission of fuel type, which obtained from [28]

i refers to Lane of electronic toll collection, ETC's lane or lane of manual toll collection, MTC's lane

After calculating the effect of fuel consumption and CO_2 emission from applying ETC, the percentage of passenger using ETC and MTC toll will be varied as follows:

Scenario I the percentage of using MTC and ETC were 67.4%, and 32.6%

Scenario II the percentage of using MTC and ETC were 50%, and 50%

Scenario III the percentage of using MTC and ETC were 25%, and 75%

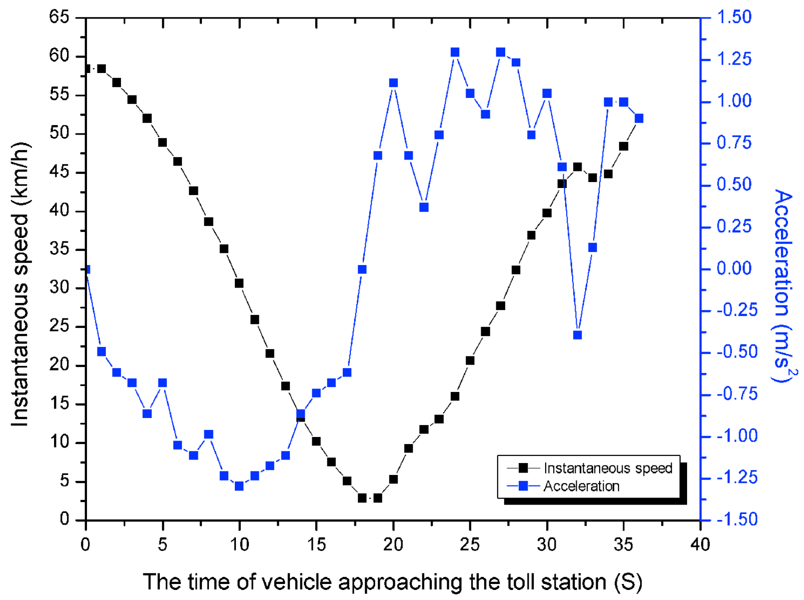
Scenario IV the percentage of using MTC and ETC were 0%, and 100%

Finally, the potential of using ETC in Thailand on energy saving and CO_2 reduction were evaluated based on these scenarios.

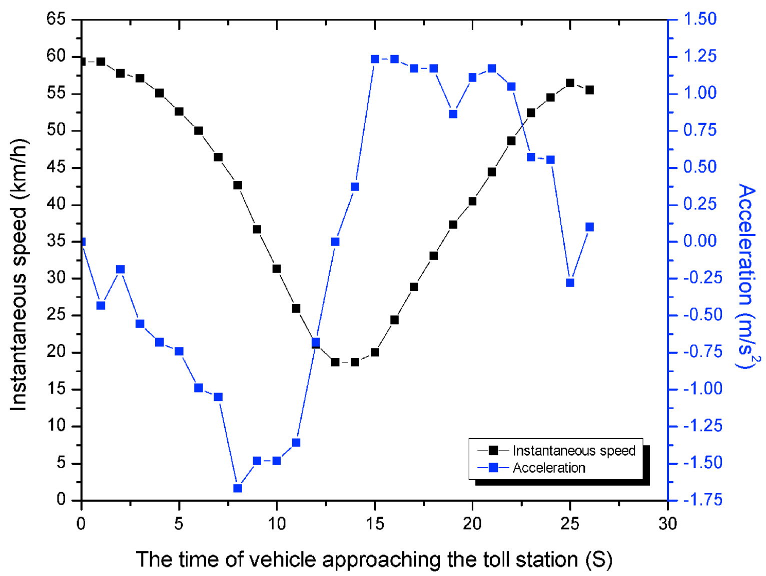
3. Results

3.1 Speed and acceleration of vehicle

Fig. 5 shows the average of instantaneous speed and the average of acceleration of vehicle when driving through MTC and ETC. In case of MTC (Fig. 5a), it can be noticed that within the first period of time (0-19 sec) the speed of vehicle was decreased from 58.4 km/h until to 2.9 km/h with the maximum leverage at -1.3 m/s^2. Time consumed 12 seconds for paying cash at the toll. The lowest speed during paying the fee was 2.9 km/h (at 19 seconds). After that, the speed of vehicle was increased from 2.9 km/h to 52.0 km/h with the maximum acceleration at 1.3 m/s^2. The result was different in the case of ETC, as shown in Fig. 5b. The speed of vehicle was decreased from 59.3 km/h to 18.7 km/h with the maximum leverage at -1.7 m/s^2. The lowest speed used for paying the fee was 18.7 km/h (at 13-14 seconds). Time consumed for paying the fee was only two seconds which is faster than MTC about six times. After that, the speed of vehicle was increased from 18.7 km/h to 55.5 km/h with the maximum acceleration at 1.2 m/s^2.



(a) MTC



(b) ETC

Fig. 5. The result of instantaneous speed andacceleration of vehicle when driving passing through MTC and ETC

Fig.6 shows the relationship between time, position, distance, speed and acceleration of vehicle when driving through ETC and MTC at entry, pay, and exit points. At time zero seconds with a distance between entry and pay point 200 meters, the vehicle has averaged speed 59.3 km/h. After that, the speed of vehicle was reduced by the maximum of leverage at -1.7 m/s^2. At the pay point, the distance was defined as zero. As shown in Fig. 6, the vehicle can drive with the speed of 18.7 km/h through the ETC toll with free stops at the toll point. In case of MTC, the driver must reduce the speed to 2.9 km/h, and accelerate the engine again to exit point, which consumes more time than ETC toll.

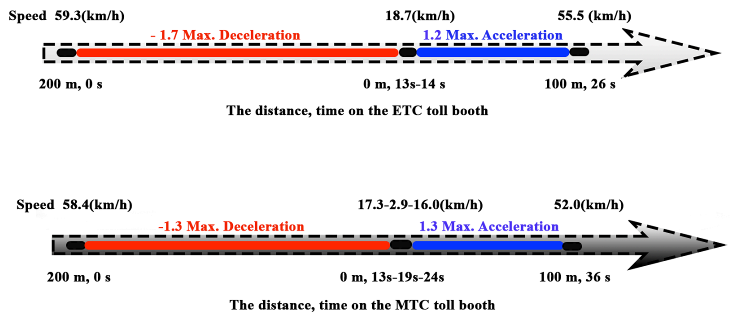


Fig. 6. The relationship between time, position, distance, speed and acceleration of vehicle when driving through ETC and MTC tolls

When determined the total time consume of experiments, it indicated that the time consumed of driving through ETC was shorter than MTC about 10 seconds per trip, as shown in Table 2.

Table 2. The data of time consumed of the experiments.

Experimental Parameter	ETC (seconds)	MTC (seconds)
Min.	23	31
Max.	32	42
Mean	26.1	36.0
Standard Deviation	2.4	3.8
Coefficient of Variation	0.1	0.1
Test Times	9	9

3.2 Fuel consumption and CO_2 emission between MTC and ETC

Table 3 shows the amount of fuel consumption usage on the experiments. It was found that the average of fuel consumption and standard deviation of ETC was about 9.7% less than MTC. In addition, it can be noticed that the amount of fuel consumption in each experiment was not steady. This is because the effect of fuel consumption was not only depended on ETC, but it can also be influenced by the driver's behavior and control procedure. From the result, it can be suggested that if the driver has changed the payment from the MTC toll to ETC toll, it will not only reduce fuel consumption by up to 4 milliliter/trip, but also reduce cost of transportation.

As shown in Table 4, the CO_2 emission from car driving through MTC and ETC toll booth was estimated. The data was collected from oxygen sensorattached to the car. This device has measured the difference percentage of oxygen between the exhaust gas and air. Then, it calculated CO2 emission based on the stoichiometric equation. It can be noticed that the average and standard deviation of CO_2 emission from ETC (100.095 g/Trip, S.D. = 9.045 g) was less than MTC (105.019 g/Trip, S.D. = 13.503 g). It accounted for 5% of CO2 reduction compared to MTC.

Table 3. Fuel consumption of vehicle of the experiments.

Type of toll	Fuel Consumption (L)									
	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	8th Test	9th Test	Average
ETC	0.038	0.042	0.038	0.038	0.034	0.042	0.026	0.038	0.038	0.037
MTC	0.042	0.045	0.030	0.042	0.034	0.038	0.042	0.049	0.049	0.041

Table 4. CO_2 emission from the car driving through the toll booth

Type of toll	CO_2 Emission (g)									
	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	8th Test	9th Test	Average
ETC	108.966	99.685	93.003	94.642	92.979	106.766	119.377	91.808	93.631	98.986
MTC	87.872	92.946	133.389	121.910	103.352	100.127	106.525	102.820	96.233	107.163

3.3 Forecasting the effect of using ETC in Thailand on fuel consumption and CO_2 emission

In this section, the fuel consumption was estimated based on equation (1) and (2). The fraction of using MTC and ETC were 67.4%, and 32.6%, the data were collected from Expressway Authority of Thailand (EXAT) [3]. This fraction will be used to calculate the existing fuel consumption of passenger cars those using express way in Thailand for year 2016 as shown in Fig. 7 (scenario 1). The fraction of using ETC will be varied to demonstrate the effect of using ETC on fuel consumption in scenario 2, 3, and 4.

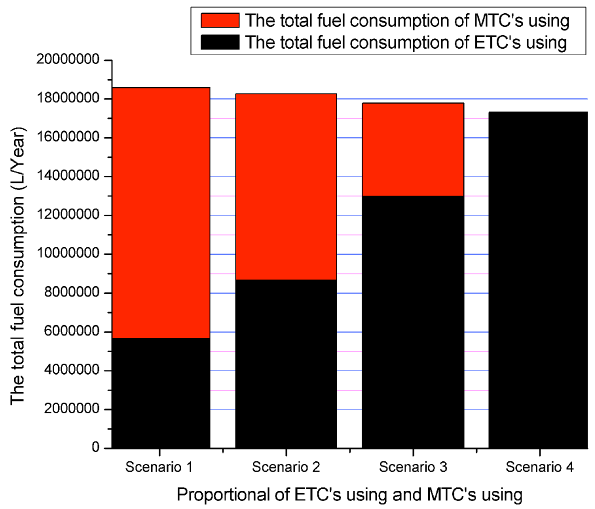


Fig. 7. The total fuel consumption on different scenarios.

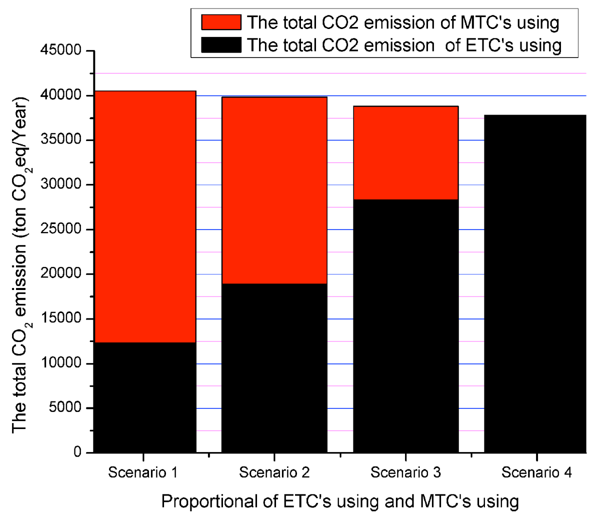


Fig. 8. The total of CO_2 emission on different scenarios.

It can be noticed that when the fraction of using ETC was increased, the total of fuel consumption decreased. This is because ETC toll can reduce the amount of fuel consumption by about 9.7% compared to MTC. Therefore, when more drivers changed to use ETC, the overview of fuel consumption for transportation in express way was reduced. It could be estimated that when all express way in Thailand used ETC toll for passenger car payment, the amount of fuel consumption can be reduced as much as 1,262,471 liters in one year. With reagrds to CO_2 emissions, it demonstrated that the CO_2 emission can be reduced as much as 2,754 tonCO_2eq in one year when all passengers using express way changed to use ETC toll, as shown in Fig. 8.

4. Conclusions

In this study, the effect of four factors (i.e. travel time, speed and acceleration, fuel consumption, and CO2 emission) on the driving through the toll was evaluated. The experiment was designed according to the criteria determination from literature review and regulation. Real experiment in actual situation was operated at Ram Inthra Toll Plaza, Thailand. After the experiment was done, it was found that, ETC can reduce fuel consumption 4 milliter/trip or 9.7 % of fuel consumption compared to MTC. In addition, when forecasting the potential of using ETC all around express ways in Thailand, it can be concluded that Thailand could reduce the fuel consumption about 1,262,471 liter/year, and also reduce CO_2 emission about 2,754 tonCO_2/year. As a result, Thai government should encourage and promote the expressway user to change the toll payment from MTC to ETC toll. This policy will reduce fuel consumption and CO_2 emission, and also reduce the time through the tolls on the expressway.

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