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MODELING AND SIMULATION STUDY OF THE VEHICLE AUTOMATIC TRANSMISSION CONTROLLER SYSTEM

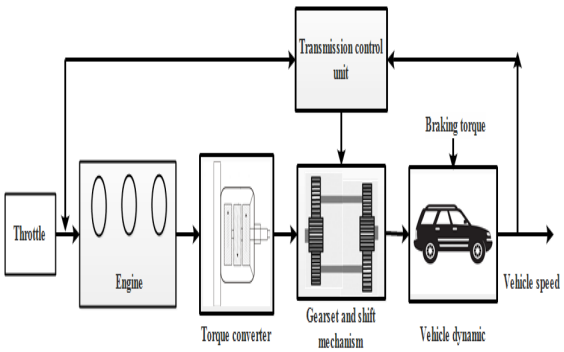
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Graphical abstract



Abstract

Road conditions vary from one country to another within the same country or between different countries. Therefore, drivers need to adjust their vehicles' speed to suit the road conditions, making the transmission system a crucial component of any vehicle. This system transfers engine power to the wheels and controls vehicle speed. In this paper, an automatic transmission model has been constructed by using MATLAB's Simulink environment. As the results were validated by comparing them with previous results. The system's performance was analyzed at various throttle ratios, specifically 20%, 40%, and 60%. Logic control (state flow) has been used to change the vehicle speed according to the vehicle speed and throttle ratio. For each throttle setting ratio, vehicle speed, engine speed, and torque were examined under two conditions: with the brakes applied for 25 seconds and without braking. The results showed that as the throttle ratio increases, both the vehicle's speed and torque increase. But the torque doesn't increase as much as the speed does. The innovation of this effort lies in merging Stateflow-based logic control with automatic transmission modeling for enhanced gear-shift reply analysis, offering a useful plan for upcoming intellectual transmission system designs.

Keywords: State flow, Simulink MATLAB, Automatic transmission, and Aerodynamic drag coefficients.

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1.0 INTRODUCTION

The operator of the vehicle is required to adjust both the speed and torque of the automobile to align with the prevailing road conditions; consequently, the car is equipped with a system that facilitates the transmission of speed and torque from the engine to the wheels. This system is commonly referred to as the transmission or powertrain system. There exist two distinct categories of this system: manual and

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automatic systems. The manual system necessitates the driver to manually alter the speed and torque. Conversely, the automatic system autonomously adjusts based on the vehicle's speed and acceleration by modulating the engine's output. Automatic transmission systems are integral to contemporary automotive engineering, offering drivers a degree of convenience, enhanced efficiency, and superior performance. Over time, innovations in automatic transmissions have progressed markedly, integrating state-of-the-art technologies aimed at improving fuel efficiency, augmenting vehicle performance, and increasing driver comfort. This analysis elucidates significant advancements, technologies, and trends within the domain.

An automatic transmission constitutes a specific category of vehicle transmission system that enables the operator to maneuver the vehicle without the necessity of manually shifting gears. In contrast to manual transmissions, which require the driver to engage and disengage the clutch while shifting gears, automatic transmissions autonomously manage this procedure. This automation culminates in a more seamless and convenient driving experience. The widespread adoption of automatic transmissions can be attributed to their user-friendly nature, rendering driving less arduous, particularly in urban environments characterized by frequent stops and starts.

Automatic transmissions function through an intricate interpa lay of hydraulic, mechanical, and electronic systems that determine the appropriate gear ratio corresponding to the driving conditions. The system comprises the following components: The first component, the Torque Converter, supplants the clutch found in manual transmissions, facilitating a smooth transfer of the engine's rotational force to the transmission system. It also serves to amplify torque during acceleration. The second component, known as the Planetary Gear Set, functions as the principal mechanism that offers multiple gear ratios. A planetary gear set is comprised of a sun gear (the central gear), planet gears (gears that encircle the sun gear and are connected to a carrier), and a ring gear (the outer gear). By selectively locking or unlocking specific components, the transmission can attain various gear ratios.

The third component, the Hydraulic System, is employed to regulate gear shifts by directing transmission fluid to designated paths within the system. The application of fluid pressure activates clutches and bands that either engage or disengage gear sets.

The fourth component, an Electronic Control Unit (ECU), is a modern innovation incorporated into transmissions that monitors variables such as vehicle speed, engine load, and other parameters to optimize gear selection and enhance overall efficiency.

Historically, the evolution of vehicle powertrain transmissions has transitioned from rudimentary systems to sophisticated automatic designs. Early automobiles utilized a clutch and belt drive system that offered only a sina gle speed. Subsequently, manual transmissions incorporated the reverse gear and multiple gear ratios. The first fully automatic transmission to gain widespread acceptance, the GM Hydramatic, was launched in the 1940s, featuring planetary gears and fluid coupling. Furthermore, Buick introduced the torque converter in 1948.

Today, the main types of transmissions are: Automatic Transmission (ATS) – Uses a torque converter, hydraulic controls, and planetary gears. Automated Manual Transmission – No clutch or shift lever, but allows driver input. Continuous Variable Transmission (CVT) – Offers seamless, step-less gear changes. Among these, the hydraulic automatic transmission remains the most common, transferring engine torque through fluid motion to propel the vehicle[1]. State-of-the-art technology is an automatic transmission system, which significantly reduces vibration and, consequently, noise. In hydrodynamic transmissions, fluid ports play a crucial role, as they are integral to a system that automatically adjusts drive speed by utilizing mechanical power supported by fluid dynamics[2].

Liu et. al [3] designed torque converters for passenger cars from the power train cothe mponent have become flatter in recent years in order to achieve a substantially and extra reduced bulk. Four fluid turning converters through different uniformity ratios were created to assess the supremacy of the smooth torus approach of design, along with a unique flat torus of the elliptic type of methodology to improve its performance.

2.0 SURVEY OF PREVIOUS STUDIES

The General Motors (GM) Two-Mode Power-Split Hybrid Transmission represents a sophisticated hybrid driveline architecture meticulously engineered to enhance fuel efficiency and operational performance. It encompasses two distinct operational modes: Input-split mode (low speed) – This mode is utilized during initial vehicle starts and low-velocity driving, wherein the power generated from the internal combustion engine and electric motors is integrated through a planetary gear assembly to optimize overall efficiency. Compound-split mode (high speed) – This mode activates at elevated speeds to achieve superior fuel economy, employing a differential amalgamation of mechanical and electric drive power. Yang [4], [5], [6] successfully executed the configuration design of automatic transmission utilizing the structural database of Power Gear Train, thereby substantiating this assertion. Should the database

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possess the capability to not only catalog the structural configurations but also encapsulate the performance characteristics, it implies that the kinematic and dynamic models of the configurations can be directly accessed during the design phase without necessitating their re-creation. Such a comprehensive database, inclusive of performance characteristics, would significantly enhance the efficiency of configuration design processes.

Zhuang [7] concentrates on the engine, motors, and output components in alignment with the GM two-mode configuration, conducting an analysis of the variances in the system dynamics matrix for each power-split mode to synthesize a hybrid configuration comprising three Power Gear Trains. The employed methodology demonstrates a high degree of accuracy in analyzing the different operational modes; however, it results in the synthesis of a singular configuration type of hybrid transmission. This limitation may stem from the absence of a simplified and unified model to adequately represent hybrid transmissions in advance, thus rendering the configuration synthesis process excessively complex.

Electric vehicles (EVs) offer numerous advantages when juxtaposed with conventional vehicles powered by internal combustion engines (ICE), including enhanced efficiency, reduced energy consumption, and diminished noise levels, among others [8]. Nevertheless, the majority of contemporary EVs are outfitted with a transmission characterized by a fixed gear ratio, which constrains the adaptability across diverse operational scenarios. In contrast, a two-speed transmission has the potential to optimize the operational range of the drive motor, enhance drivability, and extend the cruising range; consequently, it represents a crucial strategic avenue for the advancement of electric vehicles.

Hong et al. [9] conducted a study on the two-speed Inverse-Automatic Mechanical Transmission (I-AMT), as illustrated in Figure 1. Within this design, a dog clutch is employed to facilitate the reverse gear functionality of the vehicle, maintaining an identical gear ratio to that of the first gear. Furthermore, the incorporation of an electronically controlled, normally closed wet multi-plate clutch serves to enhance the smoothness of the gear shifting process while concurrently reducing the manufacturing costs associated with the transmission.

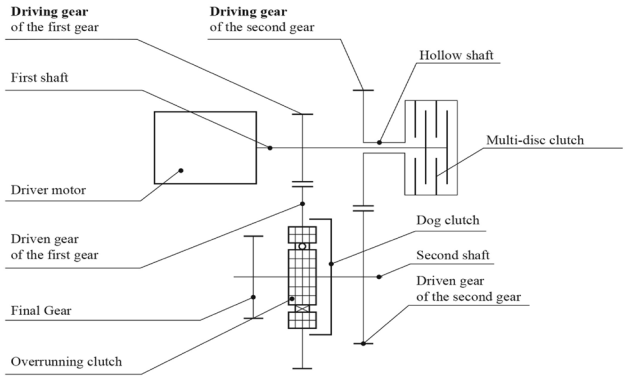


Figure 1 Layout of Inverse-Automatic Mechanical Transmission.

Figure 2 illustrates a dynamic model of the Inverse-Automatic Mechanical Transmission (I-AMT). During the gear-upshift process, in the torque phase, the multi-plate clutch is progressively engaged from its released state. As a result, the torque transmitted by the multi-plate clutch gradually increases, while the torque transmitted by the overrunning clutch decreases until it reaches zero. Subsequently, the gear shift process transitions into the inertia phase, during which the multi-disc clutch continues to engage until fully engaged. In contrast, the gear downshift process initially enters the inertia phase, where the multi-disc clutch is gradually disengaged from its combined state. During this phase, the drive motor must output torque to accelerate the active component of the multi-disc clutch until the speeds of the inner and outer rings of the overrunning clutch are synchronized. Following this, the shift transitions from the inertia phase to the torque phase, and the multi-disc clutch continues to disengage until the gear shift process is completed. From the description, it is evident that due to the transmission employing a single friction element and the involvement of motor speed regulation during the inertia phase to achieve speed synchronization in the gear downshift process, it becomes challenging to control the speed of the overrunning clutch smoothly and synchronously. Therefore, for the I-AMT, managing the gear downshift is significantly more complex than controlling the upshift process [10].

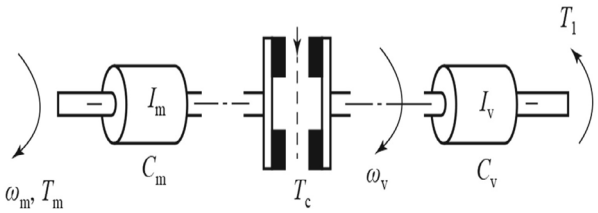


Figure 2 Two-mass dynamic model of Inverse-Automatic Mechanical

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Where T_m, T_c, and T_l represent the output torque of the motor, the transmission torque of the multi-disc clutch, and the load torque of the driven component of the multi-disc clutch, respectively. I_m denotes the equivalent moment of inertia of the active section of the multi-disc clutch. C_m and C_v signify the equivalent damping coefficients for the main and driven sections of the multi-disc clutch, respectively. ω_m and ω_v indicate the rotational speeds of the main and driven components of the clutch. Naser Rashid Manea Rahian Al-Ajmi et al. [11]. developed and simulated various simplified models utilizing MATLAB software, focusing on multiple gear-shifting techniques based on flow conditions, flow with slope, flow incorporating vehicle speed calculations, and other influencing factors. The simulations performed assess the performance of the transmission system and the vehicle's behavior. The findings indicate that reducing throttle input increased engine torque while simultaneously decreasing engine speed. The model of the automatic transmission system. To emulate the functional characteristics of an automatic transmission system, a simulation model was constructed using nonlinear equations and the Simulink modeling framework, which is well-suited for modeling dynamic and nonlinear systems. The transmission system comprises several interconnected mechanical components to operate effectively, and this model was designed to evaluate its performance. The engine, torque converter, and transmission mechanism represent the sequential steps in the power transmission process. Through throttle input, regulated by the throttle angle, the driver controls the amount of intake charge, subsequently managing both speed and torque. Figure 3 illustrates the series of the automatic transmission system.

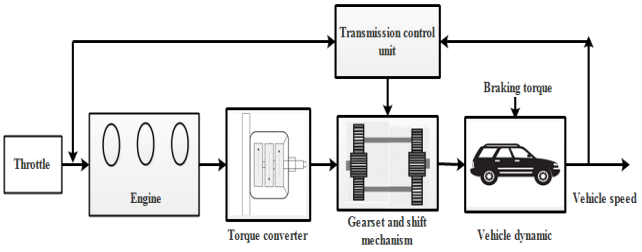


Figure 3 The series of the automatic transmission system.

As explained in reference [11], certain equations control the behavior of the torque engine and torque converter.

$$I_{ie}\dot{N}_e = T_e - T_i \quad (1)$$

Where

I_{ie} engine and impeller moment of inertia, $\dot{N}_e$ engine speed, T_e engine torque, and T_i impeller torque.

It is possible to express the torque converter's input-output characteristics as functions of both engine and turbine speed. It is always assumed in this example that power flows from the impeller to the turbine.

$$T_i = (N_e/K)^2 \quad (2)$$

$$T_i = R_{TQ}T_i \quad (3)$$

Were

T_i Turbine torque, K capacity or factor, N_{in} torque converter output, and R_{TQ} torque ratio.

Fixed gear ratios are used to model the transmission system, if gear shifts happen almost instantly with very little delay.

$$T_{out} = R_{TR}T_{in} \quad (4)$$

$$N_{in} = R_{TR}N_{out} \quad (5)$$

Were

R_{TR} transmission ratio, T_{in} and T_{out} transmission input and output torque, and N_{in} and N_{out} transmission input and output speed.

The final drive, inertia, and a dynamically varying load constitute the vehicle dynamics: -

$$I_v\dot{N}_w = R_{fd}(T_{out} - T_{load}) \quad (6)$$

Were

I_v vehicle inertia, N_w wheel speed, R_{fd}final drive, and T_{load} load torque.

The road load, which takes into consideration the combined effects of frictional resistance and aerodynamic drag, and the braking torque, make up the load torque.

$$T_{load} = sgn(V_v)(R_{load0} + R_{load2}V_v^2 + T_{brake}) \quad (7)$$

Were

T_{load} load torque, R_{load0} and R_{load2} friction and aerodynamic drag coefficients, $+T_{brake}$ brake torque, and V_v vehicle linear velocity.

3.0 THE SIMULINK MODEL OF THE AUTOMATIC TRANSMISSION SYSTEM

The Simulink model is composed of five subsystems: the engine model, the transmission model, the vehicle model, the logic control, and the torque

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converter model. The engine model operates by producing angular speed and torque through the conversion of chemical energy into heat energy, and subsequently into mechanical energy [11]. A torque converter is utilized to transform the torque produced by the engine into an appropriate torque [12]. A vehicle environmental simulation model serves as either a computational or physical model that replicates the behavior, performance, and response of a vehicle under diverse environmental conditions, including temperature, humidity, wind speed and direction, road conditions (such as wet, icy, or rough surfaces), altitude, terrain, and solar radiation (for thermal models). The logic controller manages the vehicle's acceleration and deceleration by adjusting the vehicle's speed, as illustrated in Figure 1 [13]. The transmission ratio block establishes the ratio and calculates the output torque and input speed of the transmission. The ratios employed range from a one-to-one underdrive ratio, one-to-one, to an overdrive. Figure 4 depicts the Simulink representation of the complete automatic transmission system, which encompasses five subsystems, while figures 5, 6, 7, 8, and 9 illustrate the engine model, transmission model, vehicle model, logic control model, and torque converter model, respectively

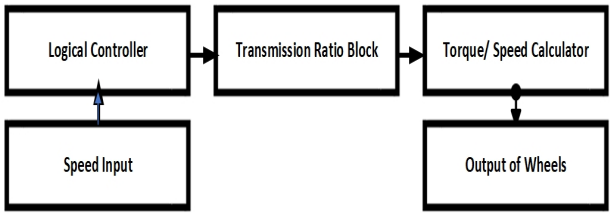


Figure 4 Block Diagram of a Logic-Based Vehicle Speed Control and Transmission Ratio.

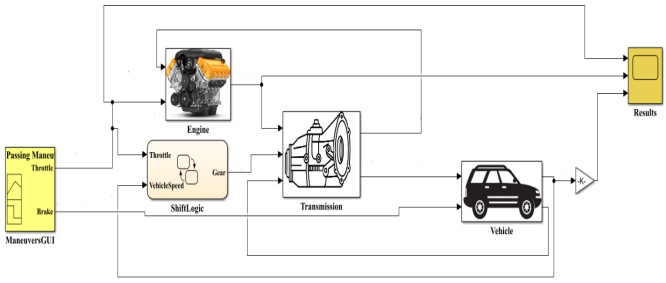


Figure 5 The Simulink of the overall automatic transmission system.

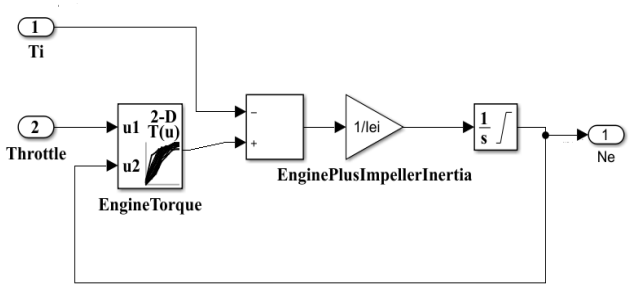


Figure 6 The engine model.

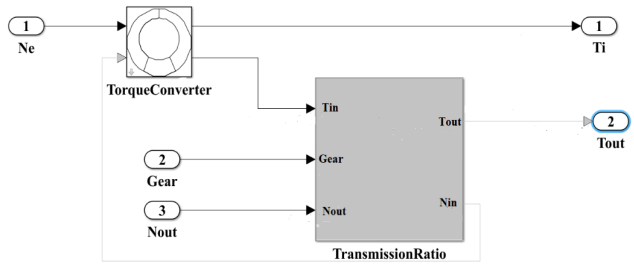


Figure 7 The transmission model.

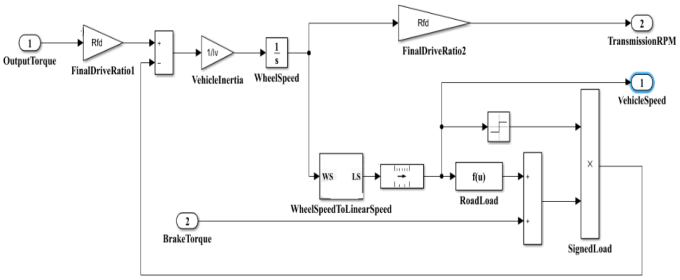


Figure 8 The vehicle model.

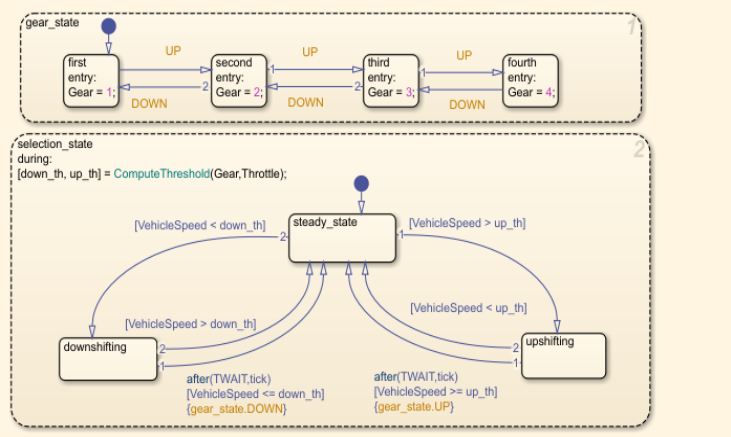


Figure 9 The logic control model.

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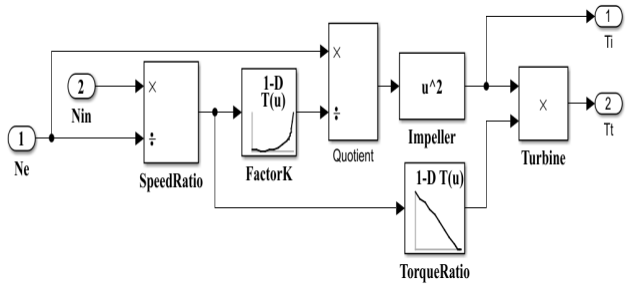


Figure 10 The torque converter model.

3.1. The automatic transmission system schedule

The automatic transmission depends on changing between speeds automatically, whether in the case of acceleration or deceleration, and in the same sequence. Figure 10 shows the operation map of the automatic transmission, whether in the case of acceleration or deceleration, depending on the throttle ratio.

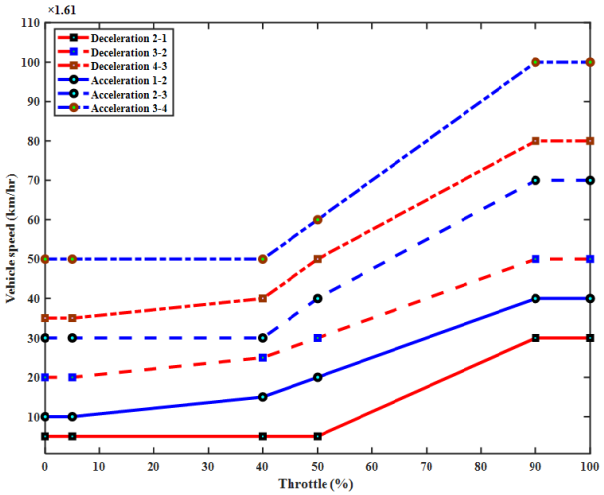


Figure 10 The operation map of the automatic transmission.

4.0 SIMULATION RESULTS AND DISCUSSION

To evaluate the performance of the automatic transmission, a model was created in Simulink utilizing several subsystems, based on equations that characterize the operation of the system [14][15][16]. Variables such as revolutions per minute, speed, and engine torque were recorded at different throttle positions, specifically 20%, 40%, and 60%. These measurements were taken under two scenarios: with and without the application of brakes. The driver is required to adjust the speed of the vehicle. Consequently, the state flow (logic control) block identifies the most appropriate gear to control vehicle speed and torque, depending on the driving conditions. The vehicle speed and throttle ratio serve as input parameters for determining the correct gear. As illustrated in Figure 10, the suitable gear selection is contingent upon whether the vehicle is in an accelerating or decelerating state; it accordingly selects the appropriate gear [17][18][19]. Modified Throttle Mapping (MTM) refers to the software-driven modification of the relationship between the driver's throttle input and the engine's throttle input. Through MTM, for a specific driver throttle input, the engine generates increased torque while maintaining the maximum torque (i.e., the torque corresponding to 100% driver throttle input) unchanged. It is important to note that MTM differs from modified 'engine mapping,' which involves altering engine characteristics through adjustments in fuel injection, air charge, ignition timing, valve timing, and other factors that affect engine performance [20][21]. Figures 12, 13, and 14 depict the dynamic behavior of vehicle speed under different throttle inputs (20%, 40%, and 60%) with and without brake application

Figure 11 illustrates the vehicle speed at a throttle setting of 20% both with and without the application of brakes. When the brakes are engaged, the speed automatically decreases upon brake application at 25 seconds, reaching 25 km/hr after 60 seconds, where it stabilizes. This pattern suggests that the braking force surpasses the engine torque. Contributing factors to this phenomenon may include Brake Override Logic, which is a safety feature that prioritizes brake input over throttle input; Modified Throttle Mapping, a software modification that restricts engine response under specific conditions [22]; and Transmission Downshifting, which involves an automatic reduction in gear ratio to facilitate deceleration. Collectively, these systems ensure the vehicle operates safely by providing effective braking, even when the throttle is partially engaged [23]. Figure 14 depicts the vehicle speed at a throttle of 40% with and without brakes, where the speed escalates to a peak of 170 km/hr and remains steady at this level after 60 seconds without brakes. Conversely, with the brakes applied, the speed automatically declines to 90 km/hr after 25 seconds, where it stabilizes. Meanwhile, Figure 17 presents the vehicle speed at a throttle of 60% with and without brakes, showing that the speed rises to a maximum of 210 km/hr and remains constant at this level for 60 seconds without brakes. However, with the brakes engaged, the speed decreases to 140 km/hr after 25 seconds, where it also stabilizes.

Increasing the throttle percentage results in a greater maximum speed for the vehicle. This aligns with the basic principle of vehicle dynamics, which asserts that the throttle position directly influences engine power output, thereby affecting acceleration and ultimate speed [24]. Impact of Braking: When at 20% throttle, the braking effect prevails, significantly lowering the speed to 25 km/hr, suggesting that the engine output is inadequate to counterbalance the

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braking force. At 40% throttle, braking decreases speed by 80 km/hr (from 170 to 90 km/hr), while at 60% throttle, the reduction is only 70 km/hr. This indicates that a higher throttle input provides more power to partially counteract the braking effect, leading to a quicker post-braking steady speed [25]. Stabilization Behavior: In every scenario, the vehicle's speed stabilizes following braking, demonstrating a consistent control response and system damping. This suggests that the brake system and powertrain function effectively under different throttle conditions [26]. The study highlights the importance of throttle-brake interactions in contemporary vehicle control systems. The results can assist in the development of adaptive cruise control and brake-by-wire systems, which depend on accurate speed modulation in response to varying throttle and braking inputs [27]. The brakes are engaged after 25 seconds. The uniform application duration allows for a controlled comparison, indicating that higher throttle levels lead to increased stabilized speeds post-braking, as engine torque surpasses some of the braking torque. The data clearly indicates that throttle input significantly affects vehicle speed and that elevated throttle levels diminish braking effectiveness due to the rise in engine torque. These findings are in accordance with vehicle dynamics principles and have ramifications for enhancing control strategies in intelligent transportation systems [28][29].

The RBS braking modes transition between one another as braking conditions change. Due to the varying dynamic response characteristics, the braking torque experiences fluctuations during mode transitions, which can impact riding comfort. Consequently, several torque compensation control methods are utilized to enhance driving comfort [30]. Figure 12 illustrates the engine speed at 20% throttle, where the engine speed rises to 2100 rpm, subsequently drops to 1600 rpm, then begins to increase again until it reaches a maximum of 2200 rpm at 35 seconds, followed by a decrease to 1700 rpm, and a slight increase to 1850 rpm at 60 seconds, where it stabilizes at this value without the brakes. However, when the brakes are engaged after 25 seconds, the engine speed begins to decline until it hits 1400 rpm at 45 seconds, then slightly increases to 1600 rpm, followed by a minor decrease to 1450 rpm at 60 seconds, where it ultimately stabilizes. In contrast, when the brakes are applied after 25 seconds, the engine speed experiences a sharp drop, reaching a minimum of 1400 rpm at 45 seconds. This behavior can be attributed to the additional resistive torque exerted by the braking system, which increases the load on the engine. A slight recovery in speed to 1600 rpm is noted, followed by a second decline to 1450 rpm at 60 seconds, where it finally stabilizes. This second decline likely indicates the engine's attempt to rebalance under the continuous braking load and diminished throttle responsiveness. The findings indicate that the feedback control strategy can manage wheel slip more smoothly and reduce braking distance by 7.68% compared to scenarios without compensation. Considering driver intention, research [31] developed an indicator to demonstrate the likelihood of activating the anti-lock braking system. Regenerative Braking can be adjusted based on this indicator to ensure that it remains at a low level when the anti-lock braking system is engaged.

The comparison of both scenarios illustrates that braking has a significant impact on the engine's dynamic response, resulting in more noticeable speed variations and a reduced equilibrium speed during braking. These results underscore the necessity for coordinated control among the throttle, engine torque, and braking systems, especially in intelligent vehicle systems where stability, responsiveness, and energy efficiency are paramount [32]. The examination of engine speed at various throttle positions (20%, 40%, and 60%) both with and without braking uncovers distinct trends that align with basic vehicle dynamics and engine control principles. Figure 15 depicts the engine speed at 40% throttle, where the engine speed rises to 2750 rpm, subsequently drops to 2250 rpm, and then begins to increase until it reaches a peak of 3800 rpm at 60 seconds, stabilizing at this level without braking. However, upon applying the brakes after 25 seconds, the engine speed begins to decline until it hits 2250 rpm at 60 seconds, where it then stabilizes. Figure 18 illustrates the engine speed at 60% throttle, where the engine speed climbs to 3500 rpm, then falls to 2750 rpm, and subsequently increases until it achieves a maximum of 4400 rpm at 60 seconds, stabilizing at this point without the brakes. Conversely, when the brakes are engaged after 25 seconds, the engine speed decreases until it reaches 3000 rpm at 60 seconds, where it then stabilizes.

At 20% throttle, the engine generates relatively low power input, leading to minor variations in engine speed. In the absence of brakes, the engine speed initially oscillates, rising to 2100 rpm, then falling to 1600 rpm, subsequently peaking at 2200 rpm for 35 seconds before decreasing to 1700 rpm and ultimately stabilizing at 1850 rpm after 60 seconds. This fluctuation may have been influenced by slight throttle adjustments and load balancing within the engine control system [33]. When the brakes are engaged after 25 seconds, the engine speed experiences a sharp decline, reaching 1400 rpm by 45 seconds and stabilizing at 1450 rpm, which indicates a more pronounced engine deceleration response due to the braking load. At 40% throttle, the engine accelerates more vigorously, achieving 2750 rpm, briefly dropping to 2250 rpm, and then steadily climbing to a peak of 3800 rpm at 60 seconds when no brakes are applied. This suggests that mid-level throttle input allows the engine to overcome moderate resistance and consistently increase speed. When the brakes are applied at 25 seconds, the engine speed gradually decreases and stabilizes at 2250 rpm after 60 seconds. Although the braking

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effect remains substantial, the enhanced engine output diminishes its relative impact. This pattern aligns with [34] energy balance models, which indicate that net vehicle acceleration is influenced by the interplay between propulsive and resistive forces.

At 20% throttle, the engine generates relatively low power input, leading to minor variations in engine speed. In the absence of brakes, the engine speed initially oscillates, rising to 2100 rpm, then falling to 1600 rpm, subsequently peaking at 2200 rpm for 35 seconds before decreasing to 1700 rpm and ultimately stabilizing at 1850 rpm after 60 seconds. This fluctuation may have been influenced by slight throttle adjustments and load balancing within the engine control system [33]. When the brakes are engaged after 25 seconds, the engine speed experiences a sharp decline, reaching 1400 rpm by 45 seconds and stabilizing at 1450 rpm, which indicates a more pronounced engine deceleration response due to the braking load. At 40% throttle, the engine accelerates more vigorously, achieving 2750 rpm, briefly dropping to 2250 rpm, and then steadily climbing to a peak of 3800 rpm at 60 seconds when no brakes are applied. This suggests that mid-level throttle input allows the engine to overcome moderate resistance and consistently increase speed. When the brakes are applied at 25 seconds, the engine speed gradually decreases and stabilizes at 2250 rpm after 60 seconds. Although the braking effect remains substantial, the enhanced engine output diminishes its relative impact. This pattern aligns with [34] energy balance models, which indicate that net vehicle acceleration is influenced by the interplay between propulsive and resistive forces:

Figure 13 illustrates the torque at 20% throttle both with and without braking, based on the optimization results; the dynamic characteristics of the transmission system have been simulated. As the speed rises, torque diminishes to 100 Nm, which is anticipated under light-load conditions.[33] However, when braking is applied after 25 seconds, torque starts to rise. This increase occurs because the speed decreases due to braking, which in turn lowers engine speed (RPM) and alters the load on the transmission system. The engine responds to this heightened load by generating greater torque to sustain motion or recover from deceleration, as well as to counteract inertia and deceleration forces [35]. At 60 seconds, torque reaches 200 Nm and subsequently stabilizes at this level, indicating that the engine-load balance has been restored under the combined influence of braking and throttle input. The stabilization of torque in transmission systems is crucial for ensuring drivability and energy efficiency [36]. The findings validate that torque control strategies can have a significant impact on vehicle performance during partial throttle and braking scenarios. Adequate torque delivery during braking facilitates smoother deceleration and improves vehicle stability, particularly in advanced powertrain systems that utilize electronic control or regenerative braking [37]. Figure 16 depicts the torque at 40% throttle with and without braking. As speed increases, torque decreases to 190 Nm; however, when braking is applied after 25 seconds, torque begins to rise. This increase is attributed to the reduction in speed caused by braking. At 60 seconds, torque reaches 200 Nm and then stabilizes at this value. Figure 19 presents the torque at 60% throttle with and without braking. As speed increases, torque decreases to 200 Nm, but when breaking is applied after 25 seconds, torque starts to increase. This is due to the reduction in speed resulting from braking. At 60 seconds, torture reaches 250 Nm and subsequently stabilizes at this level.

A similar trend can be noted at 20% throttle (not depicted in the figures but deduced from the data context). The initial torque is likely to be lower than that observed at higher throttle levels, and it tends to decrease with increasing speed due to diminished engine load. When braking is engaged, the vehicle's speed diminishes, leading to a rise in torque as the engine load increases once more. This inverse correlation between torque and speed at partial throttle aligns with the performance curves of engines discussed in internal combustion engine studies [38],[39]. At 40% throttle (Figure 16), torque gradually declines to approximately 190 Nm as speed escalates. This behavior is anticipated, as engine torque diminishes at elevated speeds due to reduced engine load and gear ratios. Upon the application of the brakes, speed begins to fall, increasing torque. This occurs because the engine operates at lower speeds with heightened loads, which leads to an increase in torque. After 60 seconds, torque stabilizes at 200 Nm, signifying a new equilibrium under braking conditions [40],[41]. Likewise, at 60% throttle (Figure 19), the engine initially generates more torque due to a wider throttle position, facilitating greater air/fuel intake. Torque decreases to 200 Nm as speed rises, but rebounds to 250 Nm when breaking is applied. The more significant increase in torque at this throttle level compared to 40% illustrates the engine's heightened responsiveness and the more substantial impact of load variation on torque output [42],[43]. The experimental patterns across all throttle levels exhibit a consistent trend: the speed reduction induced by braking transitions the engine into a more efficient torque generation zone. At low throttle (20%), the torque increase is modest. In contrast, at higher throttle levels (40-60%), the effect is more pronounced, reflecting elevated manifold pressures and enhanced engine load efficiency.

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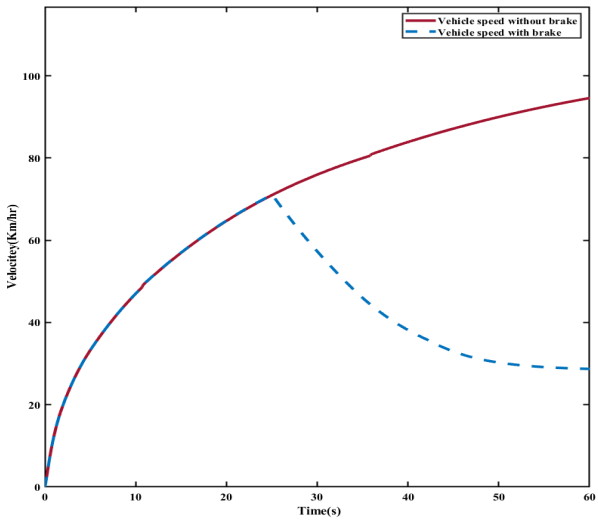


Figure 12 The vehicle speed at a throttle ratio of 20% with and without the brake.

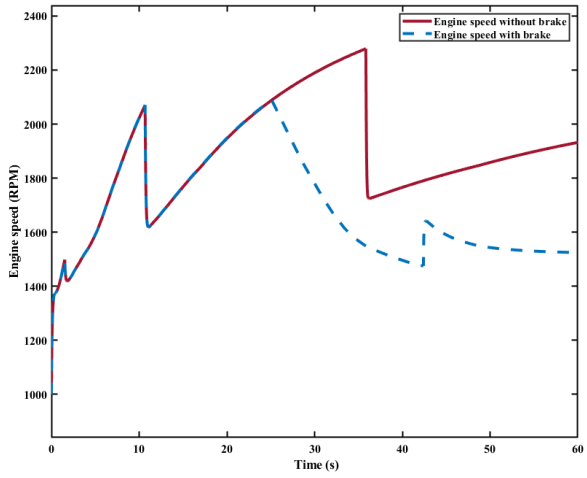


Figure 13 The engine angular speed at a throttle ratio of 20% with and without the brake.

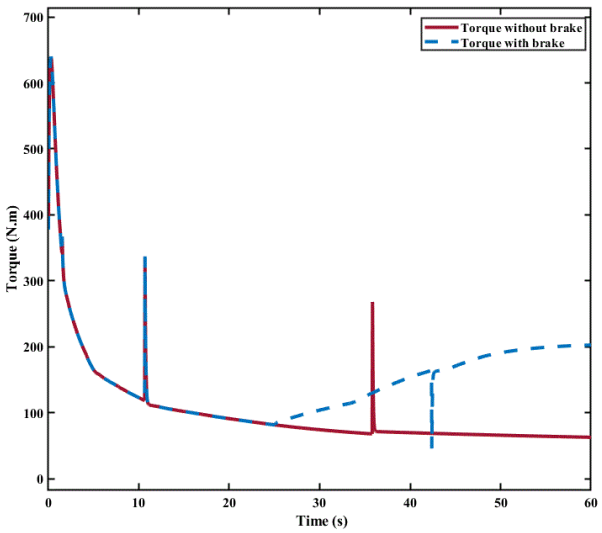


Figure 14 The torque at a throttle ratio of 20% with and without the brake.

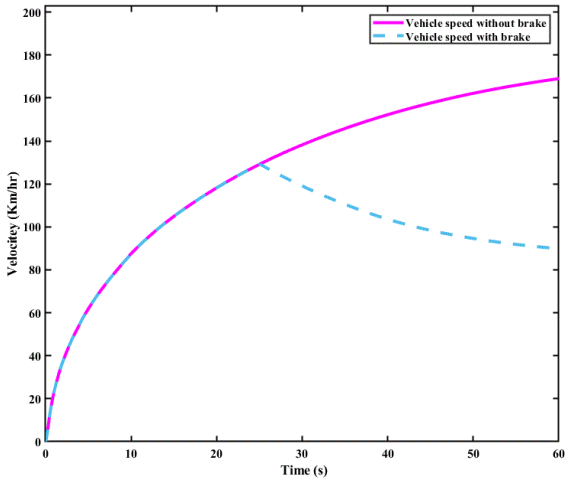


Figure 15 The vehicle speed at a throttle ratio of 40% with and without the brake.

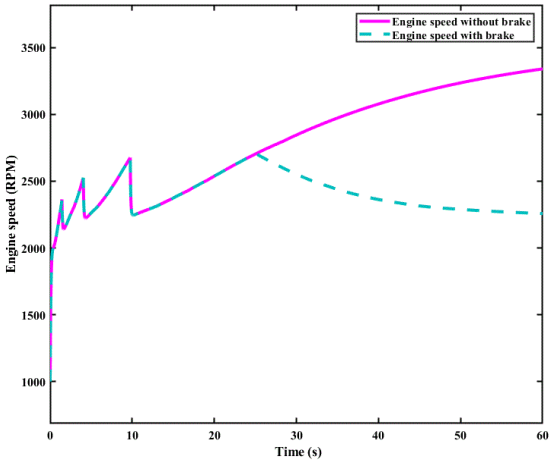


Figure 16 The engine angular speed at a throttle ratio of 40% with and without the brake.

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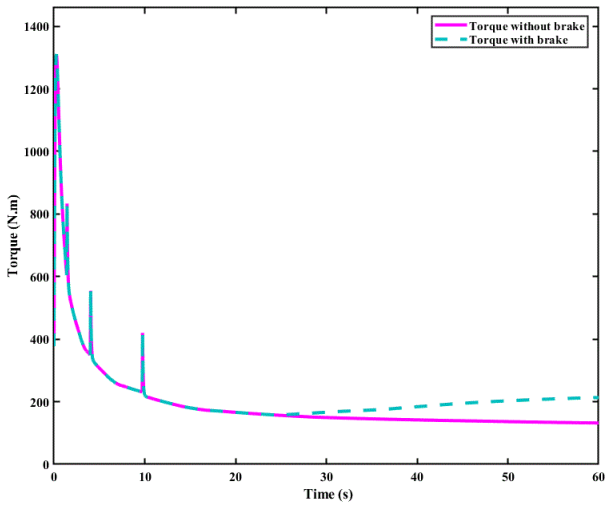


Figure 17 The torque at a throttle ratio of 40% with and without the brake.

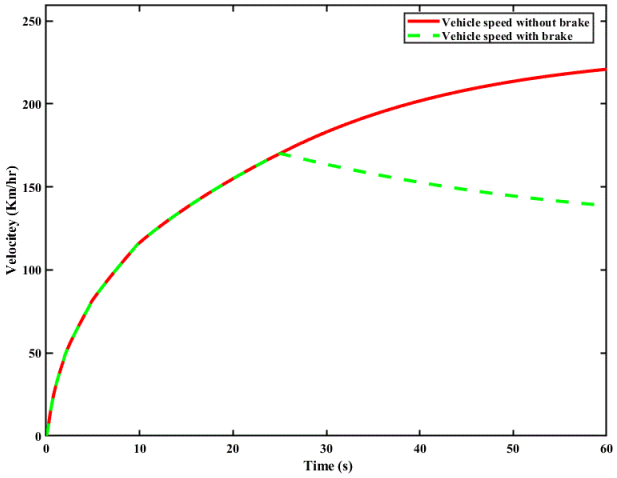


Figure18 The vehicle speed at a throttle ratio of 60% with and without the brake.

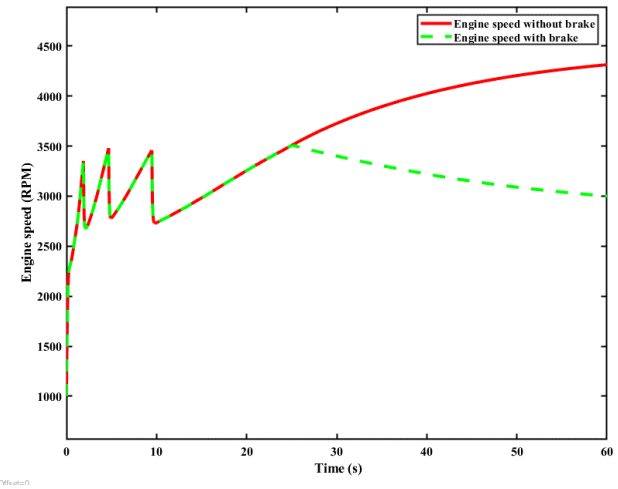


Figure 19 The engine's angular speed at a throttle ratio of 60% with and without the brake

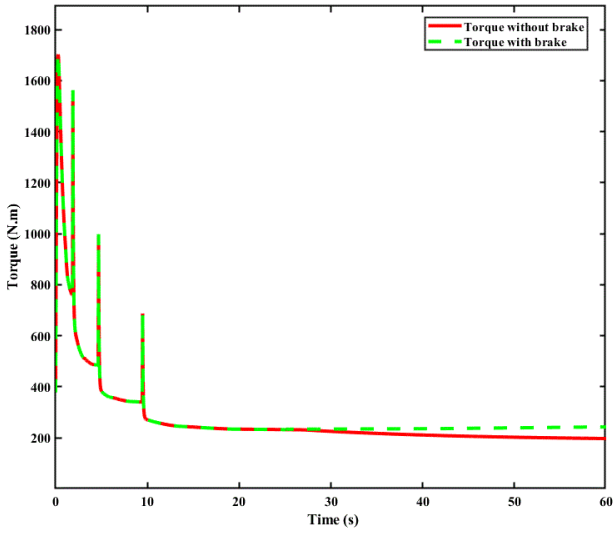


Figure 20 The torque at a throttle ratio of 60% with and without the brake.

5.0 CONCLUSION

For a vehicle to operate efficiently, it depends on a coordinated set of systems, among which the transmission system plays a vital role. The transmission system is responsible for transferring motion and torque from the engine to the wheels, thereby controlling the vehicle's speed and torque. Vehicles typically use one of two types of transmission systems. The first is a conventional (manual) transmission, which requires the driver to manually shift gears to change vehicle speed. The second is the automatic transmission, which adjusts speed by varying the throttle ratio, regulating the amount of air-fuel mixture entering the engine, and eliminating the need for manual gear shifting.

Simulating an automatic transmission system is complex due to the mathematical equations involved in modeling its behavior. For this reason, the MATLAB Simulink environment was utilized to develop a simulation model, leveraging its robust capabilities for system-level modeling and analysis.

The system's performance was evaluated by analyzing vehicle speed, engine speed, and torque at different throttle openings, under both braking and non-braking conditions. The simulation yielded the following results:

- The system demonstrated a high response rate during both acceleration and deceleration, facilitated by the control block.
- At 20% throttle, the vehicle's maximum speed reached 90 km/hr, and the engine speed was 2300 rpm.
- At 40% throttle, the vehicle's maximum speed increased to 170 km/hr, with an engine speed of 3400 rpm.

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- At 60% throttle, the maximum vehicle speed was 230 km/hr, and the engine speed reached 4400 rpm.

The simulation also showed a clear sequence of gear shifts during both acceleration and deceleration. However, it was observed that acceleration is inversely proportional to deceleration.

The innovation of this effort fabricated in the amalgamation of dynamic throttle-based control within a simplified simulation framework, enabling accurate prediction of transmission behavior. These consequences offer appreciated visions for optimizing real-time transmission controllers in current vehicles. Upcoming study will motivation on employing the model in hardware-in-the-loop testing and extending it to hybrid and electric vehicle systems.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

Formal ethical approval was not obtained for this study. However, the authors confirm that the research was conducted in accordance with established ethical principles and good research practices, with due consideration given to participant rights, informed consent, confidentiality, and responsible data handling.

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