# Development of Driving Simulator for Eco-Driving Evaluation

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***Abstract***

This paper presents a development of Driving Simulator and creating a simple algorithm to evaluate Eco-Driving skill of car drivers. This Driving Simulator has a driver seat, steering wheel, acceleration and brake pedal, TV screen and computers to run simulation software. There are two types of simulation software in this Driving Simulator. The first is a real-time vehicle model. And the second is software to simulate driving environment and visualize it to the driver. Fuel consumption for car drivers can be obtained from vehicle and fuel consumption model. Then use statistical analysis of fuel consumption data obtained from test drivers to establish Eco-Driving evaluation system.
***Keywords****:* driving simulator, eco driving, driver behavior

## 1. Introduction

Currently, more automotive industries are focusing on the ecological aspect of their vehicles and the possibility of reducing automotive carbon emission into the atmosphere. Since it is believed that carbon emissions are one of the causes of global warming, by controlling the vehicle emission rate, it might be possible to slow down the pollution that is being created.

Carbon emission rate is related to the fuel consumption rate of our vehicle. The fuel consumption rate is the speed at which fuel is combusted in the engine in order for the vehicle to run. With a higher fuel consumption rate, it is more likely that there will be a higher carbon emission rate. Thus, in order for a vehicle to have a lower carbon emission, the solution is in reducing the fuel consumption. There are a number of factors which affects the fuel consumption rate, such as human driving behavior and monitoring system [4], vehicle engine, driving and gear change speed [1], and road surfaces and terrains [7]. In this research, the main factor to be studied is the human driving behavior and its relationship with the fuel consumption rate of the vehicle.

The term “Eco-Driving index” is then used to relate the index at which a person is capable of driving at a fuel efficient rate. By ranking the driver with an accurate Eco-Driving index, an approximated fuel consumption rate of the drivers experience can be referred. Due to complication in processing data from actual driving experience, a Driving Simulator [2, 3] can be created which will rank the Eco-Driving index of the driver instead of on-field testing. Thus, this paper is aimed at creating a Driving Simulator which will rate the driver on their Eco-Driving index that can be referring to the fuel efficiency and consumption rate.

To evaluate Eco-Driving skill of driver, two factors must be controlled which are vehicle and traffic condition. These factors cannot be controlled easily in the testing on the real traffic condition. Therefore, Driving Simulator can be used to solve this problem because it can control both type of vehicle as well as traffic condition in the simulation model. In the simulation model, analytical vehicle model in longitudinal direction with medium size passenger car parameter is used. Traffic condition is simulated by using C language with graphic library. In the test, there is a preceding vehicle simulated traffic flow. Test driver will drive following this preceding vehicle. In addition, there are junctions with traffic light in the environment. Test driver must conform to it.

Data that gathered from Driving Simulator such as distance, velocity, acceleration and brake pedal position will be used to calculate real time fuel consumption in the Eco-Driving Evaluation model. These fuel consumption data will be compared for ranking each driver. In this paper, driver will be rated by using basic normal distribution curve. In future work, the algorithm for determining “Eco-Driving Index” will be carried out and test in Driving Simulator.

## 2. Development of Driving Simulator

### 2.1 Structure of the Driving Simulator

Driving Simulator consist of hardware and software part. Driver seat, steering wheel, acceleration pedal, brake pedal and display monitor are hardware for Driving Simulator. Signal from steering wheel and acceleration and brake pedal is measured by sensors such as potentiometer and encoder for using in software. Two type of simulation software model are needed in order to run the Driving Simulator. The first is to run a real-time vehicle model. The second is to simulate driving environment and visualize it to the driver shown in Fig. 1.

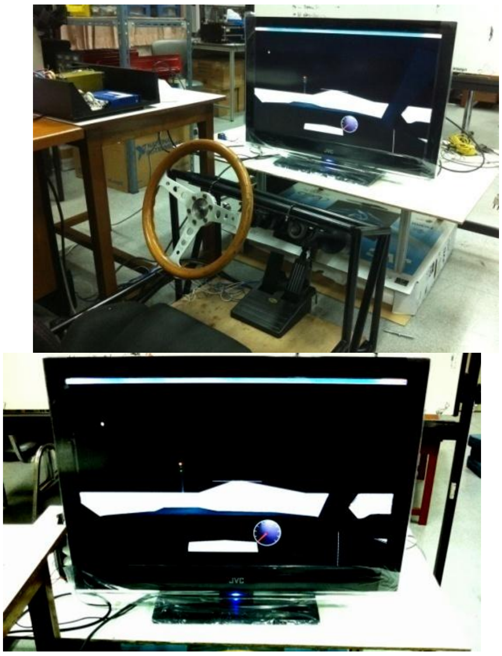

Fig. 1 Driving Simulator

Driving simulator used in this research is developed in-house by authors and colleagues. There is no motion in the Driving Simulator platform. Position of pedal, seat and steering can be adjusted to match with different test driver's ergonomic.

### 2.2. Simulation Model

Simulation model starts from Rio - Labview A/D converter. This device receive analog input signal from potentiometer in acceleration and brake pedal. It converts the signal to digital signal, pack these signals into internet protocol and send to XPC – Matlab which contains vehicle model, compute vehicle dynamics then sent results to Environment software in PC to simulate dynamics parameters to the driver. Driving simulator Schematic diagram is shown in Fig. 2.

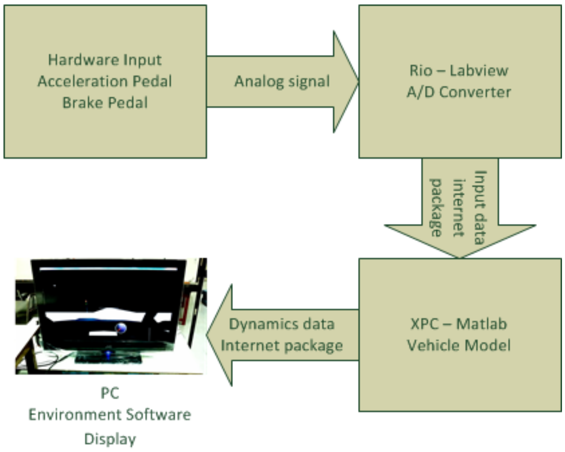


Fig. 2 Driving Simulator schematic diagram

#### 2.2.1 Vehicle Model

The simplified engine model is obtained from the maximum horsepower of 1800 cc. compact car engine equipped with CVT transmission. The ideal force-velocity graph from maximum available friction on the ground and maximum horsepower is plotted as shown in the Fig. 3. The horizontal line at the first part of graph is obtained from the maximum friction on the ground, $\mu mg$, by assuming the coefficient of friction $\mu$ to be constant at 0.8 and the mass of the car is 1226.97 kg. This horizontal line is set to limit the maximum force that can be generated from the engine through the use of ideal maximum friction model.

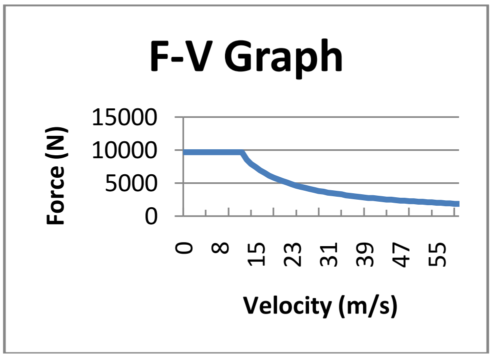


Fig. 3 The F-V graph used as an engine model

The equation for the relation between force and velocity (F-V) graph plotted in Fig. 3 is shown in Eq. 1.

$$engine\ force = \begin{cases} 9629.2610 & when\ v \leq 11.4572 \\ 110324.8125\ v^{-1} & when\ v > 11.4572 \end{cases} [N] \quad (1)$$

Fig. 3 shows the graph for when the engine is running at maximum available torque and horsepower. In reality, the car is not powered at its highest possible value all the time, but is controlled by the use of throttle valve through acceleration pedal. Instead of using the percentage of acceleration and braking to control the amount of throttle valve which will further control the engine revolution through the amount of fuel burnt, this research simplified the model and gets the driving force directly from the F-V graph of Fig. 3 and multiply with the percentage of acceleration pedal as shown in Eq. 2.

$$F = (\%accelerate \times engine\ force(from\ graph))\ [N] \quad (2)$$

Engine power that is used to generate the amount of driving force needed to move the car forward can be calculated by Eq. 3.

$$Engine\ Power = Fv \quad \left[\frac{N\cdot m}{s}\right] \quad (3)$$

From the required engine power, it can be converted to fuel energy by considering engine efficiency as shown in Eq. 4. In early stage of development, simplified fuel efficiency model is used. The simplified model also does not include other factor of efficiency such as the transmission.

$$Fuel\ Energy = \frac{Engine\ \ Power}{\eta_{engine}} \left[\frac{J}{s}\right] \quad (4)$$

$$;where\ fuel\ efficiency \quad \eta_{engine} \quad = 0.3$$

Fuel consumption model used in this research is obtained from Eq. 5. Low heating value of gasoline (LHV) is used.

$$Fuel\ Consumption \quad = \frac{Fuel\ \ Energy \quad \left[\frac{J}{s}\right]}{LHV\ gasoline \quad \left[\frac{J}{kg}\right]} \left[\frac{kg}{s}\right] \quad (5)$$

$$;where\ \ LHV\ gasoline = 44.4 \left[\frac{MJ}{kg}\right]$$

To limit the maximum cruising speed of vehicle to close to the real driving condition, road load which consists of aerodynamics drag and rolling resistance is considered.

Road load model used in this vehicle model is shown in Eq.6 and 7. All the constant are used from compact class passenger car model while rolling resistance coefficient, $f_R$, is used from the typical constant of the concrete road.

$$F = ma + \frac{1}{2}\rho C_D A v^2 + f_R W \quad [N] \quad (6)$$

$$;where \quad mass: \quad m = 1226.97 \quad [kg]$$

$$air\ density: \quad \rho = 1.225 \quad \left[\frac{kg}{m^3}\right]$$

$$drag\ coefficient: \quad C_D = 0.31$$

$$car\ cross\ section\ area: \quad A = 2.71 \quad [m^2]$$

$$RR = f_r W \quad [N] \quad (7)$$

$$;where \quad RR = Rolling\ resistance$$

$$w = weight$$

$$rolling\ resistance\ coefficien: f_r \ = 0.015$$

### 2.2.1 Environment Software

The scenario of the simulation is the controlling factors on how the drivers will react and behave on the simulating roads. In considering the fact of using the simulation in the first place to limit all unpredictable variables that occur in real life situation, the research simulation scenario is decided to be made to a simple infinite-loop straight road scene. This is basically done to narrow down the scope of variables.

In actual test, tester will be given an instruction to drive following the car in-front called ghost driver to simulate following state driving in the test.

The term “ghost driver” in this experiment is defined as the reanimation of a driver cycle through a predefined scenario. In the creation of the ghost driver, the scenario is a straight road with numerous intersections where the driver must brakes when the light turns red. A number of tests are performed before the average data is selected. Example of Driving Simulator display during actual test with ghost driver in front is illustrated in Fig. 4. Environment program was developed by using C language with Open GL library.

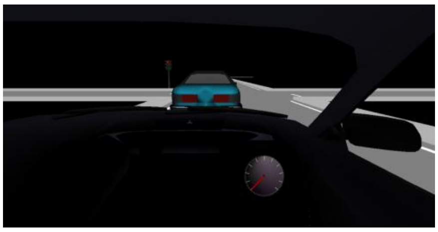

Fig. 4 Starting point in actual testing with ghost driver in-front

In drawing the infinite straight road, the easiest way is to divide the road into subsection and make the loop for the subsection road. Fig. 5 shows the layout example of each loop of the straight road in which the width is 10 meters and consists of two lanes, each lane is given 3 meters for the car to drive. The intersections are placed 210 meters apart from next intersection.

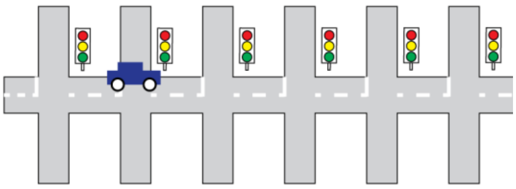

Fig. 5 Example of road layout in the Driving Simulator environment

However, the problem is 'where should the subsection be divided' and 'how long should the distance be between each subsection. From the thought that it needs some controlling factors to let the driver acts a certain way has led to the conclusion of that controlling factor is the traffic light. Traffic light always appears where there is crossroad so the decision is made to divide the subsection to be one crossroad block unit. Then onto the question of the distance between each unit, it should be made for each loop distance to be quite small for the need of flexibility in controlling the act of the driver. If the simulation provides the green light, then it is basically almost the same as the straight road without any crossroad. So this led to the conclusion to have each loop distance around 200 meters.

Fig. 6 is the top view of actual road used in the simulation.

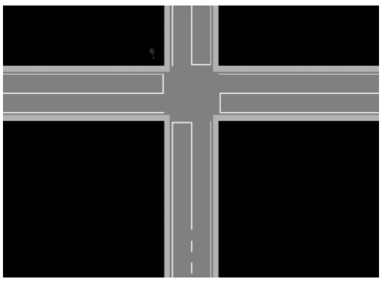

Fig. 6 Intersection from top view

## 3. Experiment and Result

In the experiment, tester drives on the Driving Simulator in the same controlled traffic condition. There is a ghost driver representing traffic flow condition. And there is a traffic light at every cross section. These traffic lights are controlled to be the same for all test drivers. Before starting the real test, test drivers are informed about how to drive and can practice on Driving Simulator. During the test, driver controls acceleration and brake panel to drive follow to the ghost driver to simulate following state driving. Test driver can see the real time speed in the speedometer on the screen as well as can sense to the speed from seeing to the lane separation line which move and change with car speed. If there is an accident such as crashing to the ghost driver the experiment will be terminated and restarted again.

The information from the experiment is used to calculate the average fuel consumption value for 25 drivers. M and F in Table 1 stand for 15 male and 10 female respectively. The average value was calculated to be 6.47 km/L. Then the standard deviation value is the value of 0.86 km/L. This value is used to plot out the normal distribution by ranging the data with a bandwidth of one standard deviation. Table 1 consists of the calculated values.

Table 1 Fuel consumption, average and standard deviation

| Tester | Km/L | Tester | Km/L |
|---|---|---|---|
| F5 | 8.29 | M8 | 6.25 |
| F9 | 8.20 | M15 | 6.22 |
| M6 | 7.78 | M10 | 6.12 |
| F8 | 7.50 | M5 | 6.06 |
| F3 | 7.29 | M14 | 6.04 |
| M12 | 7.25 | M7 | 5.93 |
| F7 | 6.96 | M13 | 5.77 |
| M4 | 6.70 | F4 | 5.75 |
| M2 | 6.70 | F6 | 5.72 |
| M16 | 6.65 | F10 | 5.70 |
| F2 | 6.45 | M9 | 5.67 |
| F1 | 6.35 | M1 | 5.48 |
| | | M3 | 4.93 |
| Avg. Km/L | 6.47 | | |
| SD | 0.86 | | |

To verify results, our test results obtained from 25 test drivers by using Driving Simulator were compared to the real test drive data from research in the US [5] as shown in Fig. 7 which is a graph between $CO_2$ emission [g/mile] and speed [mile/hour]. Fuel consumption results from our test were converted to the $CO_2$ emission by using gasoline combustion equation in Eq. 8.

$$2C7H14 + 21O2 \rightarrow 14CO2 + 14H2O \quad (8)$$

Stoichiometric analysis yields 98g of gasoline to produce 308 g of Carbon Dioxide. [6]

From Fig. 7, it shows that some of our results are close to the range of the US real test drive data. Main factor that affect the result is inaccuracy of simplified fuel consumption model. Also, our test results are in one range of speed since our experiment is fixed to one condition of following state driving.

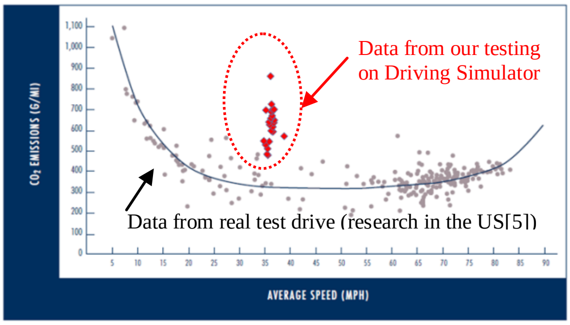


Fig. 7 $CO_2$ emission-speed plot of 25 drivers compared to results from real test drive in the US [5]

## 4. Eco-Driving Evaluation

Using the obtained normal distribution data, the rating system can then be defined in accordance to the standard deviation interval. The rating system will be from the value of "1" to "5", with the value of "1" representing a low Eco-Driving skill and "5" as a high Eco-Driving skill level. The rating of "3" will be located an interval between average and half of a standard deviation in both direction (6.46±0.86/2). This is to ensure that the average driver will fall in the "3" rating area. Table 2 is the rating of the simulation testing.

Table 2 Representation of rating system and the interval of each level.

| Rating | Meaning | Min | Max |
|---|---|---|---|
| 1 | Need Improvement | 4.32 | 5.18 |
| 2 | Below Average | 5.18 | 6.04 |
| 3 | Average | 6.04 | 6.90 |
| 4 | Above Average | 6.90 | 7.76 |
| 5 | Good | 7.76 | 8.62 |

From the rating system created seen from Table 2, rate 3 contains most drivers' data (11 people), which is conformed to the fact that the trend of the result is distributed normally. However, from the data obtained, rate 2 is the second leading data (7 people). This shows the current trend skewed positively and more drivers tends to drive using more fuel consumption than the mean value. Still, when the samplings are enough and according to this rating system, the percentage of each rating should be closed to the following graph in Fig. 8. This graph tells that as the data approaches normal distribution, rate 1 and rate 5 should consist of 6.7% drivers each. Then rate 2 and rate 4 should consist of 24.17% each and lastly rate 3 should contain the most with 38.3%.

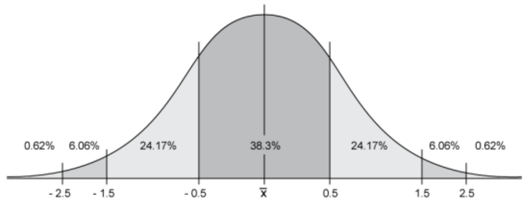


Fig. 8 Normal distribution graph of rating system

Fig. 9 shows the comparing graph between the lowest fuel consumption in the solid line and the highest fuel consumption in the dash line. In most part of the running, it can be seen that the solid line, has smoother fuel consumption than the dash line. The smoothness of graph also reflects an overall better fuel consumption.

## 5. Conclusion

This research began with the intention of creating a Driving Simulator which can evaluate a driver's Eco-Driving ability and rate them accordingly. This Driving Simulator consists of hardware and software module. In hardware module, test driver will input the driving command such as acceleration and braking while get a driving feedback from the Display. In software module, there are two main parts. The first part is vehicle model considering engine, road load and fuel consumption model. Another part is driving environment software which created from C language with Open GL library. In the first stage of this research, the experiments from 25 test drivers were carried out in order to create an information database which was used to calculate the Eco-Driving rating of the driver. The result is a driving simulator which can record and evaluate a person's Eco-Driving ability and rate it to the defined ranking system.

## 6. Acknowledgement

This research is carried out as a part of Smart Mobility Research Center, Faculty of Engineering, Chulalongkorn University. Research Funding is from Senior Project of International School of Engineering, Faculty of Engineering Chulalongkorn University.

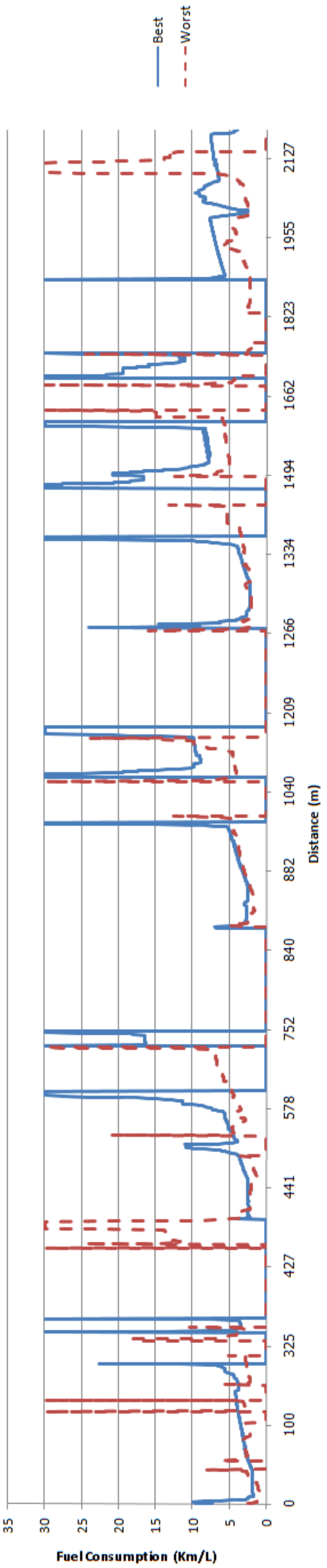


Fig. 9 Comparison between best and worst (fuel consumption) driver tested by Driving Simulator

## 7. References

### 4.1 Article in Journals

[1] Y. Saboohi and H. Farzaneh, (2009). Model for developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption. Applied Energy, Volume 86, Issue 10, October 2009, Pages 1925–1932

### 4.2 Proceedings

[2] N. Noomwongs, C. Pichipan, V. Supatravanich, S. Yongsakulrojana, S. Archavamethi and S. Chantranuwathana, (2006). “Driving Simulator Prototype”, The 20th Conference of Mechanical Engineering Network of Thailand, Nakornrachasrima Thailand (pdf in Thai)

[3] N. Noomwongs, S. Chantranuwathana, (2007). “Improvement of Driving Simulator Prototype”, The 21th Conference of Mechanical Engineering Network of Thailand, Pattaya Thailand (pdf in Thai)

### 4.3 Reports

[4] B. Kanok, V. Alexander and B. Matthew, (2010). Eco-Driving: Pilot Evaluation of Driving among U.S. Drivers. University of California Transportation Center, UCTC-FR-2010-20.

[5] B. Matthew and B. Kanok (Fall 2009). Traffic Congestion and Greenhouse Gases. Access 35. University of California Transportation Center Berkeley, Ca 94720–1782

[6] J. Barley, N Pelliccia, C Petersen, A Vendramini (2006). Eco-Route. Mechanical Engineering, Michigan University.

[7] T Kono, T Fushiki, K Asada, K Nakano (2008). Fuel Consumption Analysis And Prediction Model For “Eco” Route Search. Hitachi Research Laboratory, Hitachi, Ltd. Xanavi Informatics Corporation. Nissan Motor Co., Ltd.