INTRODUCTION AND APPLICATION OF TIRE PRESSURE MONITORING SYSTEM

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ABSTRACT

This paper shows the potential economic and social impact of the wider application of the system for controlling the pressure in the tires. It is shown that, in a very simple manner, large savings in service of vehicles (truck and trailer) can be achieved, fuel consumption and CO_2 emissions reduced, and number of traffic accidents avoided. The results of this study show that the introduction of the constant supervision of the pressure in the tires (TPMS system) should be supported for a large number of light commercial vehicles and heavy transport vehicles.

Key words: tire pressure monitoring system, regulation, general vehicle safety

1. INTRODUCTION

Exploitation of vehicles in general (trucks and trailers) showed that the working condition of tires, besides subjective approach of the driver, should be monitored objectively by controlling the air pressure inside the tire.

The importance of that approach is that the tire is sole part of the vehicle that is in constant contact with the surface, and those are the only points of contact between the vehicle and the road. Accordingly, the states in which they are located significantly affects the traffic security, and they can be the cause of accidents with fatal consequences, they can increase fuel consumption and thus higher exhaust emissions. In addition, defective tires reduce vehicle performance, reduce braking and acceleration efficiency and reduce the efficiency of management and driving comfort.

Therefore, considerable attention directed towards the control and management of the correctness of these systems by monitoring tire pressure control was recently raised. In this context, an important element of the control system and controlling the tire pressure levels, is the obligation of installing TPMS (Tire Pressure Monitoring Systems). During 2007 the Japanese tire manufacturer Bridgestone conducted extensive research in 19 EU countries. Results showed that as many as 38% cars used tires inappropriately inflated. On this occasion, they examined 38867 passenger cars, and they found that every eighth participant in traffic was driving on tires that were prone to damage due to low pressure and even posed a security risk. The low tire pressure and premature damage of approximately 40 million tires lead to

costs of approximately 3.6 billion €. In addition, it caused greater fuel consumption of approximately 5.3 billion liters.
The cost of additional fuel reaches approximately 7 billion € and further pollution of the environment with 12.3 million tons of carbon dioxide (CO_2) or additional 4.6 g/km of CO_2 for each passenger car in Europe.
All these were legitimate reasons for the legal regulation of this area and the introduction of mandatory installation of TPMS, primarily in passenger vehicles and M1 and N1 vehicles up to 3.5 tones.

2. STATUS OF EU LEGISLATION

In the EU, the legal basis of the TPMS was announced as part of the provisions adopted by the European Parliament beginning of 2009 and refers to the general vehicle safety; motor vehicles under the designation COM (2008) 316 - 2007/0243 (COD). Subsequently adopted Regulation (EC) No. 661/2009 refers to the requirements for type-approval for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended for them. This Regulation is an addition to introducing TPMS for M1 category vehicles, which introduced a series of reliefs when it comes to the process of type approval of vehicles in general, with early application of 01.11.2011.
Approval of regulation ECE R-64 in 2010 announced the mandatory possession of TPMS for new type-approved vehicles M1 and N1 categories from 01.11.2012 and for all newly registered vehicles since 11.01.2014.
All above mentioned legislation predicted the obligatory use of tires with low rolling resistance, which aims to achieve savings in fuel consumption and hence lower CO_2 emissions. These tires also need to reduce emissions and noise.
In order to achieve all of this, a very strict classification of tires that can be used according to the type of vehicle (M1-M3, N1-N3, O1-O4) or to the maximum permitted weight of the vehicle was introduced.

Numerous studies have shown that significant losses occur but with minor differences in the nominal pressures for a particular tire (Table 1).

Table 1. Some effects of insufficient pressure in the tires of a motor vehicle [2]

Criterion	**Effects of insufficient levels of pressure in the tire**	
Tire wear	↓	20% lower pressure reduces the service life of tires by 30%
Rolling resistance	↓	0.5 bar lower pressure increases the force of rolling resistance by 15%
Rolling noise	↓	Deviation of at least one of the normal pressure increases noise by 66%
Fuel consumption	↓	0.5 bar lower pressure increases fuel consumption by 2-5%
Stability when changing vehicle trajectories	↓	0.5 bar lower pressure increases the risk of side-slipping, transmission delay transmission (acceleration, braking), the effect of yield control (delay rotation)

The provisions of the TPMS are still not mandatory for heavy-duty vehicles but given its high efficiency in practice, it will probably happen.

3. APPLICATION OF TPMS

Abovementioned findings were confirmed by the "Study on tire pressure monitoring systems as a means to reduce light-commercial and heavy-duty vehicles fuel consumption and CO_2 emissions", released in July 2013.
This study was conducted by TNO Automotive, Netherlands and TU Graz, Austria, in order to show the impact of TPMS use and the reduction of fuel consumption and hence lower CO_2 emissions on light-commercial vehicles and heavy-duty vehicles.

Within that study, several approaches to the introduction of TPMS were treated:

1. Impact of TPMS on fuel efficiency and CO_2 reduction
2. The current state of the TPMS system manufacturing
3. Current and planned representation of TPMS on the market within the light-commercial vehicles and heavy-duty vehicles
4. Costs of TPMS for light commercial vehicles and heavy-duty vehicles
5. Potential safety benefits of TPMS for light-commercial vehicles and heavy-duty vehicles
6. Profitability of TPMS for light commercial vehicles and heavy-duty vehicles
7. Options or reasons for the introduction of obligatory TPMS systems

Some details about each approach are presented in the following text.

3.1. Impact of TPMS on fuel efficiency and CO_2 reduction

This research has shown that wider application of TPMS can reduce fuel consumption and thereby reduce emissions of carbon dioxide in the light-commercial vehicles and heavy-duty vehicles for around 0.2% to 0.3%. Results rely on many categories of vehicles and the observed profile exhaust emissions. The greatest reduction in CO_2 emissions can be achieved with N2 and N3 vehicles, which drive long distances. TPMS has the least impact when used in city buses.

3.2. The current state of the TPMS system manufacturing

In the practice, two systems for controlling the pressure in the tires, that work in two different ways, are used:

1. Direct control and
2. Indirect control.

The tire pressure monitoring system (TPMS) informs the driver about the condition of pressure and temperature of tires in real time, whether the vehicle is in motion or at rest.
In general, the direct system (Figure 1) consists of sensors (Figure 2) with radio frequency transmitters, fixed at each point and the receiver on the dashboard of the vehicle. It gives the information and warning of a potential problem in the tires to the driver. The system lifetime is directly related to the battery life (currently 3-10 years). Price of direct TPMS system is several times higher than the cost of the indirect system.

Figure 1. Elements of direct TPMS system

Figure 2. Sensor of direct TPMS system

The indirect TPMS system favoured by some car manufacturers, which is supported by international organizations of automobile constructors (OICA), is a cheaper option. The indirect system measures the number of revolutions of the tire at one point and compares the rotation speed of speed of other wheels. Software performs an analysis of the vibration characteristics using data from the ABS sensors within each wheel (it is essential to have ABS sensor at each wheel). The onboard computer analyzes the data and determines whether a change in diameter of the tire occurred, and software interprets it as a loss of pressure in the tire. Regardless of the number of indirect TPMS solutions, there is still significant delay until the information reaches the driver (20 to 60 minutes), which means that in case of a sudden tire pressure drop, it would not be detected and an accident would not have been prevented.
Another important difference between these two systems is that the indirect TPMS system requires driver system calibration for tire pressure adjusting or tire replacement, in order to make the system work properly. This operation depends on the accuracy of the device used to measure the pressure and the conditions in which it is done (tires should be cold). Because the drivers rarely measure the pressure in the tire, the entire process is subject to errors. This is a substantial drawback of this system because it can lead the driver into a sense of false security while driving with defective tires, because the system reports that the tires are properly inflated.

3.3. Current and planned representation of TPMS on the market within the light commercial vehicles and heavy-duty vehicles

Suppliers of TPMS equipment were consulted in order to gain insight into the current market representation of TPMS in light-commercial vehicles and heavy-duty vehicles, as well as expected trends in future market penetration in the event that fail stimulating policy measures or commitments for the application of TPMS systems.

The share of light-commercial vehicles and heavy-duty vehicles currently equipped with TPMS system is only 1% in M2 and N1 vehicles, and up to about 2.5% for N3 vehicles. Most of the system is directly installed by the vehicle manufacturer (OEM). Replacement systems occupy at least 10% and perhaps 40% of the current market penetration (these are the default data due to the limited amount of available information).

3.4. Costs of TPMS for light commercial vehicles and heavy-duty vehicles

Through a detailed questionnaire given to TPMS suppliers and other interested parties, they were requested to provide their cost estimates for the TPMS for light-commercial vehicles and for heavy-duty vehicles. Based on their response, taking into account the information available at the expense of new parts for TPMS and typical configurations of vehicles, we estimated costs of TPMS for different light-commercial vehicles and heavy-duty vehicles. Costs were estimated for the original equipment and replacement equipment, for the cases in which both truck/tractor and trailer were equipped with TPMS and for the cases where just a truck/tractor was equipped with TPMS.

3.5. Potential safety benefits of TPMS for light-commercial vehicles and heavy-duty vehicles

This research showed that tire pressure is related to almost 20% of accidents with heavy-duty vehicles. In accidents involving death or serious injuries caused by a truck/tractor driver proportion ranges from 7.5 to 10%. The introduction of TPMS should reduce the number of accidents caused by the speed and the poor condition of tires. Indicative estimate of the safety benefits introduced by TPMS system, shows benefits both in terms of reducing accidents and in terms of avoided cost.

It is estimated that properly maintained air pressure in the tires can reduce the number of accidents, caused by the speed and poor condition of the tires, between 4% and 20%, and the total number of accidents by 0.8% to 4%. The widespread use of TPMS systems in EU can reduce social costs for about 11-58 million € per year and consequently avoid mortality in individual traffic accidents with heavy-duty vehicles.

3.6. Profitability of TPMS for light commercial vehicles and heavy-duty vehicles

A cost-benefit analysis has been carried out from a social perspective as well as from end-user perspective. In the cost-benefit analysis from the social perspective the following costs and cost savings were taken into account:

- TPMS costs:
  - additional investment costs for TPMS (price excluding applicable taxes),
- Changes in usage costs:
  - fuel cost savings (based on fuel price excluding applicable taxes),
  - costs / savings associated with a change in the amount of maintenance:
    - extended lifetime of tires,
    - optimized inflation frequency,
  - cost savings associated with less service disruptions due to reduced roadside tire breakdown

- cost savings associated with a reduction of external costs:
  - reduced amount of accidents (fatalities, injuries, congestion),
  - reduced amount of pollutant emissions,

A social discount rate of 4% was used.

In the cost-benefit analysis from the end-user perspective, the following costs and cost savings were taken into account:

- TPMS costs:
  - additional investment costs for TPMS (price including applicable taxes),
- Changes in usage costs:
  - fuel cost savings (based on fuel price including applicable taxes),
  - costs / savings associated with a change in the amount of maintenance:
    - extended lifetime of tyres,
    - optimized inflation frequency,
  - cost savings associated with less service disruptions due to reduced roadside tire breakdown.

An end user discount rate of 8% is used.

3.7. Options or reasons for the introduction of an obligation to hold the TPMS system

Taking into account all considered impacts on operational and external costs, OEM-fitted TPMS is cost-effective for all considered light-commercial vehicle and heavy-duty vehicle applications. Nevertheless, suppliers expect that autonomous adoption of TPMS will be slow and that market shares will remain small in the coming years. This may be a motivation for implementing policy measures to promote the uptake of TPMS. Possible policy measures, that could be considered, can be grouped into five policy categories:

Baseline solution

- Do nothing and allow the market to take the initiative.

Stimulation measures - information

- TPMS performance standard,
- Labelling,
  - Presence of TPMS visible in tire labelling scheme,
  - In the case of introduction of an heavy-duty vehicle CO_2 labelling, the effect of TPMS influences the vehicle's CO_2 score or it could be made explicit in the label,
  - Information campaigns to better disseminate insights in end-user benefits to dealers and/or fleet managers.

Stimulation measures - financial

- Dedicated fiscal incentives or subsidies (generally at Member State level),
  - Purchase incentive aimed at end users / fleet managers,
  - Incentives aimed at vehicle manufacturers or tire manufacturers,
- Broader economic instruments promoting fuel saving and CO2 reduction,
  - E.g. CO2 tax on fuels or inclusion of heavy-duty vehicle in the EU-ETS.

Voluntary agreements with sector

- TPMS-specific voluntary agreement with OEMs and/or the transport sector,
  - Stakeholders may agree to implement one or more of the above-mentioned information-related stimulation measures,

- Stakeholders may agree to achieve certain levels of TPMS penetration in targets years,
- Broader / generic voluntary agreement with OEMs and/or the transport sector,
  - Stakeholders may agree to achieve a certain CO_2 emission reduction in target years, with increased use of TPMS as one of the reduction measures.

Regulation (mandatory fitment)

- Regulation for mandatory fitment,
  - Regulation may be aimed at vehicle OEMs or tyre manufacturers,
  - TPMS performance standard necessary to define minimum requirements for operation, malfunction, warning and pressure range,
- Classify TPMS as "eco-innovation" in a possible future CO_2 regulation for heavy-duty vehicles.

The cost of these systems depends on the distributors of original TPMS equipment and it ranges in average € 220, plus the cost of shipping and installation.
Current worldwide manufacturers of TPMS system are listed in table 2.

Table 2. Worldwide manufacturers of TPMS systems

	Direct TPMS			**Indirect TPMS**
Group	Battery-powered		Battery-free	
Sensor position	On valve / In tire	On valve		
Supplier	Schrader	P-eye	Stack	SRI/DunlopTECH
	Bridgestone		VisiTyre	NIRA Dynamics
	Pirelli			
	Wabco			
	Continental			

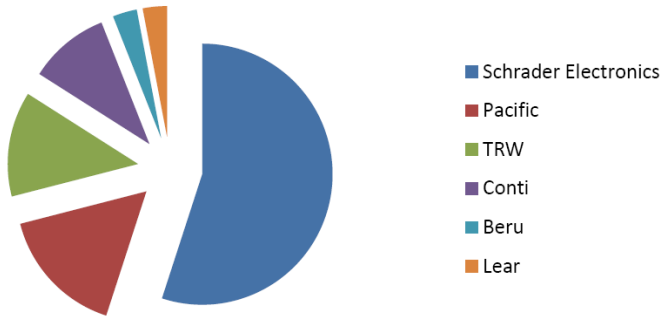

Figure 3. Representation of TPMS manufacturers by the number of sold passenger cars in 2010 [3]

4. CONCLUSION

The constant progress of human civilization aspires to greater efficiency in all aspects of life. Therefore, the goal is to constantly find ways to increase the efficiency of operation of the vehicle (motor and trailer), no matter how small they seem at first glance. To reduce fuel consumption and thereby reduce CO_2 emissions into the atmosphere, one important factor is maintaining the proper tire pressure at the vehicle. Currently, the widest application of the system is direct TPMS.

General price of TPMS equipment is installed on the vehicle has proven multiple benefits for both the owner of the vehicle, and for the wider community.

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