Transmitted by the expert from Germany

Informal document No. **GRRF-62-17**
(62nd GRRF, 25-28 September 2007,
agenda item 9(f))

Overview

- TPMS Motivations
- Principles of tire pressure monitoring systems (TPMS)
- Impact Factors for Direct TPMS
- Impact Factors for Indirect TPMS
- CO_2 and TPMS
- Effect on other regulations
- Conclusion

TPMS Motivations – Increased wear and consumption

- Fuel consumption increases by 1% every 2,9 psi / 0.2 bar the tire is under-inflated.
  - 0,4 bar under-inflation $\Rightarrow$ 2% increase in fuel consumption
  - 0,6 bar under-inflation $\Rightarrow$ 3% increase in fuel consumption

- Tire wear increases by 5% every 2,9 psi / 0.2 bar the tire is under-inflated.
  - 0,4 bar under-inflation $\Rightarrow$ 10% increase in tire wear
  - 0,6 bar under-inflation $\Rightarrow$ 15% increase in tire wear

- According to NHTSA: Tire wear increases by 15% every 2,9 psi / 0.2 bar the tire is under-inflated.

TPMS Motivations – Increased wear and consumption

- **Notice for tyre pressure devices**

- Calibration requirement according to EC 86/217
- ± 0.08 bar at calibration
- ± 0,16 bar in use

- **Notice for driving and environment influences**

- 0,1 -0,3 bar pressure boosting by driving
- Until to 0,5 bar pressure fluctuation through the change of the ambient temperature

- **Notice for acceptance by the driver**
- Drivers do not accept pressure variations <0,3 bar
  (Experience value)

Principles of tire pressure monitoring systems (TPMS)

Tire Pressure Monitoring Systems (TPMS) work by different physical principles:

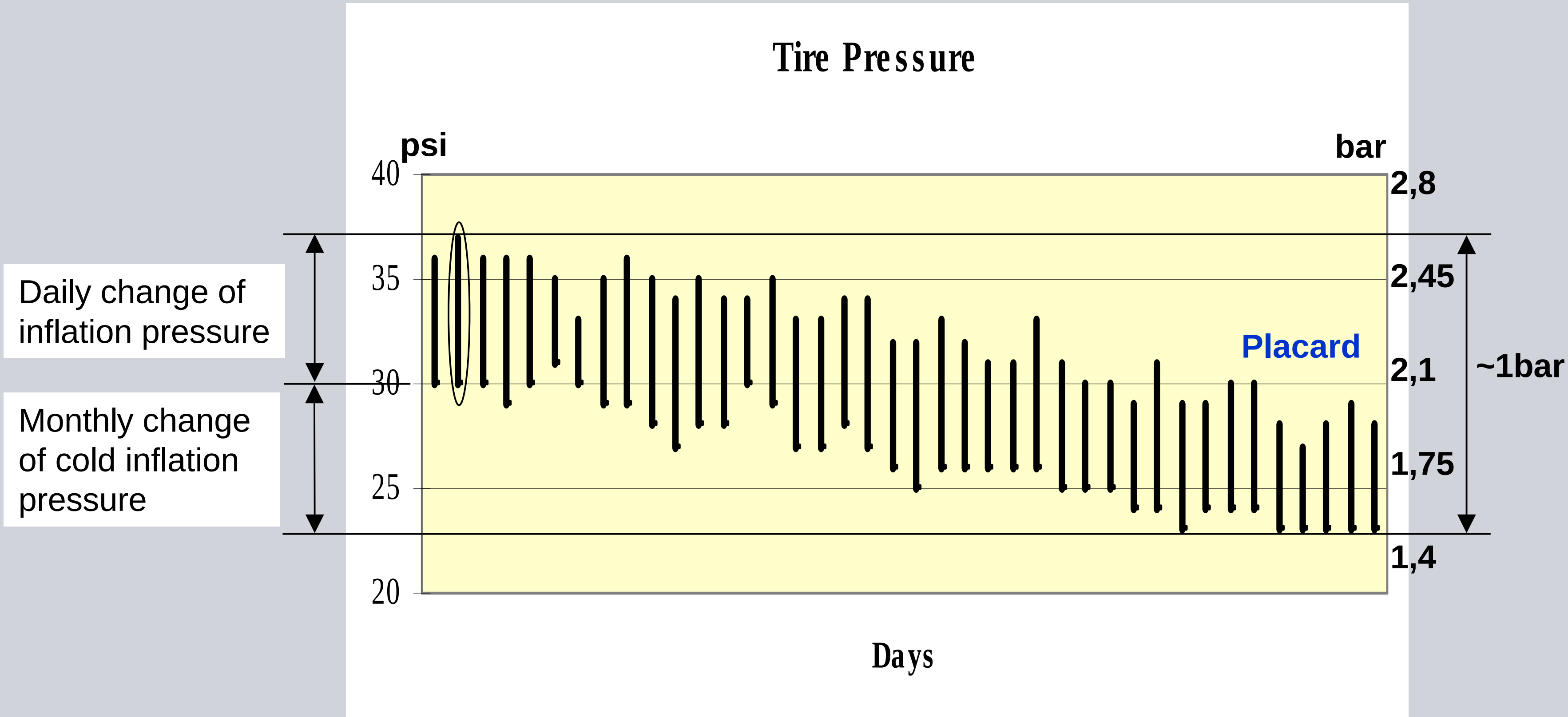
Direct TPMS are measuring the pressure directly, by having a wheel electronic which measures the pressure and transmits it by radio frequency (RF) from the tire to the chassis.

Indirect TPMS are measuring pressure indirectly, by using information from other vehicle- related sensors (e.g. ABS wheel speed sensor information) and evaluating these signals. Principles are:

- Comparison of wheel speed signals
- Analysis of resonance frequency shifts
- Comparison of wheel speed signals with absolute speed measurements (e.g. from GPS)
- Analysis of correlation patterns between wheel speed signals.
- Analysis of vertical accelerometer signals.
- Analysis of measured tire forces.
- Analysis of differences in responses to load shifts.
- Analysis of footprint
- …

Principles of tire pressure monitoring systems (TPMS): Pressure Variations over Time in one Vehicle

- Pressure changes of more than 20% of cold inflation pressure are possible during one month even the tire is not defect.



Raw Data taken from John Maxgay, GM, Presented at IQPC conference 2007, Dearborn

1 PSI = 0,07 bar

Impact Factors for Direct TPMS

I

Interact. WFC ⇔ Rim & Tire

a) Mechanical compatibility

b) Mechanical stress

c) Electromagnetic interference

II

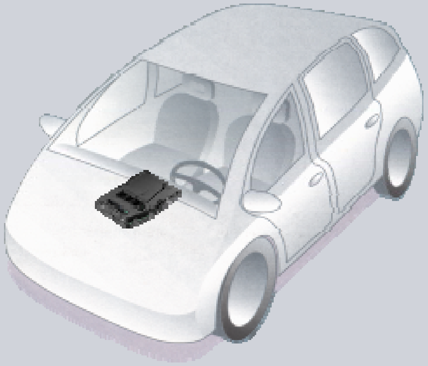
RF Channel

a) External noise

b) Jammer

c) Environmental influences

III



Vehicle

a) Electromagn. interferences Car Body

b) Car noise (EMC)

IV

User Interface

a) Warning display

b) Warning interpretation

Impact Factors for Direct TPMS: Mechanical Compatibility & Stress

Influencing Parameter	Remarks
Weight	30% less than approved solutions in the field , but with reduced functions/reliability
Compatibility w/ rims	30% smaller than today's solutions. Suitable for all ETRTO alloy and steel rims. Valve inclination 10° - 37° needs adjustable connectors Different valve lengths possible, but multiplies variants compatible with manufacturing process
Environmental stress (Mechanical, thermal, chemical, ...)	- 40° up to 160 °C

Impact Factors for Direct TPMS: Electromagnetic Interference (rim, tire)

Influencing Parameter	Remarks
Radiation power	
Rim dimensions, material	Full parametric rim model to predict RF behavior WFC low sensitivity to rim (~3 dB variance across all rims) RF performance not affected by mounting conditions
Tire a) dimensions, speed index, type b) material (electrical parameters rubber)* c) Manufacturer d) Tire design (electromagnetic field distribution)	Fit each type of tire with information from a) OEM b) Measurements of the relative permittivity and loss factor of compound rubber c) Only slight differences for the same type d) great influence from steel belt with, steel sidewall inserts

* Best would be to include electrical parameters in ECE Regulations

Impact Factors for Direct TPMS:
RF Channel

Influencing Parameter	Remarks
Environment (e.g. temperature, ground conditions, rain, snow, ...) Wheel Speed	
Jammer	Optimized data rate & bandwidth (to avoid black spots), burst / frame redundancies, randomly distributed frames, checksums, ... Remark: Fail-safe data transmission technologies, developed for military / satellite applications, meanwhile entered mass market (e.g. mobile phones) => price drop. Will become standard also in automotive applications because of rising number of wireless applications. Need of improvement of components (esp. microprocessors) to hard automotive specifications (- 40°C to 160 °C), technology not fast available)
External noise	

Impact Factors for Direct TPMS: Vehicle

Influencing Parameter	Remarks
Car body incl. wheel house (e.g. dimensions, materials, clearance to ground, ...)	Approved RF application methods 1st Simulations of wave propagation in cars using vehicle RF model from OEM (involving the complete chassis)
Damping objects (e.g. metalized windows, large/small engines, ...)	
Occupancy passenger compartment Loading	
Operating Environment Receiver (e.g. wiring harness, ground, ...	
Car noise (other devices in car)	Quality of todays EMC Specification to be improved

Impact Factors for Direct TPMS: User

Influencing "Parameter"

- Customer's perception & interpretation of warning messages
- Corrective measures derived

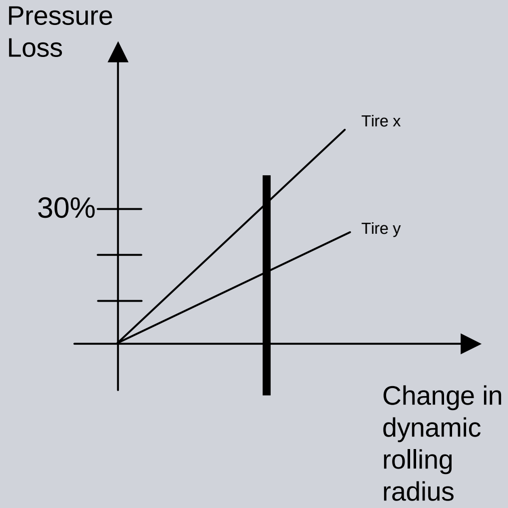
Status Today & Outlook

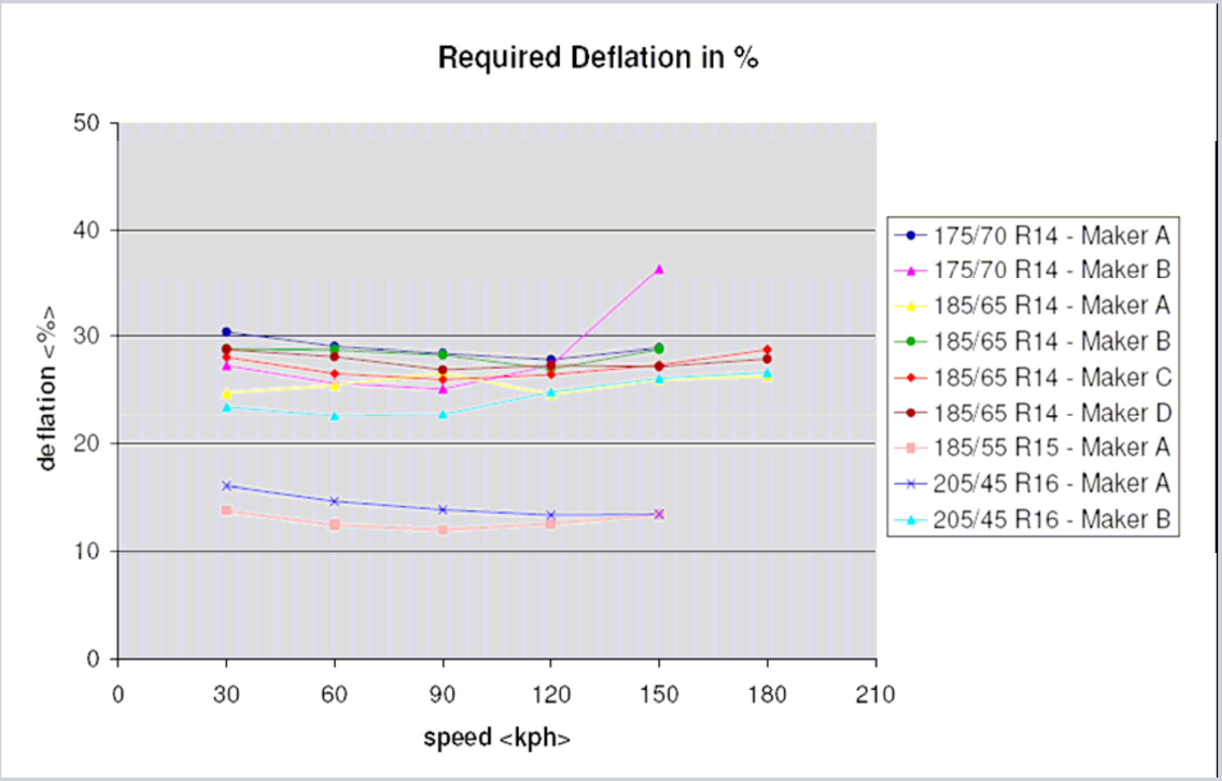
- Customers still in learning curve
- Various campaigns to increase public awareness about tire pressure maintenance started or about to start (ADAC, EC (S. Dimas, "Car of the future"), NHTSA, ...), emphasizing safety, comfort and ecological benefit.

Change of customer perception of pressure warning informations:
NEGATIV ("what's wrong again") => POSITIVE ("thanks to this I know when air in tire needs to be refilled")!

Impact Factors for Indirect Systems: Effects on Tire Construction

Tire construction would have to change, if warning thresholds are strictly defined to one warning threshold.



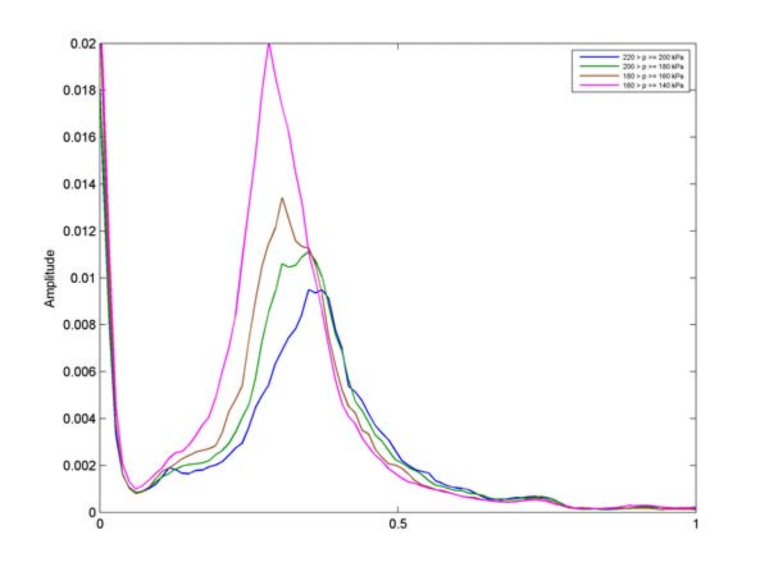


Source Dunlop Tech 2007

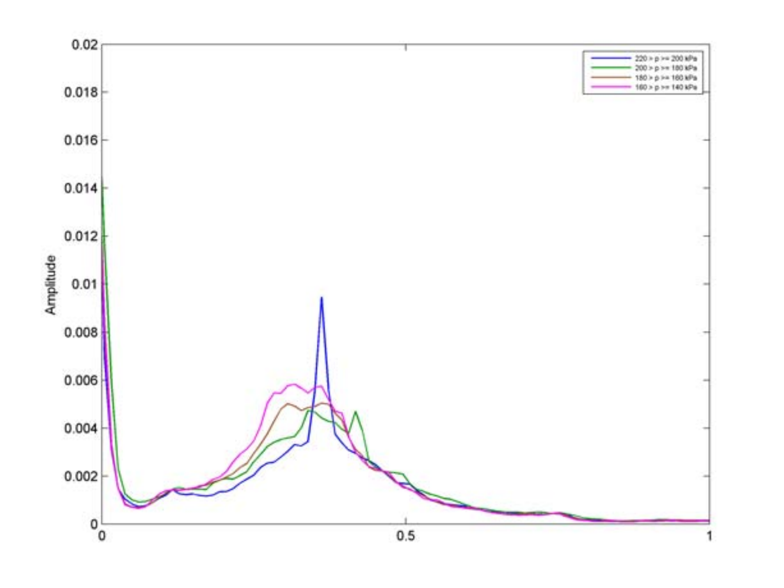
Impact Factors for Indirect Systems: Tires & spectrum properties

Tires' spectrum sensitivity to pressure changes would have to become much more uniform to achieve identical spectrum based warning behavior.

Spectrum behavior with different pressures (2,2 bar -> 1,6 bar) under otherwise identical conditions :



Sensitive tire



Insensitive tire

Impact Factors for Indirect Systems: Vehicle-related influences

Influencing Parameter	Remarks
Chassis/engine modifications	Aftermarket modifications ("tuning") can significantly influence the system => compare legislation situation for ESP systems
Adaptive chassis systems	Air suspension, adaptive dampers, …
Active driveline control	Flexible torque distribution between wheels/axles depending on road state, driving style and situation

Impact Factors for Indirect Systems:
External influences

Influencing Parameter	Remarks
Road surface/conditions	Influences are difficult to define objectively or hard to influence for a test procedure
Temperature, weather	
Driving style	

CO_2 and TPMS

The potential fuel economy benefits of low rolling resistance tire design are typically greater in magnitude, longer in duration, and more certain than the benefits from proper inflation alone. [1)]

In general assumptions are made that CO_2 – reduction can be achieved with TPMS, if always the correct pressure is applied.

Tire pressure varies during the day, caused mainly by ambient temperature and driving style.

Expensive systems may be feasible which adjust the tire always with the correct pressure

Additional technology will add additional risks to failure and misuse, which must be detected by the system

CO_2 emissions for production, transport, and storage need to be considered

[1)] Source: ecos consulting, Presentation to the International Energy Agency, 2005, “Empirical Analysis and Program Options for Low Rolling Resistance”, p18

Effect on other regulations

A TPMS regulation requires that several regulations needs to be amended.

Potential TPMS Regulations

Tires
R30/R54/R75/
R106/R108/R109

Additional Requirements
-Damping of RF transmission
-Change of dynamic rolling radius as a function of pressure change
-Change of resonance frequency shift as a function of pressure change
-Change of any potential parameter which indicates a decrease in tire's carrying capacity
- …

Rims
R124

Additional Requirements
-Mounting for TPMS wheel modules must be given
-New Regulation for rims, because ECE R124 is only for replacement wheels

TPMS
New Regulation

Definition of standard wheel Module including
- dimensions
- standard data protocols
- strength of transmission power
- temperature (ambient, tire)
-- …

Executive Summary

- Conclusion: TPMS legislation should be a technology neutral approach, applicable for all tires, rims and vehicle combinations on the market

- Consider all influencing factors and interfaces for a development of a new regulation

- It would be good to have a legislation, if the involved costs for all parties gain substantial increase for safety and environment compared to the current situation

- Improve current level of safety on roads of the contracting parties

- Find innovative solutions for solving the technological challenges