**A Study on Performance Parameters Associated with the Effectiveness of Antilock Braking System on Rough Roads**:

**Link**: [SpringerLink](https://link.springer.com/chapter/10.1007/978-981-10-6328-2_4)

**Methodology**: This study analyzes the performance of the Anti-lock Braking System (ABS) when a vehicle is driven on rough road surfaces. The primary focus is to understand how the system responds under non-ideal conditions, such as uneven terrain, gravel, or pothole-filled roads. The methodology involves investigating how certain key parameters—namely wheel speed fluctuations, tire characteristics, and suspension system dynamics—affect ABS operation and braking performance. Wheel speed sensors play a crucial role in ABS functionality, and on rough roads, rapid up-and-down motion of the wheels can lead to frequent speed fluctuations. These fluctuations are analyzed to assess how accurately the ABS can detect and respond to potential wheel lock conditions without being misled by temporary changes caused by bumps or dips.

**Novelty:** The novelty of this study lies in its focused investigation of the challenges faced by Anti-lock Braking Systems (ABS) on rough and uneven terrains, which are often overlooked in conventional ABS research. While most ABS studies emphasize performance on ideal or moderately slippery surfaces such as wet or icy roads, this work highlights a critical gap by exploring how rough road conditions—such as gravel, potholes, or unpaved surfaces—can degrade ABS effectiveness. These surfaces introduce unpredictable variations in wheel-road contact, friction levels, and wheel loading, all of which can significantly affect ABS functionality. The study provides new insights into how wheel speed fluctuations caused by terrain irregularities can lead to false lock detection, resulting in incorrect modulation of brake pressure.

**Evaluation Metrics**: The ABS performance on rough roads is evaluated using key metrics. **Braking distance** indicates how terrain affects stopping efficiency. **Slip ratio** shows how well the ABS maintains traction, while **wheel speed fluctuations** help detect false lock-up signals. **Brake pressure modulation** assesses ABS response accuracy, and **vehicle stability** is checked using yaw rate and lateral movement during braking.

**An Exploration-Exploitation Approach to Anti-lock Brake Systems:**

**Link**: [arXiv](https://arxiv.org/abs/2306.14730)

**Methodology:**

This study introduces a Dual Control for Exploration-Exploitation (DCEE) approach to improve the estimation of vehicle states and road surface parameters under uncertain and dynamic driving conditions. The methodology leverages a **Regularized Particle Filter (RPF)**, which combines Bayesian filtering with particle resampling and smoothing techniques, to estimate hidden states such as tire-road friction, vehicle velocity, and slip ratio in real-time. The DCEE framework is designed to balance **exploration** (gathering new information about road conditions) and **exploitation** (using current knowledge to optimize braking performance), making the control system adaptive to both known and unknown road surfaces.

**Novelty:**

This work uniquely combines advanced state estimation with ABS control to improve braking performance. It uses a Regularized Particle Filter to dynamically estimate vehicle states and road conditions in real time. By integrating this with a Dual Control for Exploration-Exploitation approach, the system adapts brake force application based on changing terrains. This enables better stability, shorter stopping distances, and enhanced safety compared to traditional ABS methods that rely on fixed assumptions. The seamless fusion of estimation and control makes the ABS more effective on rough and slippery roads.

**Evaluation Metrics:**

The evaluation primarily measures improvements in stopping time and stopping distance, which are critical for vehicle safety. Stopping distance refers to how far the vehicle travels from the moment brakes are applied until it comes to a complete stop, while stopping time measures how quickly this process occurs. By reducing both metrics, the braking system demonstrates its effectiveness in responding promptly and efficiently to driver input. These improvements are especially important on rough or slippery roads, where maintaining control during emergency braking is challenging.

**A Fuzzy-based Sliding Mode Control Approach for Acceleration Slip Regulation of Battery Electric Vehicle:**

**Link:** <https://cjme.springeropen.com/articles/10.1186/s10033-022-00729-w>

**Methodology:**

Tire-road interaction using a tire model like the Burckhardt model. It develops a fuzzy sliding mode controller that combines the robustness of sliding mode control with the adaptability of fuzzy logic. The controller adjusts its parameters in real time based on sensor feedback to maintain optimal slip ratio, improving traction and stability on various road surfaces. Simulations on dry, wet, and icy roads evaluate braking performance through metrics such as slip ratio control, response time, and stopping distance. The results are compared with conventional ABS to demonstrate enhanced braking performance in electric vehicles.

**Novelty:**

The paper introduces a novel method combining fuzzy logic with sliding mode control to regulate acceleration slip in battery electric vehicles. This integration addresses challenges faced by traditional controllers under varying road conditions by providing adaptive and robust control. The approach dynamically adjusts to changes in road friction and vehicle behavior, improving stability and safety. It is especially suited for electric vehicles, which require precise slip control due to their unique torque delivery. Overall, this method enhances vehicle traction, energy efficiency, and safety on difficult road surfaces.

**Evaluation Metrics:**

The evaluation focuses on braking performance under various road conditions by measuring slip ratio, response time, and vehicle stability. Slip ratio indicates how well traction is maintained, while response time shows the controller’s adaptability. Stability is assessed through vehicle dynamics to ensure safe handling. These metrics together demonstrate the controller’s ability to enhance braking safety and performance in different environments.

**Enhanced Performance and Robustness in Anti-lock Brake Systems Using Barrier Function-Based Integral Sliding Mode Control:**

Link: <https://doaj.org/article/9d10f946f261453b914aa69e6d9ce17f>

**Methodology:** The paper proposes an advanced Anti-lock Braking System (ABS) control strategy using a **Barrier Function-Based Integral Sliding Mode Control (BF-ISMC)**. The methodology starts by modeling the vehicle’s braking dynamics, including tire-road interactions and the slip ratio behavior. To maintain optimal braking performance, the BF-ISMC is designed to regulate the slip ratio while compensating for external disturbances such as varying road friction and vehicle inertia uncertainties. The barrier function ensures the slip ratio remains within safe bounds by preventing it from exceeding critical limits, thereby enhancing system stability.

**Novelty:** The novelty of this work lies in integrating a **barrier function** with integral sliding mode control to enhance the robustness and performance of ABS. This integration allows the controller to strictly enforce slip ratio constraints, which traditional sliding mode controllers might not guarantee, ensuring safer braking behavior. Additionally, the method effectively handles uncertainties related to vehicle parameters and external disturbances, improving control precision on slippery or variable road surfaces. The combined approach offers a new way to maintain optimal braking performance, preventing wheel lock and enhancing vehicle stability more reliably than conventional ABS controllers.

**Evaluation Metrics:** The evaluation focuses on metrics that reflect braking performance and system robustness. Key metrics include **slip ratio control accuracy**, which measures how well the system maintains the slip ratio within optimal limits to maximize traction. **Response time** is evaluated to assess the controller’s speed in reacting to changing road conditions and disturbances. Additionally, **wheel lock prevention** is monitored to ensure safety during aggressive braking. The system’s ability to handle **parameter uncertainties** and external noise is also tested, demonstrating robustness. These metrics are compared against traditional ABS methods, showing improvements in stopping distance, braking stability, and overall safety.

**Discrete Tire Modeling for Anti-lock Braking System Simulations:**

**Link:**[https://vtechworks.lib.vt.edu/items/65dd01cf-d761-49bf-97ce-f5285e97afef](https://vtechworks.lib.vt.edu/items/65dd01cf-d761-49bf-97ce-f5285e97afef" \t "_new)

**Methodology:** This model captures the complex interactions between the tire and the road surface, accounting for factors such as slip ratio, friction characteristics, and tire deformation during braking events. By incorporating discrete elements, the model aims to realistically simulate tire behavior under varying conditions, including different road textures and vehicle speeds. This detailed tire representation allows for more accurate analysis and testing of ABS algorithms, helping to predict system performance, optimize control strategies, and enhance vehicle safety during emergency braking situations.

**Novelty:** This work offers a novel contribution by emphasizing the detailed modeling of tire dynamics and their direct impact on the performance of Anti-lock Braking Systems (ABS). Unlike traditional ABS studies that often use simplified tire models, this approach incorporates a more realistic, dynamic tire model that captures the complex behaviors of the tire-road interaction during braking. By doing so, it provides deeper insights into how tire characteristics influence ABS effectiveness, especially under varying road conditions and vehicle speeds. This enhanced understanding enables the development of more accurate and responsive ABS control strategies, ultimately improving vehicle safety and braking efficiency.

**Evaluation Metrics:** Key performance metrics include the accuracy of slip ratio control, response time of the ABS system, and the stability of vehicle braking under various simulated road conditions. The simulations assess how well the dynamic tire model integrates with ABS algorithms to predict realistic braking behavior and prevent wheel lockup. Additionally, parameters such as stopping distance and brake torque modulation are analyzed to measure improvements in braking efficiency and safety. These metrics provide a quantitative basis to validate the effectiveness of the developed tire model in enhancing ABS performance.

**Modeling and Performance Testing of Anti-Lock Braking System with Variation of Road Friction Coefficient:**

Link: <https://journal.trunojoyo.ac.id/rekayasa/article/view/16561>

**Methodology:**

Using MATLAB Simulink, the ABS model incorporates different friction levels to represent diverse road conditions such as dry asphalt, wet surfaces, and icy roads. The simulation captures how changes in friction affect wheel slip, brake torque modulation, and overall vehicle braking behavior. By analyzing these variations, the study aims to evaluate the ABS’s capability to maintain optimal slip ratios and prevent wheel lockup, thereby ensuring safety and stability during braking across different driving environments.

**Novelty:**

Unlike many studies that assume constant or ideal road conditions, this work explicitly considers different friction coefficients to simulate real-world scenarios such as wet, icy, and uneven surfaces. By focusing on these variations, the research highlights the challenges ABS controllers face in maintaining optimal braking efficiency and vehicle stability under diverse and changing environments. This approach provides valuable insights for designing more adaptive and reliable ABS algorithms capable of handling a wide range of driving conditions.

**Evaluation Metrics:**

The evaluation focuses on measuring the braking distance of the vehicle under various road friction conditions to assess the effectiveness of the ABS. By simulating different friction coefficients representing surfaces like dry, wet, and icy roads, the study analyzes how the ABS responds in terms of stopping distance. Shorter braking distances indicate better ABS performance and safety. The evaluation also considers how well the system maintains control and prevents wheel lockup, which directly affects vehicle stability during emergency braking. These metrics help validate the ABS model’s capability to adapt to changing road conditions and ensure optimal braking performance.

**Modeling the Movement of Vehicles with an Anti-lock Braking System on Various Types of Road Surface Using the Principles of PID Control:**

**Link**: [SpringerLink](https://link.springer.com/chapter/10.1007/978-3-031-44615-3_11)

**Methodology:**

The methodology applies a Proportional-Integral-Derivative (PID) control strategy to model vehicle movement under the influence of an Anti-lock Braking System (ABS) across various road surfaces. The PID controller is designed to regulate braking force by continuously adjusting control signals based on feedback from wheel speed sensors, aiming to maintain optimal slip ratio and prevent wheel lockup. The model incorporates different road surface conditions—such as dry, wet, and icy—by varying friction coefficients, enabling simulation of the ABS’s response in diverse environments.

**Novelty:**

This paper presents a novel approach by combining Proportional-Integral-Derivative (PID) control with Anti-lock Braking System (ABS) technology to enhance vehicle dynamics. T he integration allows the ABS to more effectively regulate brake force, adapting quickly to changes in road conditions and maintaining optimal slip ratios. Unlike conventional ABS controllers, the use of PID control offers smoother and more precise adjustments, improving braking stability and reducing wheel lockup risks. This combination results in improved vehicle control and safety across various road surfaces, making it a practical solution for modern braking systems.

**Evaluation metrics:**

The evaluation focuses on assessing vehicle movement and overall braking performance to determine the effectiveness of the PID-controlled Anti-lock Braking System (ABS). Key metrics include how well the system maintains vehicle stability during braking, the accuracy in controlling the slip ratio, and the ability to prevent wheel lockup across different road surfaces. Additionally, the braking distance and response time are measured to evaluate the system’s efficiency and safety. These metrics collectively provide a comprehensive understanding of how the integrated PID and ABS control improve vehicle dynamics under varying driving conditions.

**Performance of a Road Vehicle with Hydraulic Brake Systems Using Slip Control Strategy:**

**Link**: <https://pubs.sciepub.com/ajvd/2/1/2/>

**Methodology:**

It involves modeling the dynamics of the hydraulic brake components, including brake valve behavior and the interaction between tires and road surfaces. A slip control strategy is applied, typically using a Bang-Bang controller, to regulate wheel slip and prevent wheel lockup during braking. The model simulates straight-line braking maneuvers under varying road conditions to assess how well the control system maintains the desired slip ratio. Both assisted ABS mode and non-ABS mode are compared through simulation and experimental tests to evaluate the effectiveness of the slip control strategy in enhancing braking stability and safety.

**Novelty:**

This paper introduces a novel focus on slip control strategies specifically within hydraulic braking systems. Unlike conventional ABS studies that often concentrate on electronic or pneumatic braking systems, this research emphasizes the dynamics and control challenges unique to hydraulic brakes. By applying a Bang-Bang controller to regulate wheel slip, the study offers an innovative approach to maintaining optimal traction and preventing wheel lockup during braking. This focus provides valuable insights into improving braking performance and vehicle safety in hydraulic brake-equipped vehicles, especially under varying road conditions.

**Evaluation metrics:**

The evaluation metrics focus on assessing braking performance under various road conditions to validate the effectiveness of the slip control strategy in hydraulic brake systems. Key parameters include stopping distance, brake response time, and the system’s ability to maintain optimal wheel slip and prevent lockup during emergency braking. Simulations and experimental tests are conducted across different friction scenarios, such as dry, wet, and icy surfaces, to analyze how well the controller adapts to changes in road traction. These metrics provide a comprehensive measure of the system’s capability to enhance vehicle stability and safety during braking maneuvers.

**Research on Simulation of Anti-lock Braking System Based on MATLAB:**

Link: <https://www.atlantis-press.com/proceedings/amcce-18/25895781>

**Methodology:**

The methodology involves simulating the Anti-lock Braking System (ABS) using MATLAB software by developing comprehensive vehicle and tire models. The simulation incorporates the dynamic behavior of the vehicle during braking, as well as detailed tire-road interaction models to accurately represent slip and friction characteristics. The ABS control algorithm is implemented to regulate brake pressure and maintain the optimal slip ratio, preventing wheel lockup. Various driving scenarios and road conditions are simulated to test the ABS performance, enabling evaluation of braking efficiency and vehicle stability in a controlled virtual environment.

**Novelty:**

This paper presents a novel and comprehensive simulation approach for the Anti-lock Braking System (ABS) using MATLAB. Unlike simpler models, it integrates detailed vehicle dynamics and tire behavior to closely mimic real-world braking scenarios. The approach enables precise analysis of ABS performance across various road and driving conditions, offering valuable insights for optimizing control strategies. By providing a flexible and accurate simulation platform, this work aids in the development and testing of more effective ABS designs to enhance vehicle safety.

**Evaluation metrics:**

The evaluation metrics focus on comparing the simulation results of vehicles equipped with Anti-lock Braking Systems (ABS) against those without ABS. Key performance indicators include stopping distance, slip ratio control, braking response time, and vehicle stability during braking maneuvers. The comparison highlights how ABS improves safety by preventing wheel lockup, reducing skidding, and maintaining better control on various road surfaces. These metrics provide quantitative evidence of the advantages of ABS technology over conventional braking systems.

**Modeling and Simulation of the Anti-lock Braking System Based on MATLAB/ Simulink:**

Link: <https://www.atlantis-press.com/proceedings/amcce-18/25895781>

**Methodology:**

The methodology involves modeling the Anti-lock Braking System (ABS) using MATLAB/Simulink software integrated with a fuzzy logic controller. The simulation captures the dynamic interactions between the vehicle, tires, and road surface to effectively regulate brake pressure and maintain optimal wheel slip ratios. The fuzzy logic controller is designed to handle uncertainties and nonlinearities in the braking process by adjusting control actions based on real-time feedback from sensors. Various road conditions and driving scenarios are simulated to evaluate the controller's ability to prevent wheel lockup, reduce stopping distance, and enhance vehicle stability during braking.

**Novelty:**

This paper introduces a novel approach by integrating fuzzy logic control with the Anti-lock Braking System (ABS) modeling in MATLAB/Simulink. Unlike traditional ABS controllers that rely on fixed threshold values, the fuzzy logic controller can handle uncertainties and nonlinearities inherent in vehicle braking dynamics more effectively. This integration allows for smoother and more adaptive brake pressure modulation, improving the system’s responsiveness to changing road conditions and driver inputs. As a result, the fuzzy logic-enhanced ABS provides improved braking performance, better slip ratio control, and increased vehicle stability, especially under complex and varying road surfaces.

**Evaluation metrics:**

The evaluation metrics focus on assessing braking performance of the fuzzy logic-controlled ABS under various road conditions. Key parameters include slip ratio control, stopping distance, brake response time, and vehicle stability during braking maneuvers on surfaces such as dry asphalt, wet roads, and icy patches. Simulations are conducted to observe how effectively the system prevents wheel lockup and maintains traction, ensuring safer and more reliable braking. These metrics help demonstrate the enhanced adaptability and robustness of the fuzzy logic-based ABS across diverse driving environments.