SIMPLE MODEL VERIFICATION OF PROTON PERDANA LONGITUDINAL DYNAMIC USING STANDARD DRIVE CYCLES

M. A. S. Zainuddin[1,2], S.M.S. Hossain[1], M. Abdullah[1*], K.A. Tofrowaih[3], V. R. Aparow[4] and S. F. Toha[5]

[1]Department of Mechanical and Aerospace Engineering,
International Islamic University Malaysia, Jalan Gombak, 53100, Kuala Lumpur, Malaysia.

[2]Department of Automotive Engineering Technology, Kolej Kemahiran Tinggi MARA, Masjid Tanah, 78300 Melaka, Malaysia

[3]Faculty of Mechanical Engineering Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[4]Automated Vehicle Engineering System (AVES), Department of Electrical and Electronics Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, Jalan Broga, Semenyih, 43500, Selangor, Malaysia.

[5]Department of Mechatronics Engineering,
International Islamic University Malaysia, Jalan Gombak, 53100, Kuala Lumpur, Malaysia.

Corresponding Author's Email: *mohd_abdl@iium.edu.my

Article History: Received 21 January 2025; Revised 09 May 2025; Accepted 01 September 2025

ABSTRACT: This paper presents a simplified verification approach for the longitudinal dynamic model of the Proton Perdana using standard drive cycles. The objective is to assess the model's reliability in replicating real-world vehicle behaviour by comparing simulated responses against benchmark velocity profiles from the Urban Dynamometer Driving Schedule (UDSS), Highway Fuel Economy Test (HWFET), Worldwide Harmonised Light Vehicles Test Procedure (WLTP) class 2. The model incorporates key longitudinal forces, including traction, braking, aerodynamic drag, rolling resistance, and road gradient effects. To support this verification, maximum traction and braking forces were experimentally obtained using a chassis dynamometer and brake testing machine. Simulation results demonstrate that the model can successfully reproduce the velocity profiles across different drive cycles without exceeding the actual traction and braking limits measured from the test equipment. While the verification process does not provide a fully rigorous validation, it offers a fast and practical means to build confidence in the model's suitability for simulation plant in control strategy development, particularly in early-stage research or educational settings.

KEYWORDS: *Vehicle dynamics Modelling; Drive Cycle Simulation; Controller Plant, Proton Perdana;*

1.0 INTRODUCTION

Vehicle longitudinal dynamics are fundamental to overall performance, particularly in managing acceleration, deceleration, and responsiveness. Developing an accurate model of these dynamics is essential for designing vehicles that meet safety standards and offer a comfortable driving experience [1]. Such a model plays a crucial role in testing and evaluating control systems related to longitudinal motion, such as Adaptive Cruise

Control (ACC) and Automatic Emergency Braking (AEB) [2]. Moreover, a reliable vehicle model can ensure consistent and predictable responses across a wide range of driving conditions, making it well-suited for model-based controller design.

Modelling the vehicle's longitudinal dynamics is a challenging task that requires a thorough understanding of the underlying system, governing equations, and the influence of various parameters on vehicle performance. Numerous modelling approaches exist in the literature, including linear [3], nonlinear, first-principles [4], system identification [5], and high-fidelity models [1]. For control-oriented applications, a simple yet reliable model is preferred to ensure fast computation and accurate prediction. In this context, first-principles models are particularly useful, as they provide a fundamental understanding of the system dynamics [6]. Such models require relevant equations for torque generation, gear shifting, and driver inputs, all of which significantly impact model accuracy [7,8]. However, acquiring key parameters such as gear shift strategies and engine maps from manufacturers is often difficult, and while experimental identification through manual measurements is possible, it can be time-consuming and resource intensive. Therefore, a simplified modelling approach is preferred during the initial stages of design to enable faster system development.

To simplify the model, this work focuses solely on the vehicle body dynamics, excluding detailed powertrain equations. In this approach, the traction and braking forces serve as inputs, while the output is the vehicle’s velocity. This reduced-order model enables faster controller development and analysis [9]. However, the use of a simplified model naturally raises concerns regarding its validity, particularly whether it can accurately represent real-world vehicle behaviour. Therefore, the primary contribution of this work is to propose a simple verification process, utilising available vehicle parameters to establish a preliminary level of confidence in the model’s accuracy. The second-generation Proton Perdana is selected as the vehicle of interest, and the model is developed using MATLAB Simulink.

To verify the model, three standard drive cycles were employed to evaluate its ability to track the desired velocity profiles. The resulting traction and braking forces were then analysed and compared against the actual maximum values obtained from chassis dynamometer and brake testing equipment. While full validation against real-world vehicle data is essential for final implementation, this initial verification approach provides a practical starting point. It facilitates early testing of various control strategies for Advanced Driver Assistance Systems (ADAS), which play a crucial role in enhancing driving safety and comfort.

2.0 VEHICLE LONGITUDINAL DYNAMICS

Figure 1 shows the simplified block diagram of the main components involved in vehicle longitudinal dynamics. In this representation, x_t denotes the throttle input (percentage of pedal pressing), x_b represents the brake input (percentage of brake application), and v is the resulting vehicle velocity. As discussed in the previous section, this study focuses solely on the vehicle body dynamics (highlighted in the red box) since the primary objective is to support the development of future control algorithms, rather than detailed powertrain modelling.

To develop the mathematical model, the equation of motion is derived by analysing a slope-climbing case. This approach accounts for all relevant forces acting on the vehicle, as illustrated in the free-body diagram in Figure 2.

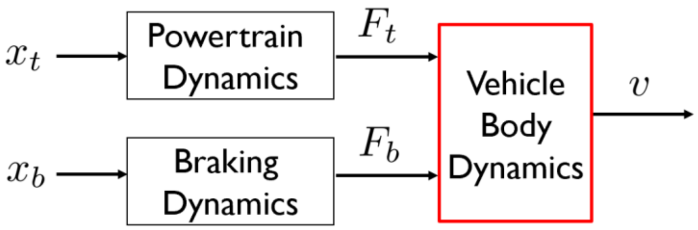


Figure 1: Overall vehicle longitudinal dynamic block diagram [10]

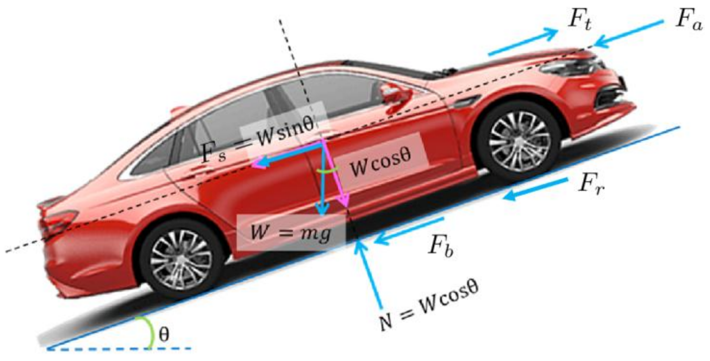


Figure 2: Free body diagram of vehicle longitudinal dynamics [9]

By applying Newton's second law, the vehicle motion can be described as:

$$F_t - F_b - F_s - F_r - F_a = ma \tag{1}$$

Where F_t is the vehicle traction force which will propel and accelerate the vehicle. While ma is the mass of the vehicle times the vehicle acceleration. The other forces such F_b, F_s, F_r, F_a are resistive forces ranging from force due to the brake, slope, rolling resistance and aerodynamic. The details of each force are given as:

$$F_s = mg \sin\theta \tag{2}$$

$$F_r = C_r mg \cos\theta \tag{3}$$

$$F_a = \frac{1}{2}\rho_a \, C_d \, A_f \, v^2 \tag{4}$$

For F_s, F_r, and F_a, the model parameters are given in Table 1 [9].

Table 1: Parameters for vehicle dynamics.

Parameter	Value
Mass of vehicle, m	1524 kg
Gravitational constant, g	9.81 m/s²
Slope angle, θ	0
Rolling resistance coefficient, C_r	0.31
Air density, ρ_a	1.202 kg/m³
Vehicle frontal area A_f	2.26 m²
Drag coefficient C_d	0.31

2.1 Maximum Traction and Brake Forces

To verify the reliability of the developed model, it is essential to compare the estimated traction and braking forces with real-world data. The maximum traction and braking forces are measured using a chassis dynamometer and a brake test machine, serving as benchmarks in the model verification process.

The vehicle is placed on rollers that mimic a road's surface for the dynamometer, allowing for controlled acceleration and deceleration tests. Figure 3 shows the chassis dynamometer from the Dyno-Dynamics brand used in this work. The system enables precise measurement of wheel torque, speed, and power output under various throttle and load conditions. During the test, the vehicle was operated under full throttle. The dynamometer's sensors recorded real-time torque data at the drive wheels, which was then converted into traction force values using the effective wheel radius.

Figure 3: Dyno-Dynamics Chassis Dynamometer setup

Figure 4 shows the results of a chassis dynamometer test conducted on a 2016 Proton Perdana to evaluate its traction performance during full-throttle acceleration. The plot shows tractive effort (N) and road speed (km/h) over time, with three curves representing repeated test runs. The vehicle achieved a peak tractive force of approximately 2,500 N and a maximum speed of around 175 km/h. The measured power outputs were consistent across runs, with maximum values of 124.3 HP, 122.0 HP, and 121.4 HP. This data provides a reliable reference for verifying the vehicle dynamics model by ensuring that simulated traction forces remain within the empirically measured limits.

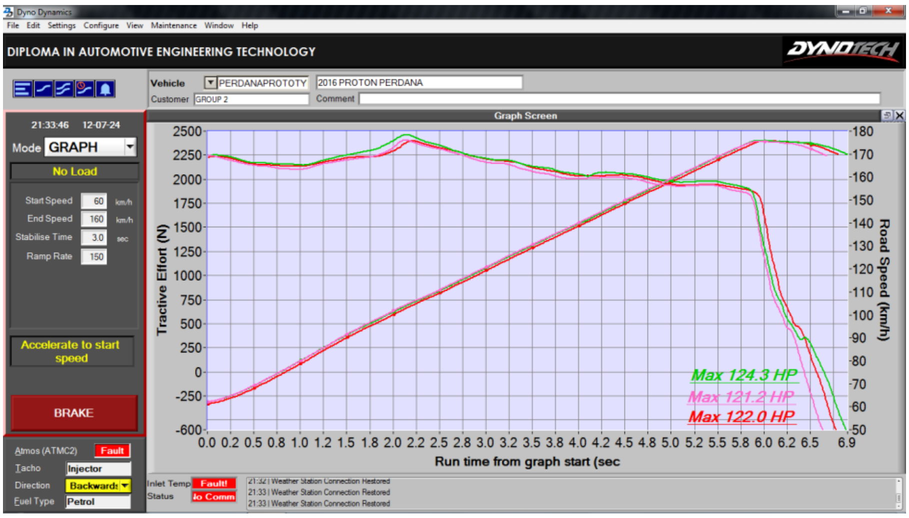


Figure 4: Traction force graph from chassis dynamometers

Similarly, to determine the maximum braking force, a roller-type brake test machine was employed, which accurately measures the braking effort at each wheel under static and dynamic braking conditions, as shown in Figure 5. The driver was instructed to apply maximum brake pressure while the machine recorded the braking force output across the front and rear axles.

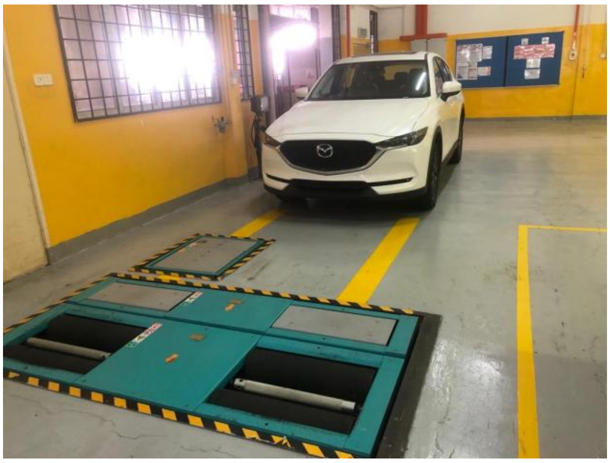


Figure 5: Cosber brake test machine

The machine outputs the individual braking forces for the front and rear axles, which are then summed to obtain the total braking force. Figure 6 presents the test results, showing the sum of a front axle braking force of 5,850 N and a sum of rear axle braking force of 1,610 N. Based on these values, the total braking force for the Proton Perdana is approximately 7,460 N.

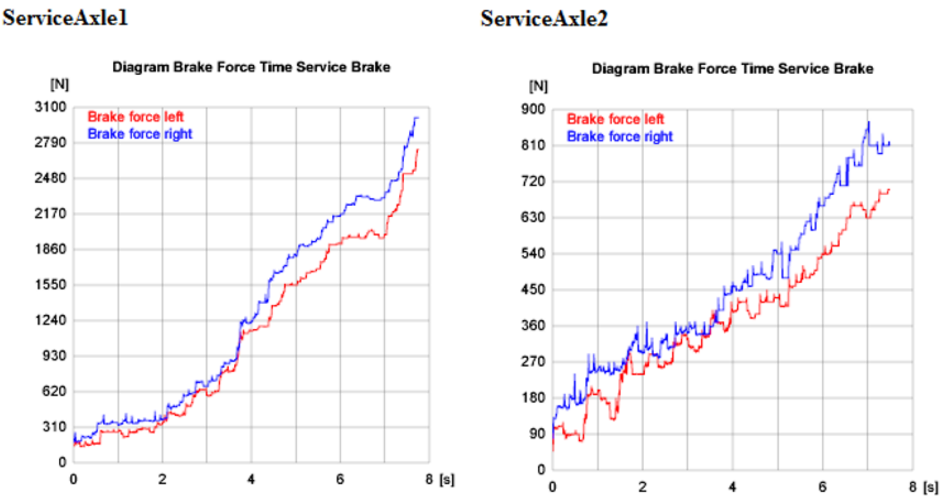


Figure 6: Measured brake force graph for Proton Perdana

Both the traction and braking force data obtained from these tests serve as upper and lower bounds for the force limits of the vehicle. These limits were later used in the simulation to verify whether the developed model operated within physically realistic constraints. Ensuring that the required forces remain within these empirically measured bounds is essential for validating the model's suitability for ADAS controller development and simulation-based testing.

ISSN 2180-1053 e-ISSN 2289-8123 Vol.17 No.2

3.0 SIMPLE VERIFICATION WITH DRIVE CYCLE

A drive cycle is a predefined profile representing a vehicle's speed over time, simulating real-world driving conditions such as acceleration, cruising, braking, and idling. Drive cycles, like the Highway Fuel Economy Test (HWFET), Worldwide Harmonized Light Vehicle Test Procedure (WLTP) or the Urban Dynamometer Driving Schedule (UDDS), are essential for evaluating and validating vehicle systems under standardised scenarios.

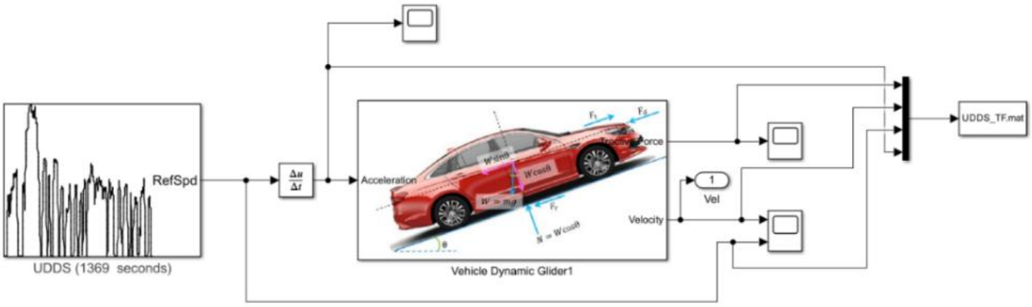


Figure 8: Drive cycle analysis setup in Simulink

Figure 8 illustrates the Simulink implementation used to evaluate the vehicle's longitudinal dynamics model under various drive cycles. In this setup, Equation (1) is rearranged so that the input to the model is vehicle acceleration, while the output consists of the resulting traction and braking forces. The velocity signal from the drive cycle block is differentiated to obtain the acceleration input. Positive force outputs are interpreted as traction forces, while negative values indicate braking forces.

The simulation is conducted using three standard drive cycles: UDDS, HWFET, and WLTP Class 2, all applied to the same model structure. The resulting traction and braking forces are then analysed and compared against the measured maximum values from experimental tests, 2,500 N for traction and -7,460 N for braking. If the simulated force values remain within these boundaries, the model is considered acceptable for use as a preliminary simulation plant. This simple threshold-based verification enables rapid model development in the early stages of control design. However, it is acknowledged that further validation with real vehicle data is essential before actual implementation.

4.0 SIMULATION RESULTS

The Urban Dynamometer Driving Schedule (UDDS) is a standardised driving cycle developed to replicate typical urban driving conditions for the evaluation of emissions and fuel economy in light-duty vehicles, including passenger cars and light trucks. It features a detailed speed profile consisting of accelerations, decelerations, and idle periods, accurately reflecting the stop-and-go nature of city traffic. Based on Figure 9, the cycle spans a total distance of approximately 11.99 km over 1,369 seconds (22.8 minutes), with an average speed of 31.5 km/h. Notably, it includes 17 stops, capturing the frequent halts and variable speeds characteristic of urban environments.

Figure 9 illustrates how the force closely follows the vehicle's dynamic response needed to track the UDDS drive cycle. During sharp increases in the velocity profile (steep upward slopes), the traction force peaks around +2300 N, indicating strong acceleration demands. Conversely, during rapid speed reductions (steep downward slopes), the force dips to approximately -2000 N, representing intense braking actions. These oscillations remain within the acceptable limits defined by experimental data, supporting the ability of the developed model to represent the real-world dynamics of stop-and-go urban traffic.

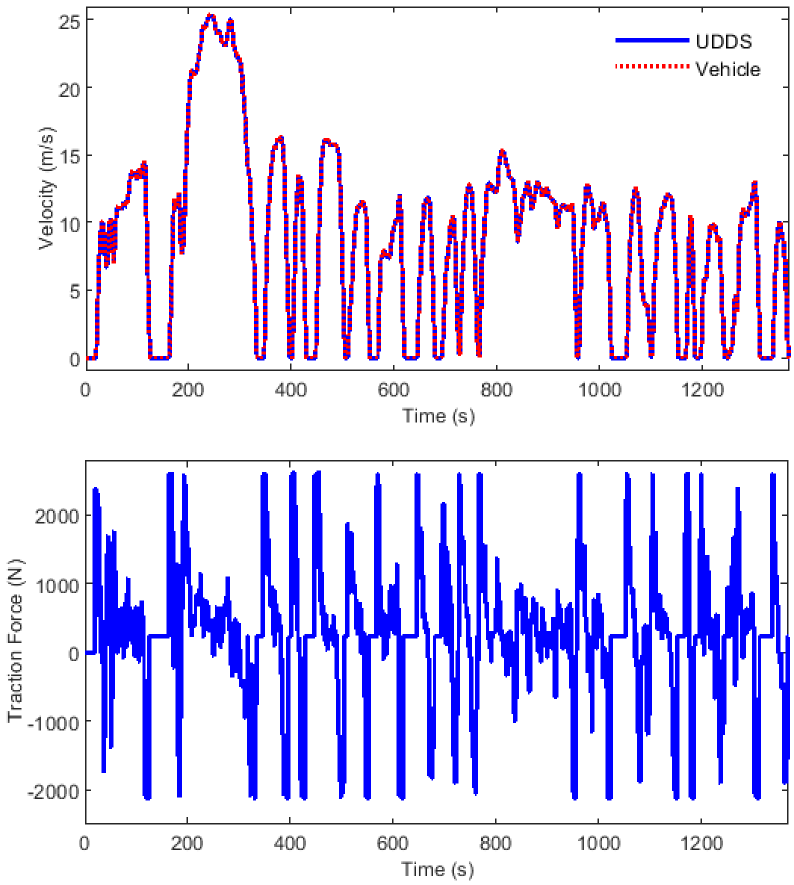


Figure 9: Plant response in tracking the UDDS drive cycle

The second case is the Highway Fuel Economy Test (HWFET), which is a standardised drive cycle developed to simulate typical highway driving conditions. It is characterised by steady-speed, high-speed driving with minimal stops and consistent acceleration and deceleration patterns. Referring to Figure 10, the cycle covers a distance of approximately 16.5 km over 765 seconds (12.75 minutes), with an average speed of 77.7 km/h and a maximum speed of 96.5 km/h. The HWFET includes smooth transitions between speed changes, representing highway travel with little traffic congestion or abrupt stops.

A similar trend is observed with the HWFET drive cycle, as shown in Figure 10. During acceleration phases, particularly within the first 100 seconds, the traction force shows distinct positive spikes reaching approximately +2400 N, indicating the substantial force required to increase speed, yet remaining close within limits. In contrast, during deceleration, the force becomes negative, approaching -2000 N, corresponding to the braking effort applied to reduce speed. During phases of constant velocity, typically between 10 m/s and 20 m/s, the traction force remains near zero, reflecting the low power demand needed to maintain steady motion. The ability to replicate these dynamics suggests the model is well-suited for use as a simulation plant, particularly for developing and tuning ADAS system.

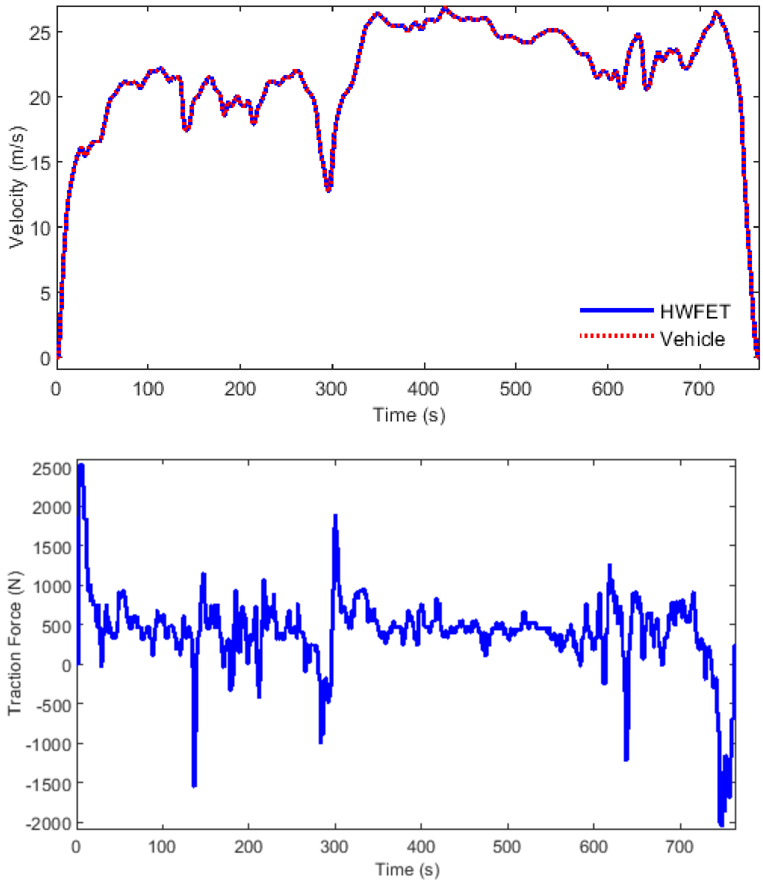
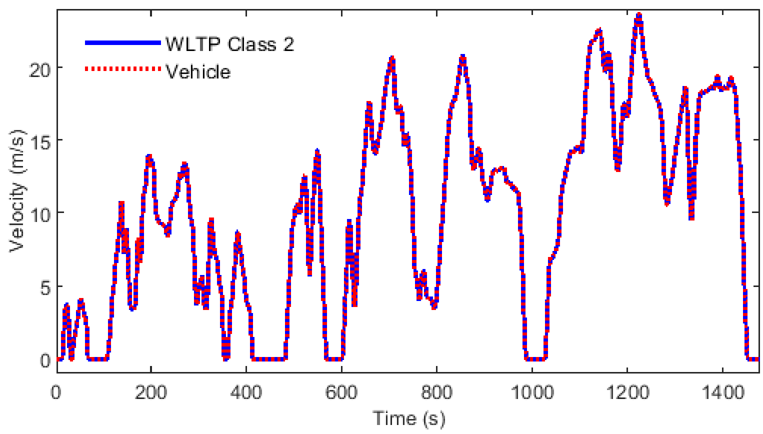


Figure 10: Plant response in tracking the HWFET drive cycle



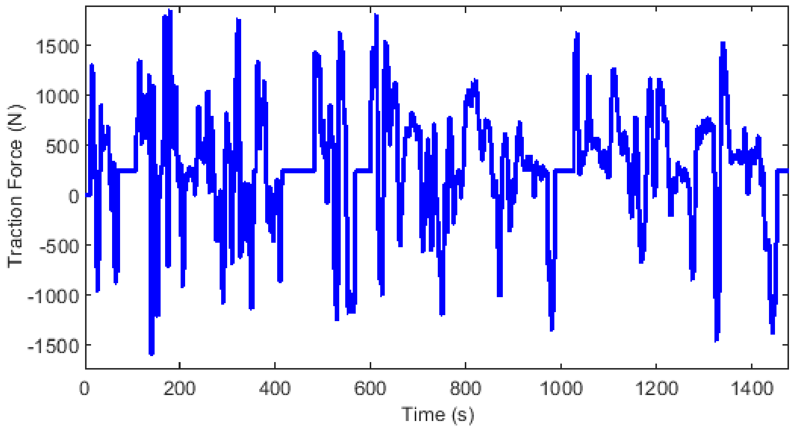


Figure 11: Plant response in tracking the WLTP class 2 drive cycle

Finally, the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) Class 2 is a standardized drive cycle tailored for vehicles with moderate power-to-weight ratios (22–34 W/kg), making it well-suited for D-segment sedans like the Proton Perdana. The cycle spans 23.26 km over 30 minutes, with an average speed of 57.1 km/h, and consists of four dynamic phases, namely low, medium, high, and extra-high speed. Each phase includes realistic driving behaviours such as variable acceleration and deceleration rates, frequent gear changes, idling, and transient speed transitions, which closely reflect the longitudinal dynamics experienced in actual driving. These dynamics provide a comprehensive basis for verifying simulation models.

Figure 11 illustrates the relationship between the WLTP Class 2 drive cycle and the corresponding force. The vehicle undergoes continuous acceleration and deceleration, with speeds reaching up to 20 m/s, characteristic of more dynamic highway or intercity driving conditions. During rapid acceleration, traction force spikes positively, up to +2000 N, to overcome inertia and increase speed. During deceleration, the force turns negative, reaching -1500 N, reflecting braking effort. The recurring oscillations in both graphs indicate frequent transitions between acceleration and braking phases, which closely follow the drive cycle's pattern. These force values remain within the validated physical limits, confirming the model's capability to realistically represent the vehicle's longitudinal dynamics under WLTP Class 2 conditions.

Table 2: Comparison of plant response in tracking different drive cycles.

Drive Cycle	Max Traction Force	Max Brake Force
UDSS	2300 N	2000 N
HWFET	2500 N	2000 N
WLTP Class 2	2000 N	1500 N

Table 2 provides a summary of the comparison in tracking three standard drive cycles: UDDS, HWFET, and WLTP Class 2. The results show that, across all drive cycles, the simulated traction force consistently remains within the predefined limits of +2500 N (traction) and -7500 N (braking). This confirms that the developed model managed to represent the vehicle's longitudinal dynamics under a range of real-world driving scenarios, thereby supporting its acceptability for use in simulation-based control system development.

ISSN 2180-1053 e-ISSN 2289-8123 Vol.17 No.2

5.0 CONCLUSION

This study presents a simple verification analysis of a longitudinal vehicle dynamics model for the Proton Perdana, aimed at serving as a simulation plant for future control-oriented applications. The model was constructed using a first-principles approach, with traction and brake forces as the inputs and vehicle velocity as the output. For the verification process, experimental data from a chassis dynamometer and brake test machine were used as a benchmark limit between traction and braking force.

The model was evaluated using three standardised drive cycles, namely UDDS, HWFET, and WLTP Class 2, and the results demonstrated that the predicted traction and braking forces remained within the validated physical limits (±2500 N for traction and −7500 N for braking) across all cycles. This indicates that the model can represent the vehicle's longitudinal dynamics for control system development at early design stages. While the current verification strategy provides a practical and efficient means of validating model accuracy, further validation against real-world driving data and hardware-in-the-loop (HIL) testing is recommended for deployment in safety-critical applications.

REFERENCES

[1] R. Rajamani, Vehicle dynamics and control. Springer Science & Business Media, 2011.

[2] H. A. Hamersma, & P. S. Els, "Longitudinal vehicle dynamics control for improved vehicle safety". *Journal of Terramechanics*, 54, 19-36, 2014.

[3] B. A. H. Vicente, S. S. James, & S. R. Anderson," Linear system identification versus physical modeling of lateral–longitudinal vehicle dynamics*". IEEE Transactions on Control Systems Technology*, 29(3), 1380-1387, 2020.

[4] S. Idros, M. Abdullah, S. F. Toha, & M. M. Said, "Modelling of vehicle longitudinal dynamics for speed control". *Journal of Advance Research in Applied Mechanics*, 123(1), 56-74,2024.

[5] S. James, & S. R Anderson, "Linear system identification of longitudinal vehicle dynamics versus nonlinear physical modelling". In 2018 UKACC 12th *International Conference on Control (CONTROL),* pp. 146-151, IEEE,2018.

[6] A. Szántó, and G. A. Szíki, "Review of Modern Vehicle Powertrains and Their Modelling and Simulation in MATLAB/Simulink," *International Journal of Engineering and Management Sciences*, vol. 5, no. 2, pp. 232-250, 2020, https://doi.org/10.21791/IJEMS.2020.2.29

[7] W. Dai, Y. Pan, C. Min, S. P. Zhang, & J. Zhao, "Real-Time Modeling of Vehicle's Longitudinal-Vertical Dynamics in ADAS Applications". *In Actuators, MDPI*, vol. 11, No. 12, p. 378, 2022.

[8] S. Buggaveeti, M. Batra, J. McPhee, & N. Azad, "Longitudinal vehicle dynamics modeling and parameter estimation for plug-in hybrid electric vehicle". *SAE International Journal of Vehicle Dynamics, Stability, and NVH*, 1(2017-01-1574), 289-297, 2017.

[9] M. Abdullah, M. S. Zainuddin, S. Ahmad, & J. Rossiter, "Performance comparison between centralized and hierarchical predictive functional control for adaptive cruise control application". *International Journal of Automotive and Mechanical Engineering*, 20(4), 10808-10820, 2023.

[10] M. A. S. Zainuddin, M. Abdullah, S. Ahmad, & K. A. Tofrowaih, "Performance comparison between predictive functional control and PID algorithms for automobile cruise control system". *International Journal of Automotive and Mechanical Engineering*, *19*(1), 9460-9468, 2022.