Experimental Validation of Vehicle Dynamic Characteristics of a Virtual Heavy Vehicle Model

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ABSTRACT

The experimental approach is usually used as a way to test, modify or optimize vehicle sub-system characteristics. This approach is a time-consuming process, costly and with various limitations. To avoid that, a simulation approach is used. However, to rely on the software, the simulation model has to be validated with the actual vehicle before it can be used for further virtual complex testing. In this paper, a validation of dynamic characteristics for full virtual heavy vehicle model with experimental results of an actual heavy vehicle is performed. The virtual heavy vehicle model was developed based on ISUZU FSR two-axle Single Unit Truck (SUT) using a multi-body dynamic software. The development process of the model can be divided into three parts; which are, the development of virtual heavy vehicle model, road design configuration, and driver and maneuvering setup. All data information to develop and simulate the virtual heavy vehicle model is taken from the actual experimental setup. The heavy vehicle will maneuver with a maximum velocity of 40 km/h on four (4) selected test field locations located at Lingkungan Budi route, Universiti of Malaya, Malaysia. The vehicle dynamic behaviors such as lateral acceleration and vehicle speed were observed during simulation and compared with the experimental data for the verification process. It is concluded that the trends between

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-05-19
Accepted for publication: 2017-06-08
Published: 2017-12-31

simulation and the experimental result were found to be almost similar with an acceptable level of percentage error.

Keywords: *Full virtual heavy vehicle model, Single Unit Truck (SUT), lateral acceleration*

Introduction

At present, heavy vehicles play an important role in transportation, assisting many developing countries around the world such as Malaysia to acquire rapid growth in the industrial sectors and infrastructure. This has led to an increase in the number of heavy vehicles on the road to transport goods, people and industrial materials. Based on Malaysia's transport statistics report, provided by Ministry of Transportation, Malaysia, as shown in table 1, the number of newly registered motor vehicles (goods vehicle category) in Malaysia is increasing with a total of 95,782 goods vehicles for 4 year period (from 2009 – 2012) [1]. This trend may contribute to the number of road traffic injuries and accidents. Among the common factors that contribute to accidents to occur are the vehicle condition, environmental condition and driver behavior [2]. To at least reduce the number of the heavy vehicle accident, a prevention step should be taken. In recent years, various experimental studies had been conducted to investigate the heavy vehicle safety and dynamic characteristics. It ranged from heavy vehicle component testing, quarter and half vehicle testing on the test rig to a full heavy vehicle dynamic testing [4, 5, 6]. However, these experimental processes could be time consuming, costly and most importantly, could lead to a dangerous situation [7]. To avoid this, a multi-body dynamic software can be used to design and develop a virtual model that is similar to an actual heavy vehicle available on the road. This approach became popular due to the fact that the virtual heavy vehicle model can be simulated beyond the experimental capabilities and able to solve multiple complex problems in a short time and cost less. As an example, Zhang et al., Yongjie Lu et al. and Ikhsan N. et al. used ADAMS software to analyze and simulate the suspension system of heavy vehicles [6, 9, 10]. However, to rely on the software, the virtual heavy vehicle model has to be validated with the actual vehicle [11, 12]. The simulation and experimental result should achieve a good agreement on the trend with as minimum percentage error or deviation as possible. F.Ahmad et al. found the trend of his experimental and simulation for the full vehicle longitudinal model was similar with acceptable percentage error, hence the validation process is accepted. Johan Wideberg et al. also concluded the same thing on his research for full electric vehicle model validation with various of experiments and simulations testing.

Table 1. *New Registered Motor Vehicles (Goods Vehicles) in Malaysia (2009-2012) [1]*

Year	No. of new registration	Total no. of active vehicles
2009	34731	936222
2010	40887	966177
2011	39718	997649
2012	40742	1032004

The main purpose of this paper is to validate the virtual heavy vehicle model with the experimental result using a similar actual heavy vehicle. To achieve that, an experiment on the dynamic behavior of the heavy vehicle is conducted and a virtual heavy vehicle model that represent the actual heavy vehicle is developed and simulated followed the same setup as the experiment. It is expected that at the end of the research, the dynamic behavior of the virtual heavy vehicle will follow the same trend as experimental results with an acceptable percentage error, hence it is validated to be used for further research.

Methodology

Experimental setup

An ISUZU FSR two-axle single unit truck (SUT) with laden weight is used for this purpose as shown in Figure 1. At the beginning of the experiment, the general dimension (e.g wheelbase, track width, and height) and vertical weight from each tire were measured on static condition on both flat and slope surfaces**.** The measurements were used to determine the location of the center of gravity (*CG*) of the truck in longitudinal, side and height, which were subsequently used to place the inertial measurement unit (IMU) data logger device. The process to determine the vertical weight and the method to identify the *CG* location is shown in Figures 2 and 7, respectively. The experimental testing was conducted along the *Lingkungan Budi* route located at the University of Malaya, Malaysia with approximately 5.1 km of total length per lap. However, only four (4) selected locations (*Loc.1, Loc.2, Loc.3 and Loc.4*) were identified and used to measure the dynamic characteristics effect for data collection for this experiment. During the experiment, the distance travel recorded was 400 m for each location and the speed of the heavy vehicle varied from 0 km/h to a maximum of 45 km/h. The average value of the speed and lateral acceleration from three (3) repeating laps were tabulated and compared with the simulation results. The schematic route layout and selected location for data collecting are shown in Figure 3.

Figure 1: An ISUZU FSR two-axle Single Unit Truck

Figure 2: Weighting the front axle of the vehicle

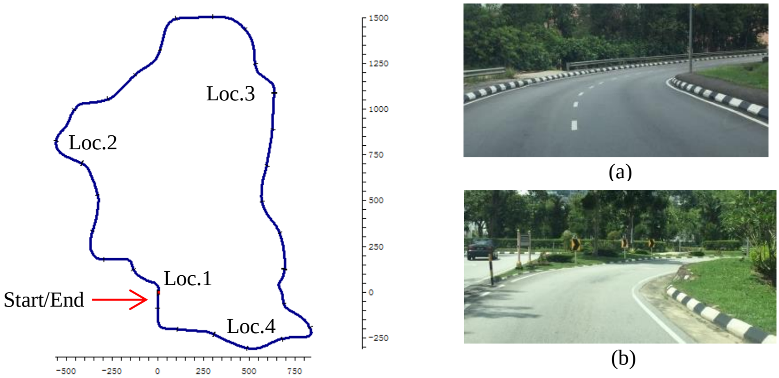


Figure 3: Experiment test field layout in 2D-bird view (left) and selected actual locations for data collection (right)

In order to obtain the real vehicle reaction and to set various parameters and experimental validation of vehicle dynamic performance characteristics, the IMU used is a model DL1 data logger from Race-Techology®. It was equipped together with high precision magnetic mounting GPS receiver. For the purpose of the experiment, an integrated 3-axis accelerometer equipped in the data logger was used to measure the lateral acceleration while the GPS receiver provides the vehicle's position in longitude and latitude coordinate and vehicle speed through a signal with 1000hz sample rate and 20hz GPS accuracy. The data logger was connected to the laptop through USB cable to monitor real-time data processing, display, and data collection through a software provided by Race Technology®. The setup of DL1 data logger during the experiment is shown in Figure 4 and its specifications are tabulated in Table 2.

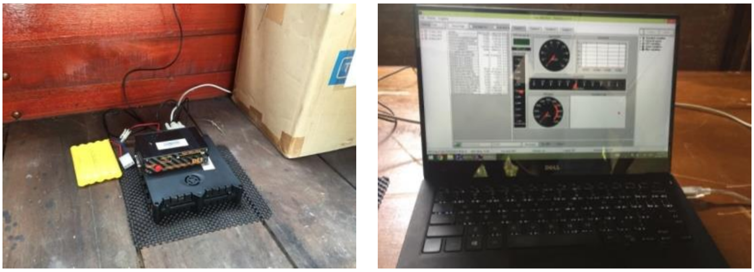


Figure 4: The DL1 data logger setup located on the vehicle's *CG* (left) and real-time monitoring software (left)

Table 2: General specification of DL1 data logger

DL1 data logger Specification	
Accelerometer	2g/6g
Sample rate	Up to 1000Hz
Logging time	24 hours
No of analog input	8
No of output drivers	4

Simulation setup

In order to develop a full virtual heavy vehicle model and run the simulation, three (3) sections were considered; the development of full virtual heavy vehicle model, road design and configuration, and driver and maneuvering setting.

Vehicle setting and development

The full virtual heavy vehicle model has been developed using an IPG Truck-Maker® multi-dynamic software package. It is capable of simulating the dynamic behavior of the model with specific vehicle and simulation configuration. The development started with the implementation of the measurement data from the experiment such as the heavy vehicle's dimension, weight and *CG* location (Table 4) to the virtual heavy vehicle model to replicate the actual vehicle. The model was assumed as a rigid body and the dynamic characterization modeling was characterized by various subsystems as the actual vehicle (e.g powertrain and drivetrain system, steering system and suspension system). The 3D-graphic of the vehicle was taken from the template library available in the IPG Truck-Maker® software. The completed full virtual vehicle model and powertrain properties are shown in Figure 5.

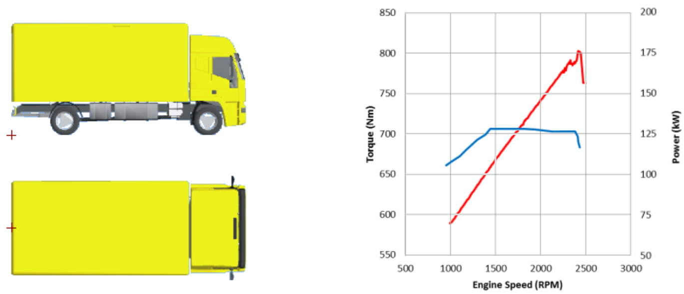


Figure 5: The full virtual 2-axle SUT model of the ISUZU FSR (left) and powertrain properties (right).

Road setup

The virtual road was plotted using longitude and latitude coordinate positions provided by the DL1 data logger during the experiment stage. To precisely replicate the actual road, the virtual road was designed to have a 3.5 m width per lane, and some road bumps, as well as road curbs, were added in selected areas. The road was assumed to have 0.7 value of the coefficient of friction along the test field and it was also assumed to have flat road condition (e.g no road patch and uneven surface). The super-elevation on the cornering section was also considered negligible as it was difficult to be measured based on the data from GPS signal. Figure 6 depicts the 3D-road design section developed using the software.

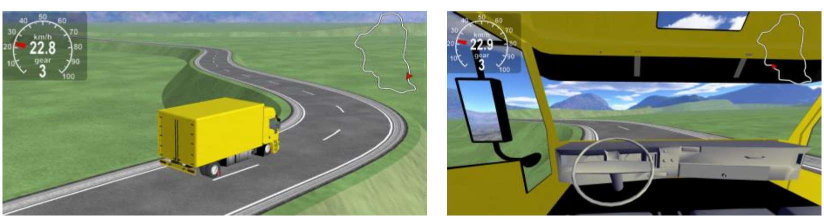


Figure 6: the 3D-road design and virtual heavy vehicle model during simulation (left) and from driver's view (right).

Maneuvering and driver setup

Using the maneuvering option on the IPG Truck-Maker and based on the speed data from the experiment, the full virtual heavy vehicle model was set to maneuver at the same speed as the experiment, as much as possible, as shown in Figure 8. However, it was difficult to replicate the actual driver behavior in the simulation driver setup although it is not impossible. Thus, the driver was assumed to be set as 'normal' condition, indicating it can withstand a possible maximum value of the longitudinal and lateral acceleration of 3 m/s^2 or approximately 0.31g (See Figure 7). Other available driver modes in the software were 'aggressive' and 'defensive' which was not suitable to represent the driver's behavior during the experimental work.

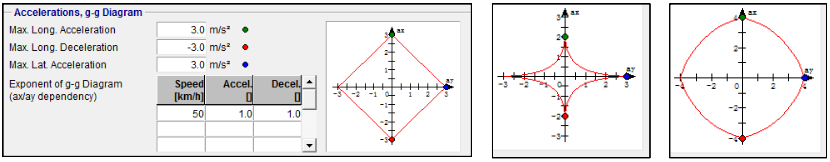


Figure 7: Selection of Driver mode base on the g-g diagram, from left normal, defensive and aggressive.

Result and Discussion

CG location

In the early stages of the experiment, measurement of the location of *CG* was conducted. The parameters observed were the position of *CG* behind the front axle and in front of the rear axle (longitudinal), on the left and right wheels (side) and the height above the ground. Based on Figure 7 and information from Tables 3 and 4, the position of the *CG* from the front axle (*C*) and rear axle (*D*) were 2390 mm and 1810 mm, respectively, and 860 mm from the right wheel, by assuming the weight distribution is equal on the left and right side (*A* and *B*), and the height of the *CG* above the ground is 2200 mm (*H*).

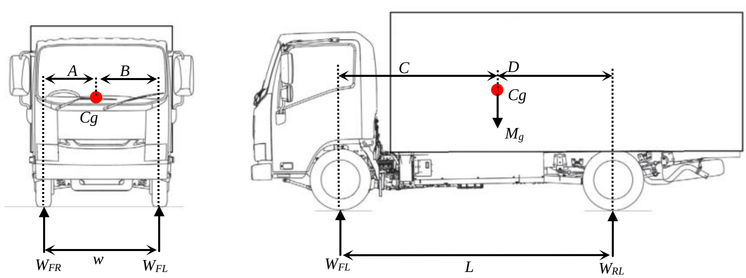


Figure 7: the location of the CG on the ISUZU FSR-2 axle SUT.

Table 3: General specification of the ISUZU FSR

General Vehicle Specification and Dimension	
Make	ISUZU
Model	FSR
Measured Tare Mass (kg)	5485
Max. GVW (kg)	11000
Overall dimension ,LxWxH (mm)	6900 x 2200 x 2700

Measured wheelbase, *L* (mm)	4200
Measured Track Width, *w* (mm)	1800
Measured Wheel Radius, *r* (mm)	460
Ramp angle, θ (deg)	2.9°

Table 4: Measured weight distribution

ISUZU FSR 2-axle SUT Weight Distribution (kg)	
Front right (W_{FR})	1175
Front left (W_{FL})	1195
Rear right (W_{RR})	1440
Rear left (W_{RL})	1675
Measured Truck Kerb Weight	5485

Experimental result and validation

The results of validation between the experimental testing and simulation in four (4) different locations are shown in Figures 8 (a-d) and 9 (a-d). In Figure 8, it shows the graph of vehicle speed against vehicle travel while Figure 9 shows vehicle lateral acceleration against vehicle travel. In these graphs, the gray line denotes the experimental testing while the dashed red line represent the virtual heavy vehicle simulation data.

Based on Figure 8(a), it shows that the heavy vehicle's speed reduced from 30 km/h to 10 km/h at distance travel of 0 m, 125 m, 200 m and 350 m. This is due to the existence of the speed bump at that particular location that required the driver to apply the brake, thus causing the vehicle to slow down. The graph in Figure 8(b) also shows the same trend as Figure 8(a) at distance travel of 0 m and 240 m, with the speed reducing from 35 km/h to 10 km/h. Apart from that, no speed bump exists on Figures 8(c) and(d). An average maximum speed of 40 km/h was recorded and illustrated in Figure 8(c) or Loc. 3 during the entire experimental testing. From the observation, it could be noted that the trends between experimental result and simulation data for heavy vehicle speed is almost similar for all locations with maximum mean absolute percentage error (MAPE) of 15.26% on Loc.1, followed by Loc.2 (7.26%), Loc.4 (3.89%) and location Loc.4 (3.27%).

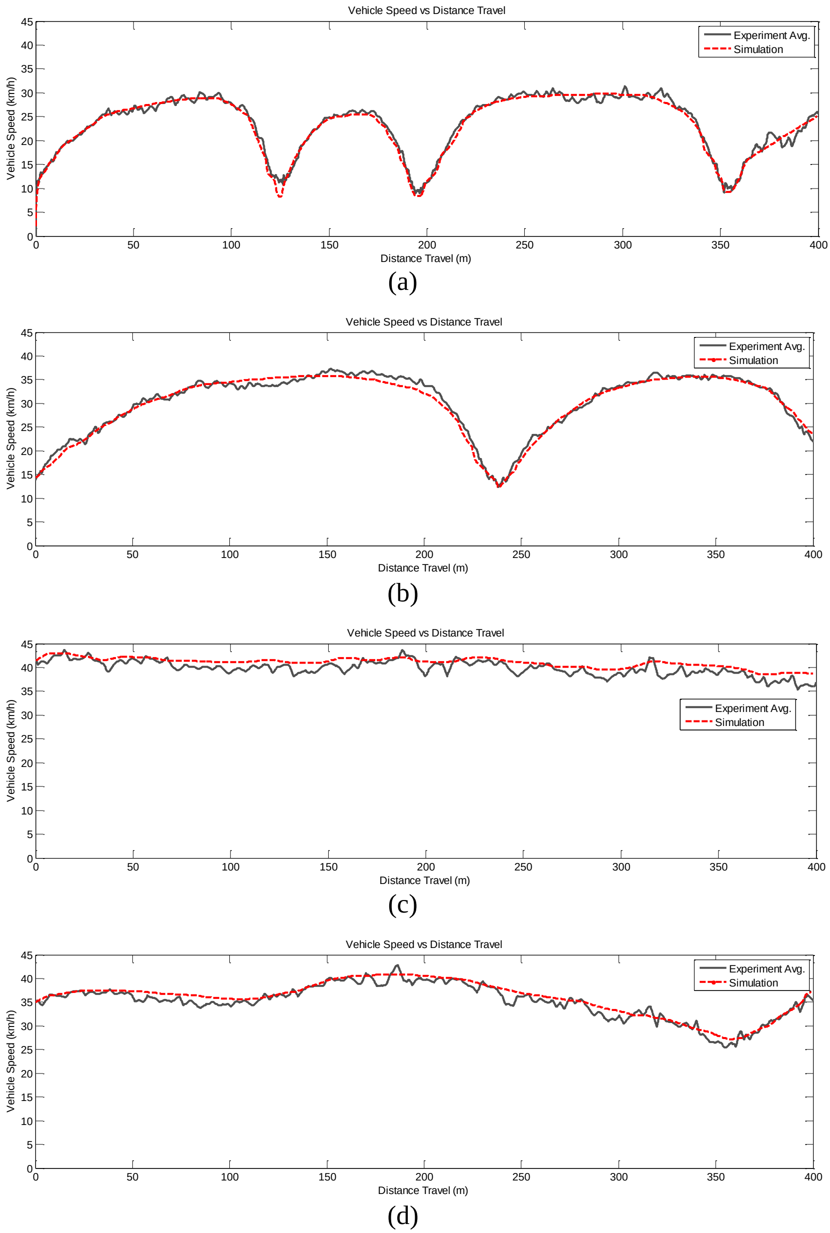
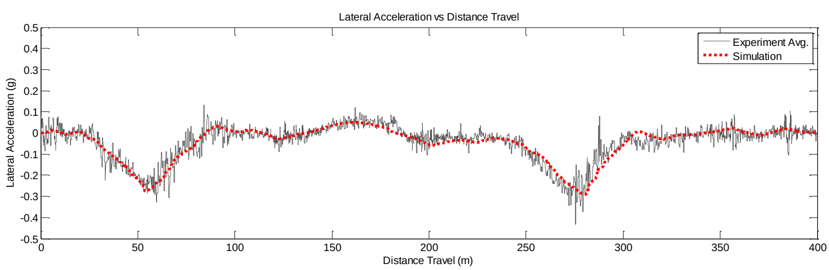
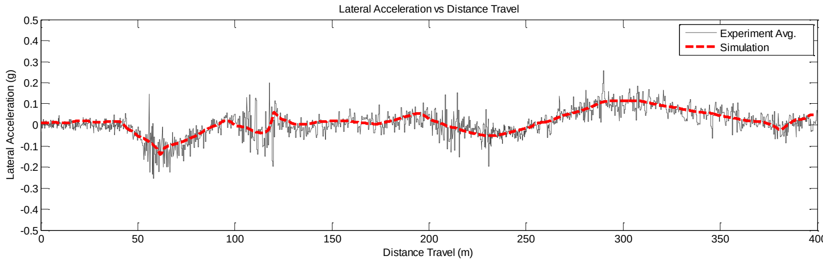


Figure 8: Graph of vehicle speed against distance travel; (a) Loc.1, (b) Loc.2, (c) Loc.3 and (d) Loc.4

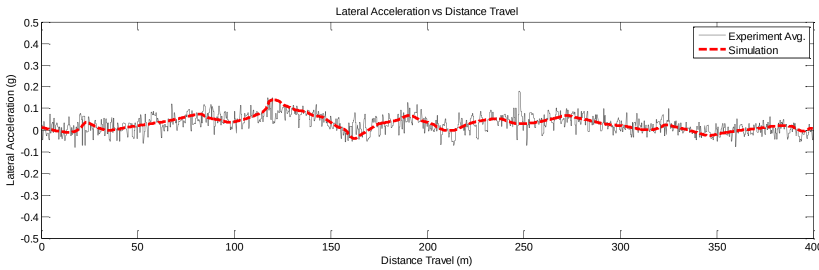
To further investigate the correlation and validation of experimental results and simulation data, the lateral acceleration of the heavy vehicle was compared. Based on Figure 9 (a-d), the highest lateral acceleration was recorded at Loc.1 at distance travel of 275 m, with -0.43 g or -4.22 m/s^2 during cornering to the left side of the test field. In general, it was also noted that the trends between experimental result and simulation data for lateral acceleration were almost similar for all locations with an acceptable percentage error. The different value of lateral acceleration between experimental results and simulation data is due to the fact that various sources of error can affect the experiment, either coming from the human factor, environmental condition, experiment setup or the vehicle condition itself. For example, during the experiment, the road profiles in the selected test area consisted of irregular surface (eg. small potholes, road patch and uneven road surfaces) that caused vibrations to occur, whilst in the simulation, it was assumed that the road has a flat surface with single surface roughness value (μ= 0.7). Another example is the vehicle condition, the wear and tear factor on some of the heavy vehicle sub-system components might affect the experimental result, whilst in the simulation, the sub-system components are only affected by the properties entered into the simulation. These sources of error lead to the inconsistent data trend such as on the graph 9(a) at distance travel between 310m to 320m and graph 9(d) at distance travel between 70m to 80m. The error and graph deviation could be reduced by fine tuning the virtual heavy vehicle model and other simulations setup such as road design, thus the model is able to represent the exact behavior and dynamic performance characteristics as the actual heavy vehicle.



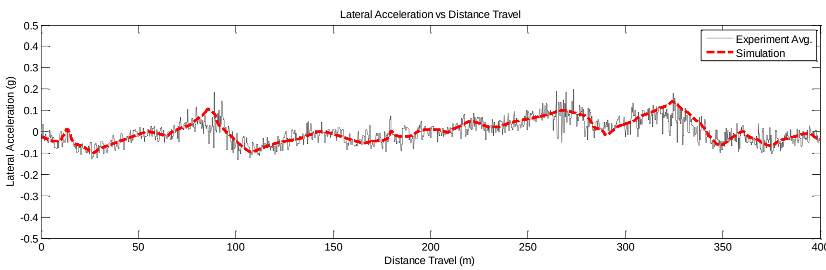
(a)



(b)



(c)



(d)

Figure 9: Graph of lateral acceleration against distance travel; (a) Loc.1, (b) Loc.2, (c) Loc.3 and (d) Loc.4

Conclusion

The full virtual 2 axle SUT based on ISUZU FSR truck has been successfully developed using IPG-Truck Maker. Based on the results, it can be concluded that the virtual vehicle model has been validated with experimental testing using an actual vehicle. Validation experiment showed that a good trend with acceptable percentage errors was obtained. The error was believed to be due to several contributing factors from the experimental setup and simulation assumptions. Finally, as the model is validated, it is suggested that this virtual vehicle model can be employed as an effective model for future studies, especially in the field of heavy vehicle safety.

Acknowledgements

The authors gratefully acknowledge the support from Sciencefund Grant (ref No: 03-01-03-SF0772), PPP (Peruntukan Penyelidikan Pascasiswazah) Grant (Project No: PG093-2013B) and also from JPPHB University of Malaya and Faculty of Mechanical Engineering, UiTM Shah Alam.

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