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MODELING OF A SHELL ECO-MARATHON VEHICLE BASED ON DRIVE-TRAIN CHARACTERISTIC AND DRIVER MODES TO PREDICT FUEL CONSUMPTION OF THE VEHICLE ON A SPECIFIC TRACK

Witantyo, Sutikno, Diva Aulia and Habibie Rahman
Mechanical Engineering Department of ITS, Sukolilo Campus, Surabaya, Indonesia
E-Mail: witantyo@me.its.ac.id

ABSTRACT

Shell Eco Marathon is a competition for fuel efficient vehicle organized by Shell annually for student around the word. Every team should present a uniquely designed vehicle targeted to be driven to an extreme distance using 1 liter of fuel. This study aimed to conduct a vehicle dynamic modelling by using Simulink program from Matlab to predict vehicle fuel consumption. The Model is build based on vehicle data and drive-train characteristic. To model the vehicle, various data such as body weight, tire/wheel weight and angular inertia, frontal area, drag coefficient and tire rolling resistance are collected. To model the drive-train, transmission ratio, engine torque and specific fuel consumption curves, mechanical efficiency of some rotating parts are also collected. Model of the vehicle is a close loop system in which engine as power unit gave its torque to wheel to move the vehicle. More speed developed by the engine would produce more resistance of vehicle dynamics. The calculations were conducted with changing vehicle speed, driver mode, and inclination of the track. Predictions of accuracy were done by using competition data from Sepang, Malaysia circuits within 5% of error.

Keywords: shell eco-marathon, vehicle dynamic modeling, fuel efficiency.

INTRODUCTION

Every year, students from all over the world compete in Shell Eco-marathon by designing vehicle to get extreme distance on one liter of fuel. ITS Team Sapuangin have been participated in Shell Eco-Marathon (SEM) Asia since 2010 and always won a title in Urban Concept category mostly in biodiesel and diesel fueled vehicle. Urban Concept category is a new class developed in 2003 in which the vehicles are designed to better represent a conventional city car with certain roadworthiness criteria required.

To accomplish an improved distance for the next competition, vehicle dynamic modeling would be built to represent the vehicle and the driver modes in the race track to minimize fuel consumed. Vehicle dynamic modelling for SEM car have been developed by Rahmanu (2011) and Adeniyi and Mohammed (2012), both for prototype category. While Rahmanu interested more on the vehicle details, Adeniyi and Mohammed have more concentration on the engine characteristics. On urban concept car category, Grundiz and Jansson (2009) have built a hybrid car modeling and Witantyo *et al.* (2013) also developed a model to evaluate vehicle specification, driver modes and track specific. In this model, drive-train characteristics and driver modes are detailed more to get a better simulation results.

VEHICLE MODELING

Vehicle modeling is built using Jeongwoo Lee (2009) schemes as shown in Figure-1. In uphill track when the engine is on, traction force (F_{trac}) from drive train would be resisted by the inertia force ($F_{inertia}$) of the vehicle, gravitational force (F_g), aerodynamic force (F_{aero}) and tire rolling resistance force (F_{rr}). When the engine is off, the vehicle would be gliding using inertia as the power source and resisted by aerodynamic force and tire rolling resistance force. In this condition, gravitational force would accelerate the vehicle in downhill track and vice versa.

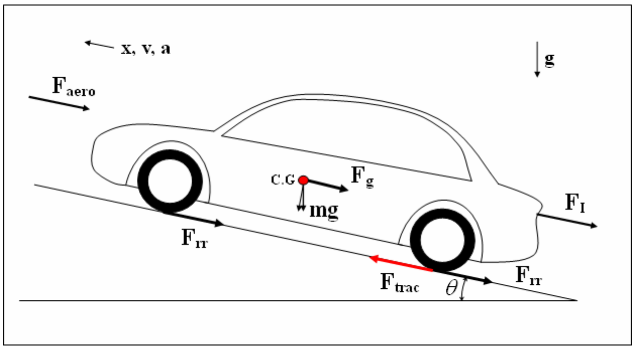

Figure-1. Vehicle dynamics. (Jeongwoo Lee, 2009).

Aerodynamic force is a function of air density (ρ), frontal area (A), drag coefficient (C_D), and vehicle speed (V). Drag coefficient actually is not a constant in lower speed but its assumed constant in this model.

$$F_{aero}=½.\rho.C_{D.}\ A\ .V^2 \quad (1)$$

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Rolling resistant force is a function of tyre rolling resistant coefficient (C_{rr}), vehicle mass (m), gravitation (g), and hill slope angle (θ). C_{rr} is a function of speed but its assumed constant in this model.

$$F_{rr}=C_{rr}.m.g.\cos(\theta) \quad (2)$$

Gravitational force is a function vehicle mass (m), gravitation (g), and hill slope angle (θ).

$$F_{grad}=m.g.\sin(\theta) \quad (3)$$

Inertia force is a function vehicle mass (m), and acceleration (a). Rotational inertia of wheels is neglected in this model.

$$F_{inertia}=m.a \quad (4)$$

At any acceleration, traction force should be in balance with sum of all resistance forces. Power traction is traction force multiply by vehicle velocity, and vehicle velocity should be up-dated continuously.

$$F_{trac} = F_{drag}+F_{rr}+F_{grad}+F_{inertia} \quad (5)$$

$$P_{trac} = (F_{drag}+F_{rr}+F_{grad}+F_{inertia})V \quad (6)$$

$$V(t)= V_0 + at \quad (7)$$

DRIVE TRAIN MODELING

Drive train model is built using engine characteristic curve from Yanmar in Figure-2. Traction force is calculated using torque curve and fuel consumed is calculated using specific fuel consumption curve.

$$T_{engine} = f(RPM_{engine}) \quad (8)$$

$$T_{actual} = T_{engine} * \eta_{clutch} \quad (9)$$

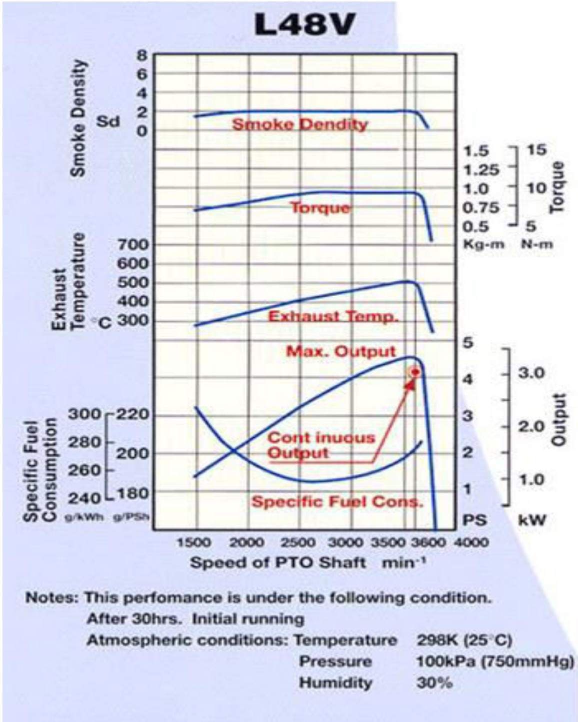

Figure-2. Diesel engine characteristic curves. (www.yanmar.com)

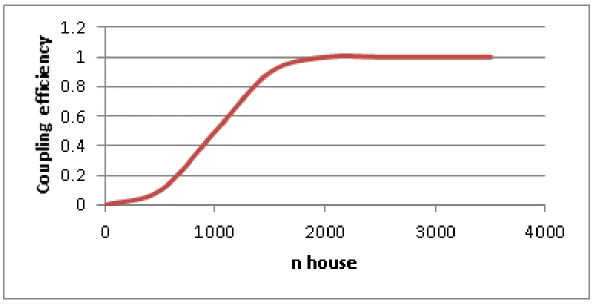

Figure-3. Clutch efficiency modeling.

Clutch model is added to connect engine rotational speed to vehicle speed especially when the vehicle starts to move. The centrifugal clutch works automatically to connect engine torque at higher speed. Clutch power transfer efficiency at increasing engine speed is modeled in Figure-3.

In engine stop mode, it was modelled that the clutch was also work as a one-way power transmission to eliminate inertia losses due to engine brake. Therefore, it will disconnect the transmission immediately when engine rotational speed is lower than vehicle speed. Gear ratio is also added in the model to get actual vehicle speed.

$$n_{house} = \frac{v_{vehicle}}{2\pi * r_{dynamic}} * 60 * gear\ ratio \quad (10)$$

Gear ratio is also used to get actual force from the engine to the wheel. Then, engine power used is also calculated.

$$F_{engine} = \frac{T_{actual}}{r_{dynamic}} \times gear\ ratio \quad (11)$$

$$P_{engine} = F_{engine} * v_{vehicle} \quad (12)$$

TRACK MODELING

Track is mapped using Google earth to get the elevation of every dot in the track. Then, by using the distance of every dot, inclination and declination along the track is calculated. Example of track mapping is shown in Figure-4 and the result of track mapping is shown in Figure-5.

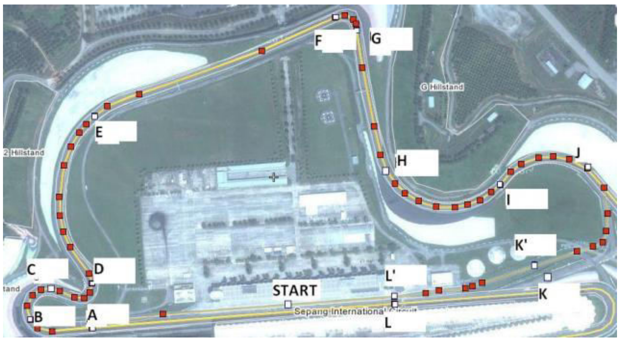

Figure-4. Mapping of Sepang International circuit *(Rahmanu, 2011)*.

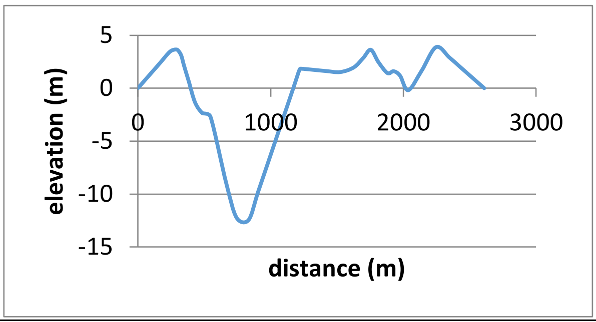

Figure-5. Sepang SEM Asia circuit, elevation vs distance *(Rahmanu, 2011)*.

DRIVER MODES

Because engine power is bigger than required power to move the vehicle along the circuit, therefore the driver should start and stop the engine at several point along the track to minimize fuel consumed. This condition was modelled as driver modes and become the important point to variate the vehicle speed to achieve less than maximum time limit and minimizing fuel consumed.

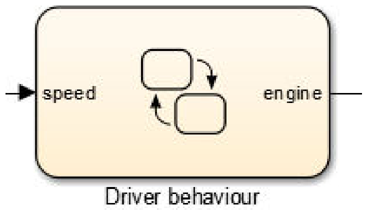

Figure-6. Driver modes to start and stop engine at several location of the circuit.

To simulate driver behaviour in this model, it was assuming that the driver will start the engine and accelerate until a certain upper speed limit of the vehicle, then the engine will be stopped. At this time, the vehicle will be gliding and decelerate due to resistance forces. When lower speed limit is attained, the driver will start the engine and accelerate again. This cycle is repeated until near the finish line. At certain distance of the finish line, the engine cannot be started. Upper and lower speed limit were adjusted accordingly to achieve the least fuel used. However, the adjustment of these speed limits should be careful not to get over the lap time limit of the competition that is 315 seconds for one race lap. Base on experiment, starting the engine consumes a certain amount of fuel without giving any power to be used. Therefore, number of engine starting should also be counted to calculate fuel used.

FUEL CONSUMPTION CALCULATION

Fuel consumption of the vehicle is calculated by using specific fuel consumption data from Figure-2 and engine rpm data. Then, absolute fuel consumption (b_e) and total fuel mass required (m) could be calculated.

$$b_e = sfc * P_{engine} * \frac{1}{3600000} \quad (13)$$

$$\int_0^t b_e\, dt = m \quad (14)$$

Distance (s) and fuel density is needed to get the vehicle fuel consumption in kilo meter per liter.

$$\text{Fuel consumption} = \frac{s}{m/\rho} \quad (15)$$

MODEL OVERVIEW

Total Simulink model was built as shown in Figure-7. Upper part of the model shown was dedicated to vehicle dynamic and track characteristic. Lower part of the model was driver behaviour and drive train modelling. Upper and lower speed limit should be chosen appropriately to give best fuel consumption.

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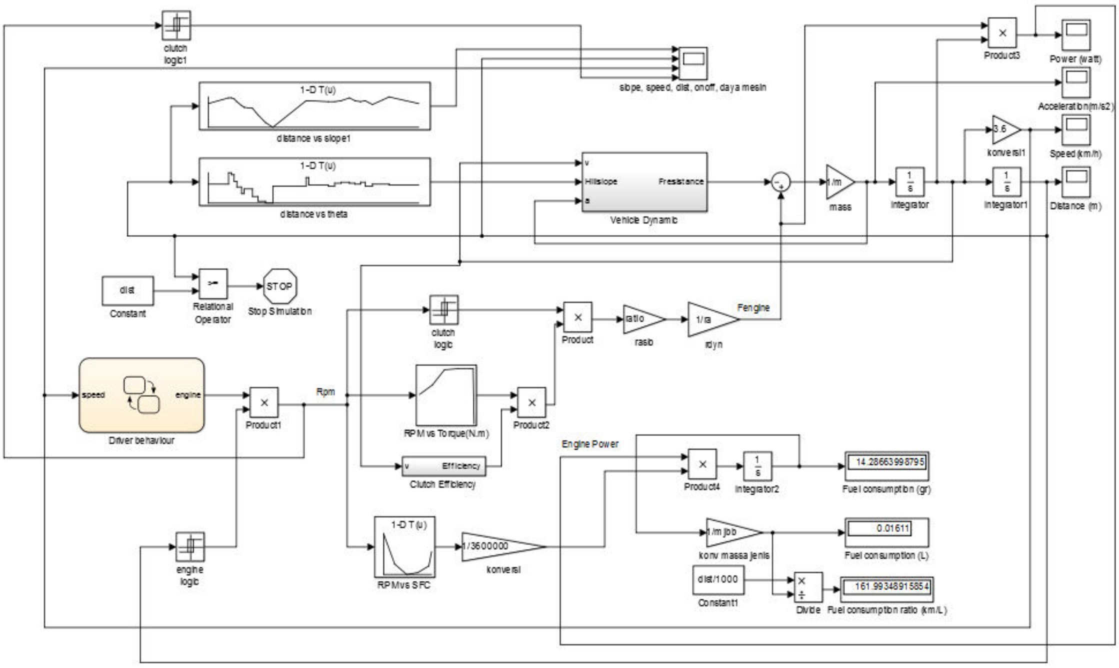

Figure-7. Complete model of vehicle, drive train, circuit and driver modes.

RESULTS AND DISCUSSIONS

Validation was done using SEM Asia 2012 vehicle and driver data at Sepang International Circuit. At that time the achievement record is 167 km per liter using 4 times start stop cycles. Similar race situation was simulated using the model in Simulink. Given the track model and all vehicle parameter inserted, the model did the simulation of the race.

Figure-8 shows the vehicle speed and engine on-off mode at upper speed of 35 km per hour and lower speed of 25 km per hour. At these speed limit there are four times engine starting in one lap.

Figure-9 shows the time required to race in the track with previous start and stop cycles. The time is just slightly less than 315 seconds for one lap race. Figure 10 shows a resulted record of 174 km per liter. A very close approximation with less than 5% of error from the real record of 167 km per liter.

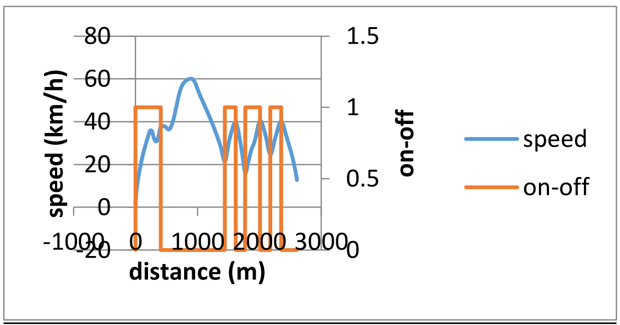

Figure-8. Vehicle speed and engine on-off mode.

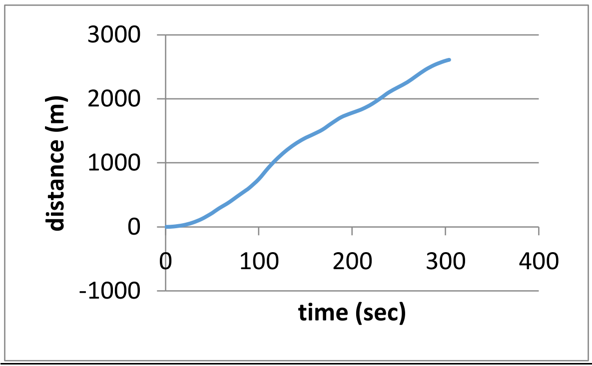

Figure-9. Time and distance traveled in one lap race.

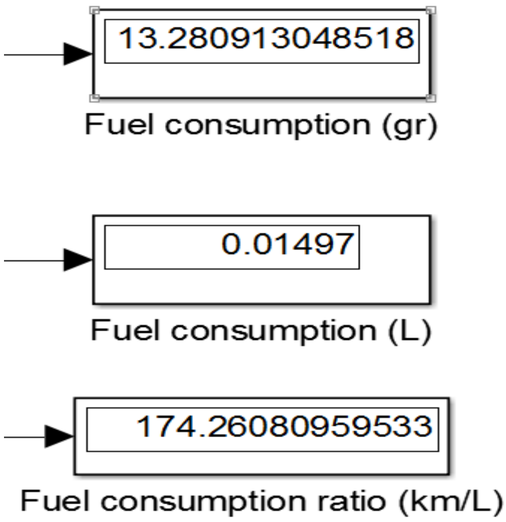

Figure-10. Simulation results of fuel consumption.

CONCLUSIONS

Even though the effect of vehicle speed on the drag coefficient and tire rolling resistance is neglected, the simulation result shows that the model almost represents vehicle and driver performance in real race condition. The model also could be used as source of information in evaluating the vehicle to improve its performance for the next SEM Asia competition.

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