MODELLING AND SIMULATION OF AUTOMATIC BRAKE SYSTEM OF VEHICLE

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ABSTRACT

The increasing rate of road accidents is alarming and any vehicle that does not have an effective braking system is vulnerable to an accident with human and property consequences. This is due to human error when driving, involving reaction time delays and loss of concentration. An automatic braking system is an active safety system equipped on modern cars to minimize the possibility of a collision while participating in traffic. The automatic braking system helps warn the driver of an impending collision and helps the driver brake with maximum force or automatically brake the car in an emergency situation. This study analyzes the working principle of the automatic braking system, designs an obstacle detection model using ultrasonic sensors, and models an automatic braking system using the rules in the controller. Fuzzy logic for the system for anti-lock braking detection and model simulation has been developed using Matlab - Simulink software to achieve high braking torque, optimum slip ratio, distance, and stopping time in shorter car. The results show that the distance and stopping time are improved compared to when the controller is not used.

Keywords: automatic brake system, Automatic emergency braking system, IBS, AEB, fuzzy logic.

Manuscript Received 21 November 2022; Revised 5 May 2023; Published 30 May 2023

1. INTRODUCTION

The brake mechanism is an active safety mechanism of the car, used to slow down or stop and park the car in necessary cases. The automobile industry is growing strongly, the number of cars is increasing rapidly, and the traffic density on the road is increasing. Vehicles are increasingly designed with higher capacity and faster movement speed; the requirements for braking are also higher and more stringent. The World Health Organization [13] reports that the total number of road traffic deaths worldwide has reached 1.35 million people each year. That is, one person is in an accident every 25 seconds, and 74% of all road traffic deaths occur in middle-income countries, accounting for only 53% of the world's registered vehicles. In low-income countries, it's even worse. Only 1% of the world's cars cause 16% of the world's road traffic deaths. This suggests that these countries bear a disproportionately high burden of road traffic deaths relative to their level of motorization. These accidents happen anytime, anywhere, and cause the most damage, serious injury, and death and are largely due to the driver's distraction and failure to apply the brakes [12]. To avoid accidents or reduce casualties due to collisions between vehicles, the braking system plays an extremely important role. There are many brake systems developed to create a smooth and compatible braking system, ABS is one of the examples of brake booster systems. But the brake system needs to be set up so that it can brake in the period that best suits the situation. If the system is not activated on time, it will be difficult to prevent or reduce the possibility of collisions between vehicles. But the sudden appearance of vehicles in front of other vehicles can cause panic among drivers. So to face those problems automatic braking system was born. Assuming the driver is not paying attention to the obstacles in front of the vehicle; the automatic braking system can send a warning to the driver and act directly to avoid potential collisions. This study aimed to automate the task of assessing the situation and deciding the correct amount of brake pressure to apply for collision avoidance. That means the car brake itself must have a controller to assist the driver on the road. This will greatly reduce the loss of property and money due to accidental damage [11]. In this paper, an obstacle detection system is designed with ultrasonic sensors to achieve the critical braking distance between a moving vehicle and a pedestrian or two moving vehicles. The brake system is designed with an anti-lock system to prevent the wheels from locking during heavy braking and to maintain the system at an optimal skid rate. Fuzzy rules are developed for both obstacle detection and braking systems to control the operation of the system and effectively ensure safe driving.

2. THEORETICAL BASIS OF INTELLIGENT BRAKE SYSTEM

2.1 Theoretical Basis of ABS

The mathematical model is the initial basis for developing a control algorithm for ABS. In this paper, a mathematical model is built which is a quarter car model. In it, different mathematical equations and expressions are used to model different components, including vehicle dynamics, wheel slip, tire, and brake actuator.

VOL. 18, NO. 7, APRIL 2023 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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2.1.1 Vehicle dynamics

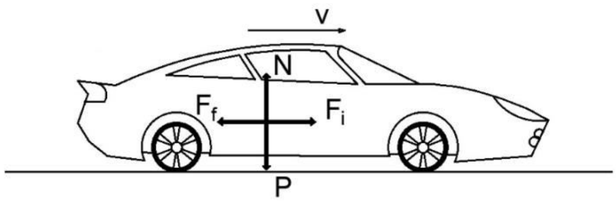

Figure-1. Forces acting on the vehicle.

Assuming that the car performs braking in the condition of uniform rectilinear motion, then we can write the equilibrium equation as follows:
- for horizontal:

$$F_f = F_i \tag{1}$$

Where: F_f [N] - the rolling resistance between the wheel and the road surface
F_i [N] - the moving inertia force of the vehicle
- for vertical:

$$N = P \tag{2}$$

Where: N [N] - normal force (reaction of the line)
P [N] – the weight of the vehicle

Rolling resistance is determined by the following formula:

$$F_f = \mu.N \tag{3}$$

Where: μ [-] coefficient of rolling resistance between wheel and road.

The weight of the vehicle is determined:

$$P = m_v.g \tag{4}$$

Substituting (2) and (4) into (3) we get the expression to determine rolling resistance as:

$$F_f = \mu.m_v.g \tag{5}$$

Where: m_v [kg] - is the total mass of the vehicle
g [m/s^2] - is the acceleration due to gravity

The moving inertia force is the product of the mass of the car m_v [kg] and the acceleration of the car a_v [m/s^2]:

$$F_i = m_v.a_v = m_v.\frac{dv_v}{dt} \tag{6}$$

Where: v_v [m/s] is the speed of the vehicle.

From equations (1), (5) and (6) vehicle acceleration is calculated according to the expression:

$$\frac{dv_v}{dt} = \frac{1}{m_v}.(\mu.m_v.g) \tag{7}$$

The speed of the car is determined by integrating equation (7).

2.1.2 Tire dynamics

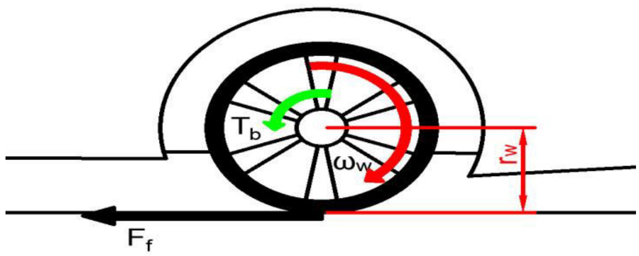

Figure-2. Forces acting on the tire.

During braking, through the brake drive system, the driver applies a braking torque T_b [Nm] to the wheels. The rolling resistance F_f [N] between the wheel and the road produces a torque opposite to the wheel radius r_w [m].

For the sake of simplicity, we will assume that the wheel is rigid and that the reaction of the road surface is transmitted through the wheel hub, thus creating no additional torque [5].

Therefore, we have the following wheel dynamics equation:

$$T_b - F_f.r_w - J_w.\frac{d\omega_w}{dt} = 0 \tag{8}$$

Where: J_w [kg.m^2] - is the moment of inertia of the wheel
ω_w [rad/s] - is the angular speed of the wheel

From equation (8) we derive the expression for wheel acceleration:

$$\frac{d\omega_w}{dt} = \frac{1}{J_w}.(T_b - F_f.r_w) \tag{9}$$

The speed of the wheel is determined by integrating the equation (9).

2.1.3 Wheel slip

The ABS brake system must control the wheel slip s [-] around an optimal target. The wheel slip is calculated as follows:

$$s = 1 - \frac{\omega_w}{\omega_v} \tag{10}$$

Where: ω_v [rad/s] is the relative angular speed of the vehicle, calculated by the formula:

$$\omega_v = \frac{v_v}{r_w} \tag{11}$$

Where: v_v [m/s] is the speed of the vehicle.

2.2 Theoretical Basis of the Obstacle Detection System

Real-time distance is the distance between a moving vehicle and a pedestrian and also the distance between two moving vehicles. The time required for the reciprocating motion of the ultrasonic wave after hitting an obstacle is the acquisition time (necessary time x2). The real-time distance d obtained from the ultrasonic sensor is said to be:

$$d = \frac{receiving\ time}{2}.v_{at} \tag{12}$$

The walking speed of the pedestrian is ignored relative to car A and is assumed to be zero [7]. Then the critical braking distance between car A and the pedestrian is said to be:

$$d_{c1} = V_A\left(t_r + \frac{t_i}{2}\right) + \frac{V_A^2}{2\mu g} + d_{min} \tag{13}$$

This equation is used for immobile obstacles or pedestrians whose velocity is assumed to be 0. The microcontroller used the car's velocity (V_A) to determine the critical braking distance ($_1$) compared with the real-time distance (d) between the vehicle and the immovable obstacle. If the relative real-time distance (d) is greater than the critical braking distance dc1, the vehicle can keep its initial speed and the pedestrian can cross the road safely. If the relative distance is less than or equal to the critical braking distance and the driver still does not decelerate or take other safety measures, the situation is considered dangerous and deceleration by automatic braking on the vehicle is considered dangerous. Motoring will be performed by the anti-lock braking system. After receiving the command from the controller to slow down or stop the vehicle.

The critical braking distance between two moving vehicles (Vehicle A and Vehicle B) can be calculated by modeling the safe distance during braking as follows [7].

$$d_{c2} = V_A t_r + \frac{(V_A - V_B)t_i}{2} + \frac{V_A^2 - V_B^2}{2\mu g} + d_{\min} \tag{14}$$

Where d_{c1}, d_{c2} = critical braking distance to decelerate, V_A = speed of car A, V_B = speed of car B, μ = coefficient of friction of the road, t_r = total reaction time of driver and brake coordination time ranges from 0.8 seconds to 1.2 seconds, t_i = acceleration time of brake deceleration varies from 0.1 seconds to 0.2 seconds, g = gravity acceleration field (9.81 m/s^2) and $dmin$ = minimum distance between vehicle and obstacle when stopping from 1m to 4m.

If the real-time distance d between vehicle A and vehicle B is greater than the critical braking distance d_{c2}, then it is in a safe state and the vehicle can travel at the current speed. Conversely, if the driver fails to decelerate or take other safety measures when the current distance is less than or equal to the critical braking distance, the situation is judged to be dangerous and the automatic brake deceleration will be reduced. Actions on car A need to be performed immediately by the driver to avoid a collision with car B.

3. BUILDING A MODEL OF SMART BRAKE SYSTEM

3.1 System Block Diagram

The block diagram of the automatic braking system with two cascaded fuzzy logic controllers and the obstacle detection sensor for the automatic braking system to avoid collisions with obstacles is shown in Figure 3. The system is shown in Fig. The model uses two fuzzy logic controllers to perform actions. The fuzzy logic controller first decides to stop the vehicle or slow down the vehicle depending on the distance of the obstacle and the speed of the vehicle at that moment. The second fuzzy logic controller takes the brake force as input to decide the magnitude of the braking force to the brake actuator and the slip ratio to maintain to avoid wheel locking. The adjustment of the slip between the tire and the road surface to prevent wheel slip is controlled by a 2nd fuzzy logic controller when the wheel sensor detects a sudden deceleration causing a difference between wheel speed and vehicle speed. car degree. The obstacle detection system has three ultrasonic sensors (two on the sides of the vehicle, and one on the front of the vehicle) to measure obstacle distances. This distance determines the braking force when compared to the vehicle speed.

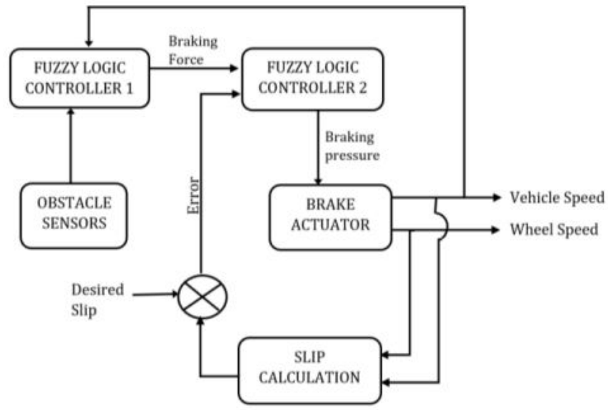

Figure-3. Block Diagram of the modeled System.

3.2 Model of Automatic Brake System

The automatic braking system implementation modeled in MATLAB - Simulink software is shown in Figure-4.

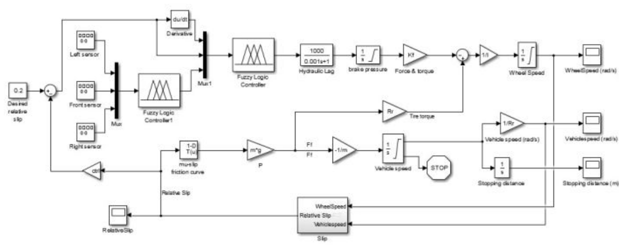

Figure-4. Model of the automatic brake system.

3.3 Fuzzy Logic Controller Design

3.3.1 Development of fuzzy rules for the first fuzzy logic controller

In this study, the first fuzzy logic controller is modeled to output a low or high brake signal to a second fuzzy logic controller to stop the vehicle or slow down vehicle. The controller receives signals from three sensors and uses rules to decide what action to take. Mamdani fuzzy logic is used for the design with 21 rules to decide the signal on the obstacle to sending to the second fuzzy logic.

The following linguistic parameters are used by the membership functions to form fuzzy rules. The input variable language values for the Left-sensor, Front-sensor, and Right-sensor include:

FO -Far Obstacle
NO -Near Obstacle
VNO -Very Near Obstacle

The language values of the output parameter for the brake mode include:

LB - Low Braking
NA - No Action
HB - High Braking

Table-1 shows fuzzy rules for obstacle detection for left and right, with front sensors as input:

Table-1. Fuzzy rule for obstacle detection system.

sensor L	sensor F	sensor R	Braking mode
VNO	NO	FO	LB
VNO	VNO	FO	HB
VNO	FO	FO	HB
FO	FO	FO	NA
FO	NO	NO	LB
NO	NO	NO	LB
FO	VNO	FO	HB
NO	VNO	NO	HB
NO	NO	FO	NA
VNO	FO	VNO	HB
VNO	VNO	NO	HB
NO	VNO	VNO	LB
NO	NO	VNO	HB
NO	VNO	NO	NA
NO	FO	VNO	LB
NO	FO	FO	LB
VNO	NO	NO	LB
VNO	FO	VNO	HB
VNO	FO	NO	HB
FO	VNO	NO	HB
FO	NO	VO	LB

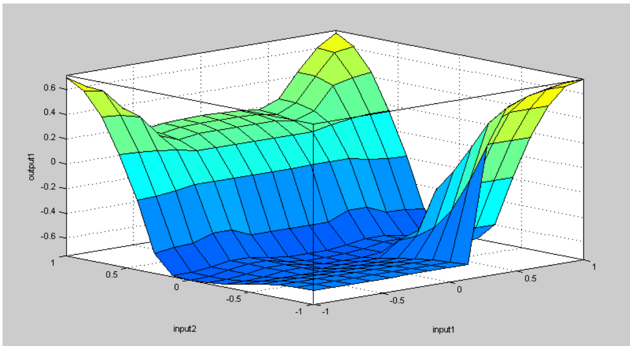

Figure-5. Surface view of the 1st fuzzy controller's rules.

Figure-5 shows a smooth surface view of the rules in the first fuzzy logic design. This gives the response of fuzzy logic when receiving signals from three sensors. When the obstacle signal is high, it means that the controller sends a high brake signal to the second fuzzy logic to apply maximum braking force to stop the vehicle. But if it is low, then the controller will command the second controller to apply a minimum braking force to slow down. We can see the adjustment as it is made here to see if the system is responding as expected.

3.3.2 Development of fuzzy rules for the second fuzzy logic controller

In this study, a second fuzzy logic controller is designed to generate braking torque such that the actual wheel slip follows the reference slip. This study is based on sliding control and collision avoidance, this controller is designed with three control objectives including reducing vehicle stopping distance, limiting slip, rate, and improving control system performance. Mamdani method is applied to design a fuzzy controller.

The following language parameters are used by the membership functions to form the operating rules of the system.

The values of the input parameters for the 2nd fuzzy logic controller are slip error, slip change rate, and braking mode including:

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NL - Negatively Large
NS - Negative Small
ZE - Zero
PS - Positive Small
PL - Positively Large
LB - Low Braking
HB - High Braking
NA - No Action

The language values of the output parameter for brake pressure include:

DPL - Quickly reduce the pressure
DPS - Slowly reduce the pressure
HOLD - Hold the pressure
IPS - Slowly increase the pressure
IPL - Quickly increase the pressure

Table-2. Fuzzy rules for ABS.

Sliding error	Sliding change speed	Distance	Pressure
NL	NL	HB	DPL
NL	NS	HB	DPL
NL	ZE	HB	DPS
NL	PS	HB	HOLD
NL	PL	HB	HOLD
ZE	NL	HB	DPS
ZE	NS	HB	DPS
ZE	ZE	HB	HOLD
ZE	PS	HB	IPS
ZE	PL	HB	IPS
PL	NL	HB	HOLD
PL	NS	HB	HOLD
PL	ZE	HB	IPS
PL	PS	HB	IPL
PL	PL	HB	IPL

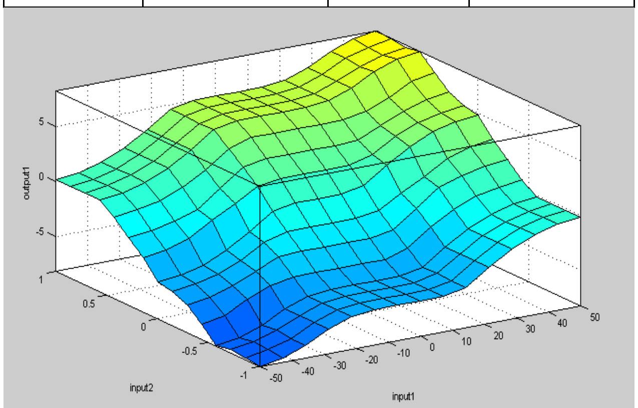

Figure-6. Surface view of the second fuzzy controller's rules.

Figure-6 provides a surface view of the rules of the second fuzzy logic controller. This shows the response of the second fuzzy logic when the signals from the fault, error change, and brake mode are received and the tasks are performed based on the fuzzy rules. Braking force is considered high if the first controller sends a high brake signal to command the second controller to increase brake pressure. Low braking force when receiving a low signal from the first controller or the vehicle is preparing to steer to control the hydraulic brake system to reduce brake pressure.

4. RESULTS AND ANALYSIS

In this paper, two criteria to evaluate the system's performance are the braking distance and the braking time, which are investigated from the moment the brake starts to the time the vehicle stops without taking into account the reaction time of the driver. The wheel slip angle is assumed to be zero, i.e. only running straight on a uniform flat surface is used. Air resistance, aerodynamics, and suspension vibrations are ignored. The input parameters used in the study are listed in Table 1. The initial speed selected was 28 m/s. Different control methods and parameters are used in different simulation cases and the results are compared and discussed.

Table-3. Input parameters of the simulation process.

Symbol	Parameter	Value
m	Mass (Kg)	360
R_r	Wheel radius (m)	0.32
g	Gravity acceleration (m/s^2)	9.81
v_0	Initial velocity (m/s)	28
K_f	Force and torque	1
I	The rotational inertia of the wheel (kg.m^2)	5
Pbmax	Maximum torque (Nm)	1800
Ctrl	Control variable	1 or 0

RESULTS

Simulink simulation will run for 10 seconds. Simulation results of automatic braking systems using fuzzy logic controllers are shown by typical graphs for braking system.

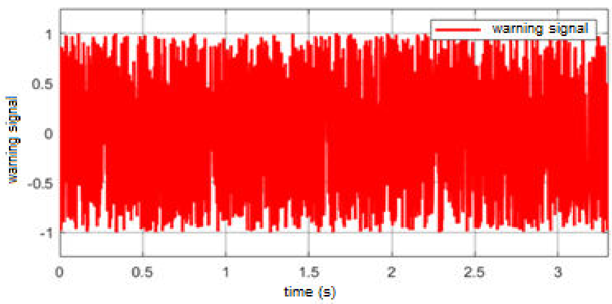

Figure-7. Warning signal.

The warning signal is shown as shown in Figure-7. Based on the graph, we can see that the warning signal is set up irregularly and continuously until the vehicle stops so that we can evaluate the effectiveness. of the sensor system as well as the obstacle detection controller for the automatic brake system model that we built.

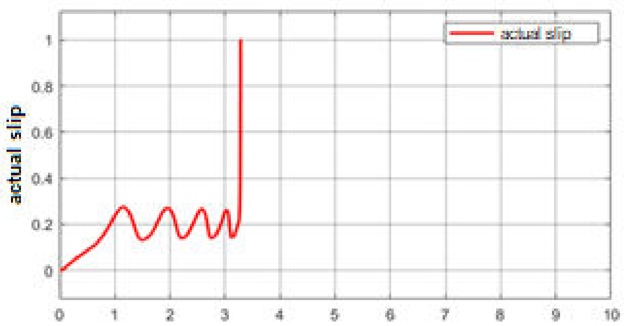

Figure-8. Variation of slip during braking.

Figure-8 shows the normalized relative slip during deceleration from the wheel speed sensor. The graph shows that when the vehicle decelerates and the slip value starts to increase up to 0.25, the controller commands the hydraulic brake circuit to release the brake, reducing the slip value to 0.15. This happens continuously but in microseconds to maintain the stability and drivability of the vehicle when braking and the skid value increases up to 1 when the vehicle comes to a stop meaning the wheel angular velocity is zero (the vehicle is at a standstill

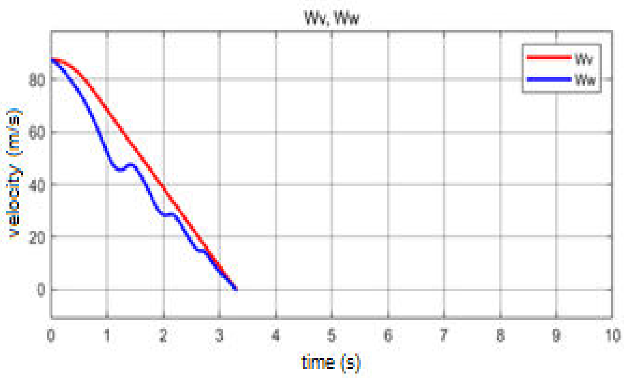

Figure-9. Vehicle speed and wheel speed during braking.

The vehicle stops during deceleration and the fluctuation of wheel speed is increased in this model. This shows that the wheel speed is continuously controlled to prevent the wheel from locking up. The speed of the car and the speed of the wheel both go to zero after 3.3 seconds. The fuzzy logic controller synchronizes vehicle and wheel speeds before the vehicle stops or turns to prevent skidding. The controller monitors the vehicle speed and adjusts the wheel speed to synchronize with the vehicle speed before the vehicle stops as shown in Figure-9.

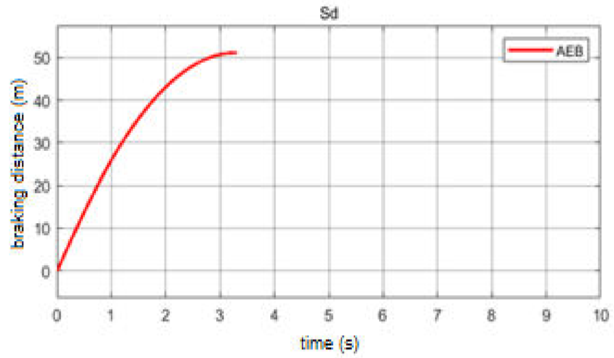

Figure-10. Braking distance.

The stopping distance of the vehicle has been reduced to 51 m in 3.3 seconds to avoid a collision as shown in Figure-10. When the system detects an obstacle, the system calculates that the critical braking distance is always higher than the stopping distance. Fuzzy logic sends a signal to the hydraulic brake system immediately after the vehicle is within the critical braking distance. Assuming the vehicle's speed is 28m/s, the critical braking distance according to equation 13 will be 77.75 m. means that the vehicle is 26.75 m away from the obstacle, then stops.

5. CONCLUSIONS

This paper focuses on modeling an automatic braking system using fuzzy logic controller based on an ABS anti-lock braking system combined with an obstacle detection sensor system used for vehicles can solve the problem when the driver fails to brake in time in an emergency and can automatically slow down due to obstacle detection. With the connection of ultrasonic sensors in the vehicle, the acquisition system can achieve measurements with high accuracy, short dwell time, and improved short-distance measurement. The system is well suited for tight parking spaces, heavy traffic conditions, emergencies and confined areas. The system modeled using a Fuzzy Logic controller gives more reliable and stable results than using a pure ABS system alone and will be accepted by consumers.

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