TYRE CLASSIFICATION TECHNOLOGY FOR IMPROVED ROAD SAFETY, REDUCED EMISSIONS, AND INFRASTRUCTURE PROTECTION

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ABSTRACT

This paper describes an innovative approach to tyre pressure and condition measurement using an automated system that is capable of checking tyres in a non-invasive, non-stop manner. In addition, real-world examples of work being conducted in the United States and Netherlands are described and the potential impact of improper tyre inflation and anomalous tyre conditions is explained. The tyre anomaly and classification system are becoming widely accepted by North American enforcement agencies for screening commercial vehicles for unsafe tyres. Much like earlier pre-screening technologies such as Weigh-in-Motion and e-screening, tyre anomaly and classification systems are enabling high throughput of commercial vehicles at inspection facilities while improving safety. As underinflated tyres negatively affect fuel economy, the system may also be used to identify vehicles that are not operating at maximum fuel efficiency. What about road surface condition? This has been a significant focus for European agencies seeking to reduce fuel consumption and emissions. Tyre anomaly and classification technology is being integrated with smart mobility and smart city transportation systems that have environmental and congestion reduction goals at the centre of their focus.

1. INTRODUCTION

Large-scale application of advanced transportation technology is an essential ingredient in today's smart(er) cities and towns, and in approaches to make mobility smarter.

Capital investment and large-scale projects can deliver major improvements in safety, efficiency, environmental performance and user experience. While these 'big ticket' efforts are vital, it is important to also recognise the cumulative effect on operational effectiveness of the application of emerging technologies at a smaller scale. Seemingly minor changes down at the individual road-user level can have, when implemented across significant numbers of vehicles and drivers, significant effects.

The subject of this paper is the application of advanced technologies to facilitate the automated monitoring and management of tyre vertical contact stress patterns and tyre condition.

The benefits revolve around a simple fact: incorrectly inflated tyres and tyres in poor condition cause more rolling resistance, leading to unnecessary fuel consumption and corresponding increases in emissions. The simple act of ensuring that tyres are properly inflated can have a dramatic effect on vehicle and road safety, fuel consumption and emissions figures for a city or region.

Proper tyre inflation and good tyre management does not require large-scale capital investment. It requires a change in behaviour amongst drivers and fleet operators.

In many cases, a change of behaviour can be brought about by the provision of decision-quality information – if you know that your tyres are incorrectly inflated or in poor condition, you are more likely to do something about it.

Evidence suggests that under-inflation and poor tyre condition is a significant problem that can yield major, positive results if addressed efficiently. For example, it is estimated that more than 60% of vehicles on the roads in the Netherlands, where IRD, Inc. has been involved in trials, have improperly inflated tyres (Sliggers, 2017). Best estimates suggest that there are least 1.4 billion vehicles in use around the world today (Car Guide Australia, 2021), so if we extrapolate the data from the Netherlands, it is likely that more than 84 million vehicles have improperly inflated tyres, or tyres that are in poor condition.

Logic suggests that this is an extremely important issue, as the tyres are the only points of contact between a vehicle and the road surface. The tyre footprint – or tyre contact patch (illustrated in Figure 1) – for a vehicle tyre varies according to the load placed on it and its inflation pressure. Heavier loads will tend to increase the contact patch and over-inflation will reduce it but the contact patch for a typical four-door sedan/saloon is approximately 237 cm^2 per tyre (Vehicle Dynamics Institute, 2014). Give a typical range for truck tyre footprints. For visualisation purposes, this is approximately equivalent to having an adult sports shoe on each vehicle corner.

This reliance for safety and handling on an exceedingly small surface area makes it important to ensure that the interface is optimised. Overall, while there are four tyres on a sedan/saloon-sized vehicle, contact with the road can still be viewed as a single point of potential failure.

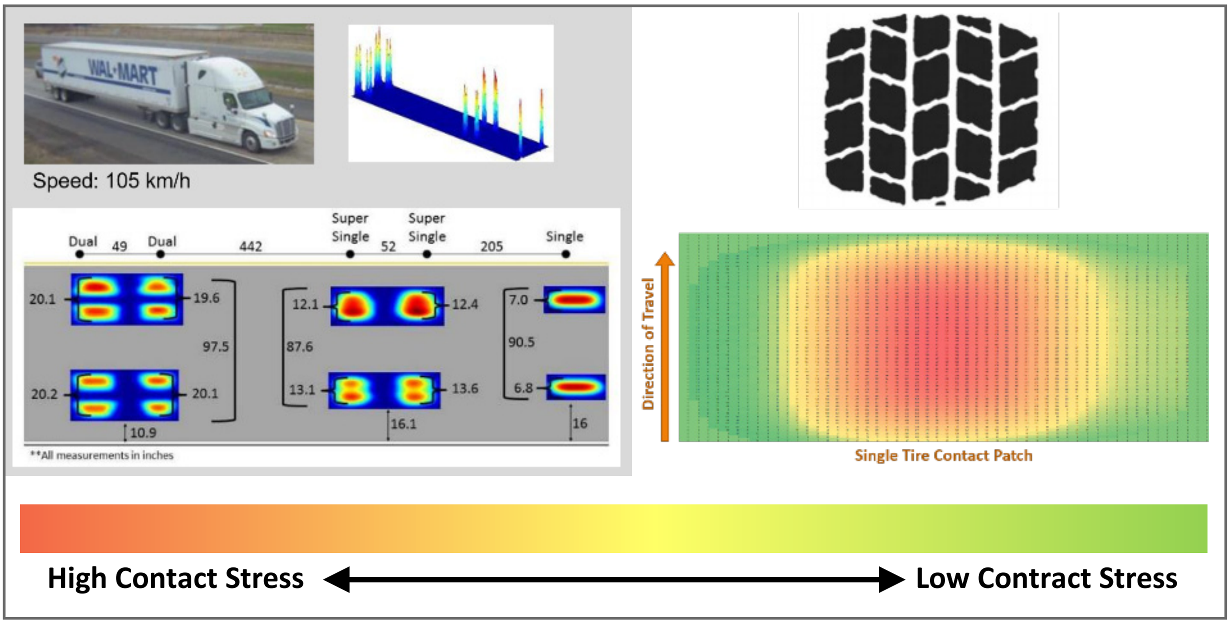

Figure 1: VectorSense sensors measure tyre-to-road contact stress every 10 mm across the lane width

Within this context, it is especially important to be able to assess vehicle tyre inflation and condition across a large sample size of vehicles in a cost-effective manner. This is where advanced measurement technology can play an important role. Providing the ability to monitor tyre to road contact patch stress distribution (for the purposes of this paper, Road Contact Patch Stress Distribution (RCPSD) in a non-invasive manner and without stopping traffic makes it feasible to sample many vehicles and take appropriate action. 'Action' can be compliance-based (the provision of information to the driver or fleet operator to enable remediation to occur) or enforcement-based (fining drivers or owners of vehicles that do not comply with rules and regulations).

It is possible for a tyre to be inefficient and remain safe, so the proportion of drivers with tyres in this category would be better served by providing information in a more compliance-based approach. Information provision could be by way of a roadside dynamic message sign or the delivery of a message to a smart phone app. In the future, the information could be delivered directly to vehicles' on-board systems.

The technology also provides a way to monitor improvements in behaviour, as it is possible to determine the number of vehicles with inefficient tyres both before and after a monitoring initiative is launched. While it is important to include the whole vehicle fleet, there is particular potential in addressing commercial vehicles. Safety issues are exacerbated by the size and weight of commercials; such vehicles also accumulate a greater number of miles travelled each year and consequently provide a large target for fuel and emission savings.

In addition, it is also likely that inefficient tyres are on the way to becoming non-compliant tyres, which attract significant financial penalties for commercial vehicles. Therefore, information on tyre condition is going to be especially valuable to fleet operators.

The remainder of this paper describes testing in the Netherlands of a dynamic RCPSD monitoring system which is focused on commercial vehicles. As trucks represent approximately 13% of the vehicle fleet, or 182 million vehicles globally, they offer significant opportunity for safety and environmental improvements.

2. THE TECHNOLOGY

The solution used in the trial described here is the Tyre Anomaly and Classification System (TACS) from International Road Dynamics (IRD). The enabling technology is VectorSense – a unique combination of in-road sensors and customised analytic software that enables high-speed, non-stop examination of truck tyre condition. The system can examine tyres on vehicles travelling at up to 160 km/hr.

The sensors embedded in the roadway at 90° to the direction of travel create a profile of tyre conditions for each axle and each tyre of the vehicle. The footprint data is converted into an intermediate calculated value and a proprietary algorithm is applied to this value in order to categorise tyre condition (Figure 2).

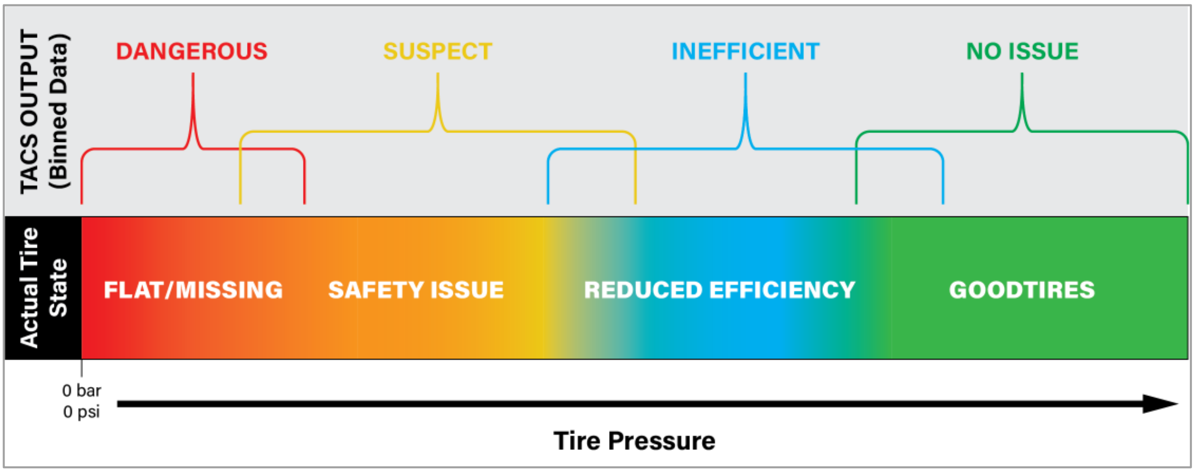

Figure 2: Relationship of intermediate value (data) to tire pressure

A tyre anomaly is considered to be a tyre that is observed to have abnormal tire to road contact pressure. This determination is made by the assessment of various parameters such as relative measurements as a comparison to other tyres on the vehicle, as well as absolute measurements of tire contact patch width, length, and pressure distribution and amplitude. Tyre anomalies can be a result of multiple factors. Inflation pressure is the primary factor, but tire condition such as tread damage or excessive wear also affect the tire to road contact pressure profile and may be identified.

The tyre contact patch for each tyre is examined in detailed slices which can be combined to provide a comprehensive data view of the tyre. The data can also be assembled to provide a map which indicates the location of any problem tyres. Figure 3 shows a truck crossing an embedded VectorSense sensor at a TACS installation.

Figure 3: Typical Tyre Anomaly and Classification System (TACS) site

<u>2.1 Implementation Experience in The Netherlands</u>

The SmartwayZ.NL mobility programme in the Netherlands consists of eight interrelated sub-projects in North Brabant and Limburg. These focus on the Breda-Venlo corridor (A58, A2, A67), the Weert-Eindhoven section of the A2 motorway, the N279 provincial road (Veghel-Asten) and the south-east Brabant region (Fig. 4).

Figure 4: Project locations in North Brabant and Limburg (Netherlands)

The programme, which started in 2016, combines smart mobility solutions and infrastructure improvements. It involves several public and private-sector organisations, as well as academia. It is a cooperative framework that supports the rapid acquisition of practical experience, knowledge transfer and the delivery of safety, efficiency and enhanced user experience along major corridors in the Netherlands.

The SmartwayZ.NL mobility programme is also intended to stimulate innovation and growth within the Southern Netherlands smart region. As part of the sub-project on the N279 Veghel-Asten road, a TACS was installed. The motivation behind this was a study conducted in 2017 which indicated that 41% of incidents involving commercial vehicles in the Southern Netherlands were caused by tyre problems. This is also consistent with national data (SmartwayZ.NL, 2018).

In this instance, the approach taken to tyre contact stress and condition management is based on providing drivers and fleet operators with decision-quality information. In other implementations of the technology, the system has been used as the basis for enforcement. There has also been a focus on the detection of 'inefficient' tyres – those which do not represent a safety threat, but which are a target for potential improvements in emissions and fuel consumption through better inflation/operational practices.

Drivers are advised if their vehicles' tyres fall within the inefficient tyre inflation pressure range via an app known as TruckMeister (Mobiliteitsplatform, 2020) (fig. 5). Tyre safety issues, however, are communicated immediately by means of a dynamic message sign located downstream of the sensor. The immediacy of the feedback to the driver can be an important element in raising the probability of corrective action. This is significant because it is not uncommon for the tractor and trailer components of a commercial vehicle to be owned by different entities. Providing immediate feedback to enable drivers to act appropriately, and quickly.

In addition to being a notification mechanism for under-inflated tyres, TruckMeister acts as a fleet management platform to support effective and efficient vehicle operations. (Olsthoorn, Arjan, 2022).

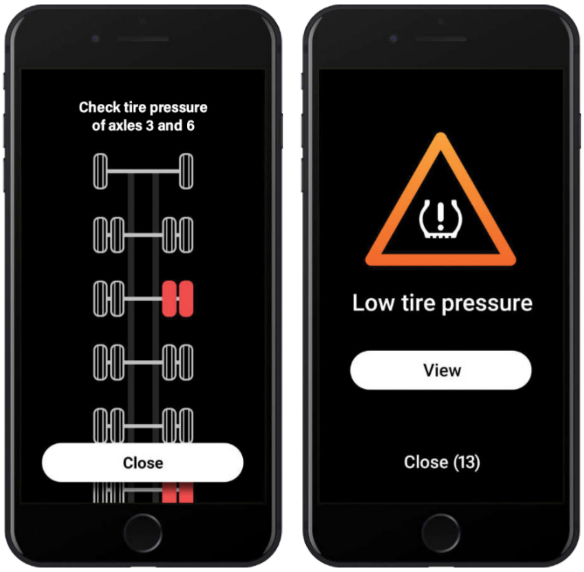

Figure 5: TruckMeister Smartphone App

Finally, the system enables a database to be accumulated that quantifies the extent of the inefficient tyre problem and will eventually provide before and after data which will show any positive effects. Sample data from the implementation is shown in Tables 1-3 below:

Table 1: Percentage of commercial vehicles with tyre problems

North Brabant (N279) Oct. 01 – Dec. 31, 2021			
	October	**November**	**December**
Tyre Anomaly (Safety)	1.61%	1.28%	1.08%
Inefficient	17.22%	18.17%	11.60%

Table 2: Percentage of commercial vehicles with one or more tyre anomalies

North Brabant (N279) Oct. 01 – Dec. 31, 2021	
Vehicle with 1 anomaly	1.13%
Vehicle with 2 anomalies	0.17%
Vehicle with >2 anomalies	0.02%

Table 3: Inefficient tyre location distribution

North Brabant (N279) Oct. 01 – Dec. 31, 2021	
Single Tyre Group	56.7%
Dual Tyre Group	43.3%
Left	45.2%
Right	54.8%
Inefficient Tyre on **Axle 1**	25.2%
Inefficient Tyre on **Axle 2**	33.2%
Inefficient Tyre on **Axle 3**	18.0%
Inefficient Tyre on **Axle 4**	11.8%
Inefficient Tyre on **Axle 5**	8.7%
Inefficient Tyre on **Axle 6**	2.9%
Inefficient Tyre on **Axle >6**	0.1%

2.2 Tyre Inflation Pressure Management Within Smart Mobility Approaches

It can be expected that the application of tyre inflation pressure and condition management to commercial vehicles will be extended in the future to cover all vehicles. This paper has shown that there is clear evidence of safety effects related to tyre inflation pressure, contact stress and condition/RCPSD. There is also a significant relationship between appropriate tyre pressure and condition/RCPSD, fuel consumption and emissions.

The approach described here focuses on the provision of decision-quality information to drivers, fleet operators and others in order to increase the probability of better operational management. The technology could also be applied within an enforcement context for the detection of unsafe tyres and the imposition of appropriate penalties.

It is important in the implementation of intelligent transportation and smart mobility systems to quantify the benefits delivered by the technology and to identify the beneficiaries.

In this case, both drivers and fleet operators are primary beneficiaries. However, there is another beneficiary group comprised of product and service providers related to tyres, for whom a raised awareness of poor tyre inflation pressure and condition should generate significant additional revenue and activity. Perhaps a future business model will involve installation and operation of the automated RCPSD monitoring system by these service providers, removing the burden from the public sector. It would seem reasonable that those benefiting commercially from the technology should contribute towards its implementation and operating costs.

Road Authorities (RAs) are also beneficiaries, as optimised tyre inflation pressure would smoothen the tyre contact stress, reducing contact stress concentrations, which may led to premature road surface failures.

In conclusion, tyre pressure and condition data are the foundation for direct benefits in terms of safety, efficiency and user experience. The technology can also be part of a larger smart mobility management system that combines data from multiple sources and provides the ability to manage all modes of transportation in an integrated and coordinated manner. It will be important to deliver results with automated RCPSD monitoring while also using the associated data and capabilities as part of this wider picture.

3. SUMMARY AND CONCLUSIONS

This paper describes an excellent example of how new technology can form the basis for new services in cities. Automated tyre pressure and condition/RCPSD monitoring can support innovative information services for drivers and fleet operators, while providing direct value to citizens and businesses by reducing fuel consumption and emissions.

Tyre inflation pressure and condition/ Road Contact Patch Stress Distribution (RCPSD) are important aspects of safe and efficient vehicle operation. There is good documentation to show a direct relationship between safety and efficiency, and tyre pressure and condition. The work conducted in the Netherlands to detect ‘inefficient’ tyres on commercial vehicles demonstrates the feasibility and practicality of the technology, while showing drivers and fleet operators the value that can be delivered. A relatively small investment in vehicle tyre pressure and condition monitoring can go a long way to addressing vital safety concerns within our transportation networks.

It is also clear that there are considerable efficiency gains in terms of fuel consumption and emissions. Because of this, drivers and fleet operators are well motivated to take corrective action. While this is a relatively small component of an overall smart mobility approach, it provides significant standalone benefits, while also offering the potential to serve as an important component in a larger multimodal smart mobility system. This offers a powerful combination of short-term incremental gains and represents valuable steps towards the bigger picture of smart mobility within a smart city.

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