Journal of Engineering Issues and Solutions

ABS and Non-ABS Braking Distance Comparison in Four-Wheelers: Simulation and Experimental Study

Lochan Kendra Devkota[1] Dipak Thapa[2], Parash Gurung[3], Chandra P. Dahal[4], Elish Khadka[5], Khem Raj Bhatta[6*]

[1,2,3,4,5]*Department of Automobile and Mechanical engineering, Thapathali Campus, Bagmati, Nepal*
[6]*Department of Civil Engineering, Everest Engineering College, Sanepa, Lalitpur*
[*]*Corresponding Author: khem.raj.bhatta@eemc.edu.np*
Received: May 12, 2026; Revised: 13 June, 2026; Accepted: July 11, 2026

Abstract

Anti-Lock Braking System (ABS) is an important safety feature on vehicles that prevent the skidding during emergency braking and helps improve the stability and braking distance. Numerous studies present how well the ABS maintain the slip around optimal value (i.e. 0.2), using mainly the quarter car model. Existing research lack on providing the full vehicle model with the physical experiment to proof how well ABS reduce the braking distance. This paper researched the braking performance of the ABS and CBS systems under different speed and road condition by means of theoretical modeling and experimental testing. The theoretical modeling was carried out in MATLAB/Simulink and CARSIM, whereas the real car used for experimental validation was a Ford Figo 2014 model driving at the speed of 40, 50 and 60 km/hr. A quarter car model was developed to assess braking performance across different surfaces. The study utilizes PID and Bang-Bang controllers to optimize ABS functionality, ensuring effective braking force modulation. CarSim had used to create real world scenario for testing with the full vehicle model as per the specification of the Ford Figo 2014 model. The simulation and experimental results confirm that the ABS had significantly reduce the braking distance. Simulation results from MATLAB/Simulink using PID controller showed that at 60km/hr, braking distances for an ABS-equipped vehicle were 16.8 m on dry asphalt, 25.13 m on wet asphalt, 17.14 m on dry concrete, and 27.3 m on dry grass. CARSIM showed that at 60 km/h, braking distances for an ABS-equipped vehicle were 17.5 m on dry asphalt, 26.4 m on wet asphalt, 17.47 m on dry concrete, and 28.3 m on dry grass. Experimental tests yielded comparable results, with braking distances recorded as 16.9 m on dry asphalt and 24.4 m on wet asphalt. To sum up, it can be inferred that ABS reduce the braking distance during emergency baking with better precision and stability on wet surface.

Keywords: *Anti-Lock Braking System (ABS), CarSim, Non-ABS, MATLAB/Simulink, Braking Distance*

1. Introduction

Engineering curiosity led to the idea of studying how Anti-lock Braking Systems (ABS) affect braking distances during emergency braking. With a traditional braking system, wheel lock-up can occur, resulting in skidding, loss of steering control, and an increased braking distance. Real-world concerns about road accidents made the study relevant, as braking efficiency is highly concern in preventing accidents**, particularly in Nepal, where road traffic accidents involving four-wheelers have shown a consistent rising trend over the past decade [1]**.

ABS has significantly ameliorated the braking system on a vehicle over slippery surface. Efficient mechanism of preventing the wheel lock helps to maintain the stability of a vehicle during emergency braking **on both dry and wet road surfaces [2]**. Proper functioning of the system includes the seamless performance of each and every part within ABS mechanism. **Within ABS, various research can be conducted on different components and their working mechanisms for better utilization of the vehicle's safety system. Numerous studies have been conducted on ABS, and a portion of the literature relevant to this research is presented here.**

Zulhilmi et al. [3] conducted real-world experiments using a Malaysian sedan, Proton Persona, to analyze vehicle dynamics under emergency braking. Their results showed that ABS significantly improved stopping distances and times across speeds of 30, 50, and 70 km/h, with notable gains at higher speeds. Similarly, Minh et al. [4] developed a real ABS laboratory platform to validate wheel lock prevention under braking. Lorenčič [2] complemented this with a study of tire aging effects, confirming that ABS enhance braking efficiency and road grip on both dry and wet surfaces.

In parallel, simulation-based investigations have been instrumental in optimizing ABS performance. Abdul Majid et al. [5] built a braking model for a Malaysian passenger car, concluding that PI control yielded accurate and responsive performance. Rohilla et al. [6] implemented and compared various classical controllers, determining PID control to be most effective in reducing both stopping time and distance. Aparow et al. [7] and Mirzaeinejad & Mirzaei [8] used detailed vehicle models to simulate ABS behavior, showing improvements in wheel slip regulation and braking torque control. Guo et al. [9] enhanced a sliding mode controller with fuzzy logic, optimizing performance through better slip maintenance.

Comparative studies across diverse road surfaces further clarified the role of controller design in improving ABS. Ulum & Arifianto Patriawan [10] conducted extensive testing on dry/wet asphalt, soil, dirt, and gravel. Their results showed that PID-controlled ABS consistently reduced braking distances compared to non-ABS setups. Xiao et al. [11] and Wafi [12] validated the effectiveness of fuzzy and PID controllers in handling variable surfaces, with PID proving particularly robust on ice and snow. Bhivate [13] reinforced this through simulations showing PID's superiority in stabilizing vehicle dynamics across multiple friction conditions.

More advanced control strategies integrated intelligent algorithms and hybrid systems. Bhuiyan et al. [14], Staputis & Žuraulis [15], and Oudghiri et al. [16] developed and tested fuzzy logic and hybrid fuzzy-sliding controllers, which yielded faster response, better slip control, and reduced vibrations under emergency braking. Geleta et al. [17] used MATLAB/Simulink and CarSim to model full-vehicle dynamics with fuzzy-controlled ABS, validating the system under different road conditions. Their results demonstrated that intelligent controllers could significantly improve braking efficiency and vehicle stability beyond classical designs.

Beside these all, Researchers have addressed broader system-level challenges, such as cybersecurity and coordinated braking control. Kang & Shen [18] developed an ABS attack detection and mitigation strategy using real-time vehicle state estimation, showing resilience against sensor and CAN bus attacks. Zhang et al. [19] proposed a multi-objective control method combining ABS with Active Front Steering (AFS) under low-adhesion conditions using predictive control. El-Bakkouri et al. [20] introduced an adaptive output feedback controller that improved robustness under varying road conditions. Complementary work by Mohebi [21] and Xu et al. [22] highlighted the integration of suspension systems and electric braking technologies to enhance stability, energy recovery, and braking response, advancing the role of ABS in comprehensive vehicle safety systems

Cao et al. [23] laid foundational work by developing a simulation algorithm for an automobile braking system using a single-wheel vehicle model in MATLAB/Simulink. This model included both tire and brake dynamics to compare systems with and without ABS, demonstrating ABS's effectiveness in improving braking performance and vehicle stability. Yadav [24] extended this approach by simulating ABS for a quarter-vehicle model in MATLAB/Simulink. Among the tested controllers, the fuzzy logic controller outperformed the traditional PID controller—reducing stopping distance by approximately 39 meters and maintaining an ideal slip ratio of 0.2, which improved stability.

Shaikh and Singh further reinforced ABS's advantages through full-vehicle simulations with and without ABS in MATLAB/Simulink. Their findings confirmed that ABS improves braking efficiency, reduces stopping time and distance, enhances steering control, and prevents wheel lock, with results strongly influenced by road surface and brake force distribution. Blancas et al. [25] conducted a focused comparison between PID and hysteresis controllers using a quarter-vehicle model. Their results favored the PID controller for quicker stabilization of wheel slip and maintaining optimal slip near 20%, underscoring PID's relevance in modern ABS design. Qasem and Abdullah [26] added depth by comparing PID, bang-bang, and fuzzy logic controllers. Their study concluded that while PID minimized stopping distance, fuzzy logic controllers provided better steerability and slip control, revealing a trade-off between stopping performance and directional stability.

Shah et al. [27] developed an ABS using fuzzy logic (FL) controllers in MATLAB/Simulink and compared it against a bang-bang system. The FL-based ABS offered smoother and quicker braking (10 seconds vs. 12 seconds), improved slip control, and enhanced steerability. The authors also suggested including road slope in future models for more accurate brake force modulation. Rohilla et al. [28] focused on optimizing traditional controllers (P, PI, PD, and PID) using genetic algorithms in a quarter-vehicle ABS model. Among the options, the PID controller performed best with a stopping distance of 42.62 m and stopping time of 2.998 s, offering precise slip control and strong braking stability.

Chen and Shih [29] introduced an adaptive fuzzy-PID ABS controller that incorporated real-time parameter tuning and pulse-width modulation. This system was designed to achieve the highest possible braking force across varying terrains, showcasing adaptability to diverse road conditions. Sahin and Ünlüsoy [30] advanced the controller design by proposing a hybrid fuzzy-PID system that estimated reference slip based on longitudinal acceleration. This controller proved effective under mixed-adhesion conditions, combining the adaptability of fuzzy inference with the precision of PID control to maintain stability during complex maneuvers. Gowda et al. [31] presented an ABS design featuring wheel slip estimation using nonlinear tracking control. Their method was validated with a dynamic pitch model and the Magic Formula tire model, demonstrating high accuracy in slip regulation and minimal braking distances, highlighting the role of detailed tire modeling. Unguritu and Nichițelea [32] improved upon the bang-bang control approach by developing a three-position controller that added a hold state. This modification reduced oscillations and increased system stability, enhancing responsiveness and braking efficiency.

Researchers have conducted the various study on the ABS including the ESC system, PID controller HILS method, longitudinal wheel model, Car tyre model, Burckhardt Friction Model, Bang-Bang control algorithm, adaptive fuzzy fractional order sliding mode control, fuzzy sliding mode control, CAE methods and also used different advanced software such as ADAMS, Fuzzy, MATLAB, Simulink, with prior work also coupling MATLAB/Simulink with CarSim for full-vehicle ABS simulation [17]. However, It was found that there is minimal research available considering the real world scenario of the road and the vehicle, speed and tire road coefficient of friction, including studies specific to Nepalese road surfaces [33]. Most of the reviewed studies also relied on a quarter-car model in MATLAB/Simulink alone, with limited use of full four-wheel vehicle simulation validated against physical testing. This study aims to address the gap by providing a result of vehicle braking distance for an ABS and Non-ABS vehicle (Ford figo 2014) performing both the real-world experiment and the simulation over CarSim for the verification of the result. A key aim is to identify under which conditions ABS yields the most significant benefits and to determine the main parameters influencing the braking distance.

The goal of this study was to model, simulate and experimentally study the braking performance of ABS and Non-ABS Ford Figo 2014 cars under dry and wet conditions at 40, 50 and 60 km/hr. The study was only carried out on one vehicle type, four road surfaces and maximum speed of 60 km/hr and was based on the Burckhardt friction model instead of on a direct friction measurement in situ. The methods and procedures presented here should be further applied to other vehicle types, to other road surfaces (e.g., snow, gravel), and to direct field measurement of the tire-road friction coefficient as a function of wheel speed.

2. Methods and Materials

2.1. Mathematical Modelling

The construction of an antilock braking system starts with the important step of mathematical modeling. Mathematical modeling, with simulation, provides useful information for understanding braking phenomena and the impact of various parameters on braking performance of a vehicle. Vehicle models used include the general vehicle model, four-wheel vehicle model and single-wheel vehicle model. In this research, the mathematical modeling is simplified to a quarter vehicle model.

2.1.1. Quarter Vehicle Dynamics Under Braking

Figure 1 shows a quarter vehicle model's free body diagram which illustrates the vehicle's straight-line motion during braking, so equations of equilibrium can be obtained as follows:

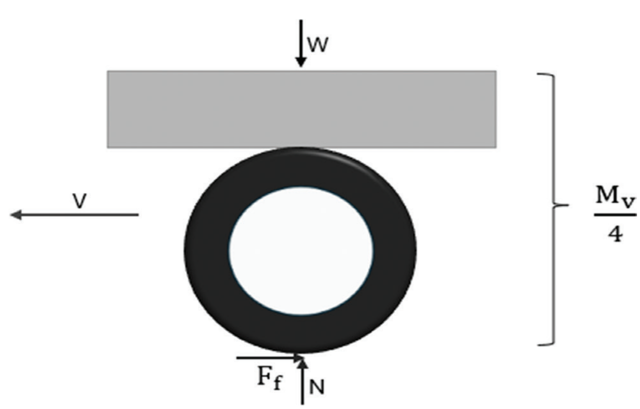

Figure 1: Forces Acting Under Braking of vehicle

By Newton's second law, equation of motion can be written as [26],

$$\mu \times \frac{M_v}{4} \times g = -\frac{Mv}{4} \times a_x \quad (1)$$

$$a_x = -\mu \times g$$

Integrating,

$$V = -\int \mu \times g \times dt \quad (2)$$

Though the vehicle is only translating, linear speed of vehicle can be transformed to angular speed as;

$$\omega = -\frac{\int \mu \times g \times dt}{r} \quad (3)$$

Hence, once the coefficient of friction is known, the speed of vehicle gives by above equations (3).

2.1.2. Stopping Distance Calculation

Simple and fundamental relationships can be derived for the case where it is reasonable to assume that the forces acting on the vehicle will be constant throughout a brake application. The simple equations that result provide an appreciation for the basic relationships that govern braking maneuvers.

$$D_x = \frac{F_{xt}}{M} = -\frac{dV}{dt} \quad (4)$$

Where:

F_{xt} = Longitudinal deceleration forces on the vehicle/Frictional force

V = Forward Velocity

This equation can be integrated for a deceleration from initial velocity, V0, to final velocity, Vf

$$\int_{V_0}^{V_f} dV = -\frac{F_{xt}}{M}\int_0^{t_s} dt$$

$$V_0 - V_f = \frac{F_{st}}{M} t_s \quad (5)$$

ts = Time for the velocity change

Because velocity and distance are related by V = dx/dt, this can be substituted for 'dt' in above equation and integrate, and obtain the relationship between velocity and distance:

$$\frac{V_0^2 - V_f^2}{2} = \frac{F_{xt}}{M} x \quad (6)$$

X = Distance travelled during the deceleration

In the case where the deceleration is a full stop, then Vf is zero, and X is the stopping distance, SD, then;

$$SD = \frac{V_0^2}{2\frac{F_{xt}}{M}} = \frac{V_0^2}{2\frac{\mu * M * g}{M}} = \frac{V_0^2}{2\mu g} \quad (7)$$

And the time to stop is:

$$t_s = \frac{V_0}{\mu g} \quad (8)$$

Thus, all other things being equal, the time to stop is proportional to the velocity, whereas the distance is proportional to the velocity square.

2.1.2. Estimation of coefficient of friction based on slip ratio

To calculate the frictional force between tire and road surface, coefficient of friction is required which varies with slip ratio and different types of road conditions such as dry, wet, snowy etc. Hence, in this study, Burck-Hardt model (1993) is used due to its better accuracy [27].

$$\mu(\lambda) = C1(1 - e^{-C2\times\lambda}) - C3 \times \lambda \quad (9)$$

Where C1, C2 and C3 are constants dependent on the state of the surface. **Table 1** shows the characteristic parameters according to the type of road.

Table 1: Parameters of Burck-Hardt Formula for Different Surfaces

Surface	C_1	C_2	C_3
Dry Asphalt	1.28	23.99	0.52
Dry Concrete	1.19	25.17	0.54
Wet Asphalt	0.86	33.82	0.35

2.2. Simulation in MATLAB/Simulink and CarSim

2.2.1. Matlab/Simulink

Based on above mathematical modelling and using PID and Bang-Bang controllers, Simulink models was developed in Matlab. This study aims to develop a quarter vehicle model that maintains target slip ratios by implementing PID and Bang-Bang controllers.

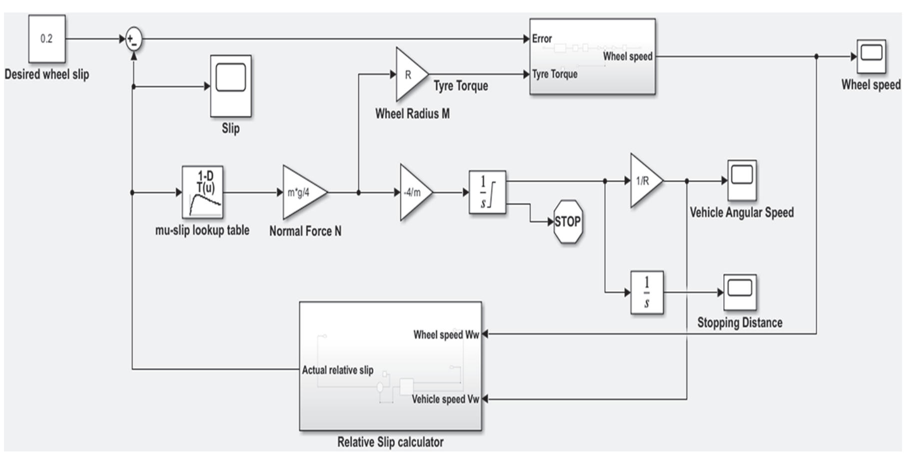

Figure 2: Simulink Model of ABS Controller

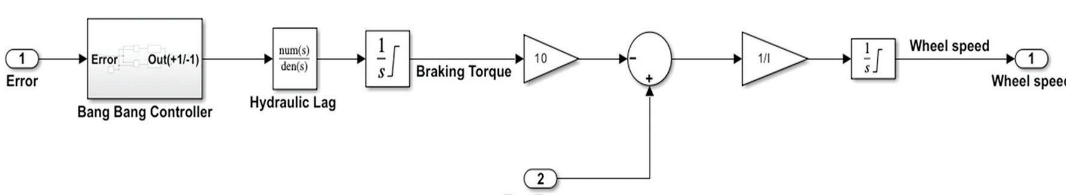

Figure 3: Simulink model of wheel speed

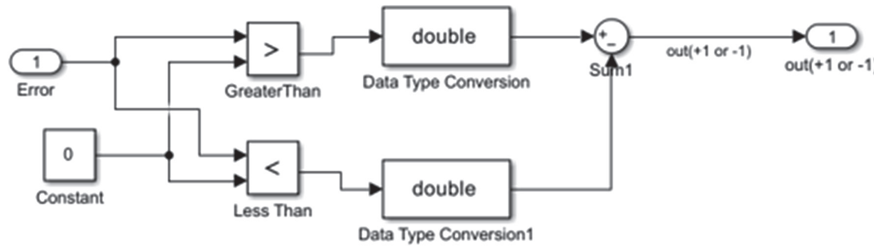

Figure 4: Bang Bang Controller

Figure 5: PID Controller

2.2.2. CarSim

CarSim program makes it possible to predict and study the dynamic behavior of a vehicle (tire-wheel interaction, suspension-chassis, etc.) in different situations, in response to a series of inputs such as the technical characteristics of the vehicle or the environment. It helps to simulate the full body real vehicle as of the experiment in vehicle (i.e. Ford figo 2014).

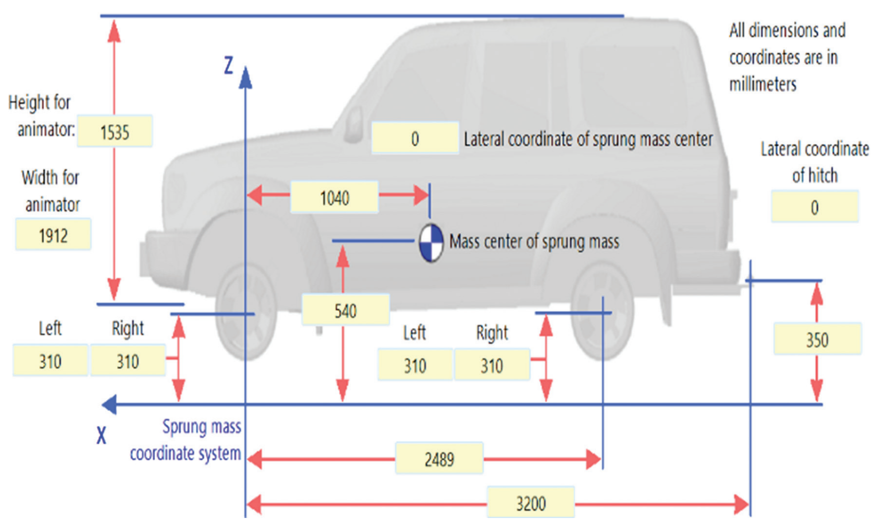

Figure 6: Carsim

2.3. Experimental Testing

2.3.1. Description of the vehicle

All the measurements carried out refer to Ford figo 2014 model equipped with a 1200 cc, 16-valve petrol engine with 68 hp of power. The car in question is a mid-class hatchback with a wheelbase of **2489 mm** and a total curb weight of **1040 kg**. The standard tires used for the tests are 175/65 R14T both at the front and at the rear.

Table 2: Test Vehicle Specification

Parameter	Specification
Engine	1.2-Liter Duratec Petrol Engine
Transmission	5-Speed Manual
Configuration	4-Cylinder, 16-Valve
Kerb Weight	1040 kg
Wheel Base	2489 mm
Radius of Wheel	292 mm
Tire	175/65 R14T

2.3.2. Test Procedure

The braking distance was obtained by means of a measuring tape with the braking point on the road marked with a chalk marker prior to each trial. Three tests were run at each speed and road surface condition with the results averaged for each. The tests have been conducted at Pulchowk Engineering Campus, Nepal. To begin with, dry-surface trials were conducted on the natural (dry) pavement. Water was then poured over the test section immediately before each wet trial to provide wet surface conditions on the same test section. Non-ABS testing included removing the ABS fuse from the vehicle's fuse box, but no other changes to the braking system.

Field instrumentation was not used to directly measure the friction of the road surface. The coefficient of friction for each surface type was instead described by the standard Burckhardt friction model parameters (Table 1) which is frequently used when direct field measurement devices like a British Pendulum Tester or a towed friction trailer are not available in braking distance studies. The values are recommended for further validation under Nepalese road conditions using the direct in-situ friction measurement in future.

3. Results and Discussion

3.1. Matlab Simulation Result

The simulation result was provided for asphalt, grass, concrete for both wet and dry condition. The graph indicates that as the friction coefficient reduces due to road condition the braking time and brake distance increases and the same is true for speed.

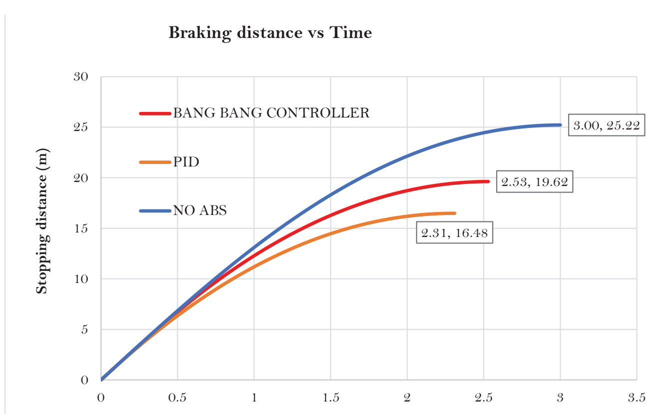

Figure 7: Braking Distance

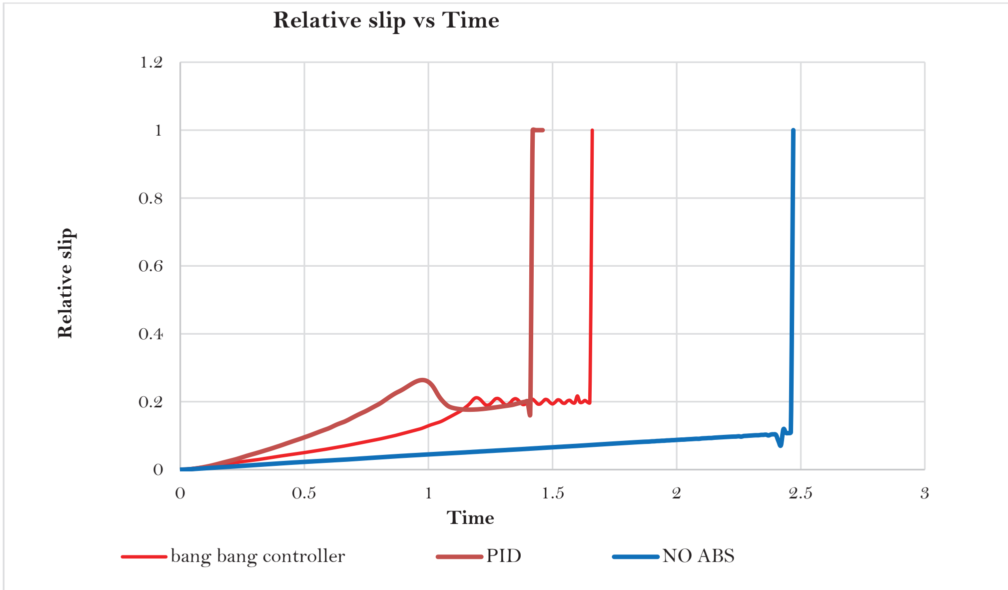

Figure 8: Relative Slip

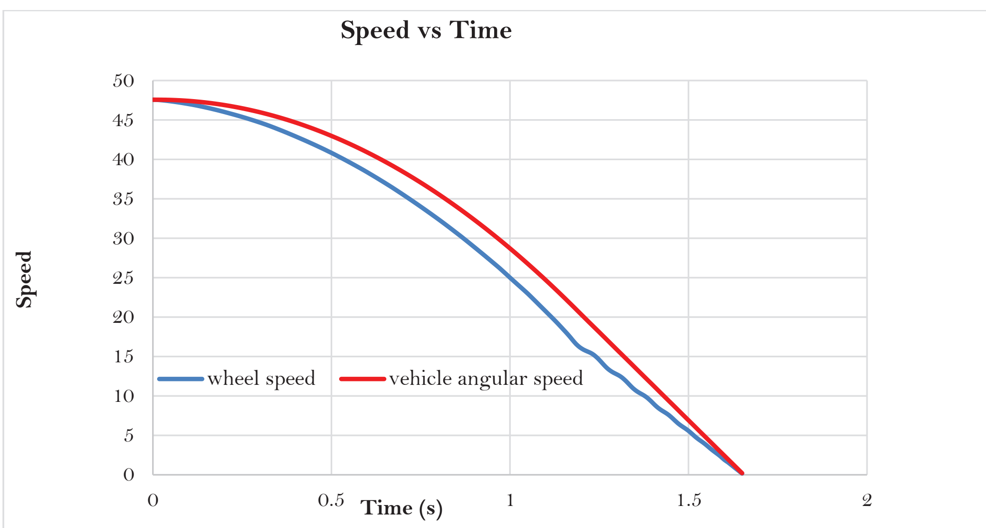

Figure 9: Velocity

The result demonstrate that the purpose of the ABS controller is to maintain slip ratio as near as possible to the value of 0.2, as shown in Figure 8. The respected figure show that the PID is the one that first achieve the required slip followed by bang bang controller and no controller mechanism.

It is notable the vehicle (running at the speed of 50 km/hr on wet asphalt) comes to a stop at 16.48, 19.62 and 25.22 meters taking 2.31, 2.53 and 3.00 seconds respectively as shown in Fig 7. It indicates PID controller work best for reducing the braking distance. With that, as shown in Fig 9 a velocity graph for both Vehicle and wheel had founded, and illustrate that both the velocity curves merge at a point when the vehicle is stopped, which ensures the vehicle stops without skidding.

3.2. CarSim Simulation Result

The ABS model of the CarSim indicate the full vehicle simulation, with the virtual scenario of the different types of roads as per the physical experiment.

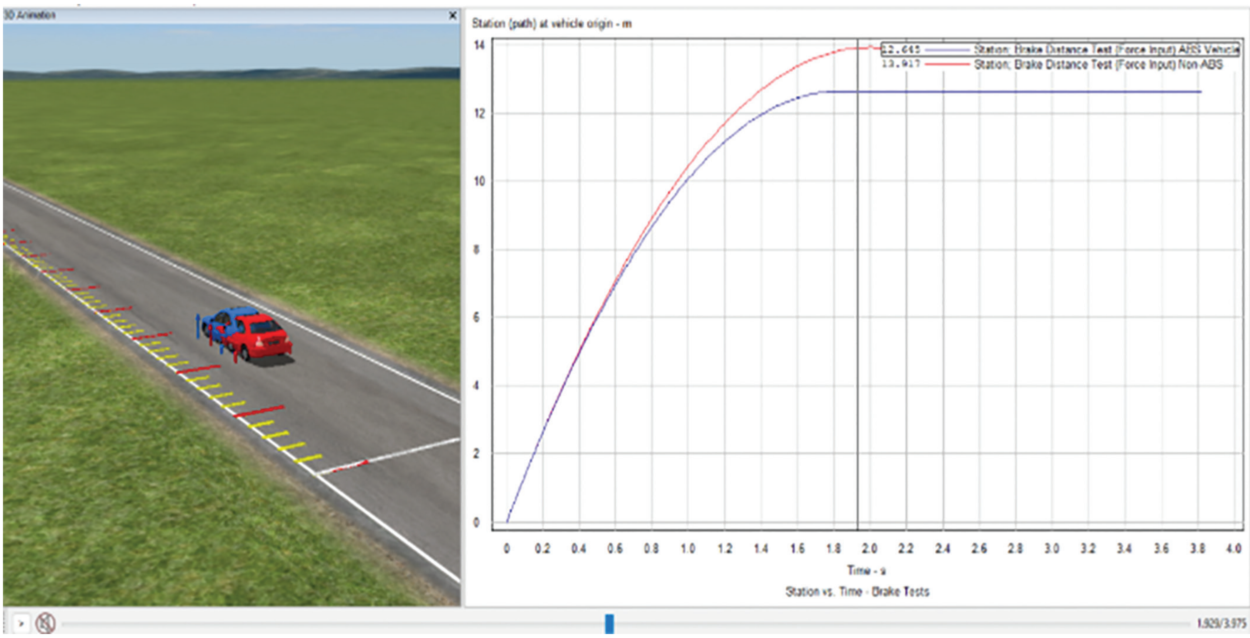

Figure 10: Braking Distance

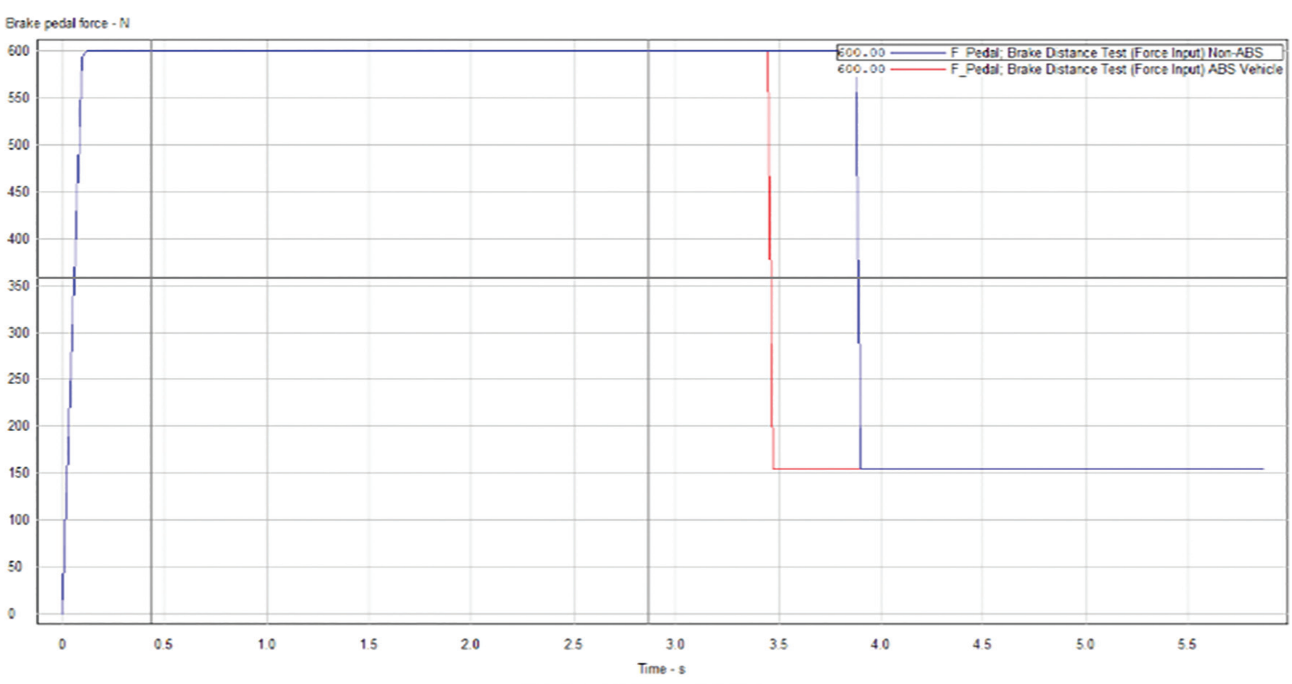

Figure 11: Pedal Force

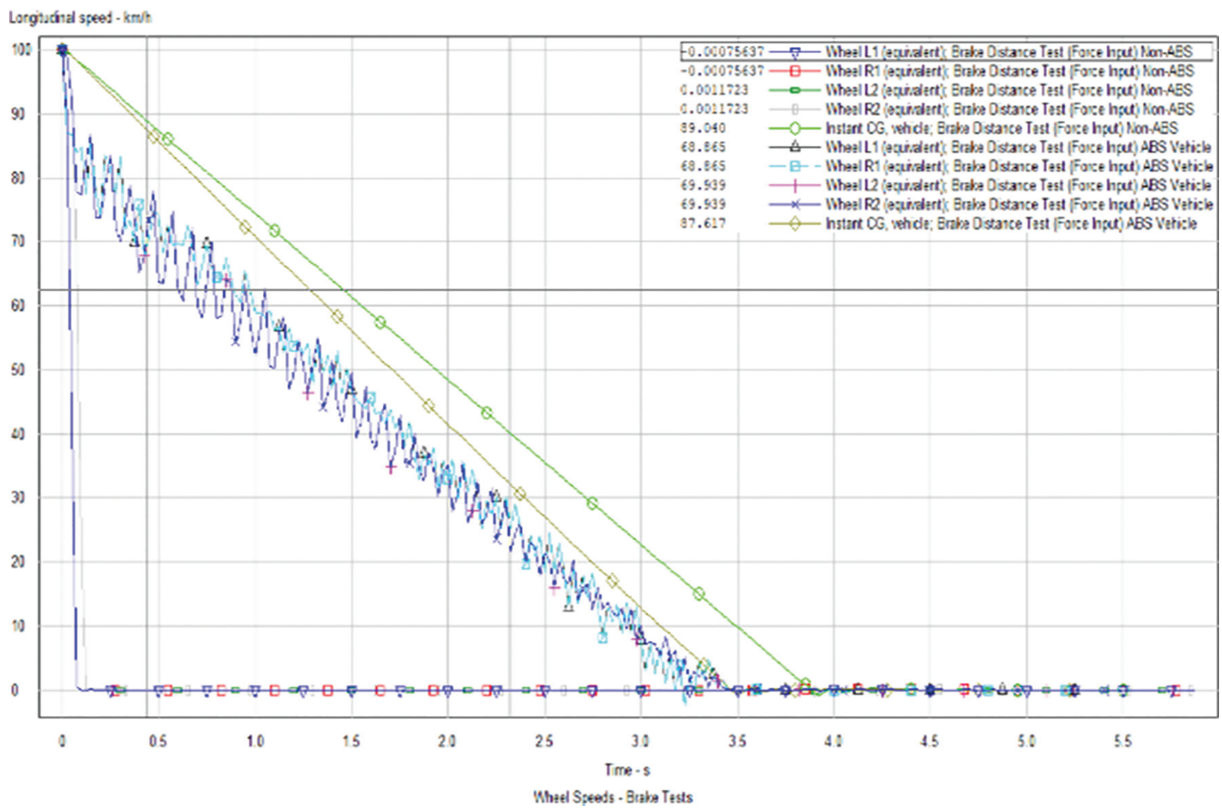

Figure 12: Velocity

The pedal force is considered to be 600N as shown in Figure 11 that remain constant throughout the experiment under different speed of the vehicle. The sudden drop of the speed is after the stop of the vehicle. Different velocity of rear and front tire is illustrated in Fig 12 with the sudden drop of the velocity for the Non-ABS and gradual drop with wave like pattern for the ABS vehicle.

Table 3: Matlab Result For Braking Distance

Surfaces	Speeds (km/hr)	Braking Distance (m)		
		Bang-bang	PID	Non-ABS
Dry Asphalt	40	10.55	8.63	15.79
	50	14.87	12.36	22.23
	60	19.75	15.74	27.43
Wet Asphalt	40	13.16	10.66	17.49
	50	19.62	16.48	25.22
	60	27.33	23.55	34.17
Dry Concrete	40	8.26	7.24	12.26
	50	12.22	10.87	17.46
	60	16.78	15.24	23.60
Dry Grass	40	12.5	12.5	17.54
	50	15.21	20.48	22.59
	60	21.4	27.3	35.27

Table 4: Carsim Result For The Braking Distance

Surfaces	Speeds km/hr	ABS		No ABS	
		Braking distance (m)	time (sec)	Braking distance (m)	time (sec)
Dry asphalt	40	8.5	1.45	9.3	1.53
	50	12.6	1.75	13.9	1.86
	60	17.5	2.21	19.3	2.34
Wet asphalt	40	11.9	1.95	13.4	1.75
	50	18.4	2.46	19.8	2.41
	60	26.4	3.24	28.5	3.67
Dry concrete	40	8.16	1.35	8.94	1.48
	50	12.2	1.67	13.46	1.39
	60	17.47	2.29	19.34	2.32
Dry grass	40	13.4	1.98	15.5	2.01
	50	21.7	3.01	23.8	3.21
	60	28.3	3.42	34.7	3.87

Table 5: Experimental Result

Surfaces	Speeds km/hr	ABS		No ABS	
		Braking distance (m)	time (sec)	Braking distance (m)	time (sec)
Dry asphalt	40	8.1	1.4	9	1.54
	50	11.8	1.65	13.2	1.76
	60	16.9	2.12	18.9	2.23
Wet asphalt	40	11.7	1.62	14.2	1.89
	50	17.4	2.32	22.8	2.86
	60	24.4	3.14	32.5	3.59

3.3. Validation of Simulation Results Against Experimental Data

The MATLAB (PID controller) and CarSim (ABS) braking distances were compared to the experimental ones for dry and wet asphalt at speed of 40 km/hr, 50 km/hr, and 60 km/hr; only experimental braking distances have been available for these speeds.

Table 6: Validation of Simulation Results Against Experimental Data

Surface	Speed (km/hr)	MATLAB PID (m)	CarSim ABS (m)	Experimental (m)	% Error (MATLAB)	% Error (CarSim)
Dry Asphalt	40	8.63	8.5	8.1	6.54%	4.94%
Dry Asphalt	50	12.36	12.6	11.8	4.75%	6.78%
Dry Asphalt	60	15.74	17.5	16.9	6.86%	3.55%
Wet Asphalt	40	10.66	11.9	11.7	8.89%	1.71%
Wet Asphalt	50	16.48	18.4	17.4	5.29%	5.75%
Wet Asphalt	60	23.55	26.4	24.4	3.48%	8.20%

The percentage error between the experimental results and the MATLAB simulation was between 3.48% to 8.89% with an average percentage error of 5.97%, while the percentage error between the experimental and CarSim results was between 1.71% to 8.20% with an average of 5.15%. The differences were explained with the fact that, in both MATLAB and CarSim, the friction coefficient as a function of pedal effort was assumed to be constant, and that the road surface irregularities during the physical testing were not fully represented. The modeling approach was considered as valid as the simulation results matched the experimental results well, with an average error lower than 6%.

4. Conclusion

The test outcomes shown a significant increase in braking effectiveness when applying the ABS, no matter the surface of the road, be dry or wet, grass or concrete.

After analyzing the data collected during the MATLAB simulations, CARSIM simulation, and experimental testing, the following conclusions were drawn:

1. A Simulink model of ABS and Non-ABS braking systems in MATLAB was made and the PID controller showed the shortest braking distance with minimum braking time compared to both the Bang-Bang controller and NON-ABS.

2. Experimental testing was done and it was found that ABS-equipped vehicles consistently achieve shorter and more controlled braking distances, particularly on low-friction surfaces like wet asphalt and grass. In contrast, non-ABS vehicles tend to experience wheel lock-up, leading to longer braking distances and reduced steering control. The experimental results closely align with the Simulink simulations, validating the effectiveness of ABS in enhancing vehicle safety with a relative error of 0.09% (MATLAB) and 1.62% (CARSIM).

3. After the simulation was done the key parameters that influence the braking performance were identified, including tire-road friction coefficient, initial velocity, braking force, moment of inertia, and wheel slip.

Conflicts of Interest

The authors declare that they have no conflict of interest that appeared to influence the work reported in this paper.

Funding Statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgement

The authors would like to thank to all staffs and faculty member of Department of Automobile and Mechanical Engineering, Thapathali Campus, Thapathali , Nepal.

Reference

A. Atreya, D. B. Shrestha, P. Budhathoki, and S. Nepal, "Epidemiology of road traffic accidents in Nepal from 2009/10 to 2019/20: A 10 year study," Journal of Nepal Health Research Council, vol. 19, no. 2, pp. 343–348, 2021, doi: 10.33314/jnhrc.v19i2.3432.

V. Lorenčič, "The Effect of Tire Age and Anti-Lock Braking System on the Coefficient of Friction and Braking Distance," *Sustainability (Switzerland)*, vol. 15, no. 8, Apr. 2023, doi: 10.3390/su15086945.

I. M. Zulhilmi, P. M. Heerwan, R. I. M. Eiman, I. M. Izhar, and S. M. Asyraf, "Investigation on vehicle dynamic behaviour during emergency braking at different speed," *International Journal of Automotive and Mechanical Engineering*, vol. 16, no. 1, 2019, doi: 10.15282/ijame.16.1.2019.6.0468.

V. T. Minh, G. Oamen, K. Vassiljeva, and L. Teder, "Development of Anti-lock Braking System (ABS) for Vehicles Braking," *Open Engineering*, vol. 6, no. 1, 2016, doi: 10.1515/eng-2016-0078.

M. M. Abdul Majid, S. A. Abu Bakar, S. Mansor, M. K. Abdul Hamid, and N. H. Ismail, "Modelling and PID Value Search for Antilock Braking System (ABS) of a Passenger Vehicle," *Journal of the Society of Automotive Engineers Malaysia*, vol. 1, no. 3, 2021, doi: 10.56381/jsaem.v1i3.57.

P. Rohilla and A. Dhingra, "Design and Analysis of Controller for Antilock Braking System in Matlab/Simulation." [Online]. Available: http://www.ijert.org

V. R. Aparow, F. Ahmad, K. Hudha, and H. Jamaluddin, "Modelling and PID control of antilock braking system with wheel slip reduction to improve braking performance," *Int J Veh Saf*, vol. 6, no. 3, pp. 265–296, Jan. 2013, doi: 10.1504/IJVS.2013.055025.

H. Mirzaeinejad and M. Mirzaei, "A novel method for non-linear control of wheel slip in anti-lock braking systems," *Control Eng Pract*, vol. 18, no. 8, 2010, doi: 10.1016/j.conengprac.2010.03.015.

J. Guo, X. Jian, and G. Lin, "Performance evaluation of an anti-lock braking system for electric vehicles with a fuzzy sliding mode controller," *Energies (Basel)*, vol. 7, no. 10, 2014, doi: 10.3390/en7106459.

M. Ulum and D. Arifianto Patriawan, "Modeling and Performance Testing of Anti-Lock Braking System (ABS) with Variation of Road Friction Coefficient to Braking Distance," *Rekayasa*, vol. 15, no. 3, 2022, doi: 10.21107/rekayasa.v15i3.16561.

L. Xiao, L. Hongqin, and W. Jianzhen, "Modeling and Simulation of Anti-lock Braking System based on Fuzzy Control," *IARJSET*, vol. 3, no. 10, pp. 110–113, Oct. 2016, doi: 10.17148/iarjset.2016.31021.

M. Wafi, "Modeling and Simulation of ABS through Different Types of Controllers Using Simulink."

P. B. Bhivate, "MODELLING & DEVELOPMENT OF ANTILOCK BRAKING SYSTEM."

M. Mazharul Islam Bhuiyan, M. Mamnun Rayhan, M. Uddin Khan, and M. Hasan Emon, "Comparative Analysis of Fuzzy Logic and Bang-Bang PID Controller Based on Anti-lock Braking Systems." [Online]. Available: https://ssrn.com/abstract=4603403

A. Staputis and V. Žuraulis, "Research of Efficiency of Anti-lock Braking System During Emergency Cornering Manoeuver," in *Lecture Notes in Intelligent Transportation and Infrastructure*, vol. Part F1379, Springer Nature, 2023, pp. 224–235. doi: 10.1007/978-3-031-25863-3_21.

M. Oudghiri, M. Chadli, M. Oudghiri, and A. El Hajjaji, "Robust fuzzy sliding mode control for antilock braking system," 2007. [Online]. Available: https://www.researchgate.net/publication/228639576

A. F. Geleta, M. Gopal, and M. T. Lemi, "Vehicle anti-lock brake system - dynamic modeling and simulation based on MATLAB Simulink and CarSim," *Research on Engineering Structures and Materials*, vol. 10, no. 2, pp. 495–511, Jun. 2024, doi: 10.17515/resm2023.22me0601rs.

L. Kang and H. Shen, "Detection and Mitigation of Sensor and CAN Bus Attacks in Vehicle Anti-Lock Braking Systems," *ACM Transactions on Cyber-Physical Systems*, vol. 6, no. 1, 2022, doi: 10.1145/3495534.

N. Zhang, J. Wang, Z. Li, S. Li, and H. Ding, "Multi-Agent-Based Coordinated Control of ABS and AFS for Distributed Drive Electric Vehicles," *Energies (Basel)*, vol. 15, no. 5, 2022, doi: 10.3390/en15051919.

J. El-bakkouri, H. Ouadi, F. Giri, and A. Saad, "Optimal control for anti-lock braking system: Output feedback adaptive controller design and processor in the loop validation test," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 237, no. 14, pp. 3465–3477, Dec. 2022, doi: 10.1177/09544070221140938.

J. Mohebi, "Full Car Model Dynamics with Anti-lock Brake system," 2020. [Online]. Available: https://www.researchgate.net/publication/349768073

Q. Xu, C. Zhou, H. Huang, and X. Zhang, "Research on the coordinated control of regenerative braking system and abs in hybrid electric vehicle based on composite structure motor," *Electronics (Switzerland)*, vol. 10, no. 3, 2021, doi: 10.3390/electronics10030223.

F. Cao, C. Chen, and L. Zhou, "Research on Simulation of Anti-lock Braking System Based on MATLAB," 2018.

D. K. Yadav, "MODELING AN INTELLIGENT CONTROLLER FOR ANTI-LOCK BRAKING SYSTEM." [Online]. Available: www.ijtra.com

A. P. Blancas1, A. L. Galicia2, and M. E. Leal, "Simulation and Comparison of a PID Controller for an Anti-Lock Braking System," *International Journal of Science and Research*, 2018, doi: 10.21275/ART20201140.

G. A. A. Qasem and M. F. Abdullah, "Anti-Lock Braking Systems: A Comparative Study of Control Strategies and Their Impact on Vehicle Safety," *International Research Journal of Innovations in Engineering and Technology*, vol. 08, no. 09, pp. 131–143, 2024, doi: 10.47001/IRJIET/2024.809016.

P. Shah, S. K. Labh, and S. P. Adhikari, "Study on Performance of Vehicle Anti-lock Braking System with Fuzzy Logic controller in Matlab/Simulink," *International Journal of Scientific Research and Engineering Development*, vol. 3, [Online]. Available: www.ijsred.com

Pradeep Rohilla, Jitender, Amit, and Akshay Dhingra, "Design and Analysis of Controller for Antilock Braking System in Matlab/Simulation," *International Journal of Engineering Research and*, vol. V5, no. 04, 2016, doi: 10.17577/ijertv5is041074.

C.-K. Chen and M.-C. Shih, "PID-Type Fuzzy Control for Anti-Lock Brake Systems with Parameter Adaptation *."

M. Sahin and Y. S. Ünlüsoy, "Design and simulation of an ABS for an integrated active safety system for road vehicles."

V. D. Gowda, M. Ramesha, S. B. Sridhara, G. N. Pai, and S. K. Patil, "Design of Antilock Braking System Based on Wheel Slip Estimation," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Dec. 2020. doi: 10.1088/1742-6596/1706/1/012216.

M.-G. Unguritu, T.-C. Nichit¸elea, and N. Nichit¸elea, "Design and Assessment of an Anti-lock Braking System Controller," 2023.

C. S. Negi, R. Khadka, and B. Pant, "Evaluation of flexible pavement friction coefficients: A case study of East-West Highway near Mahendranagar City, Nepal," Journal of Engineering Technology and Planning, vol. 5, no. 1, pp. 38–48, 2024, doi: 10.3126/joetp.v5i1.69694