Vehicle Gear Ratios Assessment: Study of the Fidelity of a Videogame to Theoretical Vehicle Dynamics

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The modification of certain vehicle dynamics attributes, such as the gear ratios of a transmission system, can generate significant impacts on vehicle behavior under different driving conditions. Such changes influence performance, such as acceleration times, maximum speed, and traction forces. With advancements in simulation technologies featured in electronic games, there has been a growing convergence between simulated dynamic and real-world behavior of theoretical engineering. In this context, modern video games have increasingly established themselves as complementary tools in the educational process, particularly related to automotive engineering, by enabling the customization of technical concepts in a math ambience. However, in-depth analysis is needed to assess whether vehicle input customizations performed in video games follow the expected results when compared to the real world. Thus, the objective of this article is to investigate the impacts caused by gear ratio changes on vehicle drivability in the videogame Forza Horizon 5. The theoretical framework studied, and the tests conducted shows that this game have already being able to simulate, within their parameters, phenomena that are well-documented in real-world studies, which means that games like this can already serve as valuable educational tools.

Keywords: Vehicle Dynamics. Transmission Ratio. Electronic Games.

The gaming market has shown significant growth over the years due to technological advancements. The increase in the player base reached 3.2%, generating revenues of USD 182.7 billion in 2024 [1]. Due to the cloud system on internet, videogames such as Forza Horizon 5 already have over 45 million players [2]. In this video game, players can modify their cars to change dynamics specifications such as suspension geometry, brake balance, down force, engines specifications, and others. Some of these parameters are primarily addressed in automotive engineering through theoretical learning, since practical demonstrations are costly. Given the wide availability of this specific game, the present study focused on the parameters of gear ratio changes, where practical effects could significantly support theoretical comprehension.

Gear ratios can be configured to give different characteristics of acceleration and speed in a vehicle. The higher the gear ratio, the higher the torque transmitted to the wheels, however, wheel speed becomes lower. These settings could affect several vehicle parameters, such as fuel consumption, engine emissions, acceleration, maximum speed, and tractive power.

The tractive power is associated with the resistances encountered while moving the vehicle, considering only a flat track with no elevation. It depends on the friction force acting on the drive wheel, as well as rolling resistance [3]. The power equation is represented as [3]:

$$Pt \cong ½.\rho.C.S.v^3 + a.M.g.v \quad (1)$$

Where: p is the air density, approximately 1.22 kg/m³ at sea level; C is the drag coefficient; S is the frontal area of the vehicle, in square meters; v is the speed, in meters per second; a is the rolling resistance coefficient, 1% of the normal force on the track; M is the mass of the vehicle, in kilograms; g is the gravitational field strength, in meters per second squared.

As an example of the application of this relationship between power and speed, data [3] was collected from different vehicles and divided into three distinct groups: Group 1 for modern

Received on 12 October 2025; revised 20 December 2025.
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J Bioeng. Tech. Health 2026;9(2):98-103

automobiles, Group 2 for automobiles from the 1960s and 1970s and Group 3, for modern sport utility vehicles (SUVs). Figure 1 shows the relationship between power and speed for all vehicles assessed in the three groups.

The maximum speed increases directly proportional to the increase in power (regardless of the year of the vehicle). According to Equation 1, similar cars (both with equal frontal area, and weight), would be different maximum speed due to their traction power (as long as they are not the same). In this sense, it is possible to customize similar vehicles in terms of gear ratio attributes to verify the differences they encounter at maximum speed. This approach allows for a playful educational simulation for various engineering students who may not have access to simulators or prototype vehicles.

Therefore, this article aims to evaluate whether the gear ratio attribute produces changes in Forza Horizon 5 cars and compare these changes with the expected results.

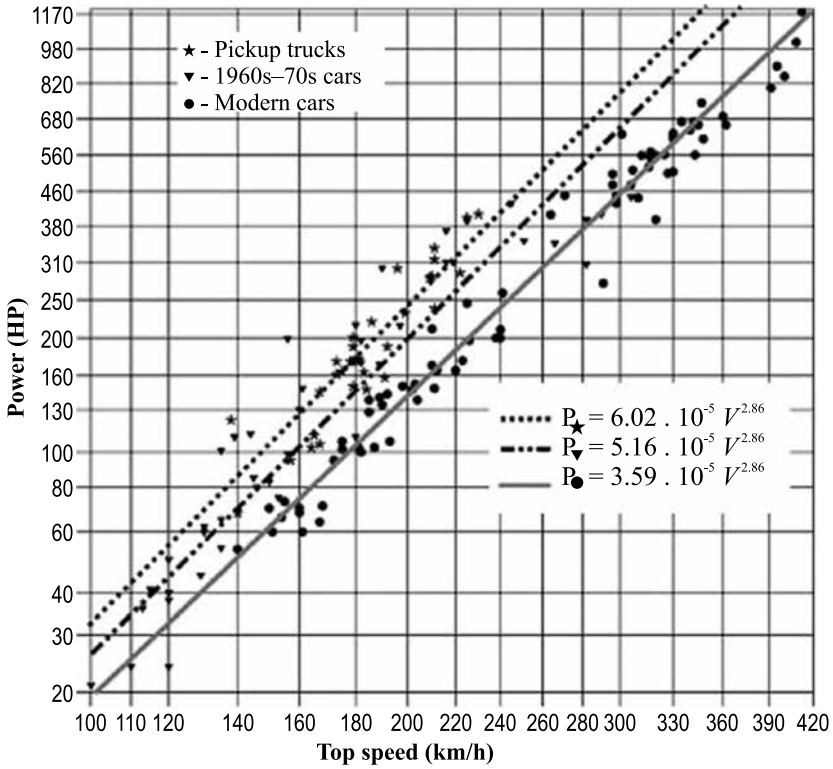
Materials and Methods

To verify the gear ratio attributes, a racing game was selected, in which the vehicles are similar to those produced commercially worldwide. There are several games in this segment (such as Racer [4]), but the one selected for this study was Forza Horizon 5, developed by Playground Games and published by Microsoft in 2021. This game was chosen due to the combination of its basic simulation parameters and its high accessibility, presenting a wide range of players worldwide [2]. The 2008 BMW Z4 M Coupé vehicle was chosen due to the availability of technical information (engine power curve, shown in Figure 2).

Therefore, a review was conducted to examine the relationship between engine power and vehicle speed presented in the game, and an experimental evaluation was conducted to determine new gear ratio parameters.

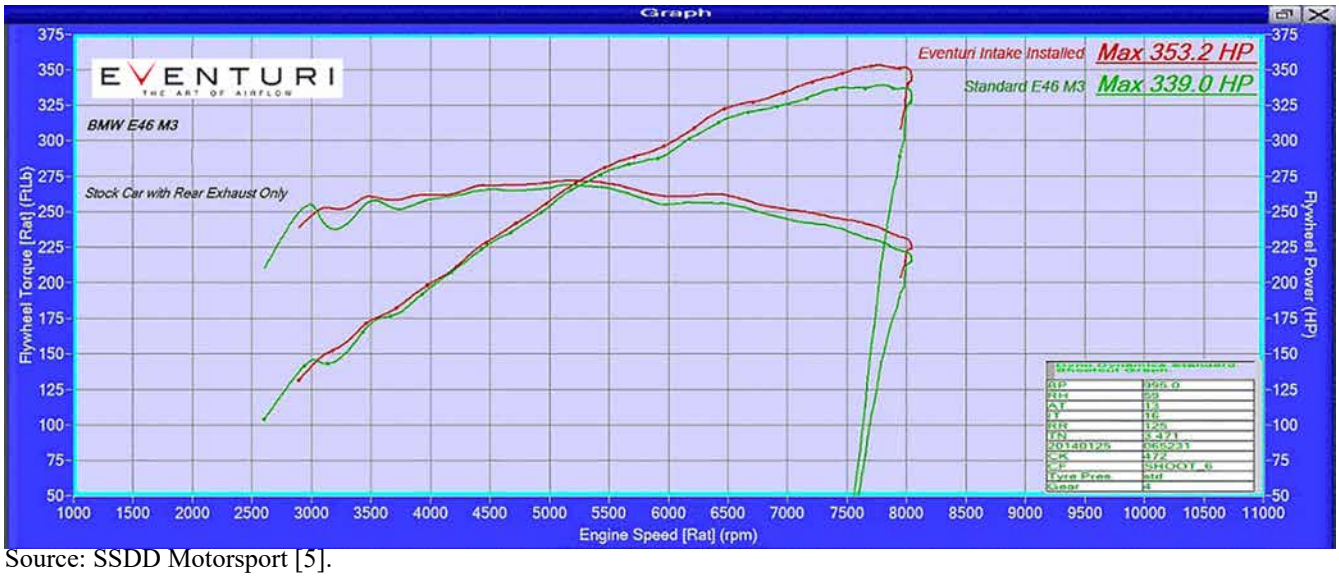
Validation was performed in a simulation environment, evaluating the vehicle's response within the game itself.

Figure 1. Relationship between power and speed for the three selected groups.



Source: Silveira (2011) [3].

Figure 2. Power and torque curve of the chosen vehicle.



Source: SSDD Motorsport [5].

Two types of tests were conducted with four different car configurations, as follows:

- Maximum speed test: The cars were tested on a 6-kilometer track, starting from the same starting point and ending at the same point, under the same weather conditions in the Forza Horizon 5 simulation environment.
- Acceleration Test: A drag strip was selected to verify the vehicles' starting times.
- The two different car configurations included:
- Standard Car: The car without modifications.
- Custom Car: The car with gear ratios adjusted according to Table 1. The new gear ratios were selected to increase torque to the wheels and serve as a benchmark for student evaluation. This type of gear ratio is common in light vehicles used in cities and urban centers.

Table 1. Gear ratios.

Gear Ratios	Standard Car	Custom Car
Differential	3.62:1	4.40:1
1st gear	4.35:1	4.55:1
2nd gear	2.50:1	2.67:1
3rd gear	1.66:1	1.82:1
4th gear	1.23:1	1.33:1
5th gear	1.00:1	1.00:1
6th gear	0.85:1	0.80:1

Sources: Adapted from Vrum [6].

Both vehicles were subjected to at least three test cycles to verify the results.

A gear diagram was calculated to compare the behavior of the relationship between vehicle speed and engine speed in different gears for the two gear ratio configurations, using Equation 2 [7]:

$$v = \frac{rpm \cdot C \cdot 3{,}6}{r \cdot D \cdot 60} \quad (1)$$

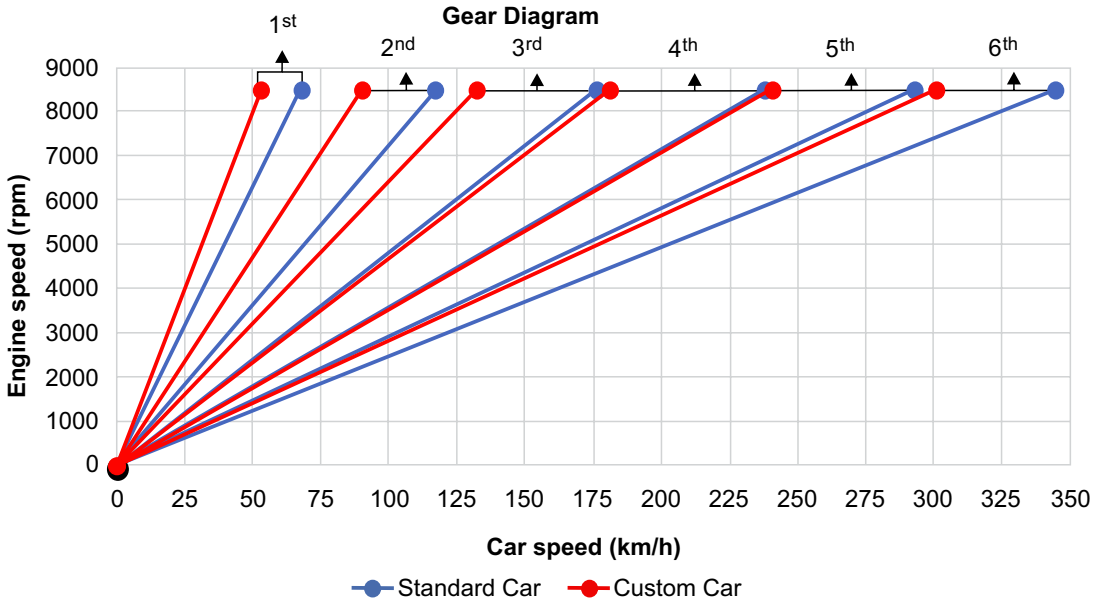
Where: RPM is the engine speed, in revolutions per minute; C is the circumference of the tire used by the car, in meters; R is the selected gear ratio (dimensionless); D is the selected final drive ratio (dimensionless).

Results and Discussion

As seen in Figure 3, the change in gear ratio (for theoretical speed, which considers an environment with no friction, no roll coefficient, and no aerodynamic coefficient) caused differences in the vehicle's speed profile. The customized vehicle had a lower top speed (approximately 300 km/h), as well as a lower maximum speed achieved by each gear.

However, this resulted in greater tractive force at the wheels, which can generate greater

Figure 3. Gear diagram of cars for maximum theoretical speed.



acceleration. Although the engine power curve shows a maximum engine speed of 8000 rpm (Figure 2), the gear ratio diagram used 8500 rpm.

This occurred because the real vehicle (marketed and sold worldwide) has an engine speed limit to minimize potential mechanical lubrication and cooling issues, which were not applied in Forza Horizon 5. Top Speed Test: In the top speed test, the standard car reached 288 km/h, while the custom car reached 291 km/h, as shown in Figures 4 and 5, respectively.

Despite a higher maximum speed than the custom vehicle, the standard vehicle was unable to overcome the maximum speed exhibited by custom car (for the selected track). This could occurred because Forza Horizon 5 uses parameters (which are not disclosed to the user) such as air mass, track inclination, and ambient weather conditions that hindering the vehicle from reaching its maximum theoretical speed (Figure 3). Another aspect is that the customized vehicle had higher tractive force (by increasing the gear ratio, as observed in Table 1), which allowed it to overcome track conditions and, therefore, produce a higher maximum speed in the simulated environment.

Regarding acceleration time (Table 2), the custom vehicle exhibits shorter acceleration times, which explains the maximum speed performance discussed above. Increasing the gear ratio generates higher torque (and higher tractive effort) at the vehicle's wheels, providing lower acceleration time for custom car.

Table 2. Acceleration test times.

Times	Standard car (seconds)	Custom car (seconds)
Time 1	24.42	24.09
Time 2	24.42	24.09
Time 3	24.42	24.09
Average time	24.42	24.09

Furthermore, the gear ratios used in this study were effective, as the custom car were consistently faster. However, if tracks with very long straights were selected, it would be noted that the standard vehicle would outperform the customized vehicle in maximum speed.

Conclusion

This study aimed to evaluate modifications to the gear ratio of a vehicle in a racing game (Forza

Figure 4. Top speed of the standard car.

Figure 5. Top speed of the custom car.

Horizon 5) that could be used as a math simulator for engineering students. The proposed changes to the vehicle's gear ratio, and the tests conducted, indicated that the game was able to reproduce the expected results.

The customized vehicle presented a faster acceleration time, consistent with the modifications designed to increase the gear ratio, contributing to an increase in wheel traction forces. Additionally, the customized vehicle also presented a higher maximum speed (for a 6km track). However, if other, longer tracks were selected, it would be evident that the custom vehicle would have a lower maximum speed than the standard vehicle.

Therefore, for students who do not have access to automotive simulators, Forza Horizon 5 could be a satisfactory tool in engineering classes, as it presents phenomena and vehicles found in the real world.

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