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Electro-Mechanical Sensor System Proposal to Address Automobile Tire Blowouts

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***Abstract*—Tire malfunctions that contribute to motor vehicle accidents in the United States vary from 19,000 to 78,000 annually [1,2] with as many as 46% of those crashes occurring at high speeds on expressways. [3] In 2017, the National Highway Traffic Safety Administration reported 738 fatalities attributable to blown tires. No other means of transportation would be allowed to operate with a similar rate of safety failure – especially with a known cause. The automobile industry has made strides developing precautions for vehicle operators with tire pressure monitoring systems (TPMSs) and run-flat tires. However, the technology is incomplete. This paper purports to aid the existing tire safety technology by providing additional electro-mechanical options capable of preventing blowout occurrences, reducing rollovers, and minimizing casualties. This proposal incorporates the existing TPMSs and RFTs with overrides, power electronics, tire sensors and voice activation with passive and active schemes based on the tire contact patch.**

Key terms: automobile tires, blowout, transportation design, mechanical system override, safety

I. Introduction

Tires are the direct contact between the vehicle and the road. Rubber tires are designed to negotiate the road surface- asphalt, dirt, mud, and concrete - in all weather conditions. The number of tires on vehicles can vary from four in passenger cars, up to six in heavy duty box trucks and ten or more on semi-trucks, work trucks. None of these vehicle types, however, are exempt from tire blowouts.

The estimate of tire malfunctions that contribute to motor vehicle accidents in the United States vary from 19,000 to 78,000 annually [1,2] with as many as 46% of those crashes occurring at high speeds on expressways [3]. In 2017, the National Highway Traffic Safety Administration reported 738 fatalities that year as the result of blown tires.

The automobile industry knows the dangers associated with an uncontrolled car that experiences a blowout on an expressway full of vehicles traveling at high rates of speed. They have designed gauges to alert drivers or tires that can drive flat. However, the technology is not yet complete as drivers can override or dismiss the indicators. Drivers can overcorrect and cause even more damage to themselves and other drivers. This paper is organized with an Introduction in Section 1, background information in Section 2, a literature review in Section 3, Methodology in Section 4, with results and discussion in Section 5, and concluding remarks in Section 6.

II. Background

A. Tire Blowouts – Major Causes

Repair shop technicians report several reasons that a vehicle experiences a blown tire. These include underinflation, overinflation, excessively heavy loads, potholes and road damage, tire aging or defects, tire punctures, and road travel in extreme heat. The vehicle operator can reasonably take responsibility in three of these circumstances: underinflation, overinflation, and wear and tear; and excessive loads.

Underinflated tires pose unsafe driving conditions and can result in blown tires.. When the tire pressure becomes too low, too much of the surface area of the tire touches the road. This increases friction, causing the side walls to flex and overheat. A tire is built on a mix of fabric and steel. When overheated, the rubber separates from this basic. Overheating can lead to the rubber separating from the body of the tire creating dangerous driving conditions such as severe vibration, uncontrollable automobile, and potentially a tire blowout.

A blown tire can also happen if it has too much air pressure. The excess pressure causes the rubber to expand beyond the manufacturer's design limits. The overinflated tire is stiff and inflexible; it does not permit proper contact with the road. Unlike its counterpart, the overinflated tire does not make sufficient contact with the road, as it will exhibit uneven tread—thus compromising driver assistance functions (e.g., anti-lock brake system) and vehicle control.

Overloading a vehicle also compromises tire tread. The stress from the weight can cause uneven wear. Tire blowout is the result of undue stress – especially for heavier truck (loads). Proper rotation is helpful. Decreased steering ability, trouble turning, decrease in maneuverability. Longer stopping distance – lack of grip on the pavement for stopping.

B. Current Approaches to Tire Blowouts

In the United States, automakers follow the regulations mandated by the National Highway Traffic Safety Administration (NHTSA) with respect to tire safety. All light duty vehicles under 10,000 pounds manufactured after September 2007 must have a tire-pressure monitoring system (TPMS) [4,5,6]. A TPMS is a real-time information system that informs the driver about the status of the air pressure inside pneumatic tires. If a tire has low pressure, a pictogram display or low-pressure warning light illuminates.

In other developments, some manufacturers have designed run-flat tires to serve as an emergency response. When impaired due to a worn or flat tire, the automobile continues to operate on the RFs but has a 50-mph speed limit or 50-mile driving distance constraint. It is expected that the vehicle operator will attend to the tire mishaps on RFs.

They share the same roads as light duty vehicle commuters; however, commercial tractor trailer drivers have a higher standard for operating their heavy-duty trucks. Federal law requires them to perform routine inspections after every 24-hour driving period and prior to delivery. These drivers can be held civilly and criminally liable for mechanical defects that they ignore.

III. Literature Review

In their study of blowouts at expressway speeds, Al-Quran & Mayyas (2021) [7] evaluate the validity of a nonlinear handling seven degrees of freedom model. They utilize Dugoff's tire model to express tire-ground interaction forces to simulate blowout scenarios. This is the perfect world where all forces and behaviors are predictable. Their approach is basically to derive the governing equations of motion, the conservation of linear and angular momentum's is applied to the vehicle/ wheels coupled system See Figure 1.

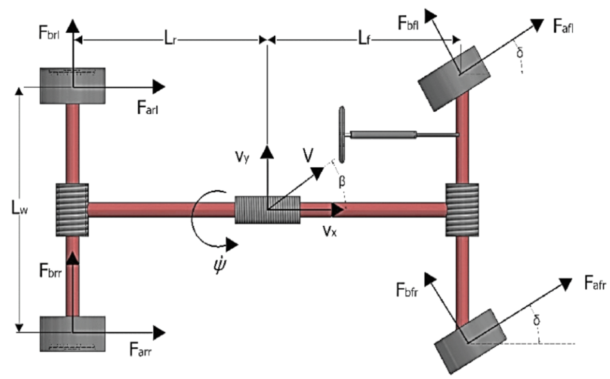

Fig. 1. Seven degrees of freedom nonlinear vehicle model. [7]

Yue *et al.* (2019) [8] proposed a two degrees of freedom bicycle model. They designed an automated hazard escaping trajectory tracking control framework for the vehicle subject to a tire blowout. They collected data from an onboard sensor and a vehicle-to-vehicle communication system. Their time-based polynomial trajectory method simulated a controlled velocity post blowout for a smooth transition from the current lane to the emergency lane.

Wang *et al.* (2018) [9] combined a triple-step nonlinear controller to solve the path following problem of an autonomous vehicle with a flat tire. Their control scheme for blowouts is a steering-only controller. Based on the feedback loop, the driving assistant system decided whether to intervene in the movement of the vehicle. It is commonly accepted that steering-only controllers are less effective during critical driving conditions associated with tire blowouts.

IV. Methodology

The tire contact patch is the location between a vehicle where the tire's tread touches when pressed against a surface. The contact patch plays an important role in tire attributes such as the treadwear, traction, and steering maneuvers. In this paper, we created two systems that depend on the effectiveness of detecting tire contact patches. We make the following assumptions:

(a) The tire contact patch is rectangular in shape
(b) Tire pressure is uniformly distributed inside the tire
(c) Tire pressure is uniformly distributed over a continuous surface
(d) Tire pressure at the tire contact patch is higher when any one tire encounters discontinuity
(e) The most hazardous driver's response to improper tire contact patch irregularities occurs at high speeds

The two questions that we plan to address are (1) What is a practical engineered process to mitigate the risk of tire failures associated with blowouts? and (2) Where is the optimal placement of additional sensors needed to assist drivers recover from tire blowouts? We created three nonlinear models that require a system of systems to aid a vehicle operator prior to and during a blowout called the Blowout Safety System (BoSS).

A. Active BoSS

Old or worn tires can have a similar appearance as new tires. With proper maintenance, it is assumed that well manufactured tires can last 60 to 80 thousand miles. However, there is not currently a system that easily identifies a tire's date of manufacture or a standard that specifies guidelines for service life for personal use vehicles.

The active BoSS is designed for vehicle operators who respond to gauges on the dashboard. They perform routines to mitigate automotive failures based on the environment, weather and road conditions, and manufacture standards for safe operation of their personal or corporate vehicle. They conduct purposed inspections and tire maintenance. They are safe to assume a tire contact patch Tcp is consistent with the generic manufacturer's calculation:

$$Tcp = Vw/Tp \quad (1)$$

where Vw is Vehicle weight in pounds and Tp is tire pressure in PSI.

B. Passive BoSS

In general, there are four tire contact patches per tire. The passive version of BoSS requires the use of tire sensor placement and contact patch calculations from the AASHTO LRFD design standards [10]. AASHTO LRFD is the acronym for the American Association of Highway and Transportation Load and Resistance Factor Design.

In this proposal tire sensor placement is dependent on uniform tire quality grading standards. Manufacturer ratings are designed to respond to temperature variations, weather conditions (wet and dry), surface continuity, traction, surface resistance, steering performance, and tread wear.

Passive BoSS is a seamless integration into the rubber or sidewall that allows for easy development and manufacturing. It is a molded-in sensor that can surround the entire sidewall to offers maximum surface area or quick analysis. The key function for the passive BoSS is detection of the tire contact area. It is designed to accommodate drivers who may be inclined to ignore Tire Pressure Monitoring System (TPMS) displays, or who depends on Run Flat Tires (RFTs), or who are not aware of load on their wheels as they operate their vehicle. In this instance, the BoSS sensor will create a voice activation when the load exceeds manufacturer's design on the rear tires of passenger vehicles according to the tire contact path area according to its length, L or weight W in the calculations

$$Tw = Sqrt((0.025) * P)$$
$$TL = Sqrt((0.004) * P) \quad (2)$$

Tw is tire width in inchers, TL is tire length in inches, and Ps the load in pounds.

However, for light and heavy-duty trucks, the tire contact area in square inches will be determined by considering the following dimensions for any wheel rolling on a surface

$$TWT = P/0.8$$
$$TLT = 6.4 * \gamma * [(1 + IM/100)] \quad (3)$$

TWT is the tire width in inches, TLT is the tire length in inches, γ is the load factor of the vehicle, IM is the dynamic load allowance, and P is the wheel design load.

When the sensor detects an out of instantaneous increase in the tire patch surface and tire depressurization, the sensor located inside the tire communicates to the driver through the dashboard display, audible instructions, then activates a governor that serves as a mechanical system override to slow the vehicle until the driver can come to a stop in a safe manner. This series of events is counter intuitive and works through mechanical design to undo the typical human response of slamming on the brakes or

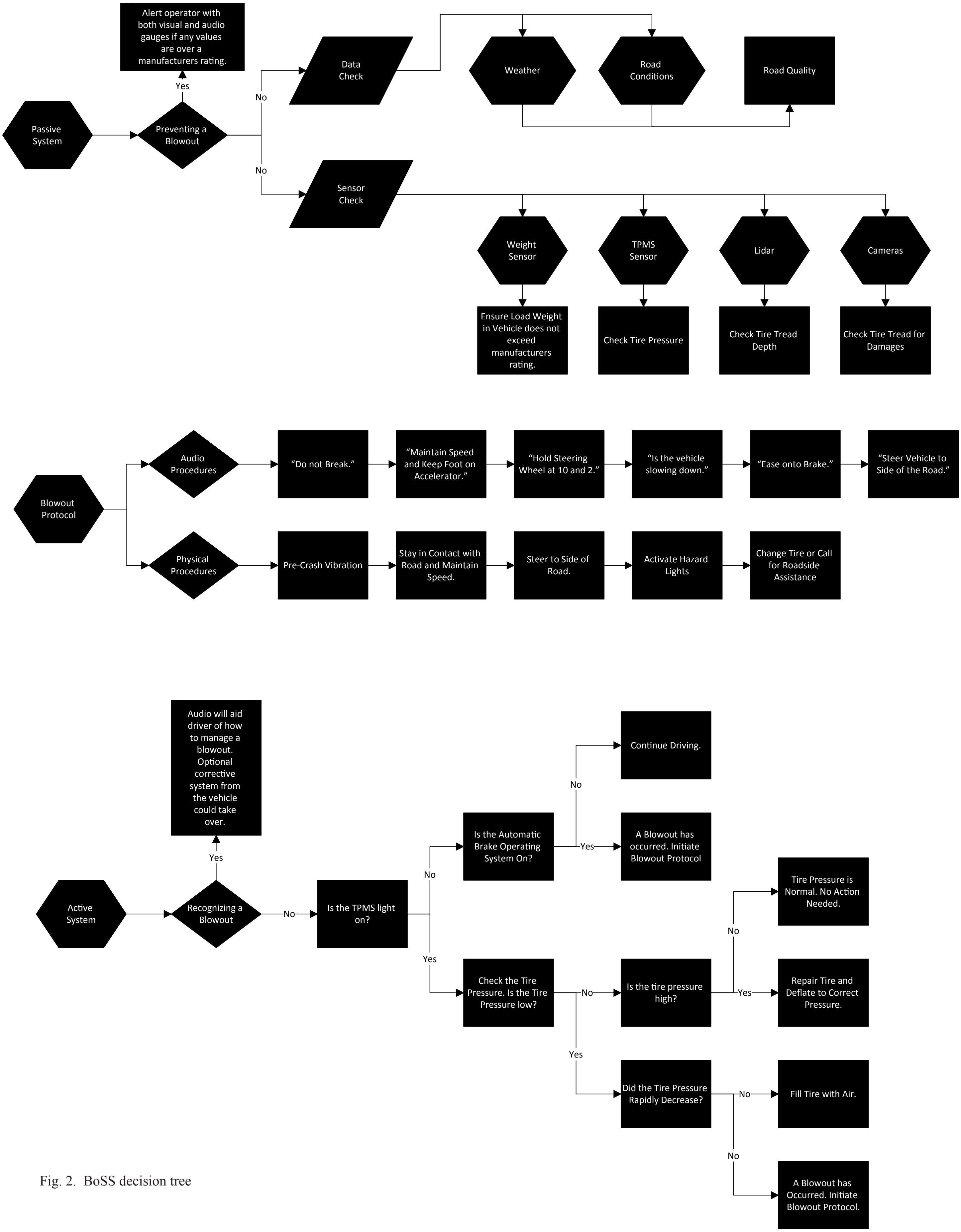

Fig. 2. BoSS decision tree

overcorrecting in the steering that typically happens at higher speeds observed by Li et. al (2020) [11]. Figure 3 includes the BoSS design.

Fig. 3. Passive BoSS sensor scheme

V. Results

This is a concept paper that includes two systems based on operator response to sensors that characterize tire attributes. An active approach to tire safety and blowout prevention is intended for the vehicle operator who develops an awareness routine to check for under and over inflated tires, load, and major road or surface discontinuities (e.g., potholes). These three factors are contributors to tire blowouts. A practical engineered process to mitigate the risk of tire failures associated with blowouts is included in the flow diagram of Figure 2.

The Al-Quran & Mayyas (2021) [7] seven degrees of freedom model in Figure 1 assumes a perfect prediction of behaviors. Their study is based on a simulation. To be effective several sensors would be required and would have to resolve the forces listed.

The BoSS operates on the generally accepted principle that there are four contact patch areas in tires. These regions help the vehicle by starting the wheels to roll, stopping, and steering under a variety of road and weather conditions. It requires the seamless placement of additional sensors to supplement the existing mandated TPMS or optional RFTs. Additionally, the BoSS can assist the driver to recover from tire blowouts by voice activation and a latent governor that has the benefit of maximum surface area analysis when road discontinuities exist – thus providing assistance to the driver recovering from tire blowouts.

VI. Conclusions

Tire pressure monitoring systems or TPMS technology is mandated for light motor vehicles sold after September 2007. TPMS serves to alert the driver about underinflated tires. This standard is effective notification for the vehicle operator who is willing to respond to dashboard gauges to check and repair tire pressure issues. However, other than dashboard sensors, there is nothing in the TPMS that encourages a casual operator to respond to tire warnings. Tires are the only contact between the vehicle and the road.

Tires age and degrade over time due to vehicle use, environmental factors, and materials. To the casual observer, a worn tire can appear the same as a new tire. An active and passive approach to tire sensors can overcome the human-machine interaction to conditions that result in tire blowouts. Use of tire contact area attributes is an effective approach incorporate existing sensors to promote road safety in the event of tire blowouts.

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