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TNO report

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Study on some safety-related aspects of tyre use

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Executive summary

Goal and scope of this study

DG MOVE has set out to assess various aspects of the tyre use and quality related to road safety, by means of the study "Study on some safety-related aspects of tyre use". This report is the result of a tender and was granted to TNO (Netherlands) with TML (Belgium) as partner.

The overall aim of the study is to propose policy options concerning the use of tyres for improvement of traffic safety. Centrally to this, is the idea that end users need to make the correct assessment in relation to the tyre condition in order to achieve a level of safety as high as possible. Within this context, the tyre condition is considered in relation to technical elements (tyre inflation pressure, tyre tread depth, tyre damage, tyre age, and meteorological influences) and one information element (driver awareness). The study addresses the topics of tyre usage and the impact on road safety (which are the potential safety improvements related to tyre usage from a technical perspective) and how can road users be supported to use tyres that have a better safety performance by policy options. The policy options are subject to a cost-benefit analysis.

Note that (apart from an accident analysis) the study does not perform new research or new tests, but instead reflects on existing studies from open data sources. By combining these insights and applying them on the study objectives, the relevant conclusions and recommendations are derived.

Tyre safety aspects

The main safety aspects that have been considered are the tyre grip level (maximum force that can be transmitted between tyre and road) and tyre failure in terms of sudden loss of inflation pressure (often referred to as blowout). The tyre grip level is mainly affected by meteorological influences in combination with the tyre condition (tread depth, ageing, inflation pressure), and tyre choice (Summer tyre or Winter tyre). A reduced grip level extends the stopping distance of vehicles and can result in vehicle instability (e.g. spin out). The risk of tyre blowout failure is related to inflation pressure being too low and tyre damage (including effects of ageing) which are strongly linked to tyre maintenance. When tyre blowout failure occurs it leaves debris on the road, the vehicle can become unstable, or may come to a halt at an unsafe location for changing tyres.

Tyre usage (Task 2)

Tyre usage concerns the condition of tyres as found on vehicles in Europe and their use in summer and winter conditions respectively. The tyre usage is assessed from several (statistical) data sources such as consumer awareness campaigns, periodic and roadside inspections and accident recordings that are either publically available, or have been provided by stakeholders. The tyre usage is assessed for passenger car tyres and for commercial vehicles (when available), and the following observations are made:

- Winter tyre use
  The use of Winter tyres is affected by national legislation in EU member states and the occurrence of winter conditions. Member states with high occurrence of winter conditions typically mandate the use of Winter tyres for a fixed period. In these member states up to 90% (some report 100%) of the vehicles is equipped with Winter tyres during the mandated periods. For member states where the use of Winter tyres is recommended a large variation is found ranging from 30% to 80%.
- Tread depth
  The share of vehicles that is equipped with tyres that have a tread depth close to or below the legal limits is estimated to between 10% and 20%. Tread depth of Winter tyres generally is more due to specific Winter tyre requirements in member states.
- Inflation pressure
  Deviations in tyre inflation pressures are generally below the recommended settings, and sources indicate that up to 20% of passenger cars have one or more tyres with a reduced inflation pressure that is considered dangerous. For heavy duty vehicles it is found that the inflation pressure of pulling vehicles is better maintained than trailers, probably due to the fact that the owner of the trailer is not always the user (i.e. rental trailers).

- Tyre damage and ageing
  Reports from visual tyre inspections for damages indicate that about 30% of vehicles with Summer tyres have at least one tyre that shows signs of ageing or other irregularities that increases the risk of tyre failure. Remarkably the results indicate that less than 10% of the vehicle population with Winter tyres shows these types of damages, suggesting that Winter tyres are better maintained than Summer tyres, or that people using Winter tyres take better care of tyre maintenance in general.

Note that tyre labels have not been considered as they have been introduced only recently.

Role of tyres in road safety (Task 3)

As mentioned above the main safety aspects of tyres are considered to be related to the grip performance of tyres and potential sudden loss of inflation pressure (e.g. tyre blowout failure). An overview of technical aspects of the tyre condition affecting these safety aspects is listed below:

- Winter tyre
  Winter tyres are engineered for better grip in a lower temperature range than Summer tyres, and the tread design is optimized for traction on winter surface conditions. Generally the industry recommends the use of Winter tyres below 7 degrees Celsius however the precise temperature below which Winter tyres excel in grip performance depends on meteorological conditions and may be tyre specific. An increased tread depth of Winter tyres compared to the legal requirement of 1.6 mm improves grip on snow (however some Winter tyres also show good grip performance at 1.6 mm).
- Tread depth
  Tyre grip performance on wet roads is better with increased tread depth as it increases the speed that can be driven without aquaplaning and shortens braking distance. A strong reduction in grip on wet roads is found for tread depths below the legal requirement.
- Inflation pressure
  Both the grip performance and the risk of tyre blowout failure are affected by inflation pressure. A deviation in inflation pressure that is too large reduces the grip level and can lead to vehicle instability also on dry roads due to the reduced stiffness. Tyre blowout failure can occur due to heat generation from large tyre deformations that result from severe underinflation.
- Tyre damage and ageing
  In general tyre damage poses a threat of tyre blowout failure. Secondly the mechanical properties of rubber change due to exposure to the environment (e.g. heat, UV, moisture), resulting in less strength, less flexibility, and in general less resistance to heat and mechanical damages. The major safety concern is the increase of the risk of tyre blowout failure, however ageing also reduces the tyre grip performance. Ageing is difficult to quantify as the extent of exposure is a mix of meteorological conditions, specific use of the vehicle (e.g. indoor parking) and tyre age.

Road accidents and tyre usage (Task 4)

The occurrence of road accidents is related to tyre usage from a causation study carried out in the scope of this project using accident records from the GIDAS[1] database, and a study presented by NHTSA[2]. With the GIDAS database, only the causation for tyre grip accidents has been analysed due to the available population. The analyses have been done for different categories of temperature and road surface conditions that are relevant for tyre grip performance of summer and Winter tyres respectively. The population of specific tyre conditions in accidents is compared to a reference group that is assumed to be representative for vehicles on the road in general to assess the potential accident reduction. A similar approach has been used on the NHTSA study data; however the information presented contains fewer details about the accident conditions. That study relates the tyre tread depth, inflation pressure and existence of damages to accidents in general.
The results of the studies are used to assess the safety potential using improved tyres for specific accident conditions. An overview of the safety potential is provided in Table E 1.

[1] German In-Depth Accident Study, http://www.bast.de/EN/FB-F/Subjects/e-gidas/e-gidas.html
[2] Tire-Related Factors in the Pre-Crash Phase (NHTSA Technical Report DOT HS 811 617), April 2012

Table E 1: Summary of identified safety potential by improving tyres.

Accident condition	Inadequate tyre	Improved tyre	Accident probability reduction / ARR*)	Source
Grip accidents on dry road, below zero	Summer tyre	Winter tyre	45.8% / 0.816	GIDAS
Grip accidents on snow covered roads	Tread depth Winter tyre below 4 mm	Tread depth Winter tyre 4 mm or more	56.1% / 1.147	GIDAS
Grip accidents on wet roads or snow covered roads (assumed)	Tread depth at or below 1.6 mm	Tread depth above 1.6 mm	84.1% / 3.722	NHTSA
Tyre related accident (assumed mainly tyre blowout failure)	Incorrect inflation pressure	Correct inflation pressure	35.1% / 0.446	NHTSA
Tyre related accident (assumed tyre blowout failure)	Damage	No damages	85.9% / 5.194	NHTSA

*) The ARR (Accident reduction rate) indicates the potential reduction of accidents for 1% increased share of improved tyres for the distribution used to calculate the accident probabilities

From these results, it is concluded that the use of Winter tyres will reduce grip accidents in winter conditions, and maintaining a tread depth of more than 4 mm will reduce grip accidents in snow conditions. In general maintaining a tread depth above the legal requirement of 1.6 mm will reduce accidents, which are assumed mainly grip accidents on wet and snow covered roads. Regarding tyre blowout failure, it is found that avoiding tyre damage and incorrect inflation pressure will reduce accidents. Typically the combination of damage and incorrect inflation further increases the risk of an accident.

The next sections address for each of the safety aspects the related regulation in member states and policy options.

Harmonization use of snow tyres (Task 5)

The benefits of harmonised measures concerning the use of the most appropriate tyres for different climatic conditions are evaluated. In relation to the definition and legislation of Winter tyres, different important aspects need to be clarified. Firstly, it needs to be noted that different definitions may apply to 'Winter tyres', corresponding to different technical properties: M+S marked tyres do not meet performance requirements in contrast to tyres marked with the Alpine symbol (3 Peak Mountain Symbol - 3PMS, see Figure E 1) which indicates the tyre meets performance requirements on snow.

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Figure E 1: Alpine symbol (3PMS).

Therefor only the Alpine symbol ensures a specific performance on snow, as it follows **UNECE Regulation 117,** to be implemented in the EU through Regulation **(EC) 661/2009,** requiring for snow tyres a minimum level of performance threshold on snow (braking and traction). The safety benefit of Winter tyres in general is described under Task 3, and has been quantified in many comparative tests that are documented and available for consumers. This distinction is also carried in the existing legislation in EU member states. Most EU member states only mention the use of M+S tyres. Specific mention of the "Alpine symbol" is only made in Germany and Sweden.

Secondly, existing legislation in EU member states comes in different varieties. Member state legislations may be formulated differently and define the following elements (a) the specific period of time (calendar dates), (b) meteorological conditions, (c) specific locations and (d) further technical requirements (tread depth requirements typically range between 1.6 and 4 mm for cars, and 5 mm for trucks).

Overall, the following distinction is made:

a) No legislation: In member states without legislation the use of Winter tyres is generally recommended by road user groups when the occurrence of conditions of snow and ice is usual.
b) Conditional: The legislation for conditional fitment is generally during occurrence of winter conditions (or mandated by road signs) within a fixed period. This type of legislation is typically used in member states with incidental winter conditions, or occurrence in specific regions of member states (e.g. mountain regions)
c) Fixed period: In member states, typically with long duration winter conditions, the fitment requirement is for a fixed period regardless of the weather conditions.

Table E 2 shows an overview of Winter tyre regulation in EU member states with an indication of the occurring winter conditions (n = none, i = incidental, s = severe, r = regional).

Table E 2: Overview of current Winter tyre legislation in EU member states.

No legislation	Conditional	Fixed period
• Belgium [i]	• Czech Republic (*) [s]	• Austria (**) [s]
• Bulgaria [s]	• France [r]	• Croatia [s]
• Cyprus [n]	• Germany [i]	• Estonia [s]
• Denmark [i]	• Luxembourg [i]	• Finland [s]
• Greece [r]	• Romania (*) [s]	• Italy [r]
• Hungary [s]	• Slovenia (*) [s]	• Latvia [s]
• Ireland [i]	• Switzerland [s]	• Lithuania [s]
• Malta [n]		• Slovakia (**) [s]
• Netherlands [i]	(*) within a period	• Sweden [s]
• Poland [s]		• Norway (**) [s]
• Portugal [n]		
• Spain [r]		(**) not all vehicle categories
• United Kingdom [i]		

This combination (different tyre requirements and different national legislations) requires a specific approach to assess the possible impacts of different policy options on safety. Within the current project, this analysis is built around the following elements:

a) The identification of accidents under relevant conditions. Relevant meteorological conditions (based on the analysis of the EFSA and DWD databases) and current tyre usage statistics are used to enrich the CADAS database and identify those accidents where the different policy options could have an influence.
b) The assessment of the possible effects linked to different policy options is based on the analysis of information presented in the GIDAS database. As a result of the comparison of grip-related accidents between two vehicle categories (those with and those without the appropriate tyre use conditions), it is possible to identify risk reduction rates for changed tyre use behaviour. This is then extrapolated to the overall fatality statistics.

In particular, the following possible policy options are identified as a result of the analysis of current legislation in relation to the use of Winter tyres:

a) Promoting the voluntary use of Winter tyres in all Member States (with and without existing legislation)
b) An increase of the use of Winter tyres in those Member States with existing (mandatory or conditional) legislation as a result of improved enforcement activities;
c) A shift of relevant legislation from M+S towards 3PMS performance requirements;
d) A minimum thread depth for Winter tyres of 4 mm.

Tyre tread depth requirements (Task 6)

Passenger cars with tyres that have a tread depth below the legal required value of 1.6 mm are significantly more involved in accidents on wet roads. The NHSTA study addressed in Task 4 indicates a reduction in accident probability of 86% when using tyres with adequate tread depth. Increased tread depth generally will improve the tyre grip level (and safety) on wet roads and snow covered roads. As a result, organisations in different member states recommend changing tyres before the minimum tread depth is reached with a margin of about 1 mm or more. For passenger car Winter tyres a variety of requirements is adopted by member states up to 4 mm tread depth. A required tread depth for truck tyres exists in a large share of member states and ranges from 1.0 to 3.0 mm, and for truck Winter tyres at least one member state requires 5.0 mm tread depth. There can be member states without tread depth requirement for truck tyres, meaning trucks are allowed on the road without any tread left on the tyres.

Increasing the minimum tread depth requires changing tyres more often, leading to higher replacement cost and environmental burden due to waste increase. The average age of tyres will reduce, resulting in less ageing effects. Tyres with reduced tread depth have less rolling resistance, and thus earlier replacement may also increase fuel consumption of vehicles. If the change in minimum tread depth requires adapting the tyre wear markings it can lead to high cost for tyre manufacturers when tyre moulds need to be modified.

To ensure sufficient traction on snow a minimum tread depth is required for truck tyres. This will reduce the risk of aquaplaning as well, which however is less likely to occur compared to passenger cars. Maintaining a minimum tread depth will also prevent too extensive wearing of the tyres that can result in tyre blowout failure.

Consumer awareness (Task 7)

Specific information on consumer awareness in relation to mobility, vehicle technology or tyre choices is very scarce. No studies were found that provided relevant information. Information about awareness of road users regarding tyres and safety was obtained from the stakeholder questionnaire. An overview is presented of relevant findings in relation to consumer awareness. In general, it is indicated that end-users (passenger car) are still lacking awareness on the importance of tyre properties and tyre use in relation to safety. Professional drivers are more aware of this. In particular national administrations may also be lacking this know-how, although this differs between member states.

From other fields of practice where consumer awareness is linked to health and safety, it was found that long-term information campaigns may elicit a behavioural response away from undesired behaviour for between 10 and 20% of the persons targeted. A good example on consumer awareness, in relation to the correct use of tyres, is present in Germany. In this example, consumers are reminded at different occasions (carwash, parking, etc.) on the importance of correct tyre use on safety, and are actively helped or engaged to check on the status of their own vehicles' tyres. In general consumers should be made aware of tyre safety behaviour when confronted with relevant situations such as purchasing, car maintenance, holiday planning, etc.

Such awareness campaigns are at least partially already conducted by the tyre industry, consumer groups and safety organisation to inform road users of the relevance of tyre for safety. However, these information campaigns are also mostly limited to the retail points. These campaigns typically address tyre inflation pressure, the use of Winter tyres and tread depth. Additionally information about tyres and road safety is provided using different media such as television and internet.

Tyre Pressure Monitoring Systems (Task 8)

Two categories of Tyre Pressure Monitoring Systems exist.

- Direct systems use devices that register the pressure inside the tyre. These systems typically are battery operated and require installation by specialists (and reset in case of mounting different specification tyres). The systems can be installed as an aftermarket solution, and generally need to be replaced when the battery life expires (5-10 year). Part of the systems is exposed to the environment and therefore can be prone to damage. For the use of Winter tyres a duplicate set of systems is required when these are mounted on separate rims. The end user can be provided with real-time inflation pressure readings in addition to the warning function, and has little interaction with the system. The cost for installation of direct systems is estimated at 50 Euros per wheel.

- Indirect systems rely on wheel speed signals from ABS to estimate underinflation of one or more tyres. These systems do not require additional hardware in the tyre wheel assembly, and are available only as ex-factory systems. The end user is required to reset the system when tyres are changed, or when inappropriate warnings could be generated (e.g. when adapting tyre inflation pressure for loading of the vehicle).

Safety related performance

- Indirect TMPS require user actions to recalibrate the system in case inflation pressure settings are adjusted to loading of the vehicle. Scenarios exist where a sequence of incorrect execution of the calibration procedure can lead to unsafe inflation pressure. There are however no accidents known that can be related to these scenarios, and therefore it is not assessed as real threat.
- Detection of underinflation on all tyres simultaneously is challenging for indirect systems due to their working principles. This scenario however does not seem to be the most important safety concern. The primary threat is quick loss of inflation pressure of a single tyre due to puncture or other reasons that can lead to tyre blowout failure. The speed of detection for this scenario should be significantly less than 10 minutes as defined in the current regulation, however based on the technical working principles it is expected that both technologies can detect this event with adequate response time.

The user needs to take action on warnings of TMPS, and therefore there is a large factor of perception on usefulness of warnings. For systems providing inflation pressure real time, users can proactively take action to keep inflation pressures at the correct level, and then it is important that the pressure indication at the air filling station matches the TPMS indications. Based on the available information on consumer behaviour it cannot be assessed if an enhancement of the current performance requirements of Tyre Pressure Monitoring Systems will lead to a better maintenance of inflation pressure. However user acceptance of Tyre Pressure Monitoring Systems is related to consumer awareness regarding the relevance of having correct tyre inflation pressures.

Stakeholder input (task 9)

A list of about 130 stakeholders has been assembled including tyre suppliers, TPMS suppliers, vehicle OEMs, road user organizations, safety institutes, national authorities, vehicle type approval organizations, etc. Almost 50 questionnaire replies have been received from organizations in more than 15 member states. The questionnaire respondents provide information mostly on the topics around "vehicle and tyre population", "tyre regulation and impact on use", and "tyre use and consumer awareness". The replies confirm that a large variation in driving conditions between member states exists. Generally the questionnaire answers indicate that the tyre usually is not the cause of an accident, but can have a significant influence on the outcome of the accident specifically for slippery road conditions. The introduction of tyre labelling is perceived as a positive step throughout Europe as it improves consumer awareness and challenges the tyre suppliers to make high quality tyres. Extensions of tyre labelling to indicate tyre performance for more operating conditions is suggested by many stakeholders.

A stakeholder meeting was held in Brussels with 41 attendants from 31 organizations. The meeting summary is included in this report, and the main conclusions are listed below:

- Winter tyre
  A unified definition of a Winter tyre is put as a requirement for European harmonisation and stakeholders propose to use the 3PMS indication for the definition of a Winter tyre. The member states however should be able to define own legislation to mandate the use of Winter tyres. On a voluntary basis additional marking can be applied to indicate when the specific tyre is designed for ice conditions (i.e. 'Nordic' Winter tyre). Consumer awareness can be improved by providing more information on tyre performance under different conditions and consumers should be supported with information from member states when travelling across borders in the winter season.
- Tread depth
  Based on the information provided, stakeholders conclude that there is insufficient evidence of a reduction of wet road accidents by an increase of tread depth to justify a revision of the current tread depth regulation for passenger car tyres. For passenger car Winter tyres an increased tread depth requirement would be supported when it is sufficiently based on evidence of improved safety and that it could lead to harmonisation across Europe. For truck tyres the introduction of an EU regulation is supported to achieve a level playing field, and also results in harmonisation across Europe.

- Inflation pressure
  Stakeholders conclude that improvement of maintaining correct inflation pressure cannot be achieved by introducing TMPS alone, but also an increase in consumer awareness and some education in adjusting inflation pressures is also required. Air filling stations should be made widely available (free of charge) and calibrated to ensure that proper inflation settings can be maintained. A more active role of member states would be welcomed. Stakeholders indicate that new requirements for TPMS should be defined; however several stakeholders state that any revision should be based on evaluation of the current regulation. TPMS should be introduced in other vehicle categories.
- Tyre ageing
  Tyre visual inspection is currently the only method to get indications about tyre ageing, and the need for of inspections is emphasized by stakeholders also regarding other tyre conditions aspects (e.g. damages, tread depth and inflation pressure). In practise for most vehicles tyres wear to the minimum tread depth before effects of ageing can be noticed.

Possible EU measures (task 10) and their cost-benefit analyses (Task 11)

Measures that could be implemented at a European level were identified for which social cost-benefit analyses were executed. The identified measures focus on (1) the harmonised use of 'Winter tyres', (2) tyre tread depth requirements and (3) tyre pressure and monitoring systems. In addition, covering all three topics, the importance of improving consumer awareness was identified as a major concern warranting specific measures. As a result of preparatory work done in the current study, it was indicated that tyre age and ageing effects are of relatively little importance towards road safety and are difficult to objectify. In contrast, tyre damages play a more important role but precise quantification remains an issue. Therefore no specific measures on tyre ageing and tyre damages were analysed.

Eight scenarios were identified as input for the Social Cost-Benefit Analysis (SCBA) that was performed in the current study:

Harmonisation of the use of Winter tyres
- Scenario 1: behavioural change through voluntary pick-up
- Scenario 2: behavioural change through enforcement
- Scenario 3: 3PMS in national legislations

Tyre tread depth requirements
- Scenario 1: behavioural change through voluntary pick-up (legal limit)
- Scenario 2: forced renewal of tyres below legal limit, depending on tyre tread depth, through enhanced enforcement (police enforcement or vehicle periodic checks).
- Scenario 3: 4 mm tread depth requirement for Winter tyres

Tyre pressure maintenance
- Scenario 1: change of performance requirements (UNECE regulation 64) on TPMS
- Scenario 2: voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations.

However, other possible measures were also identified.

Throughout the study, the importance of consumer awareness was considered. Although little evidence could be found in scientific literature (within the working domain of road safety), findings in other domains (medicine, health and safety) and practical experiences were considered important enough to incorporate improvements in consumer awareness in scenarios that rely on voluntary changes or enforcement activities to change behaviour. The German example for improving consumer awareness on the use of tyres is considered a good practice. In particular, the following elements are of interest[3] :
– Unified information, to be distributed by different organisations
– Extending information exchange in terms of frequency and content

[3] The impact of such awareness campaigns is very much product dependent. In the current project, a generic effect percentage was used (10-20% behavioural change, away from aberrant behaviour). However, a detailed market study is more appropriate to analyse the effect of consumer awareness on tyre use.

The Social Cost-Benefit Analyses is based on information on road fatalities; however the calculation considers cost reductions from a fixed ratio of fatalities, injuries and material damages. The main conclusions for the different scenarios are presented in Table E 3 (base year 2012).

Table E 3: Summary of social cost benefit analyses for policy options.

Policy	Included measures	Main cost elements	Benefit-cost ratio[4]	Safety benefits[5]
Harmonisation of the use of Winter tyres				
Behavioural change through voluntary pick-up	Consumer awareness campaign	Consumer awareness campaign, purchase of tyres and rims	0.40	Between 7 and 14 fatalities avoided (out of 588)
Behavioural change through enforcement	Police enforcement Application of regular periodic checks	Periodic inspection: time cost Enforcement actions: police time cost Purchase of tyres and rims	Between 0.33 and 0.44	Between 8 and 16 fatalities avoided (out of 588)
3PMS as standard in national legislations	Referral in national legislations to EC Regulation 117.2 and the so-called 3PMS standard	Tyre purchase costs (partial price increase) Gradual replacement of production facilities R&D costs	1.89	Between 14 and 28 fatalities avoided (out of 588)
Tyre tread depth requirements				
Behavioural change through voluntary pick-up (valid for vehicles running Summer tyres below legal 1.6 mm limit)	Consumer awareness campaign	Campaigns (replacement cost of illegal tyres not considered)	Between 34.21 and 68.43 (assuming 10 to 20% change)	Between 14 and 28 (out of 1584)
Behavioural change through enforcement (valid for vehicles running Summer tyres below legal 1.6 mm limit)	Police enforcement Application of regular periodic checks	Periodic inspection: time cost Enforcement actions: police time cost (replacement cost of illegal tyres not considered)	Between 2.63 and 5.25 (assuming 50 to 100% change)	Between 71 and 142 avoided (out of 1584)
4 mm tread depth requirement for Winter tyres assuming voluntary behavioural change	Consumer awareness campaign	Campaigns Tyre purchase cost (earlier renewal)	Between 0.88 and 0.92	Between 2 and 3 (out of 330)
Tyre pressure maintenance[6]				
Change performance requirements (UNECE regulation 64) on TPMS	Consumer awareness campaign Updating of TPMS	Campaigns TPMS purchase cost	Between 1.26 and 1.08	Between 11 and 88 (out of 12815)
Voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations.	Consumer awareness campaign Equipped petrol stations	Campaigns Tyre pressure monitoring and filling equipment	Between 3.65 and 7.61	Between 28 and 109 (out of 12815)

[4] Values lower than 1 indicate that costs outweigh benefits. Values higher than 1 indicate benefits outweigh costs.
[5] Values between brackets are estimated total of relevant fatalities (Values are for EU28 without Bulgaria for all measures and without Greece for Winter tyre related measures)
[6] SCBA for tyre pressure related measures include benefits as a result of fuel consumption improvement and CO_2 emission reductions

General conclusions and proposed actions

Regarding actions for different tyre aspects the conclusions and proposed actions are listed below. Stakeholders are generally in favour of harmonisation of the tyre use legislation to ease transport across EU member states and to achieve a level playing field.

Conclusions

- Winter tyre
  Following laboratory study results, it can be stated that Winter tyres have an improved performance relevant for road safety compared to Summer tyres for low temperatures and snow or ice road conditions. This is, to some extent, confirmed in accident data. The main interest is to define a standard for Winter tyres that is common for all member states. The unified Winter tyre definition should be based on the current 3PMS approval test. Also from a technological point of view, it can be stated that using the 3PMS test as a base is supported as it ensures a minimum level of performance for Winter tyres that exceeds the capability of Summer tyres. A more detailed assessment of tyres under specific conditions (e.g. wet grip low temperature, or ice testing) will allow consumers to choose tyres that match their use better, and increase awareness of the relevance of choosing the right tyres. Enforcement and consumer awareness campaigns can extend the use of Winter tyres under appropriate conditions.
- Tread Depth
  Firstly, technical performance testing indicates an improved safety level on wet roads when tread depth is increased. The accident data used in the current study however indicates no benefit in terms of reducing the number of accidents by increasing the minimum tread depth. Also, stakeholders do not seem to provide sufficient support to revise the current minimum tread depth for passenger car tyres. Secondly, more accidents do occur when the tread depth is below the minimum tread depth (about 25% of tyre related accidents), indicating that enforcement would bring safety improvements. For Winter tyres a harmonized tread depth is preferred, to a level that is to be chosen based on evidence of safety improvements. The results of the study suggest that 4 mm could be a suitable level based on accident analysis and existing national legislation in member states. For truck tyres a harmonized tread depth is preferred to ensure that cross border traffic is seamless. The results of the study suggest that 1.6 mm could be a suitable level based on existing national legislation in member states.
- Inflation pressure / TPMS
  Poor maintenance of inflation pressure can lead to tyre underinflation which is unsafe. This can be prevented by Tyre Pressure Monitoring Systems, however the user is required to take action and in that respect consumer awareness is very relevant. Additionally the air filling stations need to provide correct pressure indication not to confuse the driver. The major safety concern of inflation pressure is quick deflation that can lead to tyre blowout failure or vehicle instabilities. Tyre Pressure Monitoring Systems can detect such events, however the current regulation prescribes a detection time of 10 minutes while safety critical situation can take place over several seconds. There are no accidents known to result of faulty user interaction with the Tyre Pressure Monitoring System (e.g. resetting). Consumer awareness in general seems to be relevant to improving inflation pressure maintenance on vehicles.
- Tyre damage and ageing
  The most important safety impact of tyre damage and ageing is that it can lead to tyre blowout failure. Only by visual inspection the condition of the tyre can be assessed for these aspects. A safety improvement can be achieved by more inspections between regular periodic vehicle inspections on the tyre condition, during which at the same time inflation pressure and tread depth can be checked. Introducing (dedicated) tyre inspections will increase consumer awareness.

In summary the actions to improve safety on a European scale are proposed on the next page.

Proposed actions for policies (in order of cost effectiveness):

A. Increase efforts for campaigning and enforcement of current tread depth legislation
B. Increase efforts for campaigning of tyre inflation pressure maintenance
C. Provide sufficient access to calibrated air filling stations[7]
D. Define a unified Winter tyre with the requirement to have the 3PMS marking
E. Include a requirement for quick deflation detection in TPMS regulation with a short reaction time (e.g. several seconds rather than minutes)
F. Install a harmonized tread depth requirement for Winter tyres (e.g. 4 mm[8])
G. Increase efforts for enforcement of Winter tyre legislation
H. Depending on the occurrence of wintery road conditions and member state-specific mobility demand increase awareness campaigns or install Winter tyre legislation

Note: item G and H may not be cost effective as a policy option; however the estimated safety benefit corresponds to 3% reduction of the number of fatalities under wintery conditions

The following actions are not supported with a cost benefit analysis, but are expected to be beneficial:

I. Install a harmonized tread depth requirement for truck tyres (e.g. 1.6 mm)
J. Organise tyre inspections on a voluntary basis or regulated between periodic vehicle inspections

[7] CBA on introducing regulation for air filling stations is not carried out
[8] Insufficient data available to carry out CBA to define threshold value

Abstract

The tyre is a key component that affects road safety. The European commission has posted a tender aimed to study what measures on a European level can be taken in relation to the use of tyres to improve road safety. The results of this study, supported by a cost benefit analyses and carried out by TNO and TML, are described in this report. The study considers the use of Winter tyres, tread depth requirements, tyre inflation pressure maintenance and tyre ageing effects and damages. An assessment has been made of the tyre safety performance, current use of tyre and consumer awareness, tyre related accident statistics and existing regulations for the different tyre aspects (including TPMS). Results from analyses on accident records from Germany (GIDAS) and a NHTSA study provide estimation of safety benefits. Policy options are defined and estimations are made of the accident reduction on a European scale to assess the monetary benefits, which are compared to the associated cost of execution of the policies. The results indicate that extended enforcement of tread depth regulation and increase of tyre pressure maintenance are most cost effective. For Winter tyres it is cost effective to introduce a harmonised definition using the 3PMS performance criterion, and installing a dedicate tread depth requirement of 4 mm would be around break even. Promoting the use of Winter tyres, or extending the enforcement of the use of Winter tyres may not be cost effective as a policy option, however the estimated safety benefit is significant (i.e. 3% reduction in the number of fatalities during winter conditions). Installing a harmonised tread depth for truck tyres, and organising tyre inspections between periodic vehicle inspections are expected to be beneficial, but have not been subjected to the cost benefit analysis.

Contents

1 Introduction

1.1 Background

DG MOVE has set out to assess various aspects of the tyre use and quality related to road safety, by means of the study "Study on some safety-related aspects of tyre use". This report is the result of a tender and was granted to TNO (Netherlands) with TML (Belgium) as partner. The following text is taken integral from the tender specification [1] to explain the background of the study.

The Commission adopted in July 2010 the Policy Orientations on Road Safety for 2010-2020. One of the strategic objectifies identified by the Commission is the enforcement of road safety rules. The European Parliament in its report on road safety called for a harmonised approach on Winter tyres for 'passenger cars, buses and lorries in the EU regions, taking into account the weather conditions in each Member State'. It also called upon the Commission to propose 'common standards for vehicle tyres, in particular for tread depth and tyre pressure' and 'specifications for Tyre Pressure Monitoring Systems (TPMS) with a view to ensure that tyres are used properly'.

A number of Member States have already implemented measures requiring the use of Winter tyres to circulate under certain whether condition and/or during certain periods of time.

With the inclusion of UNECE Regulation No 117 in the EU legal framework, the definition of 'snow tyres for use under severe snow conditions' is based on performance requirements, notably concerning the tyre's grip during acceleration and braking on snow. These tyres are identified by a specific 'alpine' pictogram (i.e. the 3-peakmountain with snowflake symbol) on the sidewall whereas tyres with only the 'M+S' marking may be designated as 'snow tyres' by the tyre manufacturer, but without meeting specific performance criteria.

In accordance with the General Safety Regulation[9], cars (vehicles of M1 category) have to be fitted with Tyre Pressure Monitoring Systems as from 1 November 2014. Concerning the information provided to consumers it is important to note the tyre labelling scheme established for passenger car, light commercial vehicle and heavy duty vehicle tyres which applies since November 2012[10].

[9] Regulation (EC) No 661/209 concerning type-approval for the general safety of motor vehicles, their trailers
and systems, components and separate technical units intended thereof
[10] In accordance with Regulation (EC) 1222/2009

1.2 Objectives

The following study objectives are taken integral from the tender specification [1]. The purpose of the contract is to assist the Commission in its assessment of various aspects of the tyre use and quality related to road safety, including where appropriate, recommendations for EU measures. The aspects targeted in the study are the following:

a) The role of tyres as an accident factor,
b) The drivers' awareness and behaviour in relation to the safety role of tyres and their adequate choice and use,
c) The benefits, particularly for safety, derived from the use of the most appropriate tyres according to the weather conditions,
d) The minimum tread depth requirements,
e) The measures that could be effective to ensure adequate choice and use of tyres,
f) The measures that could be effective to ensure that tyres are used with the correct inflation pressure

The expected output can be summarised as follows,

a) An evaluation of the safety problems related to various aspects of tyre choice and use, like the adequate tyre characteristics according to the climatic conditions, the minimum tyre tread depth and the adequate tyre inflation pressure. An assessment of the safety benefits that could result from improvements in these areas,
b) An analysis of the drivers' awareness concerning the importance for safety of the various aspects of tyre choice and use referred to in a) and an analysis of the potential safety benefits that can result from increased drivers' awareness concerning these safety aspects,
c) Policy recommendations for measures aimed at addressing the safety problems identified above concerning tyre choice and use. For each of the measures recommended an assessment of its cost and benefits.

1.3 Approach

The overall aim of the study is to propose policy options concerning the use of tyres for improvement of traffic safety. Centrally to this, is the idea that end users need to make the correct assessment in relation to the tyre condition in order to achieve a level of safety as high as possible. Within this context, the tyre condition is considered in relation to technical elements (tyre inflation pressure, tyre tread depth, tyre damage, tyre age, and meteorological influences) and one information element (driver awareness). The study addresses the topics of tyre usage and the impact on road safety (which are the potential safety improvements related to tyre usage from a technical perspective) and how can road users be supported to use tyres that have a better safety performance by policy options. The policy options are subject to a cost-benefit analysis. This is also reflected in Figure 1.1.

Note that (apart from an accident analysis) the study does not perform new research or new tests, but instead reflects on existing studies from open data sources. By combining these insights and applying them on the study objectives, the relevant conclusions and recommendations are derived.

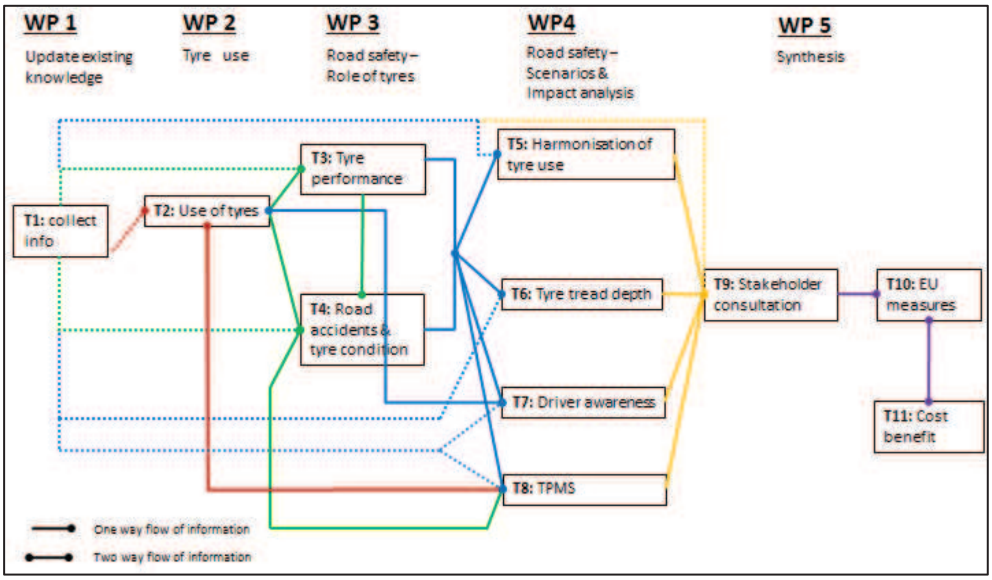


Figure 1.1: Project structure and flow of information.

1.4 Tyre safety aspects

The main safety aspects that have been considered are the tyre grip level (maximum force that can be transmitted between tyre and road) and tyre failure in terms of sudden loss of inflation pressure (often referred to as blowout). The tyre grip level is mainly affected by meteorological influences in combination with the tyre condition (tread depth, ageing, inflation pressure), and tyre choice (Summer tyre or Winter tyre[11]). A reduced grip level extends the stopping distance of vehicles and can result in vehicle instability (e.g. spin out). The risk of tyre blowout failure is related to inflation pressure being too low and tyre damage (including effects of ageing) which are strongly linked to tyre maintenance. When tyre blowout failure occurs it leaves debris on the road, the vehicle can become unstable, or may come to a halt at an unsafe location for changing tyres.

[11] Summer tyre and Winter tyre are not formally defined, these terms are used for simplicity of descriptions.

1.5 Report outline

The outline of the report follows these tasks: each chapter describes one task, except Task 1 “collect information” since the used data sources are referred to in the respective chapters. Table 1.1 contains a description of the main topic of each chapter.

Table 1.1: Contents of chapters.

Chapter	Name	Description
2	Use of tyres	Describe under what kind of conditions tyres are used in average
3	Tyre performance	Characterize the performance of tyres and the influence by the tyre use conditions
4	Tyres and accident causation	Analyse the role of tyres as a contributing factor in road accidents
5	Harmonised use of snow tyres	Evaluation of the benefits of EU-wide harmonized measures
6	Tyre tread depth requirements	Evaluation of the current tyre tread depth requirements and whether the minimum tread depth should be adapted
7	Driver awareness	Characterize the level of knowledge and awareness of European drivers concerning the role of tyres in relation to road safety
8	Tyre Pressure Monitoring Systems	Inventory of TPMS technology and potential improvements in inflation pressure resulting from its use
9	Stakeholder consultation	Organize a stakeholder consultation meeting and questionnaire
10	EU measures	Study and assess possible EU measures
11	Cost benefit analysis	Perform a Cost Benefit Analysis for the possible EU measures in Task 10

2 Use of tyres

2.1 Introduction

Tyre usage concerns the condition of tyres as found on vehicles in Europe and their use in summer and winter conditions. The tyre usage is assessed from several (statistical) data sources such as consumer awareness campaigns, periodic and roadside inspections and accident recordings that are either publically available, or have been provided by stakeholders (although limited).

2.2 Winter tyre use

Different definitions of Winter tyres are used in member states. This apparently resulted in some confusion at the stakeholders, resulting in a limited amount of useful answers about the Winter tyres use in member states, which are indicated in Table 2.1.

Table 2.1: Indicated use of Winter tyres in member states obtained from questionnaire replies.

Member state	Winter tyre in winter
Denmark	86%
Finland	100%
Germany	70%
Iceland	68%
Netherlands	32%
Norway	100%
Poland	92%
Sweden	100%

In addition to information collected through the stakeholders' questionnaire, a search in international databases and a local field-study in Leuven (Belgium) were made. The use of Winter tyres in member states is clearly affected by the national legislation and occurrence of winter conditions. Table 2.2 displays for member states experiencing relevant weather conditions the generalized use of Winter tyres in relation to the national legislation in place. Legislation in member states mandates the use of winter types in specific conditions ("conditional"), or for a fixed period ("absolute"). An overview of member states and legislation is provided in Appendix A.

This information is also used in further calculations on cost-benefit analysis, considering only member states with a relevant occurrence of winter conditions.

Table 2.2: Generalized use of Winter tyres for member states with relevant weather conditions for use of Winter tyres.

	Winter period	
	% vehicles with Winter tyres	% vehicles with other tyres
No national legislation	40%	60%
Conditional national legislation	60%	40%
Absolute national legislation	85%	15%

2.3 Tread depth

Several tyre suppliers conduct awareness campaigns. The current study considers a campaign carried out by Bridgestone, which has conducted yearly tyre safety awareness campaigns in different European member states since 2006. The campaigns took place during large events as well as at car parkings, shopping centres, etc. The 2010 campaign was conducted in eight (8) European member states, checking about 38000 tyres. The 2011 campaign took place in eleven (11) European member states, and in 2012 about 28000 checks were made. It was found that the share of vehicles with tread depth below the legal limit increased from 12% in 2010, 20% in 2011 to 25% in 2012, as is also depicted in Figure 2.1. Although the selection of member states varied over these years, Bridgestone concludes that tyre maintenance is affected by the economic crisis.

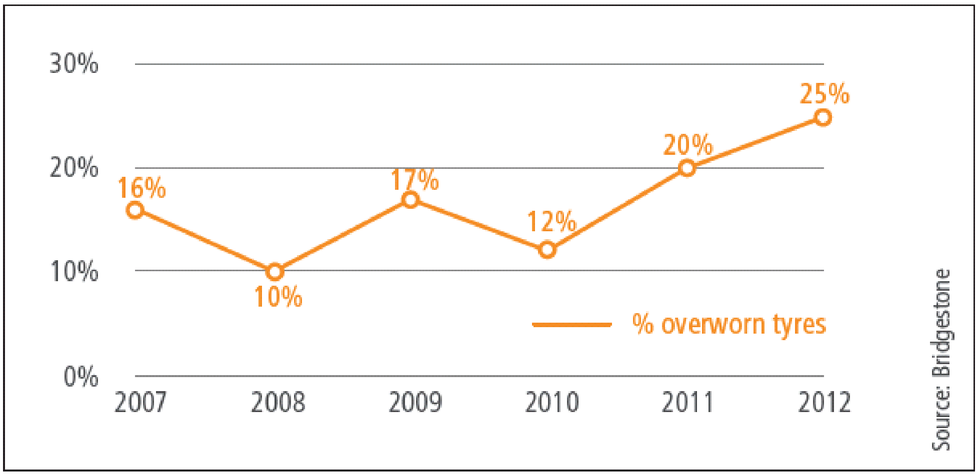


Figure 2.1: Share of over worn tyres assessed from roadside inspections in multiple EU member states in 2007-2012 [2].

In Finland a tyre safety awareness campaign is taking place every year since 1997 [3]. Approximately 12000 tyres are being checked during summer roadside inspections each year. The share of tyres with very reduced tread depth (<2 mm) has declined from 24.4% in 1997 to 13.8% in 2010, but increased again to 15.6%. This appears to be in line with the trend found in the Bridgestone campaign [2], and also shows that there are considerable differences in the share of tyres with reduced tread depth between member states. In Figure 2.2 a graphical illustration of the evolution is shown. The campaign included also Light Duty Vehicles (LDVs) although the share of them is not reported.

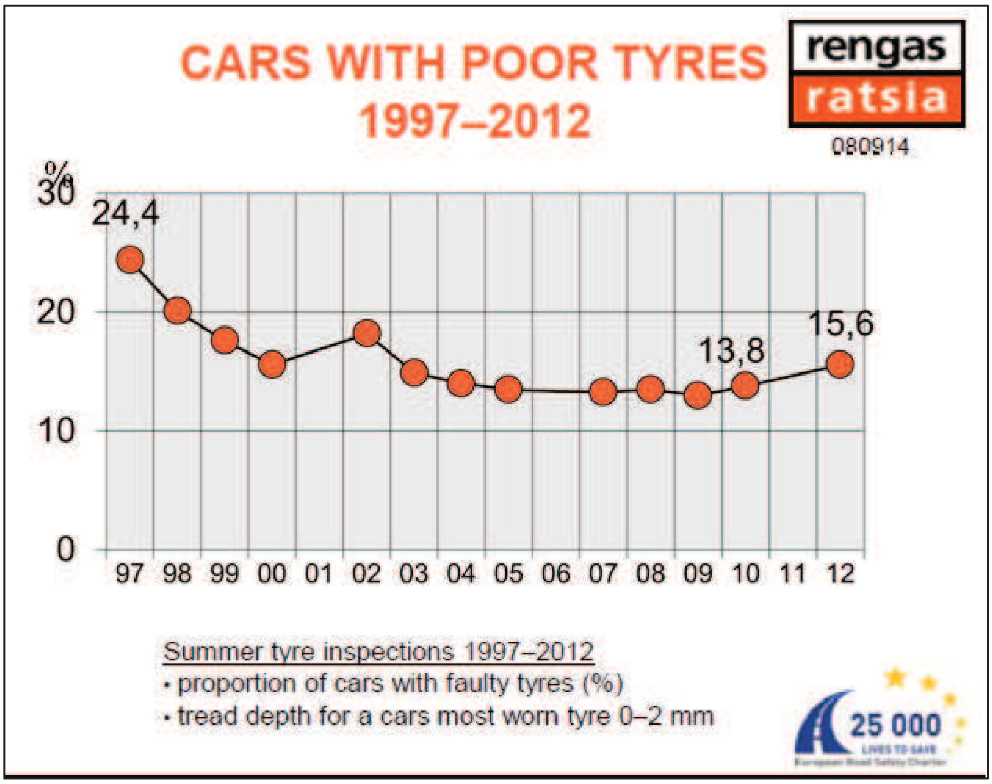


Figure 2.2: Summer tyre inspections in Finland 1997 – 2012 - Share of vehicles with very reduced tread depth (<2 mm).

The Dutch VACO organisation has recently conducted investigations into the tyre condition on vehicles in The Netherlands. Surveys were made on about 1500 vehicles in October 2012, June 2013 and January 2014 [4]. From these surveys it was found that in The Netherlands Summer tyres of about 3-4% of vehicles has at least one tyre with a tread depth below 1.6 mm, and about 17.5 % has a tread depth below 3 mm. Remarkably during the January inspection the share of Summer tyres with reduced tread depth was reduced to 10% below 3 mm and 2.3% below 1.6 mm. All inspected Winter tyres had a tread depth exceeding 1.6 mm, and 93.2% had a tread depth of more than 4 mm.

2.4 Inflation pressure

The inflation pressure has also been monitored during tyre safety awareness campaigns mentioned above. Bridgestone indicates that the share of tyres with underinflation has grown from 63% in 2011 to 78% in 2012 [2]. The evolution over the years 2007 - 2012 is depicted in Figure 2.3.

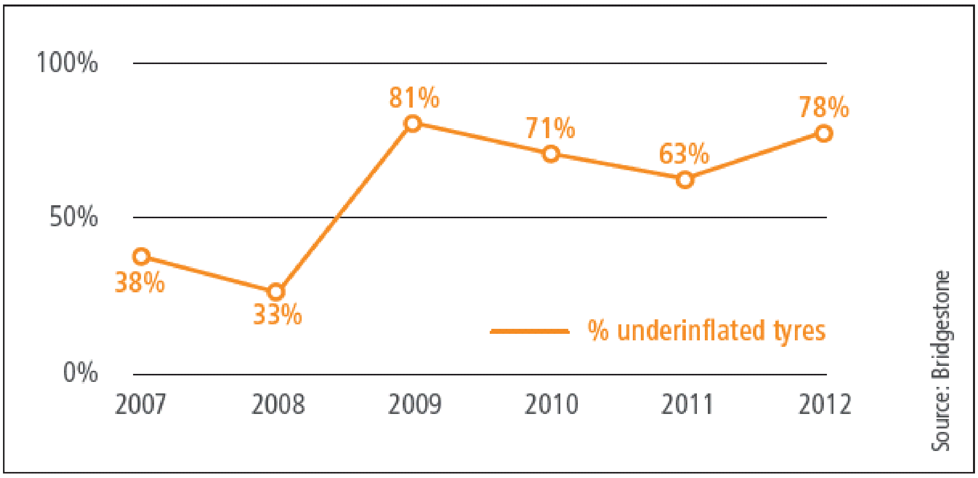


Figure 2.3: Share of tyres with underinflation assessed from roadside inspections in multiple EU member states in 2007-2012.

Figure 2.4 shows more detailed results for 2012, indicating that 28.4% of tyres are underinflated by more than 0.5 bar (which is considered the safety threshold level), and 5.2% by more than 0.75 bar.

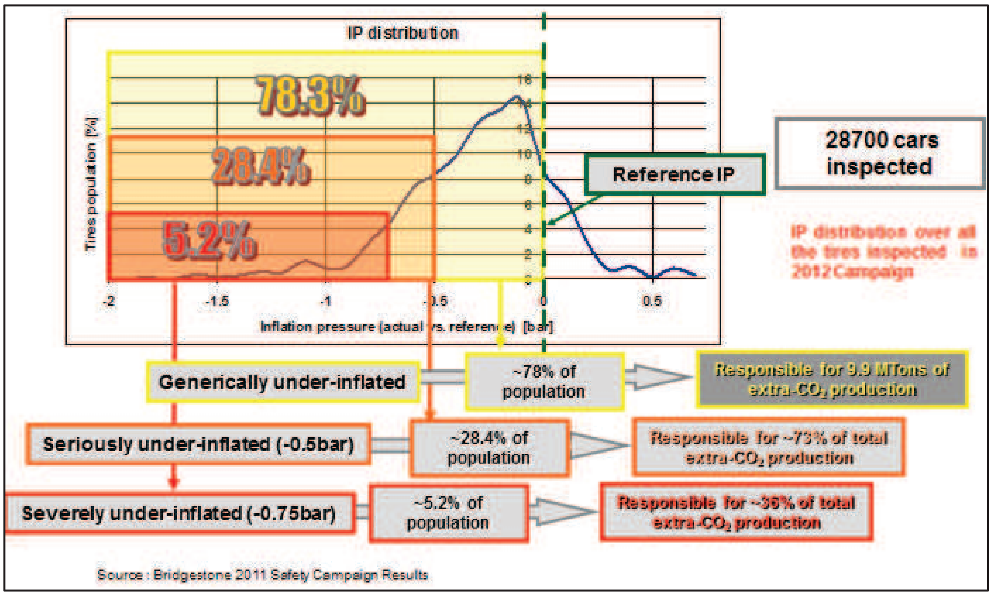


Figure 2.4: Results for inflation pressure (IP) of the 2011 Pan-European Bridgestone tyre safety awareness campaign.

A study in Finland reports that about 20% of vehicles have tyres with underinflation of at least 0.5 bar [3]. A questionnaire reply from Poland refers to a study by Michelin “Pressure under control”, reporting that more than 33% of vehicles has such an underinflation, confirming that there are considerable deviations between member states.

Tyre inflation maintenance is different for commercial vehicles as the related fuel consumption due to rolling resistance is a significant cost factor in transport of heavy goods. Statistical data regarding tyre underinflation for heavy duty vehicles (HDVs) were found from [5]. As shown in Figure 2.5 almost 25% of the HDVs drive with more than 10% underinflated tyres.

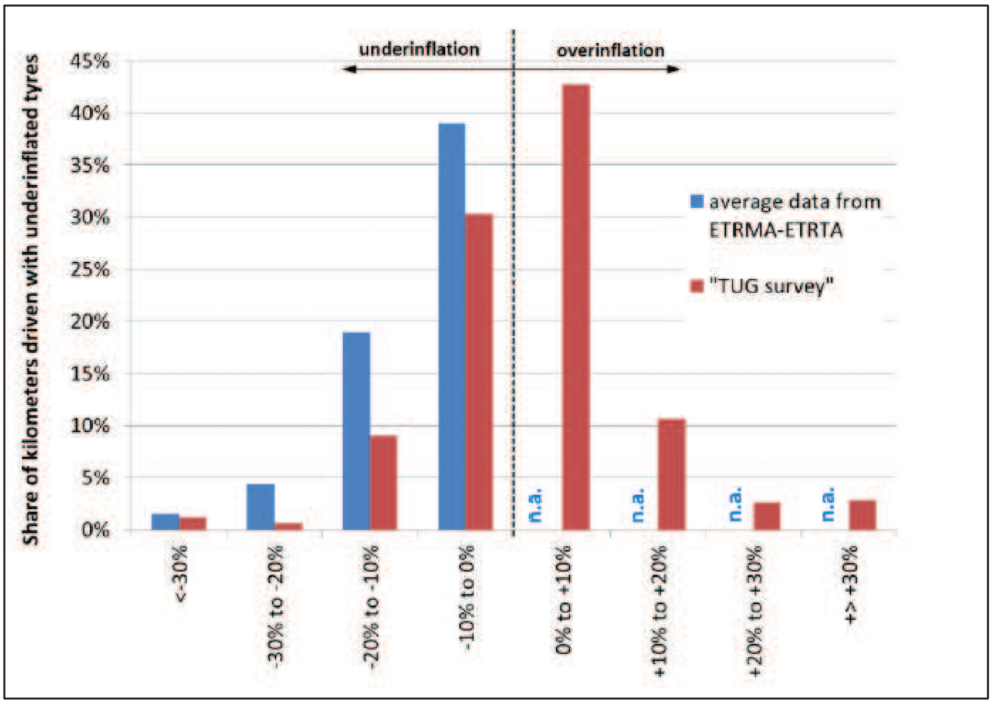


Figure 2.5: Comparison of HDV tyre inflation pressure distribution data.

Results of a field study on about 600 tractors and semi-trailers (provided by Continental in reply to the stakeholder questionnaire, no public reference found) shows that pressure maintenance is much better on tractors than semi-trailers (which often are owned by rental companies). As can be seen in Figure 2.6, semi-trailers on average have 12% under pressure, while the majority of tractors have a deviation smaller than 5% of the nominal pressure. The results also indicate that more than 40% of the tractors have an under pressure of 10% or more.

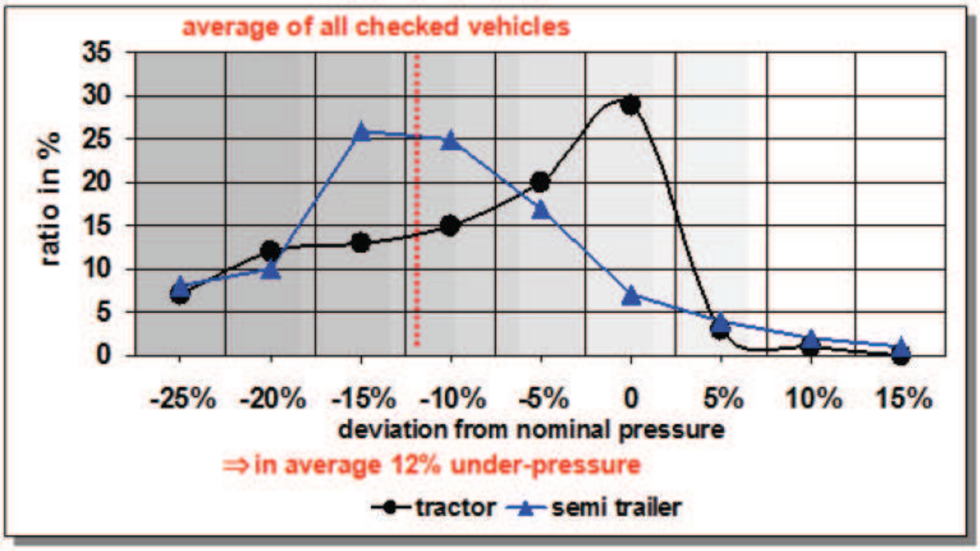


Figure 2.6: Inflation pressure distribution for tractors and semi-trailers assessed from roadside inspections by Continental on 600 vehicles.

2.5 Tyre damage and ageing

Tyre ageing is the result of exposure to the environment and the effects typically are assessed from visual inspection into tyre defects, rather checking the tyre production date.

The study by the VACO [4] provides results on the condition of tyres in The Netherlands. An overview gathered from inspections in January 2014 is provided in Table 2.3. It is remarkable that Winter tyres generally are in better condition and seem to be better maintained by consumers. About 20% of Winter tyres were older than 5 years compared to 31% of Summer tyres.

Table 2.3: Tyre conditions assessed on passenger cars projected to the vehicle population in The Netherlands.

Share in % February 2014		Situation	Equivalent population	
Summer tyres	Winter tyres		Summer tyres	Winter tyres
41.6	13.7	Passenger car with at least one tyre with an irregularity or wear or other damage	2.201.000	357.000
22.5	9.2	Passenger car with at least one damaged tyre	1.191.000	240.000
4.7	1.6	Passenger car with at least one tyre with an irregular wear pattern	249.000	42.000
31.3	6.7	Passenger car with at least one tyre with cracks or tears (aging)	1.656.000	175.000
7.2	1.8	Passenger car with at least one tyre that influences road safety	381.000	47.000
2.3	0.0	Passenger car tyres with tread depth less than the minimum legal limit (<1.6 mm)	122.000	none

Reports from visual tyre inspections for damages indicate that about 30% of vehicles with Summer tyres have at least one tyre that shows signs of ageing or other irregularities that increases the risk of tyre failure. Remarkably the results indicate that less than 10% of the vehicle population with Winter tyres shows these types of damages, suggesting that Winter tyres are better maintained than Summer tyres, or that people using Winter tyres take better care of tyre maintenance in general.

Regarding commercial vehicles it was found during roadside inspections carried out in the period 2007-2008 that on average 20.1% of the vehicles in Europe had tyre defects [6]. Detailed results are shown in Table 2.4.

Table 2.4: Deficiency rates – Roadside inspections of commercial vehicles during 2007-2008.

	Wheels/ tyres defects	
Austria	2164	13.6%
Belgium	866	14.6%
Bulgaria	335	29.9%
Cyprus	214	16.8%
Czech Republic	12224	20.6%
Germany	29511	16.6%
Denmark	13	5.7%
Estonia	356	21.3%
Finland	368	6.4%
France		
Greece	2291	45.4%
Hungary	990	5.1%
Ireland	545	15.9%
Italy		
Lithuania	1353	17.5%
Luxembourg	193	17.6%
Latvia		
Malta	778	17.2%
Netherlands	188	11.3%
Poland	15464	28.2%
Portugal	154	20.7%
Romania	5503	42.9%
Sweden	4595	13.9%
Slovenia		
Slovakia	404	23.3%
United Kingdom	19325	20%

It is known from a TPMS study performed by TNO [5] that driving behaviour and tyre average condition are correlated. There are reports that drivers that do not respect traffic legislation often have tyres in worse condition than drivers that do respect it. In this context, it is assessed that member states with the highest wheel/tyres defects seem to have also the highest road fatalities per million inhabitants. Figure 2.7 shows the ratios from accident statistics in EU member states [7].

Figure 2.7: Road fatalities per million inhabitants.

2.6 Discussion

From the empirical data collected it is evident that the average tyre use in EU member states has room for improvement. A significant number of vehicles operate just above or below the legal limits of tread depth. The derived causality that during the economic crisis the average tyre use has become worse is something to closely monitor.

The tyre usage is assessed for passenger car tyres and for commercial vehicles (when available), and the following observations are made:

- Winter tyre use
  The use of Winter tyres is affected by national legislation in EU member states and the occurrence of winter conditions. Member states with high occurrence of winter conditions typically mandate the use of Winter tyre for a fixed period. In these member states up to 90% (some report 100%) of the vehicles is equipped with Winter tyres. For member states where the use of Winter tyres is recommended a large variation is found ranging from 30% to 80%.

- Tread depth
  The share of vehicles that is equipped with tyres that have a tread depth close to or below the legal limits is estimated to between 10% and 20%. Large differences are found between member states. Tread depth of Winter tyres generally is more due to specific Winter tyre requirements in member states and recommendations from tyre manufacturers.

- Inflation pressure
  Deviations in tyre inflation pressures are generally below the recommended settings, and sources indicate that up to 20% of passenger cars have one or more tyres with a reduced inflation pressure that is considered dangerous. For heavy duty vehicles it is found that the inflation pressure of pulling vehicles is better maintained than trailers, probably due to the fact that the owner of the trailer is not always the user (i.e. rental trailers).

- Tyre damages and ageing
  Reports from visual tyre inspections for damages indicate that about 30% of passenger cars with Summer tyres have at least one tyre that shows signs of ageing or other irregularities that increases the risk of tyre failure. For commercial vehicles an average of 20% is found. Remarkably the results indicate that less than 10% of the passenger cars with Winter tyres show these types of damages, suggesting that Winter tyres are better maintained than Summer tyres, or that people using Winter tyres take better care of tyre maintenance in general.

3 Tyre performance

3.1 Introduction

The tyre is the only contact between the vehicle and the road. Every controlling function (steering, braking and accelerating) that is initiated by the driver and active safety systems (anti-lock braking system ABS, electronic stability control ESC, traction control TCS) is transmitted eventually by the tyres. Therefore the tyre is a key component in vehicle safety. The main factor for safety is ensuring that the tyre grip on the road is sufficient under all relevant operating conditions. Next of being a key safety component, the tyre also plays a significant role in fuel consumption and vehicle emissions due to its rolling resistance. Further, tyre-road noise is one of the main sources of traffic noise. Finally, (truck) tyres play a major role in road surface wear.

Irrespective of grip, rolling resistance or noise, the interaction of the tyre with the road surface is of importance. Think of the type of surface (roughness) and the condition of the surface (dry, water layer, icy, snow-covered). Further, the ambient temperature influences the tyre performance. At last, tyre performance also depends on the vehicle type. It is obvious that requirements and consequently tyre types for passenger cars, trucks and motorcycles are different. Designing a tyre that performs well under all operating conditions is a task of making compromises. Basically the tyre designer decides on rubber compounds, tread design (grooves and sipes[12]) and carcass design (belt and casing plies, bead, etc.). Unfortunately the performance of a specific tyre cannot be assessed by just ‘looking’ at the product. However, based on knowledge of the physical mechanisms involved and tyre performance test results, it is possible to characterize how the performance of the tyre is influenced by the use conditions and to quantify the characteristics and performance of ‘Winter tyres’ and other tyres in relation to the weather conditions.

3.2 Summer versus Winter tyres

Currently Winter tyres are generally understood as 'snow tyres' and 'snow tyres for severe snow conditions' defined as follows,

- ‘Snow tyres’
  - Marked “M+S” (or M.S. or M&S)
  - Supplier needs to prove that a different tread pattern, compound or structure is present that is designed for better performance in snow conditions
  - Since 2012 need to fulfil measurement criteria, but no approval marking on tyre.
- 'Snow tyres for severe snow conditions'
  - Marked with the “Alpine symbol” (also referred to as 3PMS)
  - Needs to perform a regulated test (UNECE regulation No. 117-02).

[12] Fine cuts in the tread pattern

Summer tyres and Winter tyres mainly differ by the used rubber compounds and the tread patterns. For simplicity we define the Winter tyre as a tyre designed for winter conditions as currently a variety of tyre types are considered as a Winter tyre (see Section 0). In Figure 3.1 examples of a typical winter and Summer tyre tread pattern are shown. The different tread patterns can clearly be distinguished. The tread patterns of Winter tyres have a higher void ratio (ratio of open space in the tyre footprint) and significantly more sipes (small grooves). Additionally, the initial tread depth typically is a little bit larger for Winter tyres. An attribute that contributes to the higher void ratio of Winter tyres is the higher number of blocks (separated by lateral grooves) around the tyre circumference. The higher void ratio and increased tread depth increase the tyre's ability to channel water and snow away from the footprint. Sipes increase the traction edges of the tyre to improve the grip of the tyre on wet, icy or snow-covered surfaces. The higher void ratio and sipes also significantly decrease the stiffness of the tread resulting in some decrease of steering performance on dry roads.

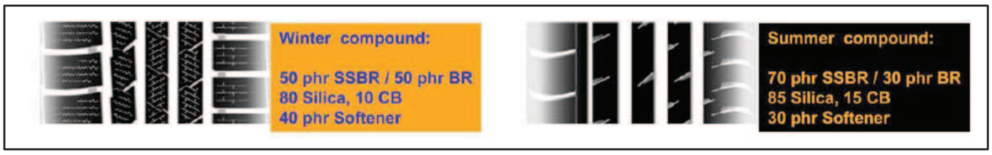


Figure 3.1: Comparison of typical winter and Summer tyre [8].

Moreover, the different tread patterns also affect tyre-road noise. Considering the recognized trade off of performances in snow versus rolling resistance and noise, those tyres have obtained the benefit of some allowances in the rolling resistance and noise performances requirements (in UNECE regulation 117 as well as in EU regulation 661/2009).

The second and probably the most important, but not visible, difference between summer and Winter tyres is the rubber compound. Rubber is a polymer, which means that it can have two solid states: it can be glassy (like hard plastics, e.g. water bottles) at low temperatures or rubbery (like flexible plastics, e.g. rubber balls or tyres) at high temperatures. The glass transition temperature (Tg) is the temperature at which a polymer switches between the glassy state and the rubbery state. Additionally, rubber belongs to the visco-elastic materials, meaning that after deformation the material reverts to its original shape, but with a certain delay (hysteresis). This delay is accompanied by a loss of energy. Close to the glass transition temperature the hysteresis is at its maximum. In this maximum hysteresis zone, rubber to road grip is also maximal. In Figure 3.2 typical curves are shown for energy loss (denoted as $\tan(\delta)$) and modulus (stiffness) versus temperature. The left figure shows the glass and rubbery states, the zone of maximum hysteresis and the glass transition temperature. Note that the energy loss or $\tan(\delta)$ curve exhibits a maximum. Further, note that the modulus (stiffness) decreases with temperature.

The right figure shows test results of a winter and summer rubber compound. It is clearly seen that the winter compound has a lower glass transition temperature than the summer compound, leading to maximum grip in a lower temperature range. It is important to note that compound tests are typically done at varying temperatures (measurement points) and at a fixed excitation frequency of for example 10 Hz. The excitation frequencies from the tyre road contact are much higher and for this reason the temperature scale is very different from normal ambient temperatures. In practice the glass transition temperature can be engineered in a range of about 60°C to 0°C at 10 Hz.

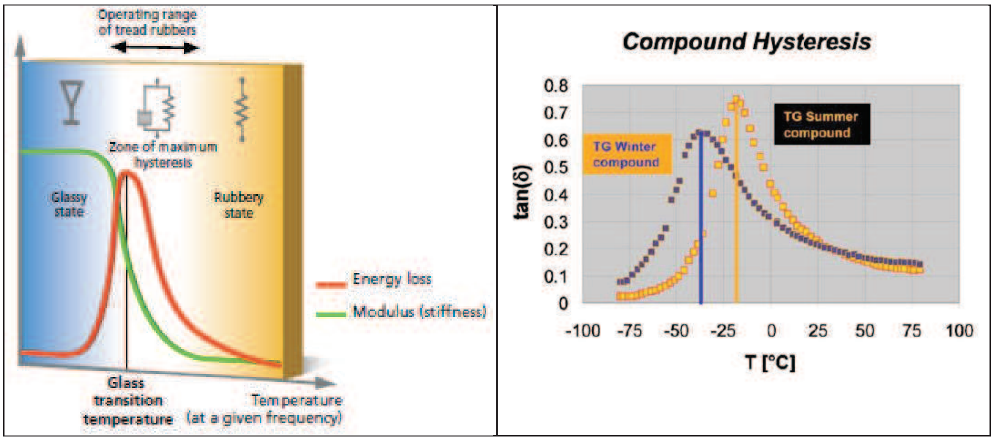


Figure 3.2: Left graph showing energy loss and modulus of tread rubber compound [9]]; right graph compares energy loss (tan(δ)) curves of a summer and winter compound [8].

In Figure 3.3 an attempt is made to indicate the stress frequencies of the compound in the energy loss graph for ABS braking on a wet road. Regions 1 and 2 are relevant for gripping the road; region 3 is relevant for rolling resistance. Note that rolling resistance and grip work at very different frequencies, thus temperatures in the test. For low rolling resistance, energy loss must be minimised. Consequently, the compound must be engineered to have low energy loss at high temperatures. Going back to Figure 3.2 (right), it is observed that for high temperatures (say above 25 °C) the differences in energy loss are relatively small compared to the change of the graph around the glass transition temperature.

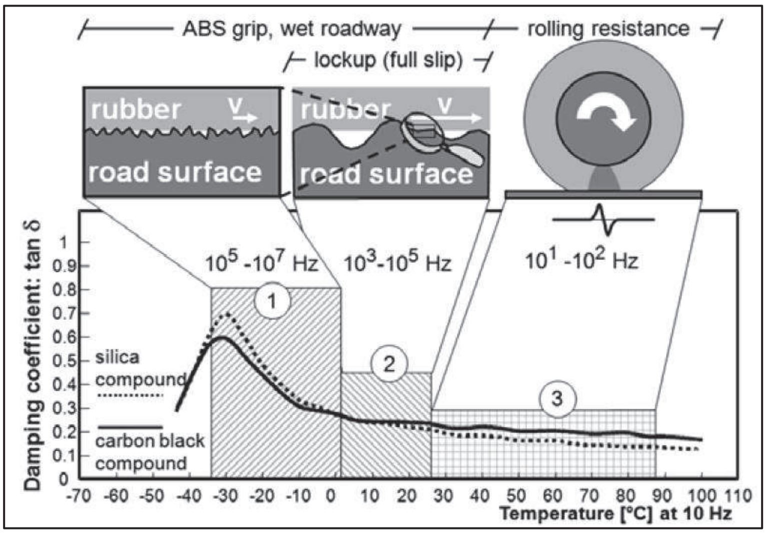


Figure 3.3: Energy loss versus temperature curve showing the excitation frequencies experienced by a tyre [10].

Another aspect is tyre tread wear. Wear of rubber is minimal close to the point where the friction is maximal, i.e. in the viscoelastic region. This is illustrated in Figure 3.4. At low temperatures wear increases, but also at high temperatures. Due to the link with friction, tyres wear less in those conditions where grip is maximal, i.e. Winter tyres wear more at very high temperatures and Summer tyres more at very low temperatures and wear is minimal in those conditions for which the tyres are targeted.

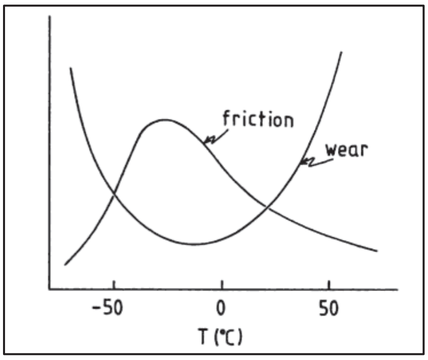


Figure 3.4: Relation of friction and wear versus temperature of a rubber compound [12].

Traction force versus longitudinal slip curves are shown for a snow surface in Figure 3.5. It is clearly seen that the combination of a Winter tyre tread and winter compound gives the best snow traction (highest and constant traction force).

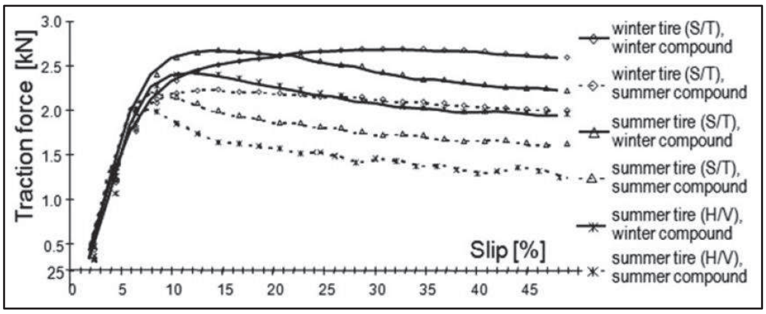
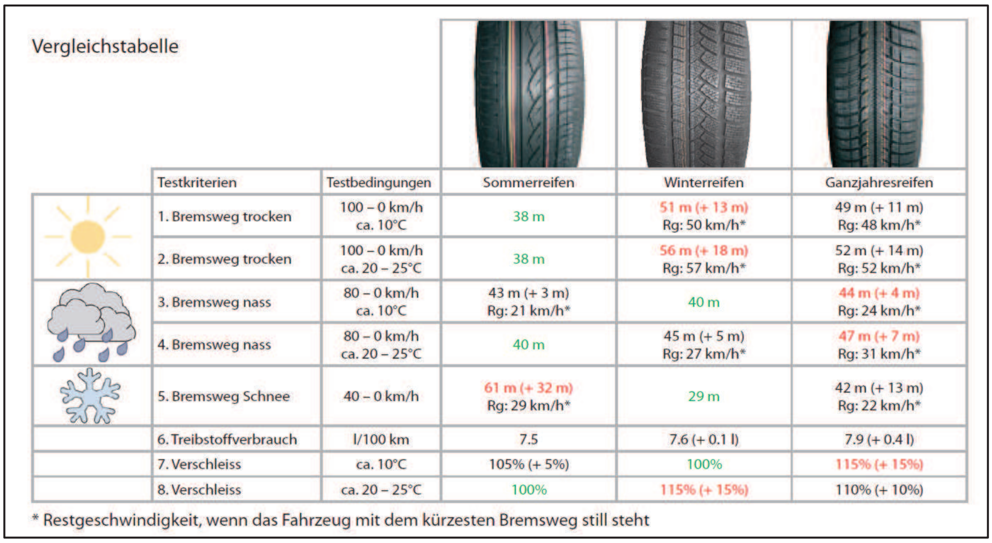


Figure 3.5: Curves showing the effects of tyre type and rubber compound on the coefficient of friction (snowy surface) [10].

Finally, as example, some test results of Touring Club Schweiz are shown in Figure 3.6. They compared the performance of summer, winter and all season tyres for different conditions. Note that the low temperature for dry and wet are still above the optimal range for Winter tyres. The all season tyres seem to be a compromise between summer and Winter tyres, at the cost of higher rolling resistance. The figure clearly shows the different performance of the tyre types: Summer tyres perform best in dry and wet conditions for higher temperatures, Winter tyres are superior in snow and have good wet performance at low temperatures. Tyre wear is similar for Summer tyres in low temperatures and Winter tyres in high temperatures respectively. Finally, note the small difference in fuel consumption for summer and Winter tyres.



Vergleichstabelle

Testkriterien	Testbedingungen	Sommerreifen	Winterreifen	Ganzjahresreifen
1. Bremsweg trocken	100 – 0 km/h ca. 10°C	38 m	51 m (+ 13 m) Rg: 50 km/h*	49 m (+ 11 m) Rg: 48 km/h*
2. Bremsweg trocken	100 – 0 km/h ca. 20 – 25°C	38 m	56 m (+ 18 m) Rg: 57 km/h*	52 m (+ 14 m) Rg: 52 km/h*
3. Bremsweg nass	80 – 0 km/h ca. 10°C	43 m (+ 3 m) Rg: 21 km/h*	40 m	44 m (+ 4 m) Rg: 24 km/h*
4. Bremsweg nass	80 – 0 km/h ca. 20 – 25°C	40 m	45 m (+ 5 m) Rg: 27 km/h*	47 m (+ 7 m) Rg: 31 km/h*
5. Bremsweg Schnee	40 – 0 km/h	61 m (+ 32 m) Rg: 29 km/h*	29 m	42 m (+ 13 m) Rg: 22 km/h*
6. Treibstoffverbrauch	l/100 km	7.5	7.6 (+ 0.1 l)	7.9 (+ 0.4 l)
7. Verschleiss	ca. 10°C	105% (+ 5%)	100%	115% (+ 15%)
8. Verschleiss	ca. 20 – 25°C	100%	115% (+ 15%)	110% (+ 10%)

* Restgeschwindigkeit, wenn das Fahrzeug mit dem kürzesten Bremsweg still steht

Figure 3.6: Example of test results of different tyre types [11].

3.3 Tread wear and aging

As mentioned above, the tread pattern channels water away from the contact patch. Moreover, the specific tread pattern of Winter tyres also provides better grip performance on snow and ice. It is obvious that with increasing tread wear the grip performance of the tyre on wet and winter surfaces decreases. Figure 3.7 shows the average increase in stopping distance from 80 km/h versus tread depth from studies conducted by MIRA in 2003 and 2004 on 4 different vehicle types [14]. It is observed that below 3.5 mm of tread depth, the stopping distance increases rapidly.

Further, it is seen that the stopping distance increases in a range of 30 % to 65 % at the legal limit of 1.6 mm.

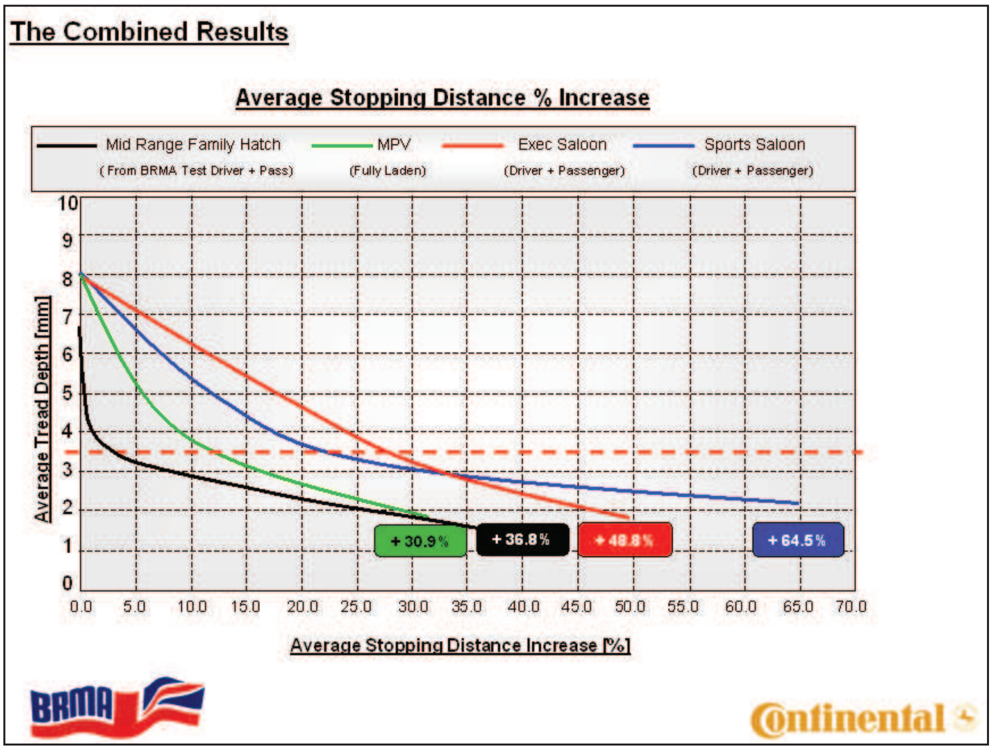


Figure 3.7: Percentage change in stopping distance versus tread depth [14].

The Technical Testing and Service division (TVS) of the MVI Group conducted a Winter tyre tread depth study commissioned by Continental [13] The results of this study are summarised in Figure 3.8. It is observed that the braking performance on snow and wet below 4 mm tread depth decreases more than proportional.

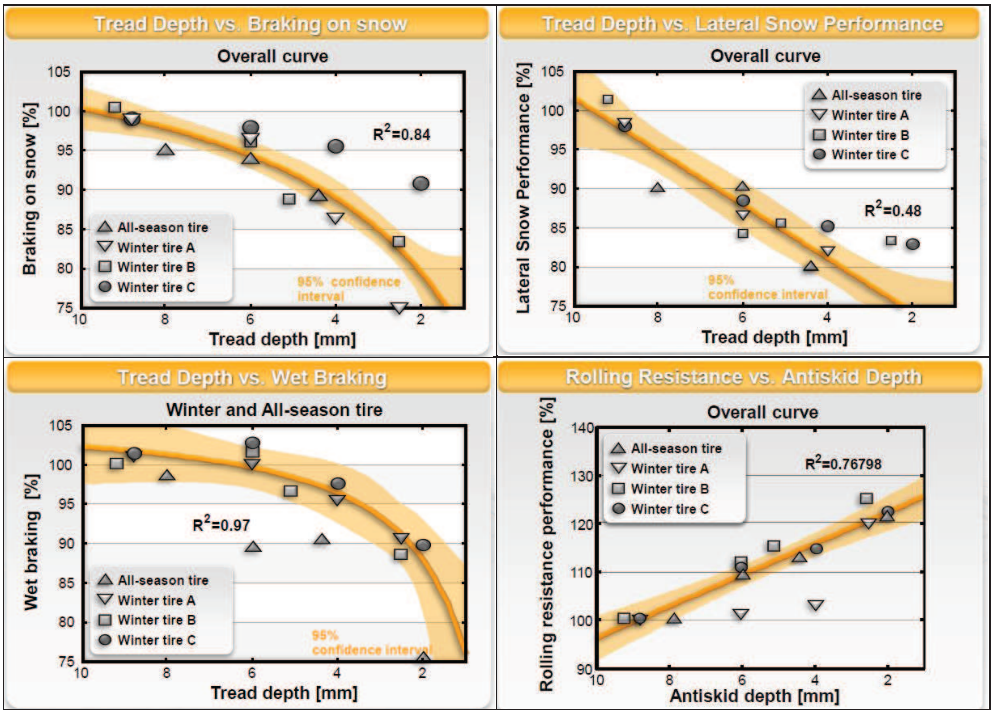


Figure 3.8: Results of Winter tyre tread depth study [13].

Finally, also the risk of aquaplaning increases with reduced tread depth; the speed at which aquaplaning can occur drops significantly as is shown in Figure 3.9.

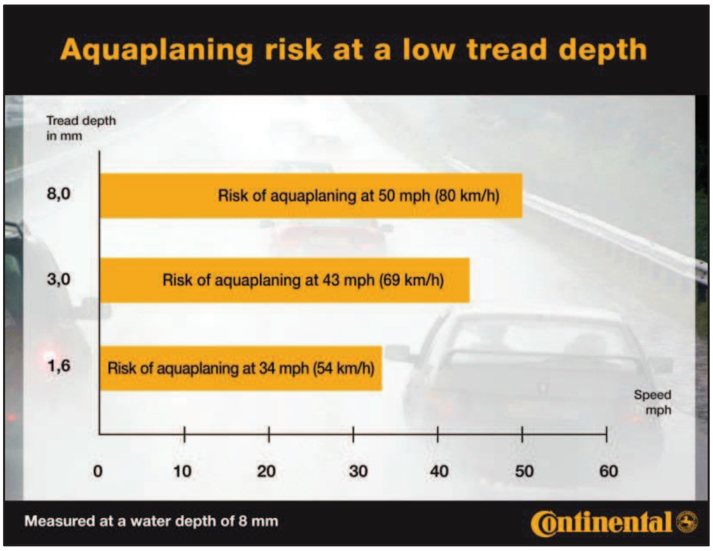


Figure 3.9: Risk of aquaplaning at different tread depths.

Additionally the ETRMA reports that "*Cars running with tyres worn down below the legal tread depth limit represent an immediate safety risk. For a car travelling on tyres with a tread depth below the 1.6 mm, the speed at which hydroplaning starts is reduced up to 40%.*"

Besides tread wear, tyres degrade naturally through exposure to heat, sunlight (Ultraviolet/UV) and rain. The rubber parts become less elastic, the steel webbing inside the tyre corrodes and the rubber mixture of which the tread is formed hardens. The amount of damage depends on the exposure and the severity of the weather. Generally tyres wear out before failure due to aging occurs. However, for vehicles or trailers that are only used occasionally (e.g. recreational vehicles) aging could be an issue. Since climate and exposure to sunlight affect aging, no date can be given at which a tyre expires. Recommendations for changing tyres range from 4 to 10 years. Aging may be observed by cracks on the tyre surface. However, according to NHTSA, tyres are primarily degrading from the inside-out, due to permeation and reaction of the pressurised oxygen within the tyre structure, with rates proportional to temperature. Cracking can eventually cause the steel belts in the tyre to separate from the rest of the tyre.

3.4 Inflation pressure

Almost all tyre properties are influenced by inflation pressure, e.g. the handling performance, ride comfort, rolling resistance, speed at which aquaplaning occurs, etc. With the correct inflation pressure, the vehicle and the tyres will achieve their optimum performance. In addition to tyre safety, this means the tyres will wear less and improve vehicle fuel consumption as result of a lower rolling resistance. Extreme under-inflation of a tyre leads to large deflections and causes excessive heat build-up and internal structural damage that may lead to tyre failure, even at a later date. Tyre Pressure Monitoring Systems (TMPS) warn the driver for incorrect inflation pressure, avoiding accidents due to tyre failure. The TPMS can be categorized as direct systems which are additional devices for measuring the inflation pressure and as indirect systems that compare rotation speeds of individual wheels on a vehicle, which is explained in more detail on the website Tyrerack.com [15].

Additionally these systems significantly contribute to the reduction of fuel consumption. Michelin categorises under-inflation for passenger car tyres as indicated in Table 3.1 [16].

Table 3.1: Overview of categories for under-inflation of tyres.

Type	Under-inflation
Correct or acceptable pressure	Below 0.3 bar
Moderate under-inflation	Between 0.3 and 0.5 bar
Dangerous under-inflation	Between 0.5 and 1.0 bar
Very dangerous under-inflation	Over 1.0 bar

This does not mean that small under-inflation is not important. As shown in Figure 3.10, 0.3 bar under-inflation for a passenger car tyre results in a rolling resistance increase of about 6 %. This would lead to about 1 % additional fuel consumption.

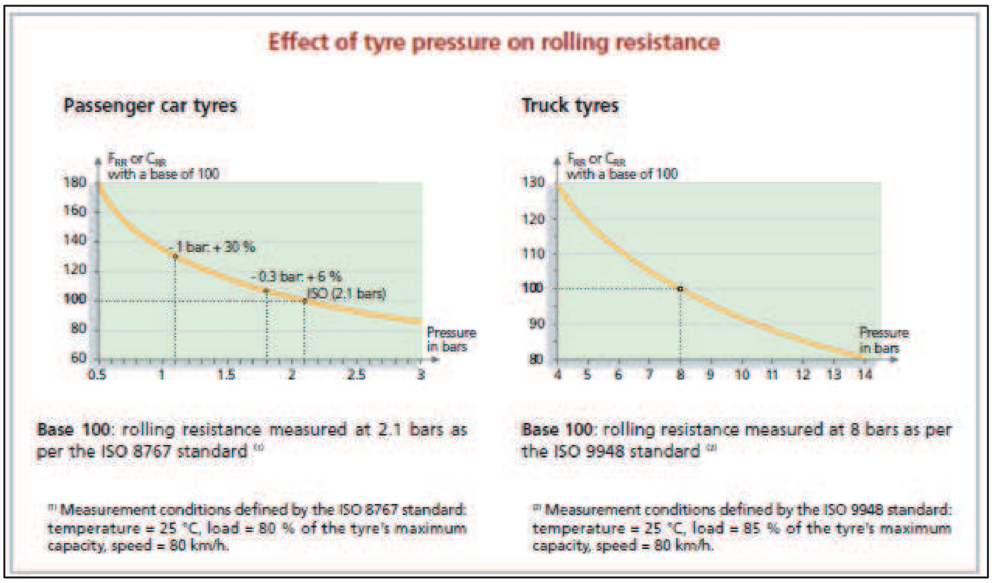


Figure 3.10: Effect of tyre inflation pressure on rolling resistance [16] .

3.5 Rolling resistance

The primary cause of tyre rolling resistance is hysteresis of the rubber material. As the tyre rotates under the load of the vehicle, it experiences repeated cycles of deformation and recovery when passing the contact zone. Due to hysteresis of the rubber not all energy necessary for the deformation is recovered, but is lost as heat. In general it can be stated that rolling resistance increases with:

- more tyre deformation;
- more tyre material;
- more hysteresis of the rubber compounds.

Apart from the tyre size and construction, the tyre deformation is affected by inflation pressure. With higher inflation pressure less deformation occurs and consequently rolling resistance reduces, which can be observed in Figure 3.10 The effect of the tyre material is seen in Figure 3.8, lower right graph. As the tread depth reduces, less tyre material is left and the rolling resistance decreases. The influence of the rubber compound is more complex as rubber behaviour is frequency and temperature dependent. As shown in Figure 3.3, the excitation frequencies relevant for rolling resistance are in the range of 10 to 100 Hz, which is in the range of the rotational frequencies of the wheel at different velocities. In general the hysteresis curve increases with frequency, contributing to an increase in rolling resistance with velocity. Further, the hysteresis curve shifts to lower frequencies if the temperature of the rubber decreases, leading to an increased rolling resistance at lower temperatures. In research by Toyota Motor Corporation, the effects of tyre thermal characteristics on vehicle performance have been investigated [17]. In Figure 3.11 taken from this research, the effect of velocity and tyre temperature on tyre rolling resistance coefficient (RRC) is shown. For the measured Summer tyre, it is seen that the rolling resistance significantly increases for low tyre operating temperatures, experienced in winter conditions.

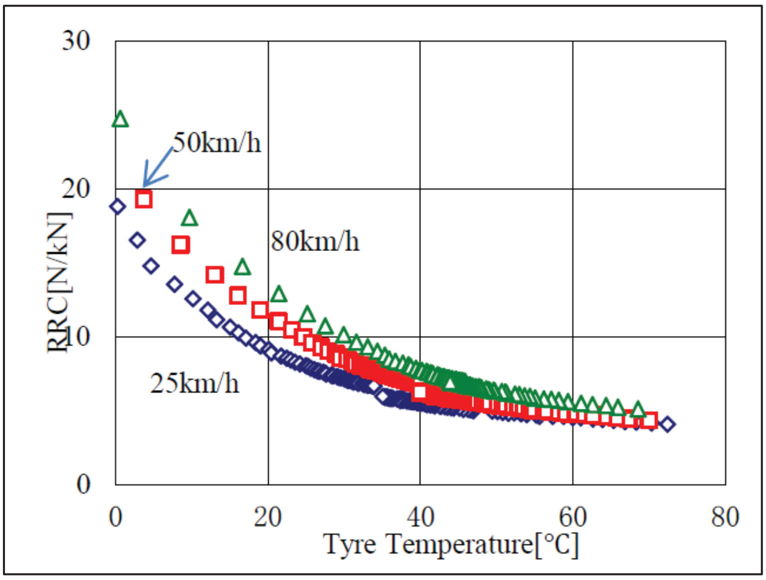


Figure 3.11: Measurement results of tyre rolling resistance coefficient (RRC) for different tyre temperatures and velocities [17].

No data was found for Winter tyres, however based on the difference in typical material properties of Winter tyres compared to Summer tyres (see Figure 3.2) it can be reasoned that Winter tyres show a smaller increase of rolling resistance when the temperature reduces.

Hysteresis is the primary cause of rolling resistance and as shown in Figure 3.12, the losses due to tyre deformation account for 80 to 95 % of the energy loss. The two other causes of rolling resistance are the aerodynamic drag of the rotating tyre (0 to 15 %) and micro slippage in the contact patch (< 5 %). The effect of tyre size and speed on aerodynamic drag is also depicted in Figure 3.12. As can be seen, a smaller tyre has less aerodynamic drag.

Given the complexity of effects on rolling resistance of Winter tyres compared to Summer tyres no indication can be provided that can be used for cost benefit analysis in Chapter 11.

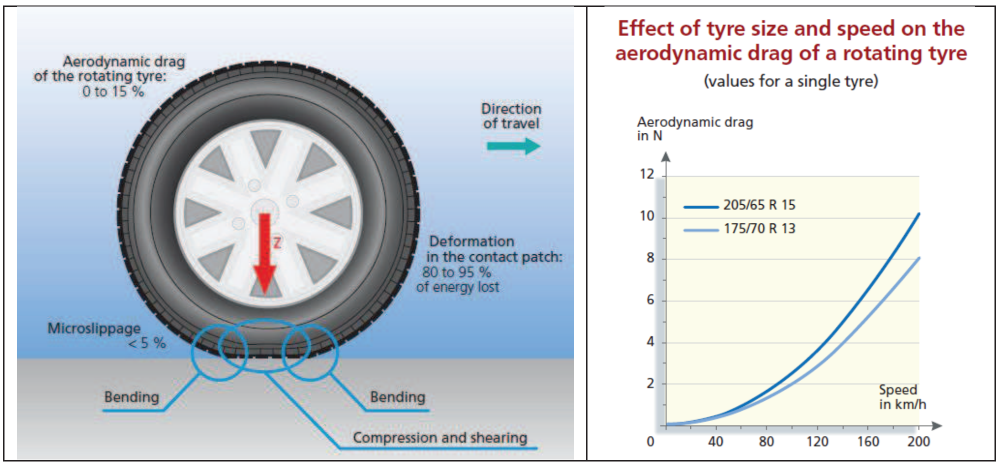


Figure 3.12: The 3 main causes of rolling resistance [16].

4 Road accidents and tyre condition

4.1 Introduction

In this chapter the identification of the tyre safety performance and assessment of the safety potential of improving tyres is described by relating road accident occurrence to the tyre condition. From a review of available literature a large variety of definitions used to classify tyre defects, or tyre states is found, and as a result most of the sources cannot be combined as the information is inconsistent. An overview of accident record sources has been made by Schick [18] and shows the large variety of information as can be seen in Table 4.1 and Table 4.2 respectively.

Table 4.1: Frequency of factor “tyre state” found in databases as listed in [18].

database	% of accidents in data sample	exact variable name
GIDAS BASt	0.2%	defects tyres
IDIADA-SCT	0.3%	old tyres
IDIADA ETAC	0.5%	tyres and wheels
BASt	0.6%	technical or maintenance faults: tyres
OTS	0.7%	Tyre worn or insufficient tread
TNO MAIDS 2000	0.9%	tyre: gross under inflation
STATS 19	0.8%	defective tyres
TNO MAIDS 2001	1.3%	tyre: gross under inflation
OTS	1.6%	Tyre pressure wrong
INRETS	7.0%	problem in tyre pressure and cold tyres
DIANA	8.7%	Vehicle state - tyres

Table 4.2: Frequency of factor “tyre defect” found in databases as listed in [18].

database	% of accidents in data sample	exact variable name
Czech Republic	0%	tyre wear out under prescribe value
INRETS	0%	blow out of tyre
SISS ELASIS	<0.1%	explosion or exceeding usury of tyres
Czech Republic	0.2%	tyre defect caused by shock or sudden decrease in pressure
OTS	1.8%	Tyre deflated before impact
TNO MAIDS 2001	2.7%	Tyre or wheel failure
TNO MAIDS 2000	5.3%	Tyre or wheel failure

A second disturbing factor is that the tyre safety capability is not utilized to the maximum, as for instance most drivers do not press the brake pedal sufficiently to try to avoid an accident. The statistics show that in accidents with casualties only 40% of the drivers utilize the tyre for 90% or more (i.e. where tyre performance matters), see Figure 4.1. Similar driver behaviour can be assumed for evasive steering action.

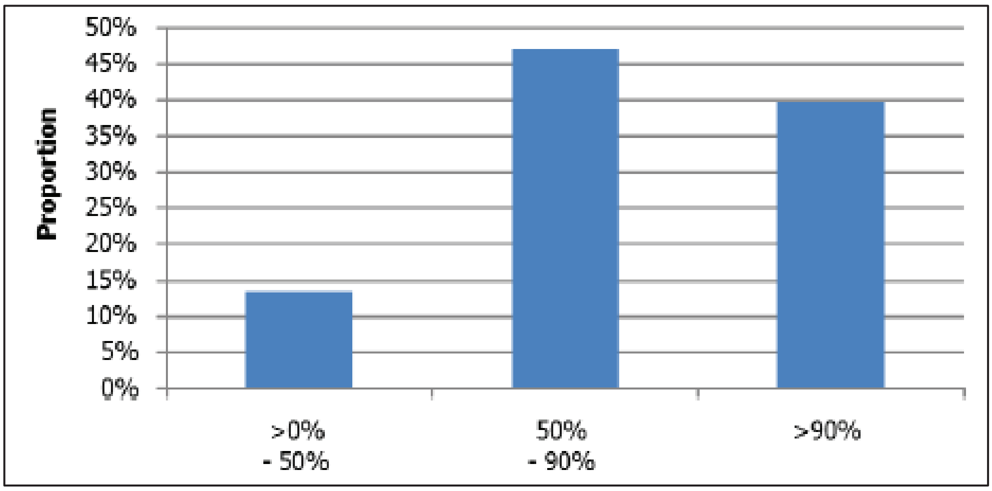


Figure 4.1: Utilization rate of braking manoeuvres of passenger cars [19] (GIDAS data Germany).

On the other hand, the relevance of tyre defects is proven using accident statistics. Table 4.3 shows that out of the accidents with casualties caused by technical failure more than 40% are caused by tyre defects; Table 4.4 shows that a large part of tyre related accidents are due to inadequate inflation pressure. The estimation of tyre defects as a cause or relevant factor in the total population of accidents with casualties is estimated between 5 and 10%, and depends on the actual driving situation [21] (e.g. at highway speeds any defect will have more severe consequences).

Table 4.3: Tyre defect share in accidents caused by technical defect that results in casualties [20].

	Technically defective assembly group							Ratio: Tyre defect/accident leading to injury or death total
	Total	Lights	**Tyres**	Brakes	Steering	Towing Unit	Others	
Year	Counts	Counts	Counts	Counts	Counts	Counts	Counts	%
1993	4,390	378	2,032	750	221	87	922	46.3
1994	4,334	411	1,925	762	208	88	940	44.4
1995	3,878	359	1,740	682	202	74	821	44.9
1996	3,521	367	1,543	591	187	76	757	43.8
1997	3,513	364	1,578	562	163	79	767	44.9
1998	3,327	363	1,486	491	120	61	806	44.7
1999	3,367	358	1,542	503	149	64	751	45.8
2000	3,288	331	1,477	519	124	83	754	44.9
2001	3,059	316	1,351	428	136	52	776	44.2
2002	3,017	278	1,374	412	115	57	781	45.5

Table 4.4: Three types of tyre-related defects [20].

Source :	DEKRA	DEKRA	MHH
Characteristic	Inadequate maintenance*	Damage in operation**	Pressure problems
Percentage of all tyre-related accidents	36.8%	14.6%	3.3%
*including pressure inflation, tread wear, over-aging etc. ** including punctures, etc.			

It has been assessed that two sources are available to relate the tyre condition to the occurrence of road accidents with a reasonable statistical significance. The first source is the GIDAS database that contains extensive records on accidents that occurred in Germany, and secondly a large scale survey has been carried out in the USA by NHTSA [22]. Both sources provide insight into the causation of accidents and are used to estimate safety effects of improving the tyre condition. The next section describes analyses on data from the GIDAS database that is based on an extraction of the database that was made by VUFO[13] specifically for the current study. Then a summary is provided from the aforementioned NHTSA study, and in the final section the results are used to derive safety effects of tyre improvement.

4.2 In-depth accident database study (GIDAS)

4.2.1 Introduction

The study has been carried out on accident records extracted by VUFO from the GIDAS database. The GIDAS database contains in-depth records of accident that can be used to assess accident causation. Since mid-1999, the GIDAS project explored about 2,000 accidents per year in the regions of Hanover and Dresden (North and East Germany respectively, having a moderate climate) and documented up to 3,000 variables per case. The project is jointly funded by the Federal Highway Research Institute (BASt) and the FAT (Automotive Research Association). The GIDAS teams investigate police recorded traffic accidents with at least one person injured following the approach "on the scene" (hence going directly at the accident site close to the time the accident has occurred) [23]. The analysis is structured as depicted in Figure 4.2 giving a detailed overview on the classification of accidents in Germany caused by direct tyre failure as well as accidents influenced by tyre performance.

Because the GIDAS database focuses on accidents within two regions of Germany (Hanover and Dresden, which experience moderate climates) it may be the case that representativeness for the entire European region is not optimal. Meteorological conditions can vary significantly across member states and relative shares of specific conditions can be different across Europe. Furthermore tyre usage is different between member states. However, the GIDAS database does present us with one of the only empirical datasets that allow for the analysis of safety effects linked to real-world tyre use under different conditions. As such, it does allow us to gain some insights in risk relations between actual behaviour and road safety.

[13] **Verkehrsunfallforschung an der TU Dresden GmbH**

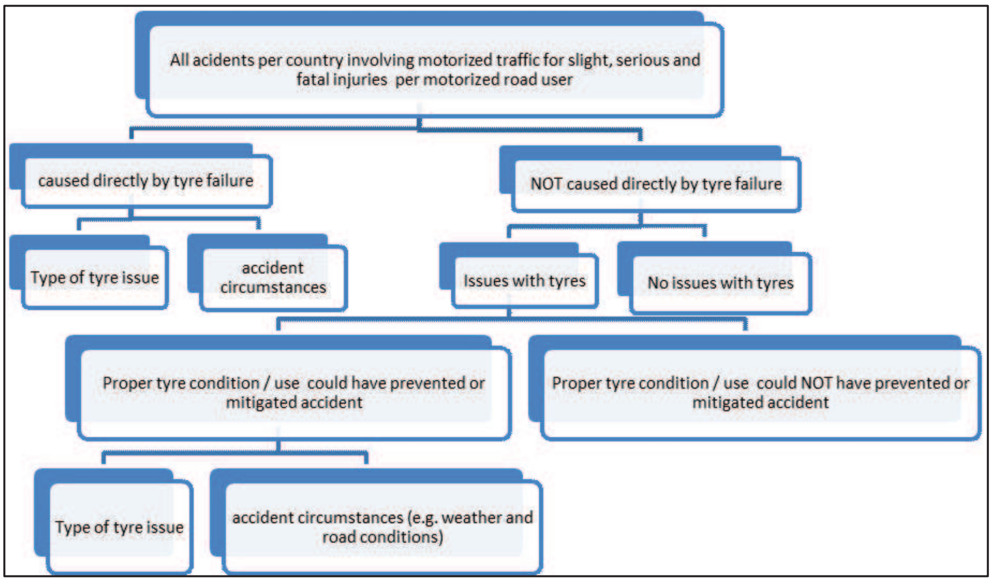


Figure 4.2: Information gathered from GIDAS accident database.

The study has been done on a selection of accidents where the tyres can be assumed to affect the accident either in its causation or the severity. A statistical analysis is conducted comparing the tyre condition of vehicles in tyre related accidents to the tyre condition of vehicles in other accidents. The injury severity is relevant, but could not be taken into account within the project boundaries for this study. For an analysis of the severity either a more detailed study is required or an investigation using some general assumptions can be made (an example is a study on using A-labelled tyres [24].

Figure 4.3 shows the overall population of accidents in the GIDAS database for passenger cars and trucks. A total of 25.288 accidents are available within GIDAS. The documentation of winter and Summer tyre use on passenger cars is not available before 2005; therefore those records are excluded for the study leaving 15.222 accidents for investigation. On trucks the use of Winter tyres is not recorded (yet). The number of passenger cars is greater than the number of available accidents as accidents can involve multiple passenger cars. Accidents where the tyres could be assumed to be of influence to the accident are classified as “Tyre grip” (involves braking or steering using at least 80% of the tyre grip potential) or “Tyre fail” where quick deflation of the tyre is identified as the cause of the accident. It should be noted, that the group of passenger cars also includes delivery vans up to 3.5 tons and the group of trucks includes LDV (>3.5 tons), Heavy Duty Vehicles (HDV) as well as busses.

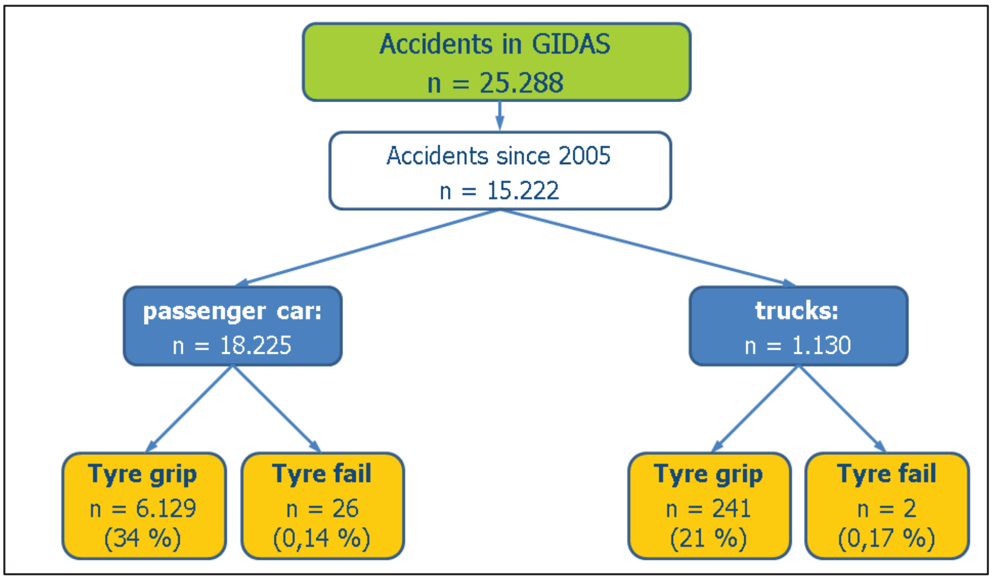


Figure 4.3: Population of accidents in the GIDAS database.

As can be seen in Figure 4.3, the number of records "Tyre fail" is very small and hence not suitable to quantify tyre condition influences (i.e. tyre ageing and tyre inflation pressure) on quick deflation of tyres. The complete analysis is described in Appendix C concerns therefore "Tyre grip" accidents only. The results that show significant trends are presented also further below in this chapter. Finally, the grip accident categories on average contain 55% guilty party (vehicles causing the accident), and 45% the victim party (vehicles being damaged as a result of the accident). This means that the data presented also contains a significant amount of vehicles that did not cause the accident and on those vehicles an improved tyre state might therefore not necessarily have helped the outcome of the accident.

4.2.2 *Approach*

The analysis is done by comparison of distribution functions of tyre conditions in specific accident categories and reference categories. A difference in the tyre condition distribution in an accident category compared to its reference group indicates that the tyre condition can have an influence on that accident category. As an example Figure 4.4 shows the distribution of tread depth on passenger cars for the grip accident category on wet roads compared to the reference category "other".

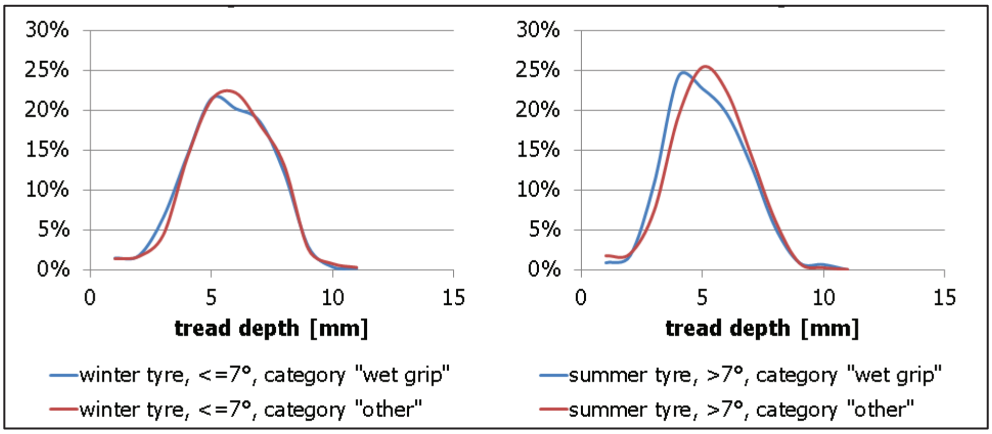


Figure 4.4: Tread depth distribution on wet roads from the grip accident category and reference category (category “other”).

Figure 4.4 suggest that for passenger cars on wet roads tread depth has a stronger influence on grip of Summer tyres than of Winter tyres. A more detailed analysis on tread depth reveals that the main benefit of an increased tread depth is found for snow conditions (see next section).
Categories for analysis are defined for combinations of temperature and road conditions as shown in Table 4.5: Overview of categories and tyre conditioning aspects. Tread depth is not investigated for dry roads as it is affecting grip level only significantly on wet roads or snow covered roads.

Table 4.5: Overview of categories and tyre conditioning aspects.

Temperature	Road condition	Tread depth	Tyre age	Inflation pressure
T > 7 °C	DRY		x	x
0°C < T =< 7°C	DRY		x	x
T =< 0°C	DRY		x	x
T > 7 °C	WET	x	x	x
T =< 7°C	WET	x	x	x
T =< 7°C	SNOW	x	x	x
T =< 7°C	ICE		x	x

x = included in the analysis

For truck accidents it appears that the sample sizes in the different categories are too small to provide any indication with sufficient statistical relevance, therefor further analysis is limited to passenger car tyres only.

4.2.3 *Main results for safety analysis*

The separation of accident records into specific weather and road conditions is relevant for the analyses on tyre performance characteristics. For passenger cars the use of Winter tyres and Summer tyres are evaluated separately in each temperature/road condition category, and the share of the tyre types in the grip accident categories is compared to the reference categories in Table 4.6.

Table 4.6: Population of Summer tyres and Winter tyres found in different accident conditions (passenger cars).

Temperature	Road condition	GRIP Sample size	Reference Sample size	GRIP Summer tyre / Winter tyre	Reference Summer tyre / Winter tyre
T > 7 °C	DRY	2024	4210	72.2% /27.8%	71.6% / 28.4%
0°C < T =< 7°C	DRY	501	1288	20.6% / 79.4%	21.4% / 78.6%
T =< 0°C	DRY	105	304	7.6% / 92.4%	4.3% / 95.7%
T > 7 °C	WET	636	4210	70.8% / 29.2%	71.6% / 28.4%
T =< 7°C	WET	651	1592	15.5% / 84.5%	18.1% / 81.9%
T =< 0°C	SNOW	139	304	5.0% / 95.0%	4.3% /95.7%
T =< 0°C	ICE	106	304	4.7% / 95.4%	4.3% /95.7%

A significant deviation of the share of Summer tyres in the grip accident category compared to the reference category that can be related to improved Winter tyre performance is found only for temperatures below zero and on a dry road. Summer tyres generally have less grip at low temperatures than Winter tyres, and the results suggest that this reduced grip results in more accidents with casualties on a dry road surface. The technical performance of Winter tyres however shows a more distinct improvement for conditions of snow and ice. This is not confirmed by the distribution listed in Table 4.6. The assumption is that it is because the GIDAS database contains only accidents with casualties and the driving speed typically is lower under conditions of snow and ice with relatively few casualties.
The main results for the distribution of tread depth for passenger car tyres are shown Figure 4.5. On a wet road there is no higher share of tyres with reduced tread depth found in accidents compared to a reference group, and no accident reduction with increased tread depth on wet roads can be identified. On the contrary for snow covered roads it is seen that the share of tread depth below 4 mm is increased in the accident population, suggesting that casualties can be reduced by increased tread depth. The results for the snow covered roads concern Winter tyre use only. The number of accidents registered with Summer tyres on snow is insufficient for analysis on the effect of tread depth.

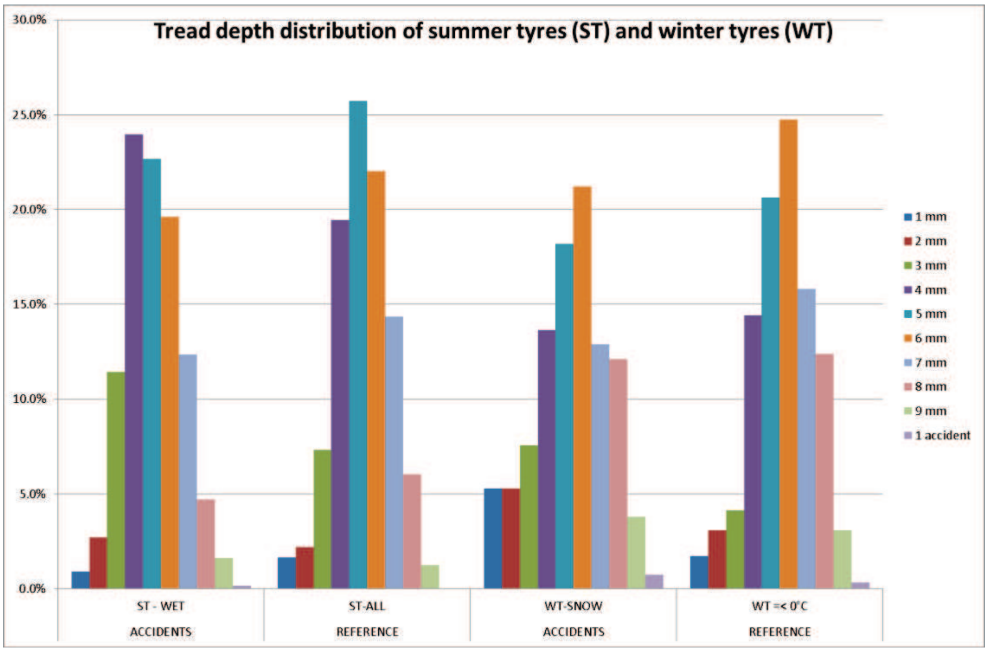


Figure 4.5: Tread depth distribution in accidents on wet roads (Summer tyres) and snow (Winter tyres).

4.2.4 *Conclusions on in-depth accident study*

The conclusions below are based on a comparison of grip accident data and reference data for corresponding road conditions and temperature. The full results are in Appendix C. The reference data is obtained from accident records in the GIDAS database as well and includes vehicles in accidents that are not categorized as a grip or tyre failure accident. Even though grip accident categories on average contain no more than 55% guilty party (the accident causing vehicles) indications of tyre influences could be identified.

Summer and Winter tyres

For accidents on a dry road and temperatures below zero the accident data suggests that the number of accidents could be reduced by using Winter tyres instead of Summer tyres (see previous section).

Tread depth

The analysis on tread depth leads to the following conclusions:

- Summer tyres
  The results do not indicate that an increase of the minimum tread depth would reduce the number of accidents. Furthermore too little data is available to identify the influence of Summer tyre tread depth on grip related accident on snow.
- Winter tyres
  Results indicate that an increase of the minimum tread depth could reduce the number of grip related accidents on snow. The results for snow conditions indicate that below 4 mm tread depth relatively more grip related accidents occur (see previous section).

- Truck tyres
  Results indicate that tread depths below 1 mm are only found in grip accidents and not in the reference group. Moreover tread depths up to 4 mm are higher represented in grip related accidents compared to the reference group. Although the sample size is limited this suggests that introduction of a minimum tread depth for trucks could lead to less grip accidents.

Tyre age

The analysis on tyre age leads to the following conclusions:

- Summer tyres
  Tyre age effects on grip accidents are observed for wet road conditions only, with a distribution shifted to older tyres in grip accidents. Too few data is available to conclude on tyre age effects for temperatures below zero.
- Winter tyres
  Tyre age effects on grip accidents are observed for temperatures below 7 degrees (wet road) and below 0 degrees (dry and snow/ice covered road). The available data however seems inconsistent at some points.

Inflation pressure

- In general at least 80% of vehicles involved in accidents seem to have a correct tyre inflation pressure prior to the accident. There is a high share of accident records that show a large deviation in inflation pressure. However, it is unclear if that deviation has been present prior to the accident, or is the result of the accident. More detailed analysis did not provide a clear indication of an influence of inflation pressure in grip accidents.

4.3 Statistical survey (NHTSA)

NHTSA [22] conducted a large scale study on tyre related factors in the pre-crash phase. This study uses data of 5470 accidents involving one of more vehicles collected through the National Motor Vehicle Crash Causation Survey in 2005 to 2007. In about 9% of the accidents at least one of the vehicles experienced tyre problems. Statistical methods are used to relate accidents to the condition of tyres prior to the accident. The study provides (amongst others) indications of the influence of tread depth, inflation pressure maintenance and tyre damages on tyre related accidents. A summary of the results is shown in the current section. The accident vehicles concern vehicles involved in tyre related accidents, which represents 9% of all recorded accidents.

The relevance of conforming to the EU legal requirement on tread depth can be assessed from the distribution of tread depth found on accident vehicles compared to reference vehicles. The accident records of the NHSTA contains a much more significant share of very reduced tread depth compared to the GIDAS study, making the NHTSA study a more useful source regarding safety effects of reduced tyre tread depth. The comparison of tread depth on accident vehicles and reference vehicles is provided in Table 4.7. As can be seen the tread depth on accident vehicles shows a much larger share at or below the EU legal requirement of 1.6 mm compared to the reference vehicles. This is an indication that the probability of an accident is reduced when tyres are maintained above the EU legal requirement.

Table 4.7: Distribution of tread depth on accident vehicles.

Tyre tread depth	Accident vehicles	Reference vehicles
<= 1.6 mm	33.88%	7.55%
1.7 - 3.2 mm	24.33%	17.86%
3.3 - 4.8 mm	27.85%	40.61%
> 4.8 mm	13.93%	33.98%

The assessed inflation pressure on vehicle is registered in different categories. A deviation of 10% compared to the nominal value is considered representative for normal vehicle operation. The comparison of inflation pressure on accident vehicles and reference vehicles is shown in Table 4.8. It can be seen that in the accident group a larger share of vehicles is found with moderate (-10 ... – 25%) or severe underinflation (< - 25%). Also the share of vehicles with severe over inflation (> + 25%) is larger in the accident group. These results indicate that maintenance of a correct inflation pressure reduces the probability of an accident.

Table 4.8: Distribution of inflation pressure on accident vehicles compared to reference vehicles.

Inflation pressure deviation	Accident vehicles	Reference vehicles
< -25%	19.01%	11.37%
-10% ... -25%	23.30%	21.36%
0% … -10%	14.99%	19.85%
0	6.68%	11.31%
0% … +10%	14.37%	15.20%
+10% … +25%	13.75%	14.10%
> +25%	7.91%	6.82%

The final result that is presented concerns tyre damage. The overview in Table 4.9 shows that damages are found much more on accident vehicles. Using tyres without damage will reduce the accident probability.

Table 4.9: Tyre Damages found on accident vehicles compared to reference vehicles.

	Accident vehicles	reference vehicles
Damage	17.00%	2.81%
No damage	83.00%	97.19%

4.4 Safety potential

The accident statistics that are described in the previous sections are used for assessment of the safety potential of improving the tyre condition. The safety potential is specific for the tyre use conditions.
Calculations are made by considering the distribution of tyre conditions in the accident category and reference category. The difference in the distribution of tyre conditions is an indication that the probability of an accident is affected by the tyre condition. An improved tyre condition will result in a lower probability of an accident, compared to a tyre in inadequate condition. The available data is suited for calculation of the ratio of accident probabilities when the assumption is made that the tyre condition is the sole influence on the occurrence of accidents under specific conditions. Furthermore the reliability of the source data is different due to the sample sizes involved. As a result the presented accident probabilities are estimated values. The estimated values are used to calculate an accident reduction ratio (ARR) which indicates the safety improvement compared to the population change of improved tyres. A higher number indicates a higher safety potential.

4.4.1 *Summer / Winter tyres*

A significant difference in the share of summer and Winter tyres is found for dry road conditions with temperatures below zero (see Table 4.6). The comparison of accident vehicles and reference vehicles for this condition is shown in Table 4.10 including the calculated accident probability

Table 4.10: Distribution of Summer tyres and Winter tyres found on accident vehicles and reference vehicles for accidents on dry road with temperatures below zero and corresponding accident probabilities.

Dry road, temperature below zero	Accident vehicles	Reference vehicles	Relative accident probability
Inadequate tyre Summer tyre	7.6%	4.3%	100%
Improved tyre Winter tyre	92.4%	95.7%	54.2%

The safety improvement that can be achieved by using Winter tyres instead of Summer tyres for the population found in the GIDAS database is 3.49%. The leads to an accident reduction ratio (ARR) of 0.816 (3.49% improvement by replacement of 4.3% Summer tyres) for the considered distribution.

4.4.2 *Tread depth*

4.4.2.1 *Winter tyres*

The results on tread depth from the GIDAS database study indicate a safety improvement potential of Winter tyres on snow by an increase of the tread depth to 4 mm (see Figure 4.5). An overview of the tread depth distributions on accident vehicles and reference vehicles is show in Table 4.11, including the calculated accident probability of using a tread depth of 4 mm or more.

Table 4.11: Distribution of tread depth of Winter tyres found on accident vehicles and reference vehicles for accidents on snow covered roads and corresponding accident probabilities.

Snow covered road	Accident vehicles	Reference vehicles	Relative accident probability
Inadequate Winter tyre Tread depth < 4 mm	18.2%	8.9%	100%
Improved Winter tyre Tread depth >= 4 mm	81.8%	91.1%	43.9%

For the tread depth distribution corresponding to the GIDAS database 10.21 % of accidents would potentially be reduced when the minimum tread depth on Winter tyres is 4 mm. This means that the accident reduction ratio is 1.147.

4.4.2.2 *Illegal tread depth*

The NHTSA study provides indications of the safety effect of ensuring that no vehicles had a tread depth below the EU legal requirement of 1.6 mm. The tread depth distribution found on the accident vehicles is compared to reference vehicles in Table 4.12, which also contains the corresponding relative accident probabilities.

Table 4.12: Distribution of tread depth found on accident vehicles and reference vehicles and corresponding accident probabilities.

Wet and snow covered roads	Accident vehicles	Reference vehicles	Relative accident probability
Inadequate tyre Tread depth <= 1.6 mm	33.9%	7.6%	100%
Improved tyre Tread depth > 1.6 mm	66.1%	92.4%	15.9%

Using the relative accident probability of 15.9% it is calculated that the potential accident reduction is 28.5% less accidents due to reduced tread depth. As tread depth is not relevant on dry roads it is assumed that this accident reduction is on wet roads or snow covered roads (not known from the NHTSA study). The accident reduction ratio amounts 3.722 for the considered distribution in tread depth in the vehicle reference population.

4.4.3 *Inflation pressure*

The influence of inflation pressure on accident probability is assessed from the NHTSA study. A comparison of the inflation pressure found on vehicles in accidents and reference vehicles is provided in Table 4.13, including the calculated accident probabilities.

Table 4.13: Distribution of inflation pressure found on accident vehicles and reference vehicles for and corresponding accident probabilities.

All conditions	Accident vehicles	Reference vehicles	Relative accident probability
Inadequate tyre Inflation pressure more than 10% too low or more than 25% too high.	50.2%	39.6%	100%
Improved tyre Inflation pressure less than 10% tool low, or below 25% too high	49.8%	60.4%	64.9%

With the accident probability reduced to 64.9% a correct inflation pressure would (for the considered distribution) lead to 17.7% less accident probability of a tyre related accident. The accident reduction ratio for this distribution is 0.446.

4.4.4 *Tyre damage*

The accident probability related to tyre damage is assessed from the NHTSA study. The share of vehicles with damaged tyres prior to the accident is compared to reference vehicles. The results are presented in Table 4.14, including the calculated accident probability.

Table 4.14: Distribution of damaged tyres found on accident vehicles and reference vehicles and corresponding accident probabilities.

All conditions	Accident vehicles	Reference vehicles	Relative accident probability
Inadequate tyre Tyre damage.	17.0%	2.8%	100%
Improved tyre No tyre damage	83%	97.2%	14.1%

For the considered distribution of vehicles with tyre damages the probability of a tyre related accident can be reduced by 14.6%, resulting in an accident reduction ratio of 5.194.

4.4.5 *Summary*

An overview of the accident probability that can be reduced by improved tyres is provided in Table 4.15. Note that the analysis concerns only accidents with causalities, and furthermore the accident probability is the result of calculations based on the available information, of which the statistical relevance varies with sample size. The calculation assumes that the tyre condition is an isolated aspect in the accident causation, which is a simplification. Therefor the accident probability reduction should be considered indicative.

The accident conditions are not described in the NHTSA study. The indicated assumptions of conditions are the most relevant in relation to the technical performance of tyres for tread depth, inflation pressure and damages respectively.

Table 4.15 Summary of identified safety potential by improving tyres.

Accident condition	Inadequate tyre	Improved tyre	Accident probability reduction / ARR*)	Source
Grip accidents on dry road, below zero	Summer tyre	Winter tyre	45.8% / 0.816	GIDAS
Grip accidents on snow covered roads	Tread depth Winter tyre below 4 mm	Tread depth Winter tyre 4 mm or more	56.1% / 1.147	GIDAS
Grip accidents on wet roads or snow covered roads (assumed)	Tread depth at or below 1.6 mm	Tread depth above 1.6 mm	84.1% / 3.722	NHTSA
Tyre related accident (assumed mainly tyre blow out failure)	Incorrect inflation pressure	Correct inflation pressure	35.1% / 0.446	NHTSA
Tyre related accident (assumed tyre blow out failure)	Damage	No damages	85.9% / 5.194	NHTSA

*) The ARR (Accident reduction rate) indicates the potential reduction of accidents for 1% increased share of improved tyres for the distribution used to calculate the accident probabilities

4.5 Conclusions

The use of Winter tyres will reduce grip accidents in winter conditions, and maintaining a tread depth of more than 4 mm will reduce grip accidents in snow conditions. In general maintaining a tread depth above the legal requirement of 1.6 mm will reduce accidents, which are assumed mainly grip accidents on wet roads and snow covered roads. Regarding tyre blow out failure it is found that avoiding tyre damage and incorrect inflation pressure will reduce accidents. Typically the combination of damage and incorrect inflation increases the risk of an accident. Note that the above conclusions concern accidents with casualties only.

5 Harmonisation use of snow tyres

5.1 Introduction

The main objective of this section is to present an evaluation of safety benefits of harmonised measures concerning the use of the most appropriate tyres for different climatic conditions. Identified benefits would be mainly situated in the domain of safety, but benefits may also exist in other domains.

In order to evaluate the benefits of harmonised measures concerning the use of different appropriate tyre types for different climatic conditions, an analysis is performed that takes into account the following elements:

- Existing legislation on the use of Winter tyres.
- Information on road safety (current statistics & causal relation with tyre choice), presented in terms of accident risk and fatality risk.
- Current tyre use information in EU member states and tyre technology information allowing for the quantification of the characteristics and performance of different tyre types (i.e. Winter tyres) in relation to weather conditions.
- Meteorological information (temperature & precipitation).

A simplified safety model was built where as much validated input data was grouped. Based on literature review, the project questionnaire and available data, a number of safety-related effects were identified and quantified.

5.2 Overview

5.2.1 Existing Winter tyre legislation

5.2.1.1 Information sources

Different sources on the national legislation in relation to the use of Winter tyres, snow tyres, winter equipment (snow chains, studded tyres, spikes, etc.), etc. were reviewed during this project. The most problematic elements that needs to be noted is the relevant time-stamp for each of the summaries provided for the documents. Some documents are more recent than others, yet the original source of information may be older. Utmost care was taken to collect the most recent, valid information. The most relevant sources reviewed for information are:

- European Consumer Centres Network (ECC-Net) [25]
- European Commission DG MOVE “Going abroad” [26]
- Automobile clubs: Automobilclub von Deutschland [27], ANWB [28] and the Latvian automobile club [29]
- National road safety institutes or relevant national partners
- Tyre manufacturers: Continental [30] [31] [32] & Pirelli [33]
- Other sources include Wikipedia [34]
- tyre retailers [35]
- rental companies [36]

The outcome of this literature study is summarised in this chapter. Overview tables are presented in Appendix A.

5.2.1.2 Tyre classification

Currently regulation (EC) No 1222/2009 of the European Parliament and of the council of 25 November 2009 [37] prescribes how tyres are labelled with respect to fuel efficiency and other essential parameters. Tyres are characterised with respect to their rolling resistance, their wet grip performance and the noise level they produce. In Figure 5.1 it is shown how tyres are classified for the safety performance. *Wet grip index ("G")*" means the ratio between the performance of the candidate tyre and the performance of the standard reference test tyre.

G	Wet grip class
$1{,}55 \leq G$	A
$1{,}40 \leq G \leq 1{,}54$	B
$1{,}25 \leq G \leq 1{,}39$	C
Empty	D
$1{,}10 \leq G \leq 1{,}24$	E
$G \leq 1{,}09$	F
Empty	G

Figure 5.1: Tyre wet grip classes (C1 category).

Requirements with respect to the braking performance on snow (Alpine symbol) are described in Addendum 116: Regulation No. 117 concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions. According to it, class C1 (passenger car / van), C2 (light duty vehicles) and C3 (heavy duty vehicles) tyres have to fulfil the requirements shown in Figure 5.2.

Class of tyre	*Snow gripe index (brake on snow method)* [(a)]	*Snow grip index (spin traction method)* [(b)]	*Snow grip index (acceleration method)* [(c)]
	Ref. = C1 – SRTT 14	*Ref. = C1 – SRTT 14*	*Ref. = C3N – SRTT 19.5* *Ref. = C3W – SRTT 22.5*
C1	1.07	1.10	No
C2	No	1.10	No
C3	No	No	1.25

Figure 5.2: Snow index value [38] .

5.2.1.3 General legislation on the use of Winter tyres, snow tyres or winter equipment

The legislation on Winter tyres has been reviewed for five vehicle categories (passenger cars, freight or passenger LDV and freight or passenger HDV). Within the study a distinction is made between three types of legislative positions on the use of Winter tyres, snow tyres or winter equipment taken in EU27 Member States, plus Norway and Switzerland.

- **member states without legislation** for passenger cars, LDV (freight or passenger), HDV (freight or passenger). In most of these member states, explicit mention is made of the use of snow chains although this is mostly through the identification of conditions under which snow chains, studded tyres or spikes are allowed (either defining a time period, road conditions or local road signs).

- **member states with conditional legislation** (weather conditions, road conditions or local traffic signs): the conditions for the use of Winter tyres, snow tyres or winter equipment can include (combinations of): a timeframe (start and end date), weather conditions, road conditions, specific roads and local traffic signs. The start-date for conditional legislation ranges from the 15th of October to the 1st of December. The end-date for conditional legislation ranges from the 1st of March to the 15th of April.

- **member states with absolute legislation**: a specific beginning and end-date is used to clearly demarcate the mandatory use of specific tyre types. The beginning period lies between 1st of November and the 1st of December. The ending period lies between the 1st of March and the 30th of April.

An overview of the member states and the types of legislation is shown in Table 5.1.

Table 5.1: Legislation on Winter tyres, snow tyres or winter equipment in different Member States.

No legislation	Conditional	Fixed period
• Belgium [i]	• Czech Republic (*) [s]	• Austria (**) [s]
• Bulgaria [s]	• France [r]	• Croatia [s]
• Cyprus [n]	• Germany [i]	• Estonia [s]
• Denmark [i]	• Luxembourg [i]	• Finland [s]
• Greece [r]	• Romania (*) [s]	• Italy [r]
• Hungary [s]	• Slovenia (*) [s]	• Latvia [s]
• Ireland [i]	• Switzerland [s]	• Lithuania [s]
• Malta [n]		• Slovakia (**) [s]
• Netherlands [i]	(*) within a period	• Sweden [s]
• Poland [s]		• Norway (**) [s]
• Portugal [n]		
• Spain [r]		(**) not all vehicle categories
• United Kingdom [i]		

[i] = incidental winter conditions, [s] = severe winter conditions, [r] = regional winter conditions

As can be seen in Table 5.1, mainly the member states with a high occurrence of winter conditions have regulation on Winter tyres.

Weather and road condition limitations refer to the presence of a winter vehicle equipment requirement when wintery precipitation is occurring, or when the road condition is wintery (sleet, ice, covered snowpack, loose snow, etc.). Local traffic signs, in a sense, constitute an absolute (although probably mostly local) condition although national traffic law linked to such signs can vary from general prohibitions (vehicles with other equipment not allowed beyond this point) to conditional prohibitions (vehicles with other equipment not allowed beyond this point *given specific road conditions*).

Also of importance is the mentioning of two cases where the use of Winter tyres is forbidden for all vehicle categories, outside of a (winter) time-frame. This is the case for Belgium and Italy. In Belgium, there is a general prohibition to use Winter tyres from the 1st of May until the 30th of September. In Italy, there is a prohibition to make use of Winter tyres and all-season tyres with a speed index that is lower than the technical maximum speed of the vehicle from the 15th of May until the 14th of October.

A short description of Winter tyre legislation in the EU and other member states is presented for each of the individual member states in Appendix A. In this overview, mention is also made of specific winter vehicle equipment if such equipment was mentioned in the original legislation. From this table, it can be seen that in general two different options for use are presented to road users. On one hand, member states with non-absolute legislation most often allow for the use of ‘Summer tyres with snow chains’ as a replacement for Winter tyres (although under specific use conditions and limitations such as road type, speed, etc.). On the other hand, member states with a more stringent legislation on the use of Winter tyres tend to make an extra provision for additional use of snow chains.

As far as the typology of Winter tyres is concerned, a distinction is made between tyres that are marked “M+S” (or M.S. or M&S) and tyres that are marked with the “Alpine symbol”. The main difference being that “M+S” tyres only need to prove that a different tread pattern, compound or structure is present that is designed for better performance in snow conditions. No other regulation or objective testing is required. Tyres marked with the “Alpine symbol” on the other hand need to perform under the specific UNECE regulation No. 117.2, which also includes objective testing (exceeding pre-defined limits). From November 2012, a regulation was implemented throughout the EC (through EC Regulation 661/2009) defining the concept of “snow tyre”[14] and “traction tyre”[15].

Currently, almost all member states’ relevant Winter tyre legislation only mention the use of M+S (or similarly marked) tyres. Specific mention of the “Alpine symbol” is only made in Germany and Sweden. From 2012 onwards however, following EC regulation 661/2009, snow tyres do need to fulfil some measurement criteria, although they need not be marked explicitly with the alpine symbol (not covered in the EC Regulation 661/2009). As such, a major uncertainty is introduced in the discrepancy in nomenclature between national legislation and European regulation.

[14] Snow tyre means a tyre whose tread pattern, tread compound or structure is primarily designed to achieve in snow conditions a performance better than that of a normal tyre with regard to its ability to initiate or maintain vehicle motion.
[15] Traction tyre means a tyre of classes C2 or C3 bearing the inscription ‘M + S’, ‘M.S.’ or ‘M&S’ and intended to be fitted to a vehicle drive axle or axles.

Figure 5.3: Alpine symbol (3PMS).

As far as the use of Summer tyres with snow chains (driven axle) is concerned, this is mentioned explicitly for passenger cars, passenger or freight LDV in Austria, Croatia, Italy (some regions), Slovenia and Norway. For passenger or freight HDV, this is also allowed explicitly in Croatia, Hungary and Slovenia.

5.2.2 *Road safety information*

The main source for road safety information that was used for the estimation of the impact effect of the introduction of harmonised legislation on the use of Winter tyres was presented through CADaS. This information source contains the information from the CARE database, migrated to CADaS (Common Accident Data Set) [39]. The data is made available by DG MOVE and for the current analysis; use is made of the data from the time period from 2000 up to 2012.

The content of CADaS is of particular interest since it contains some accident properties that are directly relevant for the current study that were recorded by police officers. An example hereof is the involvement of specific vehicle categories, the road conditions and general weather conditions. This allows us to make a relatively precise distinction between fatalities resulting from, for example, accidents during dry road and fine weather conditions and, for example, fatalities from accidents that occurred during bad weather conditions.

In itself, this database however does not contain information on the use of different tyre types during the accidents (and therefor also not the related registered fatalities). Additionally it does not contain specific information needed for the precise identification of wintery conditions. To make such risk estimation, we needed to link the information from CADaS to more specific meteorological information and information in relation to tyre use in Europe. These information sources are described in sections 5.2.4 and 2.2, respectively. The final estimations of the relevant number of fatalities to be used for the different calculations are presented in Appendix D. In the calculations also injuries and material damage is considered, see Section 11.3.1.

5.2.3 *Tyre type and road safety*

The use of correct tyre types, appropriate for different meteorological conditions is often considered a major influence on road safety. This is in particular the case when looking at commercial activities in relation to tyre purchases. As part of the current project, we specifically aim at quantifying the link between particular weather conditions that call for different tyre choices and the possible effect this has on road safety. Next to the actual accident data from CADaS, this also means that we needed to collect information on the use of different tyre types, as well as inherent technical qualities of such tyres and effects on safety.

Two main data information sources were identified that allow describing the effect of Winter tyres compared to other tyres in relation to safety: tyre-vehicle tests (experiments) and epidemiological studies. Information from laboratory tests is presented in Chapter 3. The overall indication is that, although it can be stated that different tyre types (i.e. studded tyres vs. ‘Winter tyres’ vs. all-season tyres vs. Summer tyres) perform different in terms of grip and traction, translating in shorter stopping distances, faster acceleration and improved vehicle control, the downright quantification thereof is not straightforward. In particular information on reduced braking distance is relevant, and could be used to estimate a possible accident reduction fork for accidents where braking distance plays an important role (based on epidemiological information and meteorological information). However, this also implies that direct information on the reduction of “vehicle out of control” situations such as skidding under braking or loss of control in corners needs to be collected. This information is unfortunately not available into such a level of detail for use within this study.

A second source of information concerns epidemiological information such as the one collected through the GIDAS study. Specific information and conclusions from the analysis of GIDAS data are presented in Section 4.2. The main relevant finding for the safety analysis of the influence of Winter tyres is that only for accidents on a dry road and temperatures below zero the accident data suggests that the number of accidents could be reduced by using Winter tyres instead of Summer tyres. As a result of the analysis of the data provided from GIDAS, we were provided with a number of set figures that could be used for the current safety analysis:

- 34% of accidents with passenger cars contained within the GIDAS database (that were of relevance for the current study) occurred under “grip requirement” conditions.
- The accident data indicate that a share of 4.28% Summer tyres results in 7.62% accidents. From this data it is calculated that the accident probability of Winter tyres is 54.2% compared to Summer tyres. This means that when Winter tyres are used instead of Summer tyre the probability of an accident is reduced by 45.8%.
- Given the specific German case information in GIDAS, a benefit ratio for the use of Winter tyres in comparison to regular tyres in relation to the (estimated) populations of Winter tyre use could be estimated. In the case of Germany, it was estimated that for each reduction of Summer tyres with 1%, a reduction in the number of accidents under cold and dry conditions with 0.816% could be achieved. Under the condition that similar accident ratios would be found in other Member States, this accident ratio varies between 0.561% (assuming 40% Winter tyre use in cold and dry conditions) and 0.723% (assuming 85% Winter tyre use in cold and dry conditions).

In addition to this, information was collected on the relative preponderance of Winter tyres and other tyres during wintery and other conditions. This information was collected through the consortium questionnaire, a search in international databases and a local field-study in Leuven (Belgium). Although the collected information was relatively limited, we did compose a set of “set values” to be used for the project calculations (see Table 5.2). It needs to be noted that these values can only be considered as estimates based on available information.

Table 5.2: Set-values for use of Winter tyres and other tyres during different periods of the year and under different legislative conditions.

	Winter period		Other period	
	% vehicles Winter tyres	% vehicles other tyres	% vehicles Winter tyres	% vehicles other tyres
No national legislation	40%	60%	23%	77%
Conditional national legislation	60%	40%	38.33%	61.66%
Absolute national legislation	85%	15%	11.38%	88.62%

5.2.4 Meteorological information

5.2.5 Raw data and data processing

Two main sources were used for weather data collection and analysis. Firstly, data was collected from the European Food Agency Data (EFSA) database (supported by JRC). This data is available in km² grid format and provides usable layer for a GIS-based application. In particular Layer 6 (Mean monthly temperature), Layer 7 (Mean Annual temperature), Layer 9 (Mean monthly precipitation) and Layer 10 (Total mean annual precipitation) were of interest. The source data timeframe is the period from 1950 to 2000. The exact methodology for the creation of the interpolated climate surfaces is described in Hijmans et al (2005) [40].

Weather data from the German weather services (Deutsche Wetterdienst, DWD) has been collected for the period from January 2008 until December 2013. This data consists of information from 121 locations in the EU and surrounding regions and contains the following parameters: Monthly temperature (mean, deviation, max. mean, min. mean, abs. max, abs. min), Precipitation (total, %, number of days >=1 mm), Vapour pressure, Air pressure NN, Sunshine (duration, %). This source of information was used to validate our estimations based on the EFSA data.
Data from the EFSA database was used to estimate the proportion of time (days) that a specific temperature threshold could be found within a region (NUTS1). In particular, km² grid mean monthly temperature information was averaged[16] into region monthly averages and mean temperatures were estimated. As such, we were capable of indicating for each month of the year what the likelihood was that a temperature threshold was achieved within a NUTS1 region. This was for example of use when estimating the proportion of time that a region has temperatures below 7°C (the figure often used as an efficiency cut-off temperature for Winter tyres) or 0°C (when physical road conditions change: ice can occur). These were then combined into member state averages. Graphical and tabular representations of these estimations are presented in Appendix E.

[16] After careful consideration, we choose to average temperatures within a NUTS1 area region although this would mean that local minima and maxima are discarded. This was done after detailed analysis of a set of alpine and Scandinavian regions on the presence of roads. By and large, roads did not follow the paths of local minima, which are associated mostly with mountain ranges and specific mountain ridges. Because of this, we assumed that a simple average sufficed to estimate relevant temperatures in the NUTS1 regions.

As a general comment, we point out that this methodology does take away the level of detail required to analyse the effects of Winter tyre legislation for those regions where a high diversity of temperatures can be found on a short distance. This is typically the case in regions with pronounced mountain ridges or other geological structures influencing the local climate. However, following a more detailed analysis of the regions that were mostly affected by this, we found that this was mostly the case for member states where an existing Winter tyre legislation was already in place, making this less relevant for the current analysis.

5.2.5.1 *Conditions related to Winter tyres*

There is a large variety of weather conditions in Europe, ranging from Sub-tropical climate in the South to Sub-arctic climate in the North, a Marine climate in the West and Continental climate in the East. As an example to show which member states have a high occurrence of winter conditions Figure 5.4 indicates probability of freezing temperatures during the winter season in different regions.

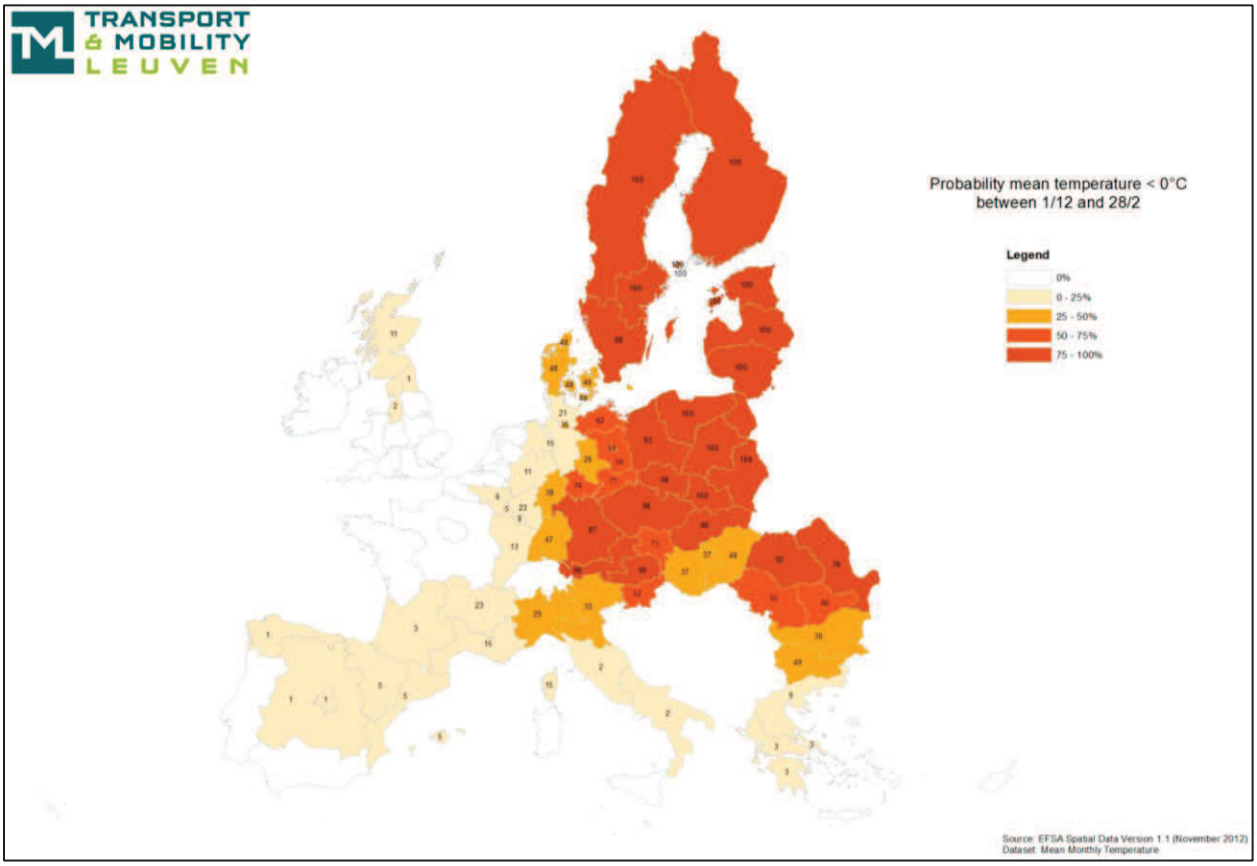


Figure 5.4: Distribution of freezing temperature probability over Europe during the winter period.

As can be seen mostly North and East Europe have low temperatures during the winter season, however also outside the coloured regions low temperatures and winter conditions can occur, although that is more incidental. The temperature range for use of Winter tyres is generally advocated to be below +7 °C, and Figure 5.5 shows the probability distribution of a maximum temperature of less than +7 °C during the winter period.

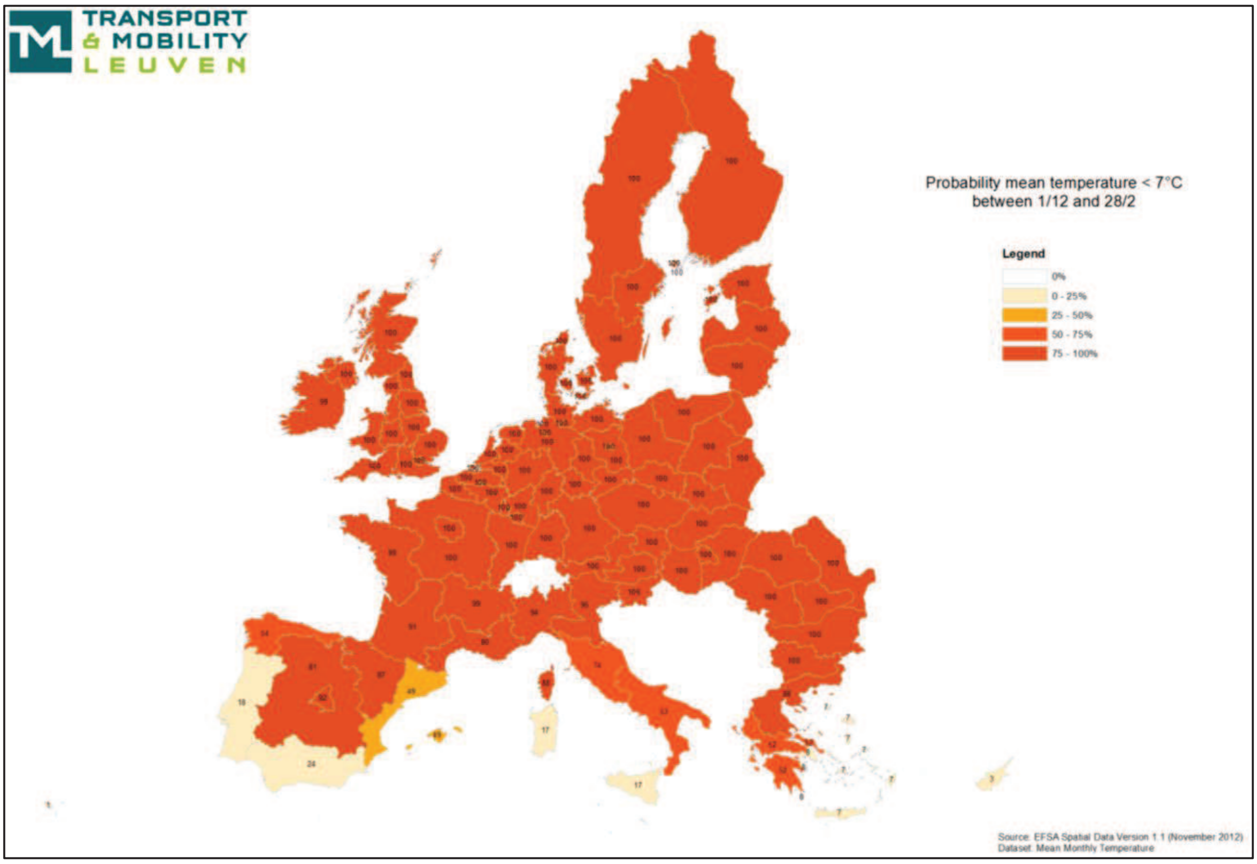


Figure 5.5: Distribution of low temperature (max temperature below +7 °C) probability over Europe during the winter period.

From Figure 5.5 it can be seen that in most European member states temperatures can occur that suit Winter tyres better than Summer tyres.
To summarize the results in this section:

- North and East Europe have a high probability of long duration winter conditions, other parts of Europe have more incidental winter conditions
- Assuming a +7 °C threshold for Winter tyres it seems that in the winter season in most European member states conditions can occur that suit Winter tyres better than Summer tyres. This makes the relevance of Winter tyres for the entire EU region clearer.

5.2.5.2 Accidents under wintery conditions

The main information source for the current analysis is the CARE database, migrated to CADaS (Common Accident Data Set) [39]. The data is made available by DG MOVE and currently covers the time period from 2000 up to 2012. Based on the information available through the EFSA database, we estimated the number of fatalities from accidents with passenger cars, busses, LGV and HGV in Europe.
As an example of the information available, Figure 5.6 shows an overview of traffic fatalities in road accidents under wintery conditions. Note that the vertical scaling in the graphs is different.

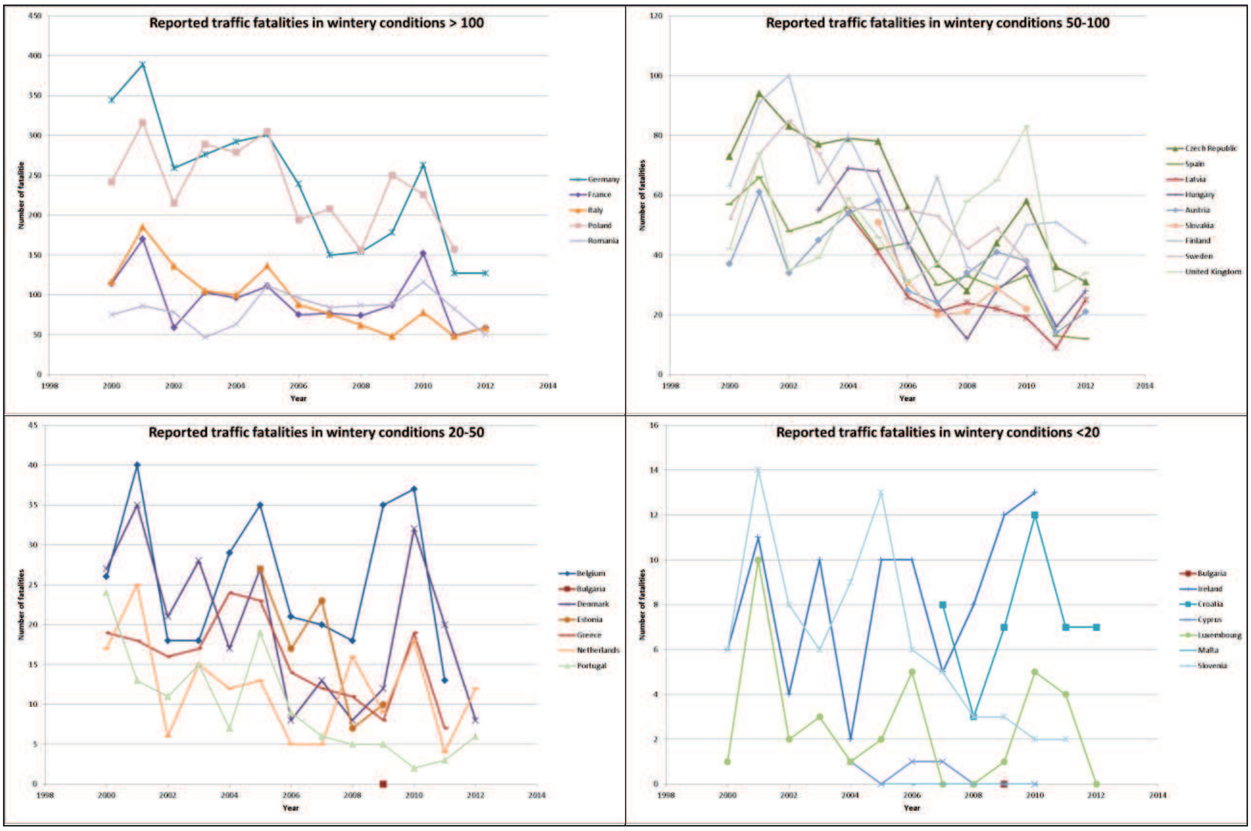


Figure 5.6: Overview of reported traffic fatalities in wintery conditions.

The top graphs in Figure 5.6 show results of member states with a large number of reported traffic fatalities under wintery conditions. As can be seen there is a general trend of a reduced number of traffic fatalities starting around 2005, which is roughly the time of introducing regulation for using Winter tyres in Germany and several other member states. However since 2004 all new vehicles are equipped with ABS, so it is unclear if the reduction of fatalities is due to extended use of Winter tyres.

Another observation is that there is an increase for more member states simultaneously around 2010, which is probably related to the general weather conditions in that specific winter season. The results for member states with a low number of reported traffic fatalities do not seem to be statistically relevant, and may be related to the incidental occurrence of wintery conditions.

Large variations in the number of fatalities seem to occur due to varying duration of winter conditions. For example, the winter of 2010-2011 was of particular strength with an early onset in November and multiple European member states reporting worse than average wintery conditions [41].

5.3 Safety effect estimations

5.3.1 Approach

The first main rationale is that a cut-off point in terms of temperature (and/or precipitation or road condition) can be objectively identified for which Winter tyres perform better than non-Winter tyres. From the technical information provided in previous chapters, two particular cut-off points may be of interest where Winter tyres may provide a technical advantage:

- 7°C general ambient temperature
- 0°C ambient temperature, but then specifically because of the formation of slippery road conditions

The second main rationale is that a number of accidents conditions could be identified for which different tyre characteristics can be allocated, compared to a reference situation. Based on the GIDAS data, we are able to get an overview of particular situations that are of interest, and how many accidents (in general) occurred where tyre types *did* play a role. This can then be used as a general rule of thumb.

The third main rationale is that we estimate the number of vehicles (in a member state) are equipped with different tyre types. Information was collected through the questionnaire[17], various direct and indirect contacts and a local field study in Leuven (Belgium). This helped make a distinction in the percentage of vehicles equipped with/without Winter tyres between three situations: member states with no Winter tyre legislation, tyres with an absolute legislation, and tyres with a conditional legislation.

Based on the combination of these three elements we can make an estimation of the number of accidents/fatalities that could be avoided (starting from actual data) through the use of Winter tyres rather than Summer tyres.

5.3.2 Identified policies for behavioural change

Within this study a number of scenarios have been identified that would help increase the use of Winter tyres (in general, but also leading to increased Winter tyre use in dry and cold conditions). Three main sets of policies were withheld: (1) voluntary change of Winter tyre use based on information campaigns, (2) forced change as a result of increased (police) enforcement and (mandatory) checks during vehicle periodic checks, and (3) changes to national legislation towards a conditional use of Winter tyres, depending on meteorological conditions.

The first policy, voluntary change of Winter tyre use based on information campaigns, builds solely on the providing of information to end users. In effect, this is discussed in more detail in Chapter 7. The example of Germany [42] is taken as a very good use case and blueprint for the identification of possible effects. Overall, it is estimated that a behavioural change of a magnitude between 10% and 20% (additional change from Summer tyres to Winter tyres) may be achieved if sufficiently detailed and accurate information can be repeatedly and personally offered to a target audience.

[17] Information was collected from Greece, Czech Republic, Continental, EMTRA & VACO.

The second policy, forced change as a result of increased (police) enforcement and (mandatory) checks during vehicle periodic checks, builds on the general notion of enhancing traffic safety through enforcement activities. As such, it builds on the findings from the FP6 PEPPER project [43] and assumes that increasing monitoring, either through police enforcement or other recognised structures, could have a possible effect on those road users who are not adhering to existing legislation.

However, in consideration to the given notion that enforcement activities are foremost aimed at the three major risk factors (speeding, alcohol, seatbelt wearing), we follow the rationale that additional actions would have to be combined with actions that are linked to enforcement actions countering any of the three major risk factors. In the case of Winter tyres, it is most appropriate to assume that vehicle technical checks can only take place while standing still, i.e. during alcohol checks for police enforcement, or during mandatory periodic vehicle checks. As a result, we follow a similar estimated fork of behavioural change, namely between 10% and 20% (additional change from Summer tyres to Winter tyres) but only in those member states where a suitable legislation in relation to the use of Winter tyres is in place.

The third policy, a voluntary or mandatory introduction of Winter tyre legislation in member states where no such legislation exists, builds solely on the harmonisation of legislation over Europe. Member States without a relevant legislation are encouraged to take up (voluntary) or more directly moved (through EU Legislation or Directives) to make use of a conditional Winter tyre legislation based on meteorological conditions or based on time. Given the diversity in meteorological conditions that can occur in Europe, and in particular in those member states without Winter tyre legislation, (on a member state level) over a given time period, it would be most appropriate to avoid a blanket legislation stating that every car should be equipped with Winter tyres from a precise starting date. The practical estimation of the effect of such a policy would then be to mimic the behaviour (Winter tyre use percentages) of member states with an existing conditional legislation in those member states that currently do not have such a legislation (i.e., copy the percentages from Table 5.2).

5.3.3 Calculations

This section performs calculations on the data from the earlier Sections. More information about these calculations is given in Appendix E.

As a result of the analysis of the GIDAS data (see Section 4.2) one particular situation was identified where a significant deviation of the share of Summer tyres in the grip accident category could be found compared to the reference category, indicating that the reduced grip linked to regular tyres could be disadvantageous compared to using Winter tyres. This is in dry, cold conditions for accidents where a grip issue has occurred as a cause for the accident.

From the CADaS database, merged with information from the EFSA database, we can identify the number of fatalities from accidents that have occurred under these cold and dry conditions. In Europe[18], 2012, we estimate a number of 588 fatalities from accident with cars, busses, LGV and HGV involved under cold and dry conditions, for which grip was a causal factor for the accident. Exact values for member states, a timeframe from 2000 up to 2012 and a predictive timeframe from 2013 up to 2030 are available in Appendix E.

Also of relevance for the estimation of the possible number of fatalities that could be avoided as a result of the use of Winter tyres rather than other tyres, is the current share of Winter tyres in Europe. In the current project, this number is estimated based on the following information: the yearly number of vehicle kilometres ran with passenger cars in Europe and for different member states [44], the temperature probability (<0°C) presenting a theoretical maximum for proper use of Winter tyres, the national legislation typologies (see above and Table 5.2) and the estimated percentage usage of Winter tyres under wintery conditions. As a result we have estimated that in Europe, 13.6 million sets of Winter tyres are currently used, under correct usage conditions.

Given the three policies that were withheld for analysis, we can then make an estimation of the possible impact of an increased use of Winter tyres. For 2012, the maximum number of fatalities that could be avoided in Europe, under the conditions described above, lies between 7 (behavioural change through voluntary pickup as a result of consumer awareness improvement) and 28 (3PMS as standard in national legislations).

5.4 Conclusion

One relevant case setting was identified for the analysis of the impact of Winter tyres based on the analysis of GIDAS data: under cold (<0°C) and dry conditions, the use of Summer tyres is associated with a higher likelihood for fatal accidents compared to the use Winter tyres. In this case setting, it was estimated that for each reduction of Summer tyres with 1%, a reduction in the number of accidents under cold and dry conditions with 0.816% could be achieved. Under the condition that similar accident ratios would be found in other Member States, this accident ratio varies between 0.561% (assuming 40% Winter tyre use in cold and dry conditions) and 0.723% (assuming 85% Winter tyre use in cold and dry conditions).Three main behavioural change options were withheld for analysing the safety effect of an increased use of Winter tyres. Overall, a possible decrease of between 7 and 28 fatalities on a European level (2012) could be anticipated.

[18] Not included are Bulgaria (insufficient data available for the identification of fatalities under specific weather conditions) and Lithuania (insufficient information available on general accidents)

6 Tyre tread depth requirements

6.1 Introduction

The main objective of this section is to present an evaluation of safety benefits of harmonised measures concerning the use of the most appropriate tyres in terms of tyre tread depth. Identified benefits would be mainly situated in the domain of safety, but also other benefits may exist. Whereas the focus of the current chapter lies on safety, other costs and benefits linked to policy options related to changes in tyre tread depth and tyre use are discussed in other chapters. The starting-point of the analysis comprises the existing legislation in relation to tread depth, current practices and existing findings describing the link between tyre tread depth and road safety. These findings are brought into relation with each other and the use of different vehicle categories where possible.
In order to evaluate the benefits of harmonised measures regarding the (minimum) tyre tread depth, an analysis is performed that takes into account the following elements:

- Existing legislation on tread depth.
- Information on road safety (current statistics & causal relation with tread depth), presented in terms of accident risk and fatality risk.
- Current tyre use information in EU member states.
- Tyre technology information allowing for the quantification of the characteristics and performance of tyre wear grades (i.e. Winter tyres) in relation to weather conditions.
- Meteorological information (temperature & precipitation).

A simplified safety model was used with grouped input data. Based on literature review, the project questionnaire and available data, a number of safety-related effects were identified and quantified.

6.2 Overview

6.2.1 Tread depth legislation

6.2.1.1 Information sources

A selection of tread depth legislation and recommendations as obtained from questionnaire replies is presented in this section. The main value, 1.6 mm for passenger car Summer tyres (and most Winter tyres), stems from the EU Council Directive 89/459/EEC of 18 July 1989. However, different organisations in member states also give recommendations for Summer tyres. Also, some member states have other legislation for Winter tyres. The results presented here are indicative of the variety of legislation and recommendation of tread depth for Summer tyres and Winter tyres respectively. Moreover, some questionnaires returned are inconsistent for the same member states, but nonetheless the results are indicative of the variety that exists between member states. Table 6.1 shows the results for passenger car tyres.

Table 6.1: Tyre tread depth legislation/recommendation for passenger car tyres.

Member state	Summer tyre Legal/recommended (mm)	Winter tyre Legal/recommended (mm)
Austria	1.6	4.0
Croatia	1.6/-	3.0/-
Czech Republic	1.6	3.0
Denmark	1.6/2.5	1.6/2.5
Estonia	1.6	3.0
France	1.6	/3.5
Finland	1.6/4.0	3.0/5.0
Germany	1.6/3.0	1.6/4.0
Greece	1.6/-	1.6/-
Ireland	1.6/3.0	1.6/-
Italy	1.6/-	1.6/-
Latvia	1.6	3.0
Lithuania	1.6	3.0
Netherlands	1.6/2.5	1.6/2.5
Poland	1.6/-	1.6/-
Slovakia	1.6	3.0
Slovenia	1.6	3.0
Spain	1.6/-	1.6/-
Sweden	1.6/3.0	3.0/-
Other EU member states	1.6	-

As can be seen in Table 6.1 the organisations in member states that provide a tread depth recommendation indicate for Summer tyres 2.5, 3 or 4 mm. Some member states have different tyre tread depth regulation for Winter tyres. It appears that EU Member States (and neighbouring member states) that require Winter tyres during the winter season, may require an increased (3 mm or more) minimum legal tread depth for Winter tyres, e.g. EU Member States Austria, Finland, Sweden, Slovenia, Slovakia, Lithuania, Latvia, Estonia, Czech Republic, Croatia. These are mainly member states with a high occurrence of winter conditions. The recommended tread depth by several tyre manufacturers for Winter tyres is 4 mm, which is often referred to in the questionnaire answers.

As far as recommendations (not legislation!) is concerned, it is also useful to take a look at the recommendations posted by the different tyre manufacturers. For most A-brand tyre manufacturers, official manufacturer sites mention the link between a reduced tyre tread pattern and the increased risk on aquaplaning. Most tyre manufacturers follow on this with recommending a higher than 1.6 mm minimum tyre tread depth for practical daily usage.

The tyre tread depth regulation for trucks and busses typically is different from passenger car tyre regulation. Table 6.2 shows some indications obtained from the questionnaire for trucks. Some member states apply the same tyre tread depth regulation for trucks as for passenger cars. It seems that for Summer tyres of trucks the recommended value of 3 mm is most common. For Winter tyres the recommended tread depth for trucks is 3, 4 or 5 mm. The majority of Member States have it set at 1.6 (exception to this rule are: Austria 2 mm, Denmark 1 mm, France 1 mm, Hungary 3 mm, Portugal 1 mm, UK 1 mm).

Table 6.2: Tyre tread depth regulation for trucks.

Member state	Summer Legal/recommended (mm)	Winter Legal/recommended (mm)
Austria	2.0	2.0
Croatia	1.6/-	1.6/-
Denmark	1.0/-	1.0/5.0
Finland	1.6/3.0	1.6/5.0
France	1.0	1.0
Germany	1.6/3.0	1.6/4.0
Hungary	3.0	3.0
Ireland	1.6/3.0	1.6/3.0
Italy	1.6/-	1.6/-
Netherlands	1.6/-	1.6/-
Portugal	1.0	1.0
Sweden	1.6/-	5.0/-
United Kingdom	1.0	1.0
Other EU member states	-	-

Based on the results from the questionnaire the following can be summarized about tread depth legislation and recommendations:

- For passenger car tyres a legal limit for Summer tyres of 1.6 mm is a general practice in the EU Member States.
- Organisations in some EU Member States post a higher recommended minimum tread depth for Summer tyres: 3 mm is most common.
- A required tread depth of 3 mm is most common for passenger car Winter tyres (followed by 1.6 and 4 mm) and 1.6 mm for trucks.
- Some EU Member States post a higher recommended minimum tread depth for Winter tyres (when they post a legal 1.6 mm tread depth).
- Several member states apply the same tread depth regulation for passenger car and truck tyres.

6.2.2 *Road safety information*

The main source for road safety information that was used for the estimation of the impact effect of the introduction of different legislations in relation to tyre tread depth was presented through CADaS. This information source contains the information from the CARE database, migrated to CADaS (Common Accident Data Set) [39]. The data is made available by DG MOVE and for the current analysis; we made use of the data from the time period from 2000 up to 2012.

The content of CADaS is of particular interest since it contains some accident properties that are directly relevant for the current study that were recorded by police officers. However, the database does not contain specific information on the tyre tread wear in the case of fatal accidents. To make an estimation of the distribution of different tyre tread wear at accidents, we needed to link the information from CADaS to other information sources, such as the GIDAS database and information received on tyre tread wear. These information sources are described in the next section.

6.2.3 *Tread depth and safety*

Two main data information sources were identified that allow to describe the effect of tyre tread depth in relation to safety: vehicle-tyre experiments (Section 3.3) and epidemiological studies (Sections 4.2 and 4.3). Two main findings are presented as a result: vehicles running with a tread depth lower than 1.6 mm suffer from a higher accident likelihood (in particular on wet or snow covered roads) and the braking performance on snow and wet below 4 mm tread depth decreases more than proportional (this appears for both winter and other tyres). Also, the speed at which the likelihood to experience aquaplaning increases under wet conditions, decreases significantly with a reducing tread depth, and can already be severely reduced at a tread depth of 3 mm.

Information on reduced braking distance is of particular relevance and could be used to estimate a possible accident reduction fork for accidents where braking distance plays an important role (based on epidemiological information and meteorological information). However, this also implies that such direct epidemiological information (from for example naturalistic driving studies) is available. This is however not the case within the scope of the current study, and as a result, one cannot directly rely on experimental tyre performance studies to estimate the reduction of “vehicle out of control” situations such as skidding under braking or loss of control in corners as a function of (remaining) tread depth.

A second source of information concerns epidemiological information such as the one collected through the GIDAS study (see Section 4.2.) and the NHTSA study documented in Section 4.3. The main relevant findings for the safety analysis of the influence of tyre tread depth are following:

- Tread depth seems to influence grip related accidents on a wet road. The results indicate that an increase of tread depth above 1.6 mm would reduce the number of accidents. A quantification of the safety effect is possible: assuming a 10% share of vehicles driving with less than 1.6 mm tyre tread depth, an accident reduction ratio of 3.772% per percentage of vehicles that change from illegal tyre tread depths is estimated (see Chapter 4).
- Winter tyres: results indicate that an increase of the minimum tread depth could reduce the number of grip related accidents on snow. The results for snow conditions indicate that below 4 mm tread depth relatively more grip related accidents occur. Assuming 7.35% usage of Winter tyres under snow conditions (road or precipitation) of Winter tyres with less than 4 mm tread depth, an accident reduction ratio of 1.147% could be achieved for each percentage of change from such reduced-tread depth Winter tyres (see Chapter 4).
- Truck tyres: results indicate that tread depths below 1 mm are only found in grip accidents. Tread depths up to 4 mm are more common in grip related accidents compared to the reference group. Because of the limited sample size, we cannot be certain about the effect of the introduction of a minimum tread depth for trucks on grip accidents[19].

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[19] From personal contacts with Belgian federal police, it also became apparent that multiple technical failures often occur with trucks. Faulty tyres (low tread depth) are often an indication of poor maintenance on a general level to equally important sub-systems of the truck or trailer (braking system, chassis torsion, etc.). As a result, we assume that the findings identified in GIDAS in relation to trucks are more than likely linked to a more general failure to maintain the vehicle and

In addition to this, information was collected on the relative distribution of different tyre tread depths in the vehicle fleet. This information was collected through the consortium questionnaire (presenting results from, a search in international databases and a local field-study in Leuven (Belgium). Although the collected information was relatively limited, we did compose a set of “set values” to be used for the project calculations (see Table 6.3). It needs to be noted that these values can only be considered as estimates based on available information[20].

Table 6.3: Distribution of tyre tread depth for passenger cars (Winter tyres and Summer tyres).

Passenger car tyre distrubutions	Summer tyres							
	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm
Front axle	1%	2%	10%	21%	27%	23%	13%	4%
Rear axle	0%	2%	11%	17%	24%	23%	16%	5%
average	1%	2%	11%	19%	25%	23%	14%	5%
Passenger car tyre distrubutions	Winter tyres							
	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm
Front axle	0%	1%	7%	23%	29%	24%	13%	4%
Rear axle	0%	1%	8%	19%	26%	24%	16%	5%
average	0%	1%	8%	21%	28%	24%	14%	5%

As a result of the analysis of the data provided from GIDAS, we were provided with a number of set figures that could be used for the current safety analysis:

- Given the specific German case information in GIDAS ,it was determined that a share of 8.9% reduced tread depth Winter tyres accounts for 8.2% of (snow-related) accidents. It was estimated that for each reduction of Winter tyres with a tread depth of 3 mm or less with 1% (i.e. from 90% to 91% use of Winter tyres), a reduction in the number of accidents under snow conditions with 1.147% could be achieved (see Chapter 4).
- From statistical data presented by NHTASA it was determined that a share of 7.55% illegal tread depth tyres accounts for 33.88% of (grip-related) accidents. It was estimated that for a 1% reduction of illegal tread depth tyres, a reduction in the number of accidents under relevant grip conditions with 3.772% could be achieved (see Chapter 4).

6.3 Safety effect estimations

6.3.1 Approach

The first main rationale is that a cut-off point in terms of an accident scenario (or road condition) can be objectively identified for which tyres with higher vs lower tread depths function better. From the technical information provided in previous chapters, one particular cut-off point was identified.

observe the relevant technical legislations. Focussing on tyre tread depth solely would not pose a solution in these cases.

[20] Information was collected from Greece, Czech Republic, Continental, EMTRA & VACO.

The second main rationale is that one accident condition could be identified for which different tyre characteristics can be allocated, compared to a reference situation. Based on the safety study presented in Chapter 4, we are able to get an overview of particular situations that are of interest, and how many accidents (in general) occurred where tyre types *did* play a role. This can then be used as a general rule of thumb.

The third main rationale is that we estimate the number of vehicles (in a member state) that are equipped with tyres with different tyre tread depths. Information was collected through the questionnaire, various direct and indirect contacts and a local field study in Leuven (Belgium). This helped to make a distinction in the percentage of vehicles equipped with 1 to 8 mm tyre tread depths

Based on the combination of these three elements we can make an estimation of the number of accidents/fatalities that could be avoided (starting from actual data) through the use of tyres with an increased tread depth rather than a reduced value (for all tyres lower than 1.6 mm and for Winter tyres lower than 4 mm tread depth).

6.3.2 Identified policies for behavioural change

During the course of the project, a number of scenarios have been identified that would increase the use of tyres with a sufficient tread depth. Three main sets of policies were withheld: (1) faster voluntary replacement of vehicles running tyres with illegal tread depth (<1.6 mm) as a result of information campaigns, (2) faster forced replacement of vehicles running tyres with illegal tread depth (<1.6 mm) as a result of police enforcement and vehicle periodic checks and (3) faster voluntary replacement of (winter) tyres with tread depth lower than 4 mm based on information campaigns.

The first policy, a faster voluntary replacement of tyres that have a reduced tread depth, builds solely on the providing of information to end users. In effect, this is discussed in more detail in Chapter 7. The example of Germany [42] is taken as a very good use case and blueprint for the identification of possible effects. Overall, it is estimated that a behavioural change of a magnitude between 10% and 20% (faster replacement of Winter tyres with low tread depth for (general) tyres with higher tread depth) may be achieved if sufficiently detailed and accurate information can be repeatedly and personally offered to a target audience.

The second policy, forced change as a result of increased (police) enforcement and (mandatory) checks during vehicle periodic checks, builds on the general notion of enhancing traffic safety through enforcement activities. As such, it builds on the findings from the FP6 PEPPER project [43] and assumes that increasing monitoring, either through police enforcement or other recognised structures, could have a possible effect on those road users who are not adhering to existing legislation.

This option was in particular also considered for Winter tyres (in relation to the 4 mm tread depth mentioned). However, given the current legislative framework, this option is not looked at: in most member states, it is not illegal to drive with Winter tyres with a lower than required (or recommended) tyre tread depth in summer time. Rather, national legislations tend to state that a Winter tyre with a reduced tread depth is no longer considered a legal Winter tyre to be used during winter conditions. The legislation does not state that such a tyre should no longer be used whatsoever.

The third policy, a voluntary (or by extension mandatory) introduction of legislation in member states that Winter tyres should not be allowed to be used with a tread depth less than 4 mm, independent of the meteorological conditions, builds solely on the harmonisation of legislation over Europe. Member States without a relevant legislation are encouraged to take up (voluntary) or are more directly moved (through EU Legislation or Directives) to make use of an extension of Council Directive 89/459/EEC of 18 July 1989 (or similar).

6.3.3 *Calculations*

This section performs calculations on the data from the earlier Sections. More information about these calculations is given in Appendix E.

From the NHTSA survey discussed in Section 4.3, it was identified that tyres with a higher remaining tread depth (>1.6 mm) have a proven advantage (in practice) over reduced remaining tread depths. From the CADaS database, enriched with specific tread depth information use, we identified that the number of fatalities for which a grip factor could be identified and that are associated to reduced tread depth can be estimated at 1584 fatalities (2012). For 2012, the maximum number of fatalities that could be avoided in Europe, under the conditions described above, lies between 14 (behavioural change based on consumer awareness improvement) and 124 (behavioural change through enforcement).

From the GIDAS data in Section 4.2, it was identified that one particular situation exists where (winter) tyres with a higher remaining tread depth have a proven advantage. This is in snow conditions for accidents where a grip issue has occurred as a cause for the accident and Winter tyres are used. From the CADaS database we can identify the number of fatalities from accidents that have occurred under these snow conditions. The calculations indicate that a possible decrease of between 2 and 3 fatalities on a European level (2012) could be anticipated.

6.4 Conclusion

Two case settings were identified as a result of the technical information on tyre tread depth collected and the analysis of real-life accidents contained in the GIDAS database: vehicles running with illegal tread depth tyres (under any condition) pose more risk than vehicles running legal tread depth tyres and, under cold and dry conditions, the use of Winter tyres with a low remaining tread depth (<4 mm) poses more risk than the use of tyres with an increased tread depth.

In these case settings, it was estimated that for every percent decrease of the use of illegal tread depth tyres (<1.6 mm), 3.772% of associated grip accidents could be avoided and that for every percent decrease of the use of (winter) tyres with a tread depth of less than 4 mm, 0.72% of the fatalities associated to accidents under these conditions could be avoided.

Two main behavioural change options were withheld for analysing the safety effect of a decreased use of illegal tread depth tyres and one behavioural change option was withheld for analysing the safety effect of Winter tyres with a tread depth of 4 mm or more.

In relation to the use of illegal tread depth tyres, a possible decrease between 14 and 124 fatalities (2012) was estimated. In relation to the use of Winter tyres with increased tread depth (4 mm or more), a possible decrease of between 2 and 3 fatalities on a European level (2012) could be anticipated.

7 Consumer awareness

7.1 Introduction

This chapter focuses on two main elements in relation to consumer awareness and road safety. In the first section, an overview is presented of the different elements in relation to consumer knowledge and tyre choice and use that play a role towards improving road safety. In the second section, current consumer awareness enhancing communication practices by stakeholders are the focus of attention, as well as an initial insight in potential safety benefits linked to these communication practices.

One of the objectives of Chapter 7 is to provide a qualitative overview of reported benefits of harmonised measures and communication practices in relation to consumer awareness, in particular concerning the use of appropriate tyres and the correct use thereof. The main benefits that are considered within this context are safety benefits.

7.2 Context of consumer awareness and road safety

Consumer awareness and the activities initiated to enhance consumer awareness are in general not described in a standardised way, or, at least such a standardised way was not found during the current study. Although consumer awareness is considered to be of great importance in a whole set of behaviours, i there does not appear to be a large knowledge database to link road safety and consumer awareness with the appropriate communication methodologies (including psychological, educational or social methods).

As such, also the scope of the term “consumer awareness” needs to be brought into an appropriate focus within the current study. Within the current context, we refer to the following elements when using the term “consumer awareness”. End-users (drivers or vehicle owners) need to be aware of:

- the importance of the use of the correct types of tyres as well as the correct use conditions of tyres in relation to road safety. Inappropriate choice of tyre types or misuse of tyres can lead to a higher safety risk.
- the relevant national or European legislation in relation to the correct use of tyres.
- the existence of different tyre types (for example Winter tyres) or equipment (such as Tyre Pressure Monitoring Systems or air pumps) that can be available in the market.
- the existence of appropriate information sources that are validated, accepted and monitored, so that they can make use of this information while choosing a suitable tyre or maintaining their vehicle.

Within this context, the focus of the term “consumer awareness” is a bit more narrow than the meaning that is more commonly used within the context of the European Commission. For example, in the current project we do not look at fair pricing practices.

Within this project no direct or indirect evidence has been found of consumer awareness activities directly influencing end user tyre purchase choice or tyre use. From discussions with consumer experts (health and safety), it would be fair to suggest that 10 to 20% of persons that are currently posing aberrant behaviour may be persuaded to change behaviour as a result of extensive information campaigns. This is in line with findings from for example smoking campaigns [45], [46], [47].

7.2.1 *Consumer awareness in the project questionnaire*

The importance of the elements that were identified above has been resulted in one of the sections in the stakeholder questionnaire that was issued within the course of the current project, as described in Section 9.2. Overall, we received 7 sets of answers in relation to consumer awareness and found quite a variety of answers. A short overview of the collected answers is presented below.

The current level of user awareness in relation to tyre usage by end-users.

Although a relative wide range of answers was selected, it was in general indicated that end-users are neutral of the importance of tyres and tyre usage in relation to road safety. Insofar as the importance of appropriate tyre choices according to meteorological conditions and tread depth, it was overall indicated that end users were neutral. This was a not so much the case for tyre inflation pressure maintenance.

When looking at the difference between car drivers and other vehicle categories (LGV, HGV, busses and coaches), it became apparent that car drivers in particular are considered to be less aware of the importance of tyres, tyre usage, etc. in relation to road safety as the other vehicle categories (where more professional drivers are included). This may be linked strongly to the courses that are followed by professional drivers and the regular training they receive.

The current level of user awareness in relation to tyre usage by national administrations.

A rather pronounced distinction could be made between the answers received on this question. On one hand, one group of answers indicated that national administrations are very much aware of the importance of tyre, tyre usage, etc. on road safety. On the other hand, the multitude of answers indicated that national administrations are more (slightly) unaware of this.

This answer does cause some concern since it is of high importance that the relevant administrations are themselves convinced of the link between tyres, tyre usage and safety before any communication campaign towards end-users would be supported.

The current level of user awareness in relation to tyre usage by insurance companies.

Four responses in relation to this question were received. The general indication is that insurance companies are neutral to aware of the link between tyres, tyre usage and road safety.

The current level of user awareness in relation to tyre usage by other stakeholder groups.

Four responses in relation to this question were received. The general indication is that other stakeholder groups are mostly aware of the link between tyres, tyre usage and road safety. In particular the FIA was mentioned as being highly aware of this link.

Consumer awareness enhancing activities currently existing in relation to tyre choice and tyre use in general.

From the collection of answers, the general impression is that end users are mostly informed by tyre industry PR activities and comparison articles by specialised public media. In some member states, information is also provided by combined private-public initiatives. The overall feeling however is that consumers make most use of pricing information and the national legislation to make a tyre purchase decision. From the stakeholder meeting, it also became clear that it may be too early for the EU tyre labelling initiative to already have a (major) influence on tyre choice.

7.3 Existing communication practices enhancing consumer awareness

A number of examples of communication practices could be found as a result of the rather extensive information collection activity that was executed during the course of the project. In addition, numerous stakeholders informed us about activities planned or finished in their respective member state. In the current section, we have made a summary of the most prevalent communication practices for which we have received information from stakeholders.

At this time, it is important to note that different information may need to be presented at different times and locations. For example, the purchase of a tyre is made once every x-thousand kilometres. It would be most rational to focus the provision of information that is relevant for this choice at tyre centres, specialised media, etc. Issues in relation to inflation pressure and tread depth on the other hand are an on-going elements throughout the lifetime of a tyre. This makes the opportunity to monitor and mediate something that is more spread over time and location.

In general, it was noticed and mentioned that these initiatives are a combination of public-private effort. On one hand, there is a need to provide as objective as possible information. On the other hand, there is a need to capture the attention of the target group at the time when they are actively engaged in a purchase, maintenance action, etc. This requires some effort from all parties involved.
An excellent example for a good (or best) practice is presented by DVR [42].

7.3.1 General practices in relation to tyre use and tyre quality

Dedicated periods of the year

The idea behind this is that a specific time period (week, month, etc.) is proclaimed and associated with a specific safety aspect. This can for example be the case for holiday traffic (July), drink-driving (festive periods), seatbelt use (first weeks of September), etc. In Germany, the month of March was proclaimed to be “tyre month” in 2013 and specific initiatives were initiated during that period, as well as information booklets provided to end users.

Information gadgets and brochures

Although it is not uncommon for people to realise that there is a link between tyre type, tread depth and inflation pressure and road safety, this link is not always actively remembered. In order to be reminded about this, small information brochures are printed and presented to end users. In addition, easy-to-use gadgets can be made that make a rather abstract situation more tangible. An example thereof is the production of “tread wear samples” in Germany that presents some form of visual recognition for end-users and tyre specialists on worn tyres. Other examples are the (free) providing of easy-to-use tread-depth gauges at car-related events, car washes, retail centres, etc.

Road safety days and targeted information campaigns

The idea behind a specific road safety day is that a wider target population is reached through a highly-focussed, highly mediatised day. Examples thereof are the national road safety days that are organised (often together with the European road safety week). During this day, the main purpose is to make road safety as a general topic known to the public, and make use of that short period of time to also drive home important tips for end-users.

Location-based activities

Information can be provided at locations that are directly linked to vehicle maintenance. Examples thereof are: petrol stations, carwashes, tyre retail centres, period check centres, garages, etc. In some cases, it may not only be information that is provided, but also the tools required to perform a safety check or improvement. An example thereof is the providing of air pumps at petrol stations in order to monitor and adjust tyre inflation.

EU Tyre labelling scheme

The EU Tyre labelling scheme was indicated by most stakeholders as assisting in increasing consumer awareness increasing actions, yet there is no direct indication of different purchasing behaviour and thus of improved vehicle safety. However, it may be too soon to expect (or analyse) the effects of such a tyre labelling scheme.

Comments from the stakeholder meeting indicate that it would be feasible to add an extra element to the tyre labelling set as far as tyre choice is considered (“grip under slippery conditions”). However, this may lead to information overload.

7.3.2 *Specific practices in relation to Winter tyres*

Campaigns linked to specific periods of the year

The idea behind these campaigns is that they make use of specific identified periods of the year, for example around the time when daylight saving time becomes active (winter to summer) or is reversed (summer to winter), that are associated with winter. Around this time, a number of information campaigns is initiated that reminds people of changing tyres towards Winter tyres (if this is required by legislation, or personnel needs would warrant such a change).

Location-based activities

The period leading to the winter-period or the winter-holiday period is for most people also an opportunity to clean their vehicle and perform regular maintenance. This can be used to provide information at those locations frequented by this target group (for example: garages, carwash, etc.).

7.4 Conclusion

An overview was presented of relevant findings in relation to consumer awareness. In general, it was indicated that end-users (passenger car) are still lacking in awareness on the importance of tyre properties and tyre use in relation to safety. Professional drivers are more aware of this. In particular national administrations may also be lacking of this know-how.

A selection of consumer awareness enhancing activities is presented that may have a particular effect. In general, consumer awareness may reduce aberrant behaviour by 10 to 20%, but this may require long-term information campaigns. The German example [42] is suggested as a good practice.

8 Tyre Pressure Monitoring System Technologies

8.1 Introduction

In [48] a Tyre Pressure Monitoring System (TPMS) is defined as a system fitted on a vehicle, able to perform a function to evaluate the inflation pressure of the tyres or the variation of this inflation pressure over time and to transmit corresponding information to the user while the vehicle is running. TPMS report real-time tyre-pressure information to the driver of the vehicle, either via a gauge, a pictogram display, or a simple low-pressure warning light. TPMS can be divided into two different types — direct (dTPMS) and indirect (iTPMS). dTPMS are provided both at an OEM (factory) level as well as an aftermarket solution.

A study presented by NHTSA [22] shows that inflation pressure maintenance is improved for vehicles equipped with TPMS, however the share of TPMS vehicles with less than 25% underinflation is higher than average. This suggests that owners of vehicles with TPMS pay less attention to inflation pressure maintenance.
The following sections describe indirect TPMS, direct TPMS and its performance, the state of legislation and finally a discussion.

8.2 Indirect TPMS

Indirect TPMS do not use physical pressure sensors but estimate air pressures by monitoring individual wheel rotational speeds and other signals available outside of the tyre itself. First generation iTPMS systems utilize the effect that an under-inflated tyre will have a larger deflection under load, resulting in a smaller rolling radius (and hence higher angular velocity) than a correctly inflated one. These differences are measurable through the wheel speed sensors of ABS/ESC systems. Second generation iTPMS can also detect simultaneous under-inflation in all four tyres using spectrum analysis of rotation speeds of individual wheels. The spectrum analysis is based on the principle that certain vibration modes and frequencies of the tyre/wheel assembly are sensitive to the inflation pressure changes. These oscillations can hence be monitored through advanced signal processing of the wheel speed signals. Current iTPMS consist of software modules being integrated into the ABS/ESC units.

iTPMS cannot measure absolute pressure values, they are relative by nature and have to be reset by the driver once the tyres are checked and all pressures adjusted correctly. The reset is normally done either by a physical button or in a menu of the on-board computer. iTPMS are sensitive to the influences of different tyres (e.g. when mounting Winter tyres) and external influences like road surfaces and driving speed or style. The reset procedure, followed by an automatic learning phase of typically 20 to 60 minutes of driving under which the iTPMS learns and stores the reference parameters before it becomes fully active. As iTPMS do not involve any additional hardware, spare parts, electronic or toxic waste as well as service whatsoever (beyond the regular reset), they are regarded as easy to handle and very customer friendly.

8.3 Direct TPMS

Direct TPMS employ pressure sensors on each tyre, either inside the tyre or external via the valve. The sensors physically measure the inflation pressure in each tyre and report it to the vehicle's instrument cluster or a corresponding monitor. Some units measure and alert temperatures of the tyre as well. These systems can identify under-inflation in any combination, be it one tyre or all, simultaneously. Although the systems vary in transmitting options, many dTPMS products (both OEM and aftermarket solutions) can display real time inflation pressures at each location monitored whether the vehicle is moving or parked. There are many different solutions but all of them have to face the problems of exposure to tough environments and the majority are powered by batteries which limit their useful life.

Some sensors utilise a wireless power system similar to that used in RFID tag reading which solves the problem of limited battery life by electromagnetic induction. This also increases the frequency of data transmission up to 40 Hz and reduces the sensor weight which can be important in motorsport applications. If the sensors are mounted on the outside of the wheel, which is the case for some aftermarket systems, they are in danger of mechanical damage, aggressive fluids and other substances as well as theft. If they are mounted on the inside of the rim, they are no longer easily accessible for service like battery change and additionally, the RF communication has to overcome the damping effects of the tyre which additionally increases the need for energy. Furthermore, for use of Winter tyres a duplicate set of wheels with sensors may be required unless tyres are exchanged on the rims. Recently dTPMS systems have been launched on the market that are glued on the tyre inner liner.

A direct TPMS sensor consists of following main functions requiring only a few external components (some systems may be more extended):

- pressure sensor;
- analogue-digital converter;
- microcontroller;
- system controller;
- oscillator;
- radio frequency transmitter;
- low frequency receiver, and
- voltage regulator (battery management).

Most originally fitted dTPMS have the sensors mounted on the inside of the rims and the batteries are not exchangeable. With a battery change the whole sensor will have to be replaced and the exchange is only possible only with the tyres dismounted, meaning that the lifetime of the battery becomes a crucial parameter.

To save energy and prolong battery life, many dTPMS sensors hence do not transmit information when not rotating (which keeps the spare tyre from being monitored) or apply a (costly) two-way communication which enables an active wake-up of the sensor by the vehicle. For OEM fitted dTPMS to work properly, they need to recognize the sensor positions and have to ignore the signals from other vehicles. There are hence numerous tools and procedures to make the dTPMS "learn" or "re-learn" this information, some of them can be carried out by the driver, others need to be done by the workshops or even require special electronic tools. There is a wide variety of spare parts, procedures and tools required in workshops to support all dTPMS. Furthermore when different specification tyres are mounted that require a different inflation pressure an adjustment of the settings may be required.

Aftermarket dTPMS units not only transmit while vehicles are moving or parked, but also provide users with numerous advanced monitoring options including data logging, remote monitoring options and more. They are available for all types of vehicles, from motorcycles to heavy equipment, and can monitor up to 64 tyres at a time, which is important for the commercial vehicle markets. Many aftermarket dTPMS units do not require specialized tools to program or reset, making them generally much simpler to use.

8.4 Performance

The information regarding the performance is provided by a supplier of Direct TPMS (Schrader Electronics) and a supplier of Indirect TPMS (Nira Dynamics) respectively.

Schrader Electronics explains its experimental results regarding the performance and robustness of iTPMS systems in [49]. The results are shown in Figure 8.1 and Figure 8.2. As observed there are cases where indirect TPMS do not show satisfactory performance.

Nira Dynamics has provided TNO with results from their test own database [50]. The NIRA TPI test case database has been analysed for original equipment (OE) and aftermarket (AM) tyre sets. The tests have been divided into four different scenarios: One-wheel-deflation (1w), Two-wheel-deflation (2w), Three-wheel-deflation (3w) and Four-wheel-deflation (4w) scenarios. For each scenario, the average detection time with OE-tyres have been set to 100% respectively. The AM-tyre detection times are then expressed relative to the OE-tyre detection times (Below 100%: faster average detection, above 100%: slower average detection than OE-tyres.) The results show that there is no significant difference in TPI detection performance between OE and AM-tyres [50]. Note that the shift in average shown in the table is well within the safety margins designed into the system.

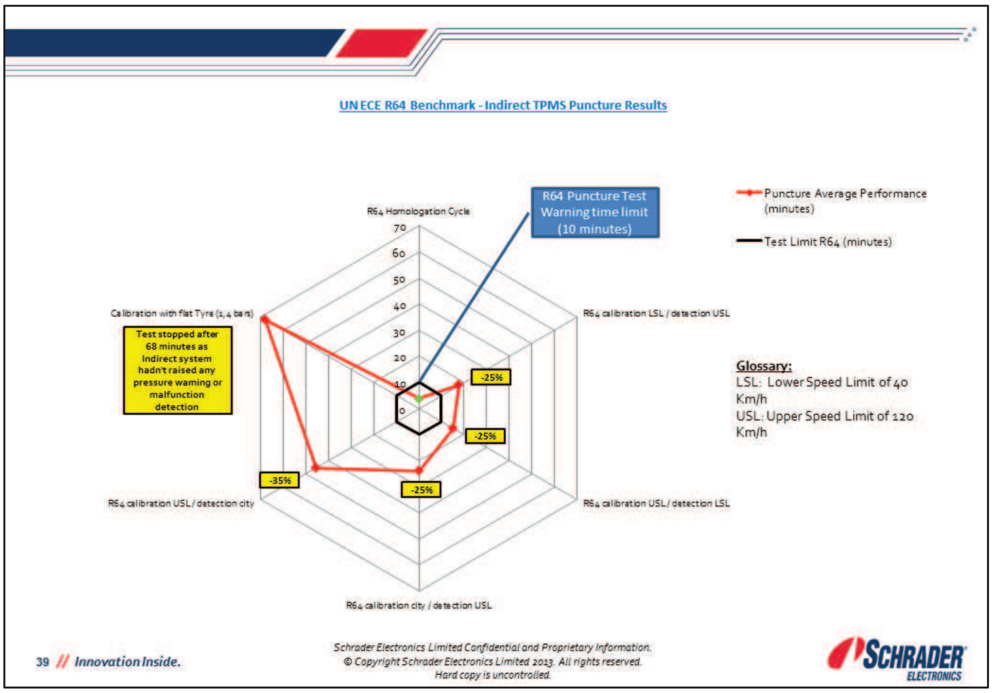

Figure 8.1: UN ECE R64 Benchmark – Indirect TPMS Puncture Results [49].

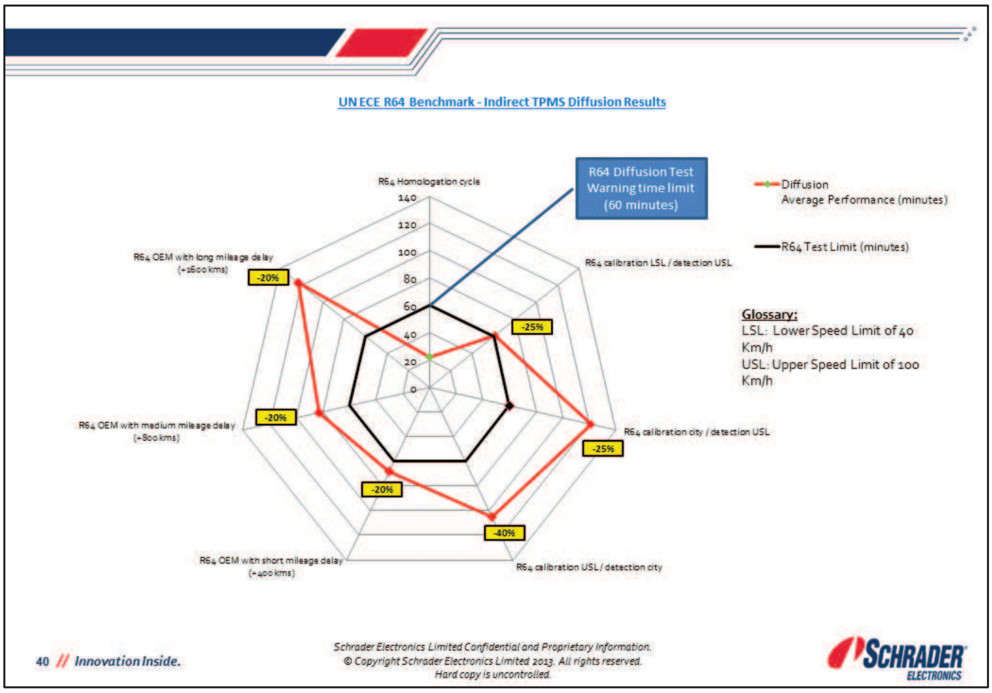

Figure 8.2: UN ECE R64 Benchmark – Indirect TPMS Diffusion Results [49].

Table 8.1: Comparison of indirect TPMS performance for OEM and AM tyres [50].

Average detection time	1w	2w	3w	4w	total # tests
Original equipment	100%	100%	100%	100%	3287
Aftermarket	91%	98%	106%	92%	921

DunlopTech has also provided a number of test results conducted by TUV-SUD [51]. From the results it is deduced that the particular iTPMS system performs satisfactorily with respect to the current ECE requirements for the OEM and AM tyres tested.

Table 8.2: Performance of indirect TPMS performance for OEM and AM tyres [50].

TÜV SÜD iTPMS Test Campaign Results 76248780-1

Test condition				Vehicle 1		Vehicle 2		Averages [min]	
Test No.	Type	Description	Wheel positions	Start pressure (cold)	Time to warning [min]	Start pressure (cold)	Time to warning [min]		
1	ECE-R64	1w puncture detection test according to ECE-R64 with 20% step deflation from warm inflation pressure after 20 min. learning phase, summer tires	1 front left	2,6 bar fr & re	2:48	2,4 bar fr, 2,6 bar re	1:10	01:57	Puncture
2	ECE-R64		1 rear right		1:17		0:58		
3	ECE-R64	4w Diffusion detction test according to ECE-R64 with 20% step deflation from warm inflation pressure after 20 min. learning phase, summer tires	4		13:45		10:33	14:10	Diffusion
4	ECE-R64	1w puncture detection test according to ECE-R64 with 20% step deflation from warm inflation pressure after 20 min. learning phase, winter tires	1 front left	2,4 bar fr & re	4:17	2,3 bar fr, 2,4 bar re	1:00		
5	ECE-R64		1 rear right		2:57		1:10		
6	ECE-R64	4w Diffusion detction test according to ECE-R64 with 20% step deflation from warm inflation pressure after 20 min. learning phase, winter tires	4		13:37		18:45		
7	Cont high	1w continuous deflation detection test with special valves simulating a puncture @ higher loss rate, summer tires	1 front right	2,6 bar fr & re	3:53 (1,93 bar)	2,4 bar fr, 2,6 bar re	2:05 (2,05 bar)	02:41	Cont hi
8	Cont high	1w continuous deflation detection test with special valves simulating a puncture @ higher loss rate, summer tires	1 rear right		2:58 (1,88 bar)		1:50 (2,30 bar)		
9	Cont Low	1w continuous deflation detection test with special valves simulating a puncture @ lower loss rate, summer tires	1 front right		5:00 (2,05 bar)		2:22 (2,20 bar)	03:35	Cont low
10	Cont Low	1w continuous deflation detection test with special valves simulating a puncture @ lower loss rate, summer tires	1 rear right		4:43 (2,15 bar)		2:16 (2,30 bar)		
11	Load change	1w rear axle puncture detection test with 20% step deflation from warm pressure with learning phase unloaded and detection phase with 250kg load on the rear axle	1 rear right		3:08		1:44	02:26	Load
12	Load change	1w rear axle puncture detection test with 20% step deflation from warm pressure with learning phase loaded (250 kg on the rear axle) and detection phase unloaded	1 rear right		4:15		2:05	03:10	Unload
13	Small step diff	Detection of a continuous 4w diffusion simulated by a sequence of 3%-deflations from warm pressure every 2 hours of driving time	4		1h 19 min at 17,7%		55:00 at 16,3%	1h 07 min	
14	Hi-speed	1w puncture detection test with 40% deflation from warm pressure at speeds > 130 km/h up to vehicle maximum speed (Autobahn)	1 front right	2,8 bar fr, 3,0 bar re	1:20 (counted from 0 km/h)	2,6 bar fr, 2,8 bar re	1:10 (counted from 0 km/h)		
15	ZPD	1w puncture detection test with 100% deflation simulating an undetected puncture day before and standstill overnight	1 front	0 bar	1:54 (not equipped with zero pressure detection feature)	0 bar	0:10		

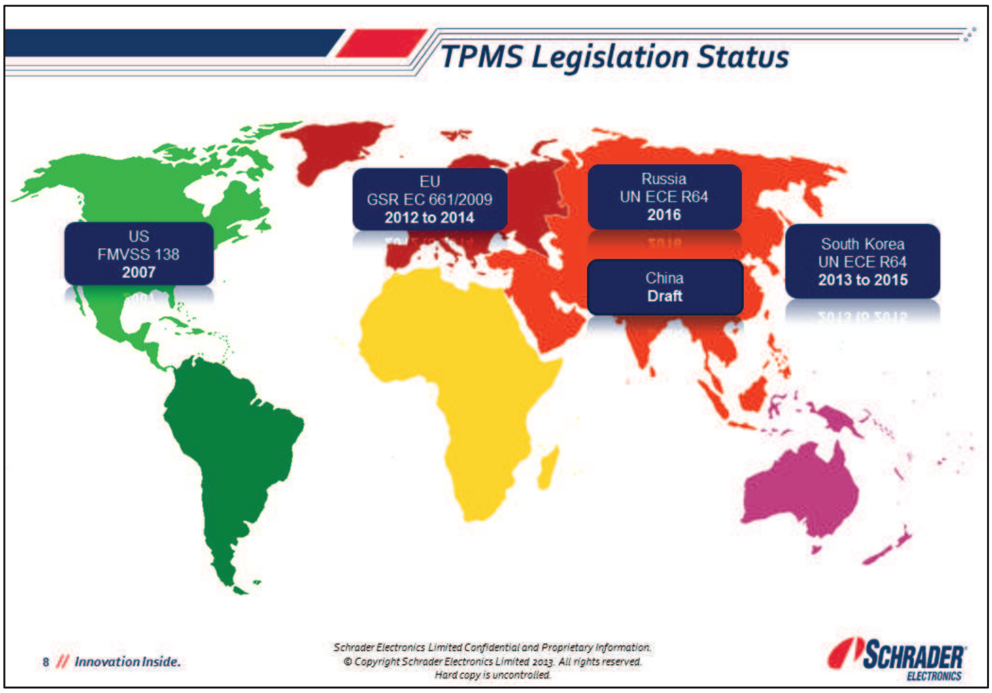

Figure 8.3: Worldwide TPMS regulations [49].

In Figure 8.3 an overview is sown of worldwide TPMS regulations. Below the different regulations are briefly summarised:

FMVSS 138 (USA)
- Underinflation pressure warning threshold is 25% below P_{cold}
- Maximum warning time for multi underinflated tyres is 20 minutes

UN ECE R64 (EU GSR EC 661/2009 + Korea + Russia) [48]
- Underinflation Pressure warning threshold is 20% below P_{warm}
- Maximum warning time for multi underinflated tyres is 60 minutes
- Puncture detection of a single tyre within 10 minutes

China, Voluntary standard (GB/T 26149-2010) which is currently reconsidered to become a Mandatory Regulation with probably amended performance requirements
- Underinflation pressure warning threshold is 25% below P_{Cold}
- Maximum warning time for multi underinflated tyres is 10 seconds

Tyre temperature increases during driving, and that also results in an increase of inflation pressure. This means that the European regulation UN ECE R64 is more stringent on warning threshold than the USA regulation FMVSS 138, but the detection time is longer.

Europe

Regarding TPMS in March 2009 the European Parliament officially approved a Directive Proposal of the Commission introducing a series of implementing measures imposing mandatory adoption of some proven existing technology including Tyre Pressure Monitoring Systems (and ESP).

As for TPMS introduction dates and technical specification this mandate officially requires that (see article 9.2 of adopted text): "Vehicles in categories M1 shall be equipped with an accurate Tyre Pressure Monitoring System capable of giving, when necessary, an in-car warning to the driver when a loss of pressure occurs in any tyre, which is in the interests of optimum fuel consumption and road safety. Appropriate limits in the technical specifications shall be set to achieve this, which shall furthermore allow for a technology-neutral and cost-effective approach in the development of accurate Tyre Pressure Monitoring Systems."

As for the introduction dates of TPMS, there is a two year phase-in schedule starting from November 1st 2012. Article 13.1 to 13.4 of the adopted text states that all vehicles type approved after this date must install a TPM System. Furthermore all newly registered vehicles after November 1st 2014 must have a TPM System.

8.5 Discussion

For safety a slow decreasing pressure (e.g. due to a puncture) is not the highest danger because this typically does not happen at all four tyres simultaneously and therefore both systems would be capable of detecting this, perhaps with a different resolution and within a different time span.

In case this does happen with all four tyres simultaneously, e.g. due to diffusion, there could be a benefit when using direct systems, but we could find no evidence that this is indeed the case and that this is a relevant situation.

The highest risk with respect to safety is a rapidly decreasing pressure. Both systems are able to detect this, but again within a different time span. We could not find data that compares the performance between the two systems for this event. The scope of this study is focused on safety impact. No evidence has been found that a direct safety benefit would result from preferring one method over the other.

Although out of the safety scope, it must be remarked that the current TPMS regulation describes systems that only provide warnings for dangerous under-inflation. However, moderate underinflation for long periods lead to significant additional rolling resistance and consequently fuel consumption and emissions (Section 3.5). Adding this to the experience in the USA (NHTSA study) that the share of TPMS vehicles with less than 25% underinflation is higher than average, and the intended fuel consumption benefit may not be achieved.

9 Stakeholder consultation

9.1 Stakeholder meeting summary

This section contains the summary of the stakeholder consultation meeting organized on June 10 2014 in Brussels. This summary is not intended to capture all the details of the discussions held during the meeting, but serves to reflect the main topics discussed and the opinions of the stakeholders that were present during that meeting. The attendees of the consultation meeting are listed in Appendix B.

The meeting was structured according to the final version of the agenda which is attached to this document.

<u>1. Introduction and welcome by the Commission.</u>
The Commission representative opened the meeting and explains the targets of the consultation.

<u>2. Presentation of the project objectives and project team</u>
TNO, the consortium leader, presented the study work programme and study team.

<u>3. Current use of tyres in relation to safety</u>
A generic overview of tyres and the usage of tyres in relation to safety was given, by TNO, including accident causation facts from the GIDAS database presented by VUFO. A wide variety of topics was discussed with stakeholders on the content of the presentations. Various stakeholders felt the presentation was not properly referenced and/or documented and that it did not adequately reflect the role of tyres concerning road safety. They requested that the final report be drafted with particular attention to this aspect.

Stakeholders pointed out to the following:

- The right tyre for the right weather condition should be used.
- Proper inflation pressure monitoring and maintenance is essential for tyre safety performance.
- The study on accident causation should focus on grip related cases and not extreme cases like tyre failure[21]. From the GIDAS database it can be concluded that that only a small share of accidents with personal injuries are caused by tyre failure. Furthermore the tyre conditions prior to failure are difficult to assess.
- Motorcycle accidents are different from passenger car accidents. The impression of some attendants is that motorcycles are driven closer towards the grip limit and tyre related issues are probably important, but this is not backed-up by studies. It is however mentioned that at the end of the summer season more motorcyclists experience reduced grip at low road temperatures or cold tyres. Few motorcyclists drive in winter conditions so the issues around Winter tyres seem less relevant.
- In the report the references to sources should be clearly referred to in order to allow verification of the results.

[21] Tyre failure in this context means failure resulting in disintegration of the tyre

- For the GIDAS database it should be explained how these results can be translated into conclusions applicable EU-wide.

4. Tyre Inflation pressure and tyre aging

An introductory presentation was provided by TNO and a set of four questions was posed to stakeholders. The answers can be summarised as follows:

1 How can consumers be better informed and made aware about tyre inflation pressure?
   - For various stakeholders, Members States could/should be more active in their support on making consumers aware of the relevance of tyre inflation pressure.
   - It was felt that users do not always know where to find the correct tyre inflation pressure for their car, e.g. summer and Winter tyres, loaded or unloaded.
   - There was agreement that TPMS is an important safety device. Anyhow drivers must still check their tyres regularly and have access to inflation gauges to inflate them. TPMS will enhance driver awareness but will not eliminate the need for regular (monthly) tyre inflation checks.

2 Are tyre inflating facilities available today sufficient?
   - Stakeholders pointed out that the current inflating facilities are not always available or in good condition, e.g. not properly calibrated.
   - Some stakeholders informed that sometimes consumers had to pay for the use of inflating equipment and this was an additional barrier for proper tyre inflation.
   - Other stakeholders underlined that some drivers do not know how to or cannot inflate their tyres (e.g. elderly people). Some drivers have never even tried it and do not feel comfortable with this operation.

3 Should tyre inflation pressure monitoring systems requirements be revised?
   - The majority of stakeholders advises to revise the requirements for TPMS in cars due to the improvement of technology. It was pointed out that UNECE Regulation 64 (R64) was an important step and it has just been implemented. However general consensus seemed that a second phase of R64 should be developed to increase the performance level, but several stakeholders strongly advise that evaluation of the current legislation (e.g. by collecting field data) is made before making changes.
   - Some stakeholders advised to include TPMS under the periodic technical inspection (PTI). Others pointed out that PTIs can only play a minor role since they are performed yearly and that only after a first period of two to four years.
   - Some stakeholders felt that TPMS should also have a fail-safe function so the driver would not be allowed to reset it to an inflation pressure that is dangerously low.
   - Some stakeholders reiterated the need that, for consistency in legislation, the TPMS obligations are extended also to commercial vehicles.
   - Consumer acceptance of the technology is an important aspect to consider, both in terms of use and cost.

4 Should tyre label inform about tyre aging performance?
- There was consensus amongst stakeholders that tyre age is not a safety issue.
- Agreement was also general that age is only a component of “tyre service life” which depends on various factors such as storage time, exposure to environment, speed, inflation pressure, use pattern etc. Therefore the safety issue is more related to proper tyre maintenance than “tyre service life”.
- Stakeholders would support that Member Stares put more effort on tyre inspection and enforcement of the existing rules (e.g. the 1.6 mm minimum tread depth).
- One stakeholder informed of the request by customers to be informed on tyre mileage or duration.

5. Summer tyres and Winter tyres

An introductory presentation was provided by TNO and a set of four questions was posed to stakeholders. The answers can be summarised as follows:

1 Is a new 'winter' tyre category required in addition to the snow tyre category?
- Most stakeholders felt there is no need for a new Winter tyre category in addition to the existing 3PMS[22].
- Should all Winter tyres be based on a standard test?
- Most stakeholders do not recommend new tests for Winter tyres.
- A common definition is useful and the 3PMS test (according to UNECE R117.2) should be used

2 Should a common definition of Winter tyres by applied across the EU?
- Most stakeholders would support that the EU requires Member States to refer to a common definition to avoid confusion when traveling across various Member States. The existing definition of 3PMS suffices although some useful aspects in some regions (e.g. grip on ice) are not included in that test.
- EU-wide legislation concerning the weather conditions of the period of the year when Winter tyres should be fitted is not advised by most stakeholders. Winter tyre definition should be EU-wide, the application as to when Winter tyres should be fitted mandatorily should be left to the member states in order to match local requirements and weather conditions. The general advice should be "the right tyres for the right weather conditions".
- Most stakeholders recognise that a special variant is the "Nordic tyre" which is used in some Scandinavian member states. This is a specific market with specific conditions, and therefore EU-wide regulation is not deemed useful. Relevant information is already given by manufactures but not in a harmonised way. An idea would be to supplement the tyre label with optional pictogram such as "grip on ice". The industry is already working on a test method for ice performance, but it is even more complicated than wet grip testing.

[22] Three peak mountain snowflake or 'snow tyres for severe snow conditions'

3 Should tyre labels inform about winter/summer performance?
- There is room for improvement on information to customers to add this to the label (e.g. ice grip). But complexity should be avoided. Moreover, key conditions should be met beforehand, such as the development of a uniform and reliable ice grip test method, as well as the establishment for a minimum required ice grip threshold.
- Some stakeholders emphasised that the label scheme is still very recent and it might be too early to change it again before assessing the results of the existing label.
- A harmonized way to test the performance in Nordic winter conditions is a precondition for possible label adaptation to such tyres; this topic is already on the working programme from DG ENERGY.

6. Tyre tread depth
An introductory presentation was provided by TNO and a set of four questions was posed to stakeholders. The answers can be summarised as follows:

1 Should the minimum tread depth (1.6 mm for passenger cars) be revised?
- There was consensus amongst the stakeholders that there was no evidence presented of a decrease in accidents when tyres are used above the existing limit. Therefore they do not see for any need to change minimum tread depth for passenger cars.
- Most stakeholders believe there is room for improvement by simply enforcing this minimum by means of roadside inspections and periodic technical inspections.

2 Should goods vehicles and buses be included under the tread depth requirements?
- There was no strong position on this particular point but nevertheless some stakeholders thought harmonizing the minimum tread depth to 1.6 mm to good vehicles and buses would be positive to ensure a level playing field in traffic across the EU. Currently the legislation differs among Member States and some have no minimum at all. Should a measure of this kind be proposed, sufficient lead time should be allowed for its implementation.
- Cross border traffic: harmonisation would be beneficial to facilitate the free movement of goods across borders.
- It was also pointed out that a thorough study would be needed to confirm that requiring a minimum makes sense. Some stakeholders underline that goods vehicle accidents seemed to be caused more often by other aspects (e.g. load distribution) than tread depth or other tyre-related aspects.

3 Should specific tread depth requirements for Winter tyres be established at EU level?
   - This could well be, but a more thorough study is needed because there are a lot of contributing effects. For example, performance in the snow and winter decreases with wear and there are other aspects that come into play, such as costs and environmental impact, but so far there is no consistent technical data to indicate at which level a threshold for tyres in winter conditions should be established. Moreover, there are various other important aspects for grip, beyond the tread depth, such as type of tyres and vehicles, load, driving style etc. Moreover, an impact study on minimum tread depth for winter should take into account other key elements such as costs, environmental impact (including used tyres consequences), etc.

4 Are “recommendations” useful, next to the legal minimum requirements?
   - Consensus from the industry is that a recommendation from the manufacturers or other parties is fine, but that it makes no sense to have a “legal” recommendation: safety legislation should be obligatory and not optional to avoid confusion concerning the rules; rules should be easy to follow and easy to enforce.

6. Cost Benefit Analysis

TML, member of the consortium, presented some preliminary options for measures to be considered for the cost-benefit analysis. The Commission and the consultant acknowledged that some of the options which had been considered for the presentation would be revised as a result of the stakeholders meeting.
A discussion followed on the policy options presented for each one of the topics described above.
The following table represents scenarios suggested by stakeholders as input for a Cost Benefit Analysis (CBA). These scenarios are not to be taken as policy recommendations; their suitability for policy depends heavily on the outcome of the CBA.

Table 9.1: Cost benefit analyses options (note that considered specific aspects are NOT by definition agreed upon by stakeholders, see conclusions).

Options	Tread depth	Inflation pressure and TPMS	Winter/Summer tyres	Ageing
No change	Existing legislation, including already accepted future changes in relevant legislation. This means that the current situation for individual Member States' legislation remains as it is.			
Consumer awareness	Voluntary take-up through improved information providing by Member States about the importance of maintenance.			
Advise to Member States	Improved enforcement on existing legislation: annual periodic checks and police inspections.		Member states with relevant winter conditions should apply rules on Winter tyres during a set period defined based on wintery conditions, and a harmonized definition of Winter tyres should be used therefor	
Legislation	• Extend scope of 1.6 mm minimum to HGV • Define specific minimum tread depth for Winter tyres.	• Availability of properly calibrated tyre inflation facilities at petrol stations free of charge. • Implement second phase of TPMS regulation (higher performance requirements) • Extend the obligation for TPMS mandatory fitment to commercial vehicles	Winter tyres require to comply to 3PMS approval procedure and tyre marked M+S only are no longer considered a Winter tyre	No legislation suitable for this aspect

<u>Summary of conclusions</u>
The main conclusions resulting from opinions of stakeholders expressed in the answers to the questions listed above can be summarized as follows:

- Stakeholders request that the final report of the study should be very precise in terms of properly referencing and justifying the assumptions presented which will be the basis for the final report.

- Stakeholders do not consider the need to increase the current minimum tread depth in order to improve road safety concerns. Instead the current minimum of 1.6 mm for car tyres should be properly enforced across all the EU member states. There might be room for extending the scope of the minimum tread depth requirements for goods vehicles and buses, at 1.6 mm, particularly in view of setting a level playing field across the EU. After further study there could be room to establish a different minimum tread depth for use of Winter tyres in winter conditions. Any proposal to this effect should be clearly justified by a thorough impact assessment taking into account all aspects.
- Stakeholders emphasize that correct tyre inflation pressure is an essential safety factor. It would be advisable to improve the performance requirements for Tyre Pressure Monitoring Systems (TPMS), along the line with improvements in technology. There was no conclusion and no consensus among the stakeholders to increase the warning level before getting experience from the field. However, TPMS cannot replace the user's awareness and action. In order to facilitate the task for the user, there is room for improvement concerning the information on adequate tyre inflation pressure and especially concerning the availability and correct functioning of tyre inflating facilities. The need for mandatory TPMS also for commercial vehicles should be thoroughly assessed.
- Stakeholders conclude there is no need for a new Winter tyre test or definition. The current 'snow tyre for severe snow conditions' or 3PMS, is sufficient. For some stakeholders it would be desirable that Member States, whenever establishing national regulations on the use of 'Winter tyres', refer to 3PMS tested tyres. For the Nordic region, additional information on ice performance (i.e. additional ice pictogram on sticker) will also be of help to inform consumers sufficiently. To that end, the necessary test procedures and performance requirements are still to be developed.
- Stakeholders do not consider tyre age to be a safety issue. The only meaningful concept of ageing is 'tyre service life' which depends on many different factors and it is therefore too complex to be regulated.

9.2 Stakeholder questionnaires

A questionnaire was created that takes into consideration the technical specifications of the current tender and relevant literature ([5], [37], [52], [53], [54] and [55]).

A list of stakeholders has been contacted asking them to validate and deliver information – as long as the questions linked to their expertise. The full questionnaire, which has a length of 40 pages, is provided in a separate document. The front page of the questionnaire is shown in Figure 9.1.

Questionnaire

Study on some safety-related aspects of tyre use

This questionnaire aims to collect information on various safety-related aspects of tyre use. Topics covered are, among others, the current situation of tyre use, tread depth, tyre pressure, consumer knowledge, meteorological aspects, etc.

Answers provided to this questionnaire are collected and analysed by TNO and Transport & Mobility Leuven as part of contract number MOVE/C3/2013/SER/2013-270/SI2.663427.

The findings from this study will result in recommendations and/or suggestions for EU legislation in relation to tyre use, winter tyres and other tyre-related aspects.

You are kindly invited to fill in the questionnaire to your best knowledge and/or provide source material (statistical information, sales numbers, research papers, project reports, etc.).

The questionnaire is partly about gathering information, and partly about gathering your opinion. All ***your input will be treated confidentially***: your answers will be used anonymously and will not publicly be associated with your name and company unless explicitly consulted with you.

We request you to provide as much input as possible, but acknowledge that no one can/will answer all questions. When skipping a question, please checkmark the applicable box:

☐ Question does not match my expertise
☐ Related to my expertise, but I have insufficient information available

For example, chapters 1 to 5 are in particular of interest for road safety institutes, national administrations, user organizations, etc. Chapter 6 is more of interest for manufacturers. But please try to fill in as much as possible.

Please provide your input in English.

We kindly ask you to reply to this questionnaire before 10 March 2014. This allows us to integrate the results in a ***stakeholder meeting that is planned on June 10, 2014 in Brussels***. You are invited to attend this meeting.

CONTACT PERSON FOR QUESTIONS REGARDING THIS QUESTIONNAIRE AND SUBMISSION OF ANSWERS:

Sven Jansen
TNO
PR-EUtenderTyreRoadSafety@tno.nl

Your contact details

Please provide your contact details below:
Name:
Authority / Organization:
Telephone:
Email:

Figure 9.1: First page of the questionnaire.

About 130 stakeholders have been contacted, out of which almost 50 replies have been received. Figure 9.2 shows the distribution of the stakeholder’s type. Generally speaking, the national bodies had the most response where the industry provided the most detailed response.

Figure 9.3 gives the origin member state of each stakeholder's organization. The response is well distributed over Europe. In particular a high response from Finland, France, Germany and the Netherlands has been observed.

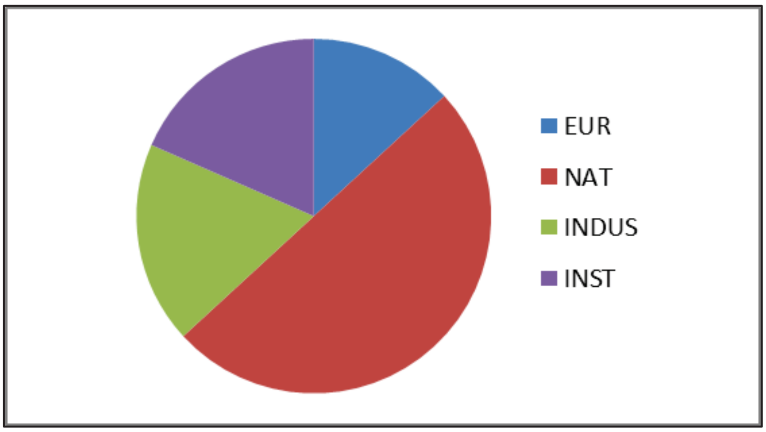

Figure 9.2: Stakeholder type.

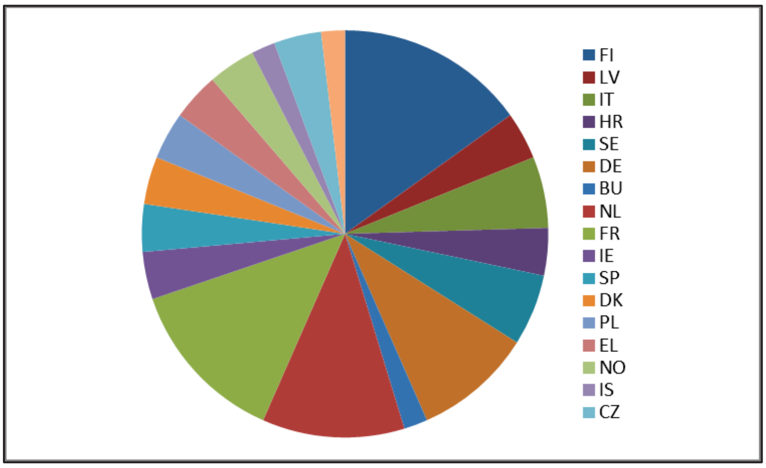

Figure 9.3: Origin member state of the stakeholder's organization.

Typically a stakeholder fills out only a part of the questionnaire that is mostly related to his/her expertise. The questionnaire has been divided in six topics. Each topic contains detailed questions. Figure 9.4 shows a histogram of the amount of responses given to each question. What can be observed is that the topics around "vehicle and tyre population", "tyre regulation and impact on use", and "tyre use and consumer awareness" received most feedback. However, the feedback was mostly based on opinions (subjective) or proprietary tests and not always supported by large open source studies.

Empirical data targeting the tyre average condition and the tyre as an influencing factor for accident causation is missing. The input available with significant statistical relevance is only available for Finland and Germany. For other member states data has not been provided or is based only on relatively small sample sizes (<100).

Figure 9.4: Response to Questions.

The questionnaire contained a number of open questions. In the remainder of this section, the indicate remarks have been listed. *Note that by no means this represents a consensus between the stakeholders nor does it reflect the opinions of the authors.* Rather it shows the diversity and type of answers that has been received. The answers have been made anonymous.

Summary of indicative answers	
Labels	• Enhanced tyre development (rolling resistance, fuel, wet grip, noise) • Danger of sub optimization (label score vs. practice vs. sustainability) • Too early to tell effect on consumer behaviour • Higher reliability of label: more enforcement for existing legislation
Winter tyres	• Need for harmonization: minimum tread depth • Tests on winter and summer conditions and wet grip
Suggested improvements	• More label diversity (dry & show grip, temp, wear). BUT: trade-off vs. cost • Minimum label: worse tyres are not allowed to be sold • Tyre expiration date, TPMS and regular pressure checks • Inspect calibration of air pumps (e.g. at petrol stations) • Include worn tyres performance in tests • More representative testing (not only on blank steel drum) • Promotion of “rubber asphalt”

Labels: current situation	
Effect on the tyre industry? (Q2.4: 22 yes, 1 no)	• Enhanced tyre development and pushed industry • But higher costs for development, testing, sale material (e.g. >30Meuro) • Sub optimization: focus on scale (EC 1222/2009) rather than other relevant tyre characteristics in practise • Consumer behaviour changes but at mid-long term
Effect on the tyre market (competition)? (Q2.5: 10 yes, 10 no)	• Too early to tell and no real campaign has been established • Label not sufficiently reliable because the values are provided by manufacturers and not verified (Q2.1).
Effect on quality of tyres? (Q2.6: 18 yes, 3 no)	• Better performance (rolling resistance, fuel efficiency, wet grip, noise) • Sub optimization: trade-off between high labelling and sustainability. Focus on label does not mean better tyres in practise. • More high quality tyres are offered in market

Should current standards be extended	
Fuel efficiency (Q2.8: 12 yes, 4 no)	• Inflation pressure has high influence • Testing should include worn tyres performance • Testing not only on blank steel drum
Wet grip (Q2.9: 13 yes, 5 no)	• Tyre age is important • Enforcement needed for existing legislation
Rolling noise (Q2.10: 10 yes, 6 no)	• ISO 2011 surface does not match real road conditions • Promotion of “rubber asphalt” • Not really important for consumers (Q2.3)

Suggestions for new standards	

Other aspects (Q2.12): 12 yes, 1 no	• Wear estimation
	• Ice grip
	• Tyre age (expiry date)
	• Better annual inspection for tyres and enforcement of existing rules
	• Test results for partly worn tyres
	  • Related to expected mileage
	  • Also relevant for 2nd hand tyres (additional inspections)

Winter tyres: needs	

More standards/definitions around Winter tyres? (Q2.11: 18 yes, 2 no)	• More harmonization useful
	  • 3PMS is the only test that guarantees specific performances in winter conditions
	  • Definition of minimum tread depth for Winter tyres under winter conditions.
	• Define performance
	  • Snow and ice grip braking results of Winter tyres of different companies vary a lot (compared to dry/wet grip)
	  • Wet grip requirements
	  • Tests at different temperatures

Consumer behaviour: new tyres	

How to enhance purchasing of more appropriate tyres? (Q2.7: 18 answers)	• National campaigns (compare with white goods and car labels)
	  • Include enforcement
	  • Include tyre expiration date
	• Label
	  • More label diversity: dry grip, snow grip, temperature, wear
	  • minimum label: worse tyres are not allowed to be sold
	  • Higher reliability of label: more enforcement by surveillance authorities
	• Winter tyres
	  • Performance under winter conditions should be introduced
	  • Test Summer tyres in winter conditions and vice versa
	  • Harmonized EU-wide definition. E.g. use 3peak symbol instead of M+S (too much interpretation).

Consumer behaviour: Tyre use	Actions to improve tyre use (Q2.13: 17 yes, 2 no) • Mandatory TPMS • Mandatory regular pressure checks • Regularly inspect the calibration of air pumps (at petrol stations) • Campaigns on proper tyre selection and maintenance + show easiness of operating the air pump yourself

9.3 Additional stakeholder input

This section contains additional input from stakeholders received after the stakeholder consultation meeting held on June 10th, 2014. The section is meant to provide some more in-depth input and clarify some statements. The opinions expressed here do not necessarily represent the opinions of similar companies or organizations.

9.3.1 Tyre industry (Michelin / ETRMA)

- TPMS / Inflation pressure
  The major safety concern is a loss of inflation pressure occurring over a (very) short time. The requirements of TPMS should be defined for a quick detection of these instances, preferably before vehicle stability is affected. The current detection time of 10 minutes is considered far too long. This quicker puncture detection could be part of the Phase 2 requirements of TPMS.
- Tyre testing standardisation
  The ETRTO is working on several testing procedures to assess tyres under specific operating conditions. An example is testing on ice surfaces, to add marking for “Nordic tyres”.
- Tyre lifetime performance
  The performance (change) of the tyres over its lifetime is relevant for road safety, and the end of life performance should meet minimal requirements.
- Periodic inspections
  Periodic inspections are the best way to check for tyre inflation pressure tread depth, damages, ageing effects.
- Truck tyre tread depth in winter conditions
  Specifically for truck tyres mainly the tractive properties are challenging in winter conditions. The load distribution between driven and non-driven axles is a dominant factor. Next to the friction between tyre and road it is the ratio of the vertical load on the driven axle compared to the total vehicle weight that determines the maximum traction capability. There is a loss of lateral stability when the driven wheels reach the limit of friction, which can be much more affected by the load distribution than the tread depth.
- Tread depth
  Enforcement of minimum tread depth should be stepped up, there are too many vehicles with tyres having less than 1.6 mm tread depth. For truck tyres a harmonization of 1.6 mm would be beneficial provided that a sufficient lead time for the implementation is foreseen
- There is an update of the wet grip test method, incorporated in Reg 228/2011. The temperature for Summer tyres is 20 °C and for snow tyres 10 °C.
- Winter tyre label performance
  A Winter tyre is designed to perform under a much larger variety of road surface conditions. As a result the performance for the labelling can be less than Summer tyres.

- Tyre labelling tests
  Tyre testing for labelling purposes may be executed by any institute provided the requirements and accreditations are complied with (alignment of laboratories, existence of proving grounds, accordance with ISO 17025 etc. of Regulation 1222/2009 and implementing regulations 1235/2011 and 228/2011).

  The facilities fulfilling these requirements are either owned by tyre manufacturers or by other companies/institutes. Should the tests be limited to independent institutions alone (provided that the criteria for "independency" would be defined), the overall testing capacity would be drastically reduced, with higher costs of the final products and no actual benefits in terms of tests reliability (actually the tyre manufacturers have in general newer and more accurate equipment than independent institutes).

9.3.2 Car industry (ACEA)

- TPMS / Inflation pressure
  Future technology will allow cars to communicate with air filling stations to prevent mistakes in air pressure. There is a standard for air filling stations (describing also the calibration requirements) to make maintaining inflation pressure for cars with ECE-R64 compliant TPMS possible. It is very important that any new requirement for TMPS ensures neutrality of technology, and to retain the possibility of using indirect TMPS. Secondly, the second phase R64 should not be introduced before evaluation of the first phase R64-TPMS Technology is completed. An important aspect is that the driver is sufficiently informed how to operate TPMS to prevent user mistakes. Measures to reduce inflation pressure loss in general should be developed.

9.3.3 FEMA (Motorcycle association)

- Tread depth
  The tread depth is the most relevant aspect for grip on wet roads. However little accident data is available showing the influence of tread depth in accidents.
- User awareness
  Motorcycle riders should be made aware that tyres will not have optimal grip performance for the first use, until the factory layer has worn. The tyres should be available without the factory layer. Secondly riders should be informed that the grip performance is very much depending on tyre temperature, which improves during driving. Finally, road authorities should provide warnings for unexpected slippery road conditions.
- TPMS/Inflation pressure
  TPMS could be beneficial, however the rider should be able to check and correct the inflation pressure at petrol stations.
- Tyre age
  Tyre expiration dates exist for motorcycle tyres.

9.3.4 *Swedish Transport Agency*

- TPMS /Inflation pressure
  The evaluation of TPMS should be done over sufficient time, and not on the technical performance only, but maybe more important on how drivers use and perceive the system, e.g. warnings for too small pressure deviations may lead to drivers ignoring the system. The cost benefit analysis of TMPS should (also) be made for member states requiring both Summer tyres and Winter tyres.
- Summer tyres / Winter tyres
  Ice grip information towards road users is very useful for member states with occurrence of ice condition.

9.3.5 *MOBIVIA (Vehicle servicing organisation)*

- Awareness
  There is a role of European public authorities to provide optimal information and sensitization of motorists concerning Winter tyres to ensure that they will use the tyres, resulting in improved traffic safety. The EU Commission should inform car drivers on varying legislation for travelling abroad, and the “Going abroad” application is a good initiative. Still Winter tyre rules are really (too) complex and it is not clear to what extent foreigners are subjected to local rules.
- Summer/Winter tyres
  Road users should be made aware of differences between M+S and tyres marked 3PMS, and that it is required to use four Winter tyres on a vehicle. A suggested minimum tread depth for Winter tyres should be 4 mm, and below that threshold Winter tyres should not be used further (neither winter nor summer).

10 Task 10 – EU measures

10.1 Introduction & purpose

This chapter provides an overview of the different measures that were considered in relation to the current study. Different measures related to 4 topics are the focus of our attention in relation to the formulation of EU measures and policies:

- Harmonisation of the use of Winter tyres
- Tyre tread depth requirements
- Tyre Pressure Monitoring System technologies
- Consumer awareness

Within the current project, we followed a multi-step approach towards the identification and selection of possible EU measures and policies. In first instance, we looked at available scientific literature, stakeholder information and third-party background information to identify the existing problems in relation to tyre use and road safety. Based on this information, we proposed a set of possible measures[23]. These measures were qualitatively analysed for possible synergies and practical applicability. Measures were grouped in three main themes: behavioural change through voluntary adaptation or enforcement, voluntary national adaptation of identified best practices and mandatory adaptation of EU legislation. These themes were presented at the stakeholder meeting and subject to discussion.

As a result of the input received from different stakeholders, and after internal project discussions, a number of changes were made in the grouping of measures and final content. These changes were mainly driven by identified barriers, additional stakeholder information received and qualitative indications for practical implementations. As a result, a wider set of EU measures that would fall within the current scope of the project was identified. It needs to be mentioned that measures in relation to consumer awareness are integrated in the measures for the other three topics. The outcome of these two steps are presented in the next section.

In order to build policy options that are suitable for a cost-benefit analysis however, two additional steps were undertaken. In first instance, qualitative information was collected on the possible relevance towards improving road safety. In second instance, the quantification of possible policy options was considered. Generally policy options were composed for which indications were found that they address an existing and sufficiently large safety problem as well as for which quantifiable information is available.

[23] With “measures” we mean individual, low level solutions that may be considered to solve identified safety problems in relation to the use of tyres. This stands in contrast to policy options where combination of measures are used to build a realistic scenario towards improving road safety.

10.2 Overview of initial EU measures

This section contains an overview of different EU measures that were identified throughout the project. For each of the four main topics within this project, a short section is presented containing background information on the different measures. The starting point for the comparison of each of the measures mentioned is the so-called “business as usual” scenario where existing legislation and practices are continued without adding additional measures.

10.2.1 Harmonisation of the use of Winter tyres

In the case of Winter tyres, two sets of legislation need to be considered for the business as usual cases. In first instance, there are national legislations that regulate the use of Winter tyres (or prohibit the use thereof in other than wintery periods or conditions). In second instance, there is the European regulation (EC) No 1222/2009 where the technical qualities of snow tyres are defined. The scenarios that are presented here can have an impact on either of the regulations.

10.2.1.1 Overview of different possible measures aimed at improving road safety

The following measures are considered:

- **Measure 1: improved voluntary take-up** of the use of tyres that are appropriate to (relevant) meteorological conditions through the providing of relevant information.
  Within this measure, the final responsibility for making an informed choice lies with the end-user (driver or vehicle owner). A voluntary change of (purchasing) behaviour is targeted. This can for example be achieved through informing the end-user on relevant aspects in relation to the use of Winter tyres (or other) : (1) existing risks in relation to meteorological conditions and tyre use, (2) the current legislation, (3) his current choices and (4) possible tyre choices and technologies.

- **Measure 2: improved forced take-up** of the use of tyres that are appropriate to (relevant) meteorological conditions through enhanced enforcement (police enforcement or vehicle periodic checks).
  This measure assumes that member states that experience wintery conditions are typically also the member states which have some relevant legislation already in place (see Section 5.2.1, and that at the same time these member states have the highest potential[24] safety risk related to wintery conditions. Yet, at the same time tyre use statistics that were collected indicate that not all vehicles are always properly equipped. Overall enhancing of police enforcement and/or checking for the appropriate application of regular periodic checks may push current “non-users” towards the use of appropriate tyres. Particular harmonization of legislation can be considered between member states (with existing legislation). In some cases this may mean making use of stricter or more lenient legislation compared to the current situation.

[24] Potential: meteorological and geographical conditions make that they most often experience potentially dangerous wintery conditions. This is not saying that they are the least safe member states.

- **Measure 3: technical requirements made for snow tyres, as mentioned in national legislations, are improved.**
  This measures aims at aligning the current technical legislation and the effective national legislations on the use of Winter tyres. EC Regulation 117.2 has been amended to accommodate largely for the better testing qualities of tyres with the so-called ‘alpine logo’ or ‘3PMS’. However, national legislations on Winter tyres mostly still allow for M+S (or similarly type marked) Winter tyres. This measure would mean that Winter tyres, marked 3PMS, would become the common standard.

- **Measure 4: EC recommendations on the use of Winter tyres based on time period.**
  This measure focuses on the coordination between a European and national level. A manual with recommendations on possible national legislations in relation to the use of Winter tyres (what elements need to be adjusted or considered) is presented. Different member states can choose to fill-in their national legislations following these recommendations. An absolute legislation, from time period A until time period B (based on averages from historical climatological data) is suggested across Europe, even if this may mean that not in all regions the precise meteorological conditions exist that would warrant the use of Winter tyres. In a more detailed variant, it may be possible to identify zones for similar legislation (for example: Nordic or Scandinavian, Alpine, Pre-alpine, Central European, etc.).

- **Measure 5: EC recommendations on the use of Winter tyres based on meteorological conditions (historical).**
  Similar to Measure 4 coordination between a European and national level is supposed and a manual with recommendations on possible national legislations in relation to the use of Winter tyres (what elements need to be adjusted or considered) is presented. Different member states can choose to adjust their national legislations following these recommendations. In this measure however, a conditional legislation, based on the presence of identified meteorological conditions, is suggested across Europe, even if this means that the start date and end date is not harmonised across Europe.

- **Measure 6: EC legislation (Directive,…) on the use of Winter tyres based on time period.**
  This measure is similar to Measure 4, but with a mandatory application by EU Member States.

- **Measure 7: EC legislation (Directive,…) on the use of Winter tyres based on meteorological conditions (historical).**
  This measure is similar to Measure 5, but with a mandatory application by EU Member States.

- **Measure 8: Introduction of a minimum tread depth for Winter tyres (4 mm).**
  Within this measure, the definition for a Winter tyre is extended with an additional tyre tread depth requirement (4 mm).

10.2.2 *Tyre tread depth requirements*

In the case of tyre tread depth requirements, the current technical requirements for vehicles in the individual member states are considered for the business as usual case.

10.2.2.1 *Overview of different possible measures aimed at improving road safety*

- **Measure 1: voluntary earlier replacement of tyres, relative to the remaining tyre tread depth, through the providing of relevant information.**
  Within this measure, the final responsibility for making an earlier purchase decision on the renewal of tyres lies with the end-user (driver or vehicle owner). A voluntary change of (purchasing) behaviour is assumed. The end-user is to be informed on relevant aspects in relation to the importance and role of tyre tread depth: (1) existing risks in relation to tyre use and reduced tread depth, (2) the current legislation, (3) his possible choices.

- **Measure 2: forced earlier replacement of tyres, depending on tyre tread depth, through enhanced enforcement (police enforcement or vehicle periodic checks) of current regulation.**
  Within this measure, the assumption is made that the most aberrant behaviour (driving with illegal tyre tread depths) can be monitored and enforcement actions can be undertaken on a more regular basis. The improvement of police enforcement and/or checking for correct technical standards in relation to tread depth may push users who are in violation towards the replacement of tyres.

- **Measure 3: change of (passenger car) minimum tread depth legislation to 3 or 4 mm.**
  Within this measure, the minimum tyre tread depth stipulated from EU Council Directive 89/459/EEC is changed to 3 or 4 mm. EU Member States adapt to these changes.

- **Measure 4: change of (HGV, bus or coach) minimum tread depth legislation to 1.6 mm.**
  Within this measure, the minimum tyre tread depth for tyres for HGV, bus or coach is harmonised across Europe to 1.6 mm. EU Member States adapt to this harmonisation.

- **Measure 5: introduction of performance based criteria for the use of tyres instead of a tread depth legislation.**
  Within this measure, the concept of a minimum tyre tread depth is abandoned. That is to say, the starting rationale is that tyres need to fulfil a specific performance requirement throughout their entire lifetime (and that lifetime is defined not by tyre tread depth). As such, it would be possible for tyres to have a high enough tyre tread depth remaining (>1.6 mm) but not fulfilling performance requirements (for example wet grip), but also the other way around.

10.2.3 *Tyre Pressure Monitoring System technologies*

In the case of Tyre Pressure Monitoring System requirements, the current technical requirements for vehicles in the individual member states are considered for the business as usual case.

In practice, this means that mandatory TPMS for new (passenger cars) vehicles and the annual inspection (roadworthiness periodic check) on the proper functioning of TPMS and inflation pressure are foreseen in this Business as usual case.

10.2.3.1 *Overview of different possible measures aimed at improving road safety*

- **Measure 1: fitting of after-market TPMS systems on existing vehicles.**
  Within this measure, existing passenger car vehicles that are currently not equipped with a TPMS system would be retrofitted with aftermarket TPMS systems. System requirements would be the same as existing TPMS systems.

- **Measure 2: mandatory fitting of TPMS systems on other vehicle categories.**
  Within this measure, also new commercial vehicles would be equipped with OEM TPMS systems. System requirements would be the same as existing TPMS systems.

- **Measure 3: change of performance requirements (UNECE regulation 64) on TPMS.**
  Within this measure, the performance requirements as stipulated in UNECE regulation 64 for TPMS systems that are applied to passenger cars are changed, considering TPMS Phase II [56].

- **Measure 4: extended voluntary monitoring of tyre pressure, through the providing of relevant information.**
  Within this measure, the end-user (driver or vehicle owner) assumes a more active role in the monitoring of the tyres inflation pressure. The end-user is to be informed on relevant aspects in relation to the importance and role of tyre pressure: (1) existing risks in relation to tyre pressure, and underinflating in particular (2) the current legislation, (3) his possible choices. This measure does not assume legislative changes.

- **Measure 5: providing of (free) air pressure monitoring equipment and air filling equipment at publicly available locations.**
  Within this measure, the end-user (driver or vehicle owner) assumes a more active role in the monitoring of the project technical status of the vehicles' tyres. The end-user is to be informed on relevant aspects in relation to the importance and role of tyre pressure: (1) existing risks in relation to tyre pressure, and underinflating in particular (2) the current legislation, (3) his possible choices. This measure does not assume legislative changes.

10.3 Policy options selected for SCBA

In this section, a short description of the different potential measures is given that were withheld and merged into policy options for the calculation of costs. Although a range of measures was suggested, not all were withheld or combined for the estimation of costs and benefits in the SCBA. The reasons for this may be practical limitations (simply on information available on the safety or other effects that may or may not be expected), legislative limitations, high similarity between measures or other.

10.3.1 Harmonisation of the use of Winter tyres

Policy option 1: behavioural change through voluntary pick-up
Within this policy option, the final responsibility for making an informed choice lies with the end-user (driver or vehicle owner). A voluntary change of (purchasing) behaviour is assumed. The end-user is to be informed on relevant aspects in relation to the use of Winter tyres (or other) through tailor-made information campaigns. These information campaigns can be provided by national administrations, industry stakeholders, etc. The main element is however that a significant amount of end-users are reached when they are most susceptible to relevant information (beginning of winter period, in the vicinity of parking places, etc.).

Policy option 2: behavioural change through enforcement
The overall enhancing of police enforcement and/or checking for the appropriate application of regular periodic checks is used to reduce the number of violations against the proper use of Winter tyres. Use is made of the existing enforcement activities (i.e. alcohol checks) and vehicle periodic checks.

These policy options are expected be comparable with the introduction of EU-wide specific formats of legislation (based on meteorological or time-frame conditions) that are influence behaviour through either voluntary pick-up or enforcement activities.[25]

Policy option 3: 3PMS in national legislations
This policy option is built around the assumption that the current technical legislation and the effective national legislations on the use of Winter tyres are brought into alignment. EC Regulation 117.2 has been amended to accommodate largely for the better testing qualities of tyres with the so-called ‘alpine logo’ or ‘3PMS’. This would mean that Winter tyres, marked 3PMS, would become the common standard. An introduction period can be foreseen.

[25] From the analysis of fatalities over member states and meteorological conditions (CADAS & GIDAS), in combination with existing legislation, it is apparent that the total number of fatalities that fall under appropriate conditions is relatively limited. Appropriate conditions are conditions where Winter tyres would prove to be technologically beneficial.

10.3.2 *Tyre tread depth requirements*

Policy option 1: behavioural change through voluntary pick-up
Within this policy option, the final responsibility for making an informed choice on the renewal of tyres as a result of tread wear lies with the end-user (driver or vehicle owner). A voluntary change of (purchasing) behaviour is assumed. The end-user is to be informed on relevant aspects in relation to the use of Winter tyres (or other) through tailor-made information campaigns. These information campaigns can be provided by national administrations, industry stakeholders, etc. The main element is however that a significant amount of end-users are reached when they are most susceptible to relevant information (beginning of winter period, in the vicinity of parking places, etc.).

Policy option 2: forced renewal of tyres, depending on tyre tread depth, through enhanced enforcement (police enforcement or vehicle periodic checks). The overall enhancing of police enforcement and/or checking for the appropriate application of regular periodic checks is used to reduce the number of violations against the proper use of Winter tyres. Use is made of the existing enforcement activities (i.e. alcohol checks) and vehicle periodic checks.

Policy option 3: change in legislation on the minimum tread depth for Winter tyres (4 mm)
The policy option aims solely at the redirection of existing legislation for the use of Winter tyres. In the technical definition of Winter tyres, a minimum tread depth of 4 mm is foreseen. Users are expected to adjust behaviour based on a voluntary pickup, supported by information campaigns.

10.3.3 *Tyre Pressure Monitoring System technology*

Policy option 1: change of performance requirements (UNECE regulation 64) on TPMS
Within this scenario, the performance requirements as stipulated in UNECE regulation 64 for TPMS systems that are applied to passenger cars are changed, considering TPMS Phase II [56].

Policy option 2: voluntary monitoring of tyre pressure and availability of calibrate air filling equipment at petrol stations.
Within this scenario, the end-user (driver or vehicle owner) is made aware of the link between tyre pressure and road safety. In order to facilitate the appropriate behaviour, air pressure equipment is made available at for example all petrol stations (and calibrated yearly).

11 Task 11 – Cost Benefit Analysis

11.1 Introduction and purpose

This chapter presents an assessment of the effects of scenarios that are developed as a result of the policy options that are described in Chapter 10. Both costs and benefits as a result of the implementation of policy options are considered, compared to the current status. Although a full CBA incorporates a wide range of effects (safety, energy consumption, noise, emissions, etc.), the focus of the current study lies on the safety effects. Effects in relation to energy consumption and emissions are only also estimated in policy options related to inflation pressure. This assessment serves as a basis for the selection of a set of policy recommendations for each of the four domains that were investigated in the current study, with a focus on the safety outcome.

The method used is that of a social cost-benefit analysis (SCBA). The idea behind a SCBA is that all welfare effects (cost and benefits) which follow from the scenario are brought together. In the current study, the focus lies on monetary effects associated to improvements in safety. For other effects, associated to energy consumption and emissions, only limited qualitative information is provided as a support to the safety estimations. SCBA requires that all of the impacts of a project are valued in economic opportunity cost terms (the costs of the resources used or the benefits foregone as a result of an action). As such, a SCBA converts all costs and benefits to money.

The general outline for an SCBA is presented in Appendix D. In the current chapter, we focus on the particular elements that were withheld for the current study.

11.2 Identification of relevant effects

For each of the identified scenarios, the different relevant effects are analysed and where applicable monetised. Four possible (general) effects were analysed. Effects from consumer awareness were integrated in scenarios for the three other options.

- The **costs of the project**: this is the cost that is directly required to implement the policy.
  - Winter tyres: costs associated to tyre and rim purchase (over vehicle lifespan as a result of the purchase of a second set of rims), enforcement and consumer awareness campaigns are integrated in the SCBA.
  - Tread depth: costs associated to tyre purchase (over tyre lifespan as a result of the earlier replacement of a new single set of tyres), enforcement, consumer awareness campaigns, etc. are integrated in the SCBA.
  - Tyre Pressure Monitoring Systems: costs associated to the purchase of TPMS systems; enforcement, consumer awareness campaigns, etc. are integrated in the SCBA.

- The **direct effects** on the transport system: these are the effects that are directly associated to the transport system such as changes in fuel cost, the amount of transport, etc.
  - Winter tyres: no significant change in the cost of transport is expected. No significant difference in fuel consumption between Winter tyres and other tyres is expected, under the condition that they are used correctly and during wintery periods.
  - Tread depth: no change in the cost of transport is expected. Although rolling resistance is affected by tread depth (see Chapter 3), no evidence for significant differences in fuel consumption between new or used tyres was found.
  - Tyre Pressure Monitoring Systems: a slight reduction in the cost of transport may be expected as a result of the better maintenance of appropriate inflation pressure under operating conditions. This is for example described in the CARS21 report. We expect this however to be small (1-5%). In addition, inflation pressure (deflation) is linked to reduced fuel efficiency and an increase of emissions.

- The **indirect effects** outside the road transport market: these are effects on other road modes, wider economic effects (tyre centres, retailers, etc.), etc.
  - Winter tyres: no modal shift is expected since no major cost for road transport is expected. A change in government revenue may be expected linked to the increased purchase of tyres and rims. No effects are expected for tyre centres or garages, although a larger number of tyre sales and changes may be expected, these would be limited to certain periods and no continuous change is foreseen. Similarly, no major changes for tyre manufacturers are foreseen with a gradual introduction of Winter tyre legislation or type approval changes (3PMS), tyre manufacturers should be capable of covering changed legislations through regular renewal of equipment.
  - Tread depth: no modal shift is expected since no major cost for road transport is expected. A change in government revenue may be expected linked to the replacement rate of tyres. No changes are foreseen for tyre centres or garages, although a slightly higher continuous work rate may be expected as a result of earlier tyre renewal.
  - Tyre Pressure Monitoring Systems: the slight reduction in the cost of transport that may be expected is not considered to be high enough to warrant a significant modal shift. Government revenue may grow as a result of the purchasing of new TPMS equipment (aftermarket or OEM), but would decrease when less fuel is consumed. No changes are foreseen for tyre centres or garages: tyre repair may happen a little bit sooner, but at the same time major tyre damage as a result of underinflation would be avoided.

- The **external effects** on society for which there is compensation: this includes safety effects, emissions, etc.;

  – Winter tyres: Different arguments can be presented in relation to possible fuel efficiency increases/decreases (and the associated emissions). Technical elements are discussed in Chapter 3, which indicate that Winter tyres are slightly less fuel efficient than regular tyres. Similarly, project findings indicate that Summer tyres are run up to a reduced tread depth level, which is also linked to better fuel efficiency. However, at the same time it needs to be noted that from a comparison of vehicle registration certificates, Winter tyre width is typically smaller than regular tyre width, which would have a positive influence on Winter tyre fuel consumption (in comparison to regular tyres). Also vehicles with Summer Tyres also have a less fuel efficiency at low temperatures. Furthermore, Winter tyres are more efficient in terms of grip compared to Summer tyres under low-temperature or wintery conditions. This combination makes it very difficult to precisely predict energy consumption in relation to Winter tyre use and it was decided that it should not be included in the current project. As a result emissions effects are also not included. A safety effect may be expected (see Section 4.4.1).
  – Tread depth: Similar to the section above, not direct fuel efficiency gains or losses are estimated. A safety effect may be expected (see Section 4.4.2).
  – Tyre Pressure Monitoring System: since a change in energy consumption may be expected, we may also expect a change in emissions (CO2-equivalent). At the same time, a limited safety effect may be expected (see Section 4.4.3).

11.3 SCBA scenarios

In the current section the different effects as discussed for each of the scenarios that were withheld for the SCBA are presented.

11.3.1 Harmonisation of the use of Winter tyres

11.3.1.1 Reference scenario and assumptions

The reference scenario for all scenarios in relation to the harmonisation of the use of Winter tyres is built on the assumptions presented below.

Assumptions in relation to relevant legislation:

- Existing national legislation in relation to the use of Winter tyres, including the type of tyres mentioned, time periods, conditional use, etc. remains the same for the time period 2010-2030.
- Existing European legislation on the labelling of tyres (EC regulation No 1222/2009, including the Requirements with respect to the braking performance on snow, as described in EC Regulation No. 117.2) remains the same for the time period 2010-2030.
- Existing national legislation on tread depth requirements, where relevant for Winter tyres (as described in Chapter 6) remains the same for the time period 2010-2030.

Assumptions in relation to vehicle usage:

- Vehicle usage, for which the statistics are made available through Eurostat remains proportionately the same for the time period 2010-2030 (Eurostat passenger vehicle kilometre data, available for the time period 2003 to 2012 was extrapolated).

Assumptions in relation to road safety:

- The evolution or road safety (number of fatalities from accidents) is extrapolated from the information that is made available through CADaS. In first instance, relevant fatalities for the different scenarios were identified for the time period 2000 to 2013. Over this data, an exponential function was estimated that is used for extrapolation of fatalities up to the time period 2030. As a result, this data covers the time period 2000-2030 (CADaS fatality data, available from the time period 2000 to 2013 was extrapolated).
- Information on the number of severe injuries, slight injuries and material damage are extrapolated based on the number of fatalities. The ratio fatality to severe injury is estimated at 1 to 8. The ratio fatality to slight injury is estimated at 1 to 50. The ratio fatality to material damages only accident is estimated at 1 to 300[26].

Assumptions in relation to pricing:

- An average harmonised inflation rate of 1.97% is used for Europe based on Eurostat data for the period of 1997 up to 2013. This ratio is used for an extrapolation of cost prices up to 2030, using 2012 as reference year. We assume the following costs for different Winter tyre related purchases (2012): 1 set of 4 tyres costs 500€, 1 set of rims costs 200€, mounting wheels alone costs 20€, assembling tyres on rims and the mounting of wheels costs 66€, storage costs are 24€. These prices are estimated based on an internet search of online tyre retailers and direct price comparisons of large retailers.
- We assume that most Winter tyres are purchased without rims. We assume half of the persons elect to swap Winter tyres with other tyres on the same rims while the other half of persons elect to buy new rims. However, this 'second set or rims' remains with the vehicle for the entire lifespan of the vehicle (14 years). Under the assumption that Winter tyres are replaced every 4th year (as suggested by tyre manufacturers), this means that 83% of Winter tyre purchases include only the tyres and 17% include both tyres and rims.
- We assume that half of the people who have Winter tyres (on a second set of rims) will mount them themselves. The other persons pass through a tyre shop. Tyres are changed twice a year.
- We assume that 80% of people who have Winter tyres (on a second set of rims) will store them themselves during the summer period. The remaining 20% has to pay for storage facilities. This is a yearly cost.

[26] These estimates are based on http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm and http://www-nrd.nhtsa.dot.gov/CATS/index.aspx

- For the monetisation of the road safety effects, we build on the values presented by the update of the handbook of external costs of transport (fatalities, severe injuries and slight injuries) which are updated to 2010. For the cost of material damages we refer to De Brabander (2005)[27] where the average cost for material damages-only accidents in Belgium was estimated at 3066€. These values were adjusted for all EU member states based on the PPP values provided by Eurostat[28] and adjusted to 2012 values.
- Costs are converted to the price level of 2012 based on an average inflation rate of 1.97%.

Assumptions in relation to Winter tyre use:
- Current Winter tyre use is estimated based on information gathered from stakeholders and a limited number of datasets. We have identified three relevant legislative conditions, with associated Winter tyre usage in wintery period. In member states without existing legislation, we assume that 40% of passenger cars are equipped with Winter tyres. In regions with conditional legislation, we assume 60% of vehicles are equipped with Winter tyres. In regions with mandatory legislation on the use of Winter tyres, we assume 85% of passenger cars are equipped with Winter tyres.
- Based on the number of vehicle kilometres driven in passenger cars (Eurostat) and the number of days for which appropriate meteorological conditions, reflected in low temperatures (<7°C), can be found (EFSA database), we can estimate the number of vehicle kilometres driven under cold conditions. Given a use life expectancy of 50.000km per set of tyres, this could serve as an approximation for the number of Winter tyres that are required each year within Europe and individual Member States. This ratio is expected to increase linearly, depending on the vehicle usage extrapolated up to 2030.
- We assume that Winter tyres have an effective lifespan of less than 5 years (4 years and 51 weeks) or 50.000km. Given the annual mileages ran by vehicles (estimated from Eurostat based on the number of vehicle kilometres ran per year and the number of registered vehicles), we can estimate what happens first: change of Winter tyres based on age or based on kilometres ran. As a result, across Europe, we assume that Winter tyres are effectively changed sooner as a result of calendar age rather than distances ran, and the average European Winter tyre is changed 27% short of the 50.000km mark (in effect around the 37.000 km mark). This percentage is used as an estimation of the true purchase cost for Winter tyres, rather than using the full purchase price since a vehicle can only use one set of tyres at the same time.

11.3.1.2 *Scenario 1: behavioural change through voluntary pick-up*

Scenario definition:

Within this scenario, a voluntary change of (purchasing) behaviour is assumed that is triggered through providing information on relevant aspects in relation to the use of Winter tyres (or other) through tailor-made information campaigns.

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[27] De Brabander, B. (2005). Investeringen in verkeersveiligheid in België.
[28] http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tec00120

Table 11.1: Harmonization of Winter tyres – Scenario 1.

Costs of the option As a result of the information collection described in Chapter 5, we assume that the providing of specific and detailed information in combination with practical advice may lead to a voluntary behavioural change that translates in an increased use of Winter tyres between 5% (lower limit) to 10% (upper limit), relative to the existing usage percentages. These gains are expected to be achieved once, but to be upheld over the 2012-2030 time period. These percentages are related to the number of vehicles that would additionally change Winter tyres, in Europe (2012). As a result, it is estimated that between 410.000 and 822.000 Winter tyres sets would be purchased, costing between 51.48 and 102.96 million € for tyre and rim purchases alone. Additional costs associated to the project are linked to tyre change and tyre storage. For tyre change, the costs are estimated between 31.22 and 62.44 million € (2012). For storage, the costs are estimated between 1.97 and 3.94 million € (2012). The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012).
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.
External effects The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). For the current scenario, we expect a yearly reduction compared to the business as usual scenario of between 14 and 29 fatalities. Using adjusted figures from the HEATCO study, we can monetise this to a cost benefit between 33.88 and 67.76 million € (2012)[29].
Summary For the year 2012, we estimate the sum of costs to lie between 68.55 million € and 170.33 million €. The sum of benefits is estimated to lie between 33.88 million € and 67.76 million €. This means that the benefit to cost value is 0.4 for the range of estimates.

11.3.1.3 Scenario 2: behavioural change through enforcement

Scenario definition:

The overall enhancing of police enforcement and/or checking for the appropriate application of regular periodic checks is used to reduce the number of violations against the proper use of Winter tyres. Use is made of the existing enforcement activities (i.e. alcohol checks) and vehicle periodic checks.

[29] Including fatalities, severe injuries, slight injuries and material damages only accidents.

Table 11.2: Harmonization of Winter tyres – Scenario 2.

Costs of the option As a result of the information collection described in Chapter 5, we assume that the making use of two types of enforcement activities may lead to a (involuntary) behavioural change that translates into an increased use of Winter tyres between 10% (lower limit) to 20% (upper limit), relative to the existing usage percentages. These gains are expected to be achieved once, but to be upheld over the 2012-2030 time period. This information is used to estimate the number of vehicles that would additionally change Winter tyres. This is done for those EU member states with existing legislation in relation to the use of Winter tyres (2012). Following these percentages of increased use of Winter tyres (lower limit: 10%, upper limit 20%), it is estimated that between 367.000 and 734.000 additional Winter tyres sets are purchased, costing between 35.29 and 70.58 million € for tyre and rim purchases alone. Additional costs associated to the project are linked to tyre change and tyre storage. Costs for tyre change are estimated between 27.89 and 55.78 million € (2012). Tyre storage costs are estimated between 1.76 and 3.52 million € (2012). The estimation of the enforcement costs associated to this scenario is based on the findings from the PEPPER project. Police enforcement in relation to Winter tyres could be combined with other enforcement activities where a mandatory vehicle stop is required. In particular alcohol checks could be efficiently combined. Other monitoring practices are associated with the vehicle periodic check. In both cases, we assume that an additional 30 seconds per vehicle is required to perform a proper check. For both relevant labour categories, Eurostat provides with labour cost estimations (cost per hour). Further assumptions are: one vehicle in 6 is checked by police on a yearly basis and vehicles report for their periodic check on a two-year average. Police enforcement is estimated to cost 14.24 million € (2012). Enhanced monitoring during periodic vehicle checks is estimated to cost 49.46 million € (2012). The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012).
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.
External effects The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). For the current scenario, we expect a yearly reduction compared to the business as usual scenario of between 16 and 32 fatalities. Using adjusted figures from the HEATCO study, this effect is monetised a cost benefit between 42.87 and 85.75 million € (2012).
Summary For the year 2012, we estimate the sum of costs to lie between 130.26 million € and 194.57 million €. The sum of benefits is estimated to lie between 42.87 million € and 85.75 million €. This means that the benefit to cost ratio lies between 0.33 (for the lower limit of behavioural change effect) and 0.44 (for the upper limit of behavioural change effect).

11.3.1.4 Scenario 3: 3PMS in national legislations

Scenario definition:

This scenario is built around the assumption that the current technical legislation and the effective national legislations on the use of Winter tyres are brought into alignment. EC Regulation 117.2 has been amended to accommodate largely for the better testing qualities of tyres with the so-called ‘alpine logo’ or ‘3PMS’. This scenario would mean that Winter tyres, marked 3PMS, would become the common standard and would replace other tyres such as M+S tyres or all-season tyres (used under wintery conditions). An introduction period is foreseen.

Table 11.3: Harmonization of Winter tyres – Scenario 3.

Costs of the option
Currently, 3PMS approved tyres are already on the market and have taken a significant portion of the market. As a result, only a limited amount of non 3PMS tyres are considered. From samples taken from 3 on-line tyre shops, we found that 85-92% of Winter tyres offered (July 2014) did already carry the 3PMS logo. The others were only marked as M+S or similar. We assume that a similar division can be found "in real life" vehicles equipped with Winter tyres. Relating this to the number of vehicles that would additionally change Winter tyres from M+S to 3PMS tyres in Europe, it is estimated that between 681.000 (assuming 50% compliance) and 1,36 million (assuming 100% change) additional 3PMS Winter tyres sets would be purchased. In order to estimate the total cost of purchasing 3PMS compared to regular M+S tyres, we analysed existing market price differences from two main online tyre retailers. A cost increase of around 25% was found. This results in the estimation of a surplus cost between 39.53 and 79.07 million € for altered Winter tyre purchases alone is estimated. Compared to the other scenarios, additional costs are associated to the introduction of 3PMS tyres as a sole alternative for Winter tyres. As far as manufacturing costs are concerned, some tyre lines would need to be replaced. We follow the assessments made for the tyre/road noise study presented by FEHRL [57] , and in particular the valuation of costs for discontinuing specific tyre lines. Within the FEHRL study, the assumption was made that replacement of (older) tyres with tyres conforming to newer legislation is made on a gradual basis. This appears to be the most common introduction for a lot of relevant EU legislations and directives. As such, we would suspect that effectively, the cost for replacing moulds would not need to be introduced to a SCBA[30]. Additional R&D costs for the replacement of M+S with 3PMS tyres are estimated. We make similar assumptions as to the FEHRL study: 6000 tyre lines, 3.5 to 5% R&D expenditure per year (400 million €/year). Assuming that one third or all tyre lines are Winter tyres, a 15% replacement rate and linear division of R&D costs over all tyre lines, this would mean that around 60 million € would be invested for the replacement of existing M+S (only) tyres with 3PMS tyres. However, it is assumed that such a cost is spread over a period of time (4 years).

[30] Prices for a working tyre mould appear to be in the region of 50000-100000 US$ (**Invalid source specified.**). If we would assume that 1/3 of tyre lines (6000 in total) are Winter tyres. Therefrom 15% is M+S that needs to be replaced. A total cost would be around 30 million US$.

An additional cost with the introduction of new legislation is foreseen in the format of information campaigns. The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. In the current scenario, such a campaign is only initiated in member states with existing legislation in relation to the use of Winter tyres. This amounts to a cost of 0.59 million € (2012). The estimation of the enforcement costs associated to this scenario is based on the findings from the PEPPER project. We assume that police enforcement in relation to Winter tyres will be combined with other enforcement activities where a mandatory stop is required. In particular alcohol checks could be efficiently combined. Other monitoring practices are associated with the vehicle periodic check. In both cases, we assume that an additional 30 seconds per vehicle is required to perform a proper check. For both relevant labour categories, Eurostat provides with labour cost estimations (cost per hour). We assume one vehicle in 6 is checked by police on a yearly basis and vehicles report for their periodic check on a two-year average. Police enforcement is estimated to cost 14.23 million € (2012). Enhanced monitoring during periodic vehicle checks is estimated to cost 23.7 million € (2012). However, for the direct estimation of costs as a result of making 3PMS tyres mandatory, these extra costs (campaign, enforcement and moulds) are not considered.
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.
External effects The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). Given the qualitative issues (see for example tests from ADAC or GTÜ) of such tyres, we would assume that M+S tyres that are currently being offered are only are better than a Summer tyre and all-season tyre, but do not stand at the level of 3PMS tyres. As a result of the analysis of the GIDAS data, this would mean that for every 1% of increased use of 3PMS tyres, 0.778% of fatalities could be avoided. For the current scenario, a yearly reduction compared to the business as usual scenario between 28 and 57 fatalities is then expected. Using adjusted figures from the HEATCO study, this corresponds to cost benefit between 74.9 and 149.8 million € (2012).
Summary For the year 2012, we estimate the sum of costs to lie between 39.53 and 76.06 million €. The sum of benefits is estimated to lie between 74.09 and 149.8 million €. This means that the benefit to cost ratio lies at 1.89. Note that this is a rather higher ratio, which may be the result of that the assumed safety effect linked to the use of 3PMS tyres in comparison to M+S tyres is similar to using Winter tyres instead of Summer tyres.

11.3.2 Tyre tread depth requirements

11.3.2.1 Reference scenario & assumptions

The reference scenario for all scenarios in relation to the harmonisation of the tread depth is built on the assumptions presented below.

Assumptions in relation to relevant legislation:

- Existing national legislation in relation to tyre tread depth (as described in Chapter 6) remains the same for the time period 2010-2030.

Assumptions in relation to vehicle usage:

- Vehicle usage, for which the statistics are made available through Eurostat remains proportionately the same for the time period 2010-2030 (Eurostat passenger vehicle kilometre data, available for the time period 2003 to 2012 was extrapolated).

Assumptions in relation to road safety:

- The evolution or road safety (number of fatalities from accidents) is extrapolated from the information that is made available through CADaS. In first instance, relevant fatalities for the different scenarios were identified for the time period 2000 to 2013. Over this data, an exponential function was estimated that is used for extrapolation of fatalities up to the time period 2030. AS a result, this data covers the time period 2000-2030 (CADaS fatality data, available from the time period 2000 to 2013 was extrapolated).
- Information on the number of severe injuries, slight injuries and material damage are extrapolated based on the number of fatalities. The ratio fatality to severe injury is estimated at 1 to 8, The ratio fatality to slight injury is estimated at 1 to 50. The ratio fatality to material damages only accident is estimated at 1 to 300[31]. As a result, this data covers the time period 2000-2030 (CADaS fatality data, available from the time period 2000 to 2013 was extrapolated).
- From the analysis of data received from stakeholders and direct measurement, we estimate that Winter tyres with less than 4 mm are involved in 3.46% of grip-related accidents in member states without Winter tyre legislation, 5.19% in member states with conditional Winter tyre legislation and 7.35% in member states with absolute Winter tyre legislation. From the study of the GIDAS data, we find that decreasing 1% of these tyres would account for a reduction of 0.72% (no legislation), 0.85% (conditional legislation) and 1.15% (absolute legislation).

Assumptions in relation to pricing:

- An average harmonised inflation rate of 1.97% is used for Europe based on Eurostat data for the period of 1997 up to 2013. This ratio is used for an extrapolation of cost prices up to 2030, using 2012 as reference year.
- We assume the following costs for different tyre related purchases (2012): 1 set of 4 tyres costs 500€, 1 set of rims costs 200€, mounting tyres alone costs 20€, mounting tyres and rims costs 66€, storage costs are 24€. These prices are estimated based on an internet search of online merchants and direct price comparisons of large retailers.

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[31] These estimates are based on http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm and http://www-nrd.nhtsa.dot.gov/CATS/index.aspx

- The tyre renewal costs associated to vehicles that are equipped with Winter tyres (with a tread depth lower than 4 mm) and are operated during wintery conditions, are estimated based on the assumptions that 50% of people who drive with reduced tread depth Winter tyres will continue to use the tyre nevertheless to "end the life cycle" and can change to Summer tyres without additional purchases. The other 50% who drive with reduced tread depth Winter tyres need to purchase new tyres. Similar to the Winter tyre scenarios, we do not count the entire purchase cost for Winter tyres but rather the cost associated to suboptimal use of Winter tyres during non-wintery conditions. We assume that these people would buy Winter tyres again, although Winter tyres suffer from higher tread wear than Summer tyres during higher temperatures. Because of this, we would assume that a 20% cost "underuse" is validated.

Assumptions in relation to tyre tread depth levels (tyre use):

- Current tyre tread depth levels are estimated based on information received through the stakeholder questionnaire as well as through data collected by TML during road-side inspection of 1450 parked vehicles (129 equipped with Winter tyres) in Leuven during the month of July (1 week). In addition, information from VACO, Continental & ETRMA was used to estimate a distribution for tyre tread depth. This is presented in Table 11.4.

Table 11.4: Distribution of tyre tread depth.

Passenger car tyre distrubutions	Summer tyres							
	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm
Front axle	1%	2%	10%	21%	27%	23%	13%	4%
Rear axle	0%	2%	11%	17%	24%	23%	16%	5%
average	1%	2%	11%	19%	25%	23%	14%	5%
Passenger car tyre distrubutions	Winter tyres							
	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm
Front axle	0%	1%	7%	23%	29%	24%	13%	4%
Rear axle	0%	1%	8%	19%	26%	24%	16%	5%
average	0%	1%	8%	21%	28%	24%	14%	5%

- We assume that tyres have an effective lifespan of 50.000km.

11.3.2.2 *Scenario 1: Behavioural change through voluntary pick-up*

Scenario definition:

Within this scenario, a voluntary renewal of tyres that are running below the legal limit (1.6 mm) is assumed that is triggered through providing information on relevant aspects in relation to the use of tyres with reduced tread depths through tailor-made information campaigns. The focus of the information campaign lies on avoiding the use tyres with reduced tread depth.

Table 11.5: Behavioural change – Scenario 1.

Costs of the option The number of vehicles in Europe that are equipped with regular tyres with a tyre tread below 1.6 mm conditions is estimated to be around 20 million vehicles (10% of passenger cars are estimated to run with tyres lower than the legal limit). As a result of the information collection described in Chapter 6, we assume that providing specific and detailed information in combination with practical advice may lead to a voluntary behavioural change that translates in an increase tyre renewal rate of 10 to 20% (lower and upper limit for behavioural change respectively), relative to the existing usage percentages[32]. This corresponds with 1 to 2 million vehicles (2012) for which behavioural change may occur. The additional tyre renewal costs associated to these vehicles are not considered since the effective maximum running life of the tyre has been reached and a tyre change is warranted. The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012).
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.
External effects The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). For the current scenario, we expect a yearly reduction compared to the business as usual scenario of 14 to 28 fatalities. Using adjusted figures from the HEATCO study, we can monetise this to a cost benefit of 34 to 68 million € (2012).
Summary For the year 2012, we estimate the sum of costs to lie at 0.99 million € . The sum of benefits is estimated to lie between 34 and 68 million €. This means that the benefit to cost ratio is calculated at 34 to 68. This is an extremely high value which is solely dependent on the assumption that a behavioural effect of up to 20% would be achieved.

11.3.2.3 Scenario 2: forced renewal of tyres, depending on tyre tread depth, through enhanced enforcement

Scenario definition:

Within this scenario, a forced early renewal of tyres is assumed that is triggered through active police enforcement and vehicle periodic checking. In particular, the illegal use of regular tyres with a tyre tread depth below 1.6 mm is actively checked for.

[32] This percentage is considerably higher than for example voluntary change of Winter tyres. We believe this to be the case since the relative cost for purchasing (regular) tyres is lower per individual since there is little mileage left to be gained by continuing with illegal tyre tread depths;

Table 11.6: Behavioural change – Scenario 2.

Costs of the option The number of vehicles in Europe that are equipped with regular tyres with a tyre tread below 1.6 mm conditions is estimated to be around 20 million vehicles (10% of passenger cars are estimated to run with tyres lower than the legal limit). As a result of the information collection described in Chapter 6 and the findings from the PEPPER project, it is assumed that the providing of specific and detailed information in combination with practical advice in combination with enforcement activities could lead to a voluntary behavioural change that translates in an increase tyre renewal rate of 50% (lower limit of behavioural change) to 100% (upper limit of behavioural change), relative to the existing usage percentages. These gains are expected to be achieved once, but to be upheld over the 2012-2030 time period. The additional tyre renewal costs associated to these vehicles are not considered since the effective maximum running life of the tyre has been reached and a tyre change is warranted. The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012). The estimation of the enforcement costs associated to this scenario is based on the findings from the PEPPER project. We assume that police enforcement in relation to tyres will be combined with other enforcement activities where a mandatory stop is required. In particular alcohol checks could be efficiently combined. Other monitoring practices are associated with the vehicle periodic check where all vehicles are assumed to be checked on average once every two years. In both cases, we assume that 30 additional seconds per vehicle is required to perform a proper check. For both relevant labour categories, Eurostat provides with labour cost estimations (cost per hour). We assume one vehicle in 6 is checked by police on a yearly basis and vehicles report for their periodic check on a two-year average. Police enforcement is estimated to cost 14.23 million € (2012). Enhanced monitoring during periodic vehicle checks is estimated to cost 23.7 million € (2012).
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.
External effects The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). For the current scenario, we estimate a yearly reduction compared to the business as usual scenario of 71 to 142 fatalities. Using adjusted figures from the HEATCO study, this corresponds to a cost benefit of 170 and 340 million € (2012).
Summary For the year 2012, we estimate the sum of costs to be around 64.7 million €. The sum of benefits is estimated to lie between 170 million € and 340 million €. This means that the benefit to cost ratio is lie between 2.63 and 5.25

11.3.2.4 *Scenario 3: change in legislation on the minimum tread depth for Winter tyres (4 mm) in combination with voluntary behavioural change*

Scenario definition:

Within this scenario, a redirection of existing legislation for the use of Winter tyres takes place. In the technical definition of Winter tyres, a minimum tread depth of 4 mm is foreseen. Users are expected to adjust behaviour based on a voluntary pickup, supported by information campaigns. Users can remain to use these tyres with less than 4 mm, but not during when legislation stipulates the use of Winter tyres. In effect, 'Winter tyres' with less than 4 mm tread depth would be considered regular (summer) tyres.

Costs of the option The number of vehicles in Europe that are equipped with Winter tyres with a tyre tread below 4 mm during winter conditions is estimated to be around 7.35% (in member states with Winter tyre legislation). As a result of the information collection described in Chapter 6 and the findings from the PEPPER project, it is assumed that the providing of specific and detailed information in combination with practical advice in combination with enforcement activities could lead to a voluntary behavioural change that translates in an increase tyre renewal rate of 10 (lower limit of behavioural change) to 20% (upper limit of behavioural change), relative to the existing usage percentages. These gains are expected to be achieved once, but to be upheld over the 2012-2030 time period. The additional tyre renewal costs associated to these vehicles are partially considered: half of the vehicles is considered to be able to run these tyres until the end of life (effectively using them as Summer tyres), whereas half would require a tyre change. Tyre purchase costs associated with this lie between 9.95 and 19.9 million € (2012). The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012). The estimation of the enforcement costs associated to this scenario is based on the findings from the PEPPER project. We assume that police enforcement in relation to tyres will be combined with other enforcement activities where a mandatory stop is required. In particular alcohol checks could be efficiently combined. Other monitoring practices are associated with the vehicle periodic check where all vehicles are assumed to be checked on average once every two years. In both cases, we assume that 30 additional seconds per vehicle is required to perform a proper check. For both relevant labour categories, Eurostat provides with labour cost estimations (cost per hour). We assume one vehicle in 6 is checked by police on a yearly basis and vehicles report for their periodic check on a two-year average. Police enforcement is estimated to cost 14.23 million € (2012). Enhanced monitoring during periodic vehicle checks is estimated to cost 23.7 million € (2012).
Direct effects No direct effects on the transport mode(s) are assumed.
Indirect effects No indirect effects on other transport modes are assumed.

External effects
The main external effect that is associated to this scenario is an increase in safety (reduction in the number of fatalities). For the current scenario, we estimate a yearly reduction compared to the business as usual scenario of 3 to 8 fatalities. Using adjusted figures from the HEATCO study, this corresponds to a cost benefit of 10.47 to 20.94 million € (2012).
Summary
For the year 2012, we estimate the sum of costs to lie between 11.9 and 22.8 million €. The sum of benefits is estimated to lie between 10.47 and 20.94 million €. This means that the benefit to cost ratio is lie between 0.88 and 0.92

11.3.3 *TPMS*

11.3.3.1 *Reference scenario*

Scenario definition:

The reference scenario in relation to TPMS consists of the ongoing situation with current legislations. That is to say: passenger cars are mandatory equipped from 2012 onwards with TPMS systems, and these systems adhere to the quality norms posed in EC Regulation No 661/2009.

As a result of information collected through the project questionnaire, we have estimated the distribution of passenger cars that are running with different inflation pressures. This is presented in the table below:

Table 11.7: Distribution of tyre inflation status for passenger cars.

	0 – 10% over inflation	Correct inflation	0 – 10% underinflation	10 – 20% underinflation	> 20% underinflation
Distribution passenger cars	10%	33%	28%	20%	9%

11.3.3.2 *Scenario 1: Fitting of TPMS on other vehicle categories than passenger cars*

Scenario definition:

Within this scenario, we assume that the legislation in relation to TPMS is broadened to include other vehicle categories than only passenger cars. In effect, this is an analysis that has been performed within a TPMS study for HDV [5].

Within the TPMS study, four scenarios were tested for both OEM-fitted and retrofitted TPMS systems:
- “Current cost / high savings potential”: This scenario represents the current situation in terms of TPMS production volumes and voluntary adoption. Voluntary fitment results in the highest savings potential, since it is likely that end users that invested in TPMS voluntarily will act on pressure warnings.
- “Prospective costs / high savings potential”: This scenario can be thought to represent a situation in which TPMS application is mandated (leading to high production volumes and therefore low investment costs) and user response to TPMS signals is high.

- “Current costs / low savings potential”: This scenario is used as a worst case scenario. It may represent a future situation in which investment cost remain high while TPMS only results in low savings potential. But it also can be considered representative for a current situation in which TPMS application leads to a reduction of tyre over-inflation, which partly counteracts the estimated savings due to full prevention of under-inflation.

- “Prospective costs / low savings potential”: This scenario could occur in a situation in which TPMS application is mandated (leading to high production volumes and therefore low investment costs) but where user response to TPMS signals is low and/or systems are tampered with. It also caters for the possibility that TPMS application leads to a reduction of tyre over-inflation, which partly counteracts the estimated savings due to full prevention of under-inflation.

Cost-effectiveness has been estimated for OEM-fitted and retrofit systems and for different LDV and HDV applications separately. Results have been calculated as function of the oil price (through a direct relation between oil price and diesel price). TPMS is considered cost-effective from an end-user perspective when the payback time is shorter than the average TPMS lifetime of 7 years, determined from supplier responses to the questionnaire.

If CO2 abatement costs are negative, TPMS is definitively cost-effective from a societal point of view. But TPMS can also be considered cost-effective from a societal point of view if the abatement costs are positive. This depends on the level of CO2 abatement costs that is considered acceptable in view of a CO2 reduction target to be achieved or in comparison with other CO2 reduction options.

Taking all cost factors into account the following conclusions can be drawn from the scenario analyses for OEM fitted TPMS systems:
- In the “prospective costs / high savings potential” scenario, the cost-effectiveness of OEM-fitted TPMS is better than in the ”current cost / high savings potential” scenario. Payback times are generally 2 years or less, and abatement costs are negative (order of magnitude -500 €/tonne).
- In the “current costs / low savings potential”, with 50% lower fuel savings potential, OEM-fitted TPMS is only cost-effective from an end-user point of view for application in service/delivery vans, regional trucks and long haul trucks. Abatement costs are negative for these applications too, with the exception that for regional trucks with TPMS on truck and trailer this is only the case for oil prices above 115 €/barrel.
- In the “prospective costs / low savings potential” scenario, payback times for OEM-fitted systems are generally 3.5 years or less. Abatement costs are negative (order of magnitude -200 €/tonne or less).

Taking all cost factors into account retrofit TPMS is cost-effective for:
- all applications in the “prospective costs / high savings potential” scenario;
- most applications in the “current costs / high savings potential” scenario, with the exception of e.g. service/delivery vans, municipal trucks and construction vehicles with TPMS on truck and trailer. Abatement costs are always below zero only for long haul applications, regional trucks and truck & trailers and service / delivery vans and around zero for a few other applications;

- long haul applications only in the “current costs / low savings potential” scenario.
- most applications in the “prospective costs / low savings potential” scenario, except for construction TT and municipal vehicles, for which cost-effectiveness depends on the oil price. Above 110 $/barrel, both societal and end-user costs are favourable.

11.3.3.3 Scenario 2: Change of performance requirements (UNECE regulation 64) on TPMS

Scenario definition

Within this scenario, we assume that the performance requirements that are posed on TPMS systems are made stricter so that higher detection rates for deflated tyres can be found. The regulation remains valid for passenger cars only.

Table 11.8: TPMS – Scenario 2.

Costs of the option As far as the end user is concerned (driver or vehicle owner), an additional cost is foreseen compared to the reference scenario. We assume that posing stricter performance requirements could influence the consumer price, causing prices to rise by up to 10%. Using a car-renewal rate of 8 years (average age of EU passenger car), this would mean that on a yearly basis, an additional cost between 300 and 749 million € is estimated to be the result of implementing TPMS equipment with better detection rates (2012). Other possible extra costs, such as enforcement, monitoring, campaign costs, etc. remain unchanged in comparison to current practices. On the manufacturer side, extra R&D costs may be required to fulfil a change of performance requirements. However, no information on existing or projected R&D costs for such systems was found. From a general list of R&D expenditure of technology companies, it appears that between 5 and 10% of revenue is (re)invested in R&D. As a result of a change in policy, it may be that this percentage is shortly increased to cover immediate R&D needs. No absolute cost figure was estimated for additional R&D costs.
Direct effects A direct effect associated to the use of TPMS systems is a reduction in the direct fuel cost as a result of underinflation. From the project questionnaire, we learn the following distribution in additional fuel consumption: 0.5% for 0 to 10% underinflation, 1.5% for 10 to 20% underinflation, 2.5% for more than 20% underinflation. We use these figures to estimate the costs related to tyre wear, fuel consumption and CO2 emissions using TREMOVE (v3.4) where overall fuel costs coming from passenger cars are modelled. Following the methodology of the TNO study on TPMS for commercial vehicles, we assume that the current TPMS system would in practice identify 55.6% of severe tyre underinflation situations. Improving the TPMS requirements could in practice boost this percentage, however we have no direct indications up to what extent this is possible. For the current estimations, we propose that the systems would reach an 80% underinflation identification (in practice). This means that an improvement of 24.4% would be achieved, compared to the existing TPMS requirements. When using the existing detection rate (55.6%) with the hypothesised detection rate (80%), we can estimate the outcome of implementing stricter TPMS requirements compared to existing requirements.

For fuel consumption, it is estimated that a reduction of 0.53% of fuel consumption is feasible under the 80% underinflation detection condition, compared to 0.37% under the existing 55.6% underinflation detection rate. This corresponds to a potential reduction in fuel cost of 148.8 million € (2012). An additional effect associated to the use of TPMS is an improvement on the expected tyre lifespan compared to underinflated tyres. This effect is reported to be up to 30% for severely underinflated tyres (more than 20% underinflated). For tyres underinflated by 10 to 20%, we assume this to be 12.5%, for tyres underinflated by less than 10%, we assume this to be 5%. Assuming a tyre lifetime of 5 years and a tyre purchase price of 500 € (per set), it is possible to estimate the change in tyre purchase behaviour over a vehicle lifetime of 14 years (average lifetime expectance for a passenger car in Europe) by estimating the costs associated to earlier tyre purchases compared to when inflation pressure was appropriately maintained throughout the vehicles' lifespan. In Europe, this would come to a total avoided cost of 27.03 million € (2012).
Indirect effects No indirect effects on other transport modes are assumed.
External effects Two external effects as a result of the current scenario are expected. Firstly, the reduction of CO2 emissions as a result of reduced fuel consumption is foreseen. Compared to the existing systems, implementing a higher detection rate for TPMS systems would reduce CO2 emissions associated to running passenger cars with underinflated tyres by 0.17%. A reduction of 0.53% in fuel consumption (over the entire fleet) is equivalent to 0.88 million tonnes of CO2 less emitted. Following the handbook on estimation of external costs in the transport sector, we use a value of 20€/ton CO2 to monetise this reduction. This results in a cost reduction of 17.5 million € (2012). Secondly, a safety effect can be identified as a result of the introduction of stricter TPMS requirements. Following a study on TPMS and commercial vehicles [5] , we estimate that between 0.9% (lower limit) and 3.4% (upper limit) of all fatal accidents are linked to tyre problems, and more precisely underinflation. This corresponds to between 154 and 436 fatalities. Under the current TPMS requirements (business as usual scenario), we assume that 55.6% of underinflation cases would be actually recognised and remediated. Under the current scenario, we assume this percentage to be 80%. This is a difference of 24.4%, which corresponds to 28 (lower limit) and 109 (upper limit) fatalities. Or, monetised, this corresponds to a cost benefit between51.8 (lower limit) and 200.4 (upper limit) million € (2012).
Summary For the year 2012, we estimate the sum of costs for implementing a higher standard TPMS to lie between 300 million € (lower cost limit) and 749 (upper cost limit) million €. The sum of benefits is estimated to lie between 378 million (lower limit) € and 806.8 million (upper limit) €. This means that the benefit to cost ratio lies between 1.26 (lower cost limit) and 1.08 (upper cost limit).

11.3.3.4 Scenario 3: Voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations.

Scenario definition:

Within this scenario, we assume that the general behaviour of the end-user can be changed as a result of a targeted information campaign, together with the availability of the required equipment to check and adjust inflation pressure at petrol stations.

Costs of the option As far as the end user is concerned (driver or vehicle owner), we do not foresee an extra cost. He is only required to regularly check for under-inflation of tyres. This can be done, for example, when the driver refuels his vehicle. The estimation of the campaign costs associated to this scenario are based on the German tyre information campaign practice (costing 180.000€/year), and extrapolated for different member states based on the number of registered vehicles relative to Germany. For the EU, this amounts to a cost of 0.99 million € (2012). Specific costs are foreseen for petrol station holders (or associated companies). In Europe, there are around 204.600 petrol stations [58]. We estimate that around 70% of them are equipped with (free or paid for) compressed air pumps. From direct contacts, we estimate the price for a suitable system to be cost between 3.000 and 6.500 € (installation and maintenance, over a 5-year period). In Europe, this would mean that a yearly cost between 36.9 and 79.8 million € would be required to install an air compressor in all petrol stations (2012).
Direct effects A direct effect associated to the use of TPMS systems is a reduction in the direct fuel cost as a result of underinflation. From the project questionnaire, we learn the following distribution in additional fuel consumption: 0.5% for 0 to 10% underinflation, 1.5% for 10 to 20% underinflation, 2.5% for more than 20% underinflation. We assume that a behavioural change between 10 (lower behavioural change limit) and 20% (upper behavioural change limit)reduction in vehicles driving with underinflated tyres may be achieved. In terms of CO2 emission reductions, this would correspond to a reduction between 0.07% and 0.13% of CO2 emissions and fuel use (cost) over the entire fleet. This corresponds to a reduction between 73.9 (lower behavioural change limit) and 147.8 (upper behavioural change limit) € in fuel cost (2012). An additional effect associated to the use of TPMS is an improvement on the expected tyre lifespan compared to underinflated tyres. This effect is reported to be up to 30% for severely underinflated tyres (more than 20% underinflated). For tyres underinflated by 10 to 20%, we assume this to be 12.5%, for tyres underinflated by less than 10%, we assume this to be 5%. Assuming a tyre lifetime of 5 years and a tyre purchase price of 500 € (per set), it is possible to estimate the change in tyre purchase behaviour over a vehicle lifetime of 14 years (average lifetime expectance for a passenger car in Europe) by estimating the costs associated to earlier tyre purchases compared to when inflation pressure was appropriately maintained throughout the vehicles' lifespan. In Europe, this would come to a total avoided cost between 10.81 million € (lower behavioural change limit) and 21.62 million € (upper behavioural change limit) (2012).
Indirect effects No indirect effects on other transport modes are assumed.
External effects Two external effects as a result of the current scenario are expected. Firstly, the reduction of CO2 emissions as a result of reduced fuel consumption is foreseen. A reduction of 0.07 to 0.13% in fuel consumption (over the entire fleet) is equivalent to 0.35 to 0.68 million tonnes of CO2 less emitted. Following the handbook on estimation of external costs in the transport sector, we use a value of 20€/ton CO2 to monetise this reduction. This results in a cost reduction of between 7 and 13.6 million € (2012). Secondly, a safety effect can be identified as a result of the introduction of stricter TPMS requirements. Following the TNO study on TPMS and commercial vehicles, we estimate that between 0.9% and 3.4% of all fatal accidents are linked to tyre problems, and more precisely underinflation. Under the current scenario, we assume the percentage to be 10 of 20%. This corresponds to an extra reduction in the number of fatalities by between 0.09 and 0.68%. In absolute figures this corresponds to 12 and 87 fatalities. Or, monetised, this corresponds to 19.2 and 147.07 million euro (2012).

Summary
For the year 2012, we estimate the sum of costs to lie between 41.87 million € and 84.83 million €. The sum of benefits is estimated to lie between 152.86 million € and 645.44 million €. This means that the benefit to cost ratio lies between 3.65 (lower behavioural change limit) and 7.61 (upper behavioural change limit). The majority of this cost ratio is dictated by the gain in energy efficiency (and the associated lower fuel cost prices for consumers and lower government revenue). As far as safety is concerned, a positive effect is anticipated with 12 to 87 possible fatalities avoided.

11.4 Summary and conclusions

The current chapter focusses on the analysis of a number of policy options that could be considered in relation to the harmonised use of Winter tyres, tyre tread depth requirements and TPMS and voluntary tyre pressure monitoring. The analysis focussed on the assessment of the costs and benefits that are related to different policy options.

A summary of the results of the SCBA is presented in Table 11.9 below.

Table 11.9: Summary of social cost benefit analyses for policy options.

Policy	Included measures	Main cost elements	Cost-Benefit ratio[33]	Safety benefits[34]
Harmonisation of the use of Winter tyres				
Behavioural change through voluntary pick-up	Consumer awareness campaign	Consumer awareness campaign, Cost for tyres and rims	0.40	Between 7 and 14 fatalities avoided (out of 588)
Behavioural change through enforcement	Police enforcement Application of regular periodic checks	Periodic inspection: time cost Enforcement actions: police time cost Cost for tyres and rims	Between 0.33 and 0.44	Between 8 and 16 fatalities avoided (out of 588)
3PMS as standard in national legislations	Referral in national legislations to EC Regulation 117.2 and the so-called 3PMS standard	Tyre purchase costs (partial price increase) Gradual replacement of production facilities R&D costs	1.89	Between 14 and 28 fatalities avoided (out of 588)

[33] Values lower than 1 indicate that costs outweigh benefits. Values higher than 1 indicate benefits outweigh costs.
[34] Values between brackets are estimated total of relevant fatalities (Values are for EU28 without Bulgaria for all measures and without Greece for Winter tyre related measures)

Tyre tread depth requirements				
Behavioural change through voluntary pick-up (valid for vehicles running Summer tyres below legal 1.6 mm limit)	Consumer awareness campaign	Campaigns	Between 34.21 and 68.43 (assuming 10 to 20% change)	Between 14 and 28 (out of 1584)
Behavioural change through enforcement (valid for vehicles running Summer tyres below legal 1.6 mm limit)	Police enforcement Application of regular periodic checks	Periodic inspection: time cost Enforcement actions: police time cost	Between 2.63 and 5.25 (assuming 50 to 100% change)	Between 71 and 142 avoided (out of 1584)
4 mm tread depth requirement for Winter tyres assuming voluntary behavioural change	Consumer awareness campaign	Campaigns Tyre purchase cost (earlier renewal)	Between 0.88 and 0.92	Between 2 and 3 (out of 330)
Tyre Pressure Monitoring System technology [35]				
Change of performance requirements (UNECE regulation 64) on TPMS	Consumer awareness campaign Updating of TPMS	Campaigns TPMS purchase cost	Between 1.26 and 1.08	Between 11 and 88 (out of 12815)
Voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations.	Consumer awareness campaign Equipped petrol stations	Campaigns Tyre pressure monitoring and filling equipment	Between 3.65 and 7.61	Between 28 and 109 (out of 12815)

Before moving to the specific conclusions of the SCBA it is important to be aware of a number of related findings and assumptions.

Firstly, the number of fatalities that were associated to the non-use of Winter tyres is considered to be small. This has a direct repercussion on the potential cost-benefit ratios that are estimated. One of the steps in the estimation of this ratio is the estimation of the safety baseline. In this baseline, we take into account the current (and future) number of fatalities that are associated to accidents under relevant conditions (such as grip accidents under wintery conditions). As the table above indicates, this number is usually rather limited, also implying that advances in safety have a relatively limited absolute effect.

[35] SCBA for tyre pressure related measures include benefits as a result of fuel consumption improvement and CO2 emission reductions

A direct reason for this was not found and one hypothesis was formulated that needs further investigation. The hypothesis builds on the concept of risk-homeostasis, which implies that individuals tend to perform behaviour that is more or less linked to a constant (set-value) associated risk. In the case of driving under wintery conditions, this would mean that drivers (automatically or through active choice) adjust their driving behaviour to adverse conditions and drive slower. This could result in the finding that although technical information and laboratory studies indicate that a major difference exists between Winter tyres (3PMS but also M+S and similar), this is not reflected in differences in the number of persons killed during wintery conditions between vehicles with or without Winter tyres.

Secondly, the current study focusses on rather individual policy options rather than combined effects. One of the main guiding elements in calculation of cost-benefit values is the estimation of effects of particular measures. In the current case, measures can generally be split into three groups: purely technical measures (3PMS, TPMS, etc.), voluntary behaviour change as a result of information campaigns and forces behaviour change as a result of enforcement campaigns. It needs however to be noted that it is typically the combination of measures from different categories that has the most effect (i.e. the combination of enforcement actions with information campaigns, as is suggested in both the PEPPER and CAST projects).

In real life, information campaigns and enforcement activities tend to go hand in hand. However, the combined effect size is very difficult to estimate. Also, it needs to be considered that enforcement activities will only have an effect if a specific legislation is valid. However, within the current setting, we were not capable of providing an accurate estimation of such combined effect sizes. To estimate these, it would be more appropriate to have a more experimental setup rather than a literature-based analysis.

Thirdly, the overall tendency of benefit to cost ratios that depend heavily on safety outcomes is to decline over time for the different scenarios. This is mostly due to the fact that those elements that are integrated on the cost-side are assumed to increase (the number of vehicle kilometres, the number of tyre sets purchased, the enforcement effort with a growing number of vehicles, etc.) while those elements that are integrated on the benefit-side are assumed to potentially decrease (the number of projected fatalities decreases strongly). As a result, the benefit-to-cost ratio will decline over time if the policy option is implemented in the same way over time.

The degree to which such a decline is found can be different for scenarios where fuel costs and emissions are included on the benefit side since an overall increase in the number of vehicle kilometres (vkm) (linked to fuel costs and emissions) is assumed. However, over time, it is also fair to assume that more environmental friendly technologies are incorporated in the vehicle fleet and that a baseline with decreasing fuel costs and emissions can be assumed [36].

[36] http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf, pg 44

Winter tyres

- Four scenarios related to the use of Winter tyres were analysed. Safety effects were identified in all four scenarios. The SCBA did not include fuel efficiency or emission reduction effects.
  - Scenario 1: Behavioural change through voluntary pickup
  - Scenario 2: Behavioural change through enforcement
  - Scenario 3: 3PMS as standard in national legislations
  - Scenario 4 (this is Scenario 3 on tyre tread depth requirements): a 4 mm tread depth requirement for Winter tyres, assuming voluntary behavioural change.
- Two scenarios provided a low benefit-to-cost ratio:
  - Scenario 1: Behavioural change through voluntary pickup: 0.4
  - Scenario 2: Behavioural change through enforcement: 0.33 to 0.44
- One scenario provided a close to break-even benefit-to-cost-ratio:
  - Scenario 4: 4 mm tread depth requirement in combination with voluntary behavioural change: 0.88 to 0.92
- One scenario provided a clearly positive benefit-to-cost ratio:
  - Scenario 3: 3PMS as standard in national legislation: 1.89
- The total number of fatalities that could be avoided by measures on the use of Winter tyres from relevant accident types varies between 2 and 28.
- The current analysis is limited to safety effects. Additional effects that may be included on the benefit side are congestion effects since more continuous traffic may be the result of the use of Winter tyres. Fuel efficiency effects are difficult to estimate. On one hand, Winter tyres provide more efficient transmission of energy between vehicle and road, which would have a positive effect. On the other hand, Winter tyre tread depth may have a negative effect on fuel efficiency while tyre width (Winter tyres typically are more narrow than regular tyres) has a positive effect.

Tread depth

- Three scenarios were analysed. Safety effects were identified in all four scenarios. The SCBA did not take into account fuel efficiency or emission reduction effects.
  - Scenario 1: Behavioural change through voluntary pickup (regular tyres running below 1.6 mm)
  - Scenario 2: Behavioural change through enforcement (regular tyres running below 1.6 mm)
  - Scenario 3: a 4 mm tread depth requirement for Winter tyres, assuming voluntary behavioural change.
- One scenario provided a close to break-even benefit-to-cost-ratio:
  - Scenario 3: 4 mm tread depth requirement in combination with voluntary behavioural change: 0.88 to 0.92
- Two scenarios provided high benefit-to-cost ratios
  - Scenario 1: Behavioural change through voluntary pickup (regular tyres running below 1.6 mm): between 34.21 and 68.43 (note: this is likely to be the result of a high assumed effect of information campaigns).
  - Scenario 2: Behavioural change through enforcement (regular tyres running below 1.6 mm): between 2.63 and 5.25
- The total number of fatalities that could be avoided by tread depth measures from relevant accident types varies between 2 and 142.

TPMS and inflation pressure maintenance

- Three scenarios were identified, of which two were analysed within this project. This SCBA takes into account road safety, fuel efficiency and emission reduction effects.
  - Scenario 1: Fitting of TPMS on other vehicle categories than passenger cars
  - Scenario 2: Change of performance requirements (UNECE regulation 64) on TPMS
  - Scenario 3: voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations
- Two scenarios provided high benefit-to-cost ratios:
  - Scenario 2: Change of performance requirements (UNECE regulation 64) on TPMS: between 1.08 and 1.26
  - Scenario 3: voluntary monitoring of tyre pressure and availability of air pressure equipment at petrol stations: between 3.65 and 7.61
- Scenario 1 provided a different type of indication for cost efficiency (payback time), mostly based on fuel efficiency and emission reduction effects. Payback times were overall lower than 3.5 years.

12 General conclusions and proposed actions

Regarding actions for different tyre aspects the conclusions and proposed actions are listed below. Stakeholders are generally in favour of harmonisation of the tyre use legislation to ease transport across EU member states and to achieve a level playing field.

Conclusions

- Winter tyre
  Following laboratory study results, it can be stated that Winter tyres have an improved performance relevant for road safety compared to Summer tyres for low temperatures and snow or ice road conditions. This is, to some extent, confirmed in accident data. The main interest is to define a standard for Winter tyres that is common for all member states. The unified Winter tyre definition should be based on the current 3PMS approval test. Also from a technological point of view, it can be stated that using the 3PMS test as a base is supported as it ensures a minimum level of performance for Winter tyres that exceeds the capability of Summer tyres. A more detailed assessment of tyres under specific conditions (e.g. wet grip low temperature, or ice testing) will allow consumers to choose tyres that match their use better, and increase awareness of the relevance of choosing the right tyres. Enforcement and consumer awareness campaigns can extend the use of Winter tyres under appropriate conditions.
- Tread Depth
  Firstly, technical performance testing indicates an improved safety level on wet roads when tread depth is increased. The accident data used in the current study however indicates no benefit in terms of reducing the number of accidents by increasing the minimum tread depth. Also, stakeholders do not seem to provide sufficient support to revise the current minimum tread depth for passenger car tyres. Secondly, more accidents do occur when the tread depth is below the minimum tread depth (about 25% of tyre related accidents), indicating that enforcement would bring safety improvements. For Winter tyres a harmonized tread depth is preferred, to a level that is to be chosen based on evidence of safety improvements. The results of the study suggest that 4 mm could be a suitable level based on accident analysis and existing national legislation in member states. For truck tyres a harmonized tread depth is preferred to ensure that cross border traffic is seamless. The results of the study suggest that 1.6 mm could be a suitable level based on existing national legislation in member states.
- Inflation pressure / TPMS
  Poor maintenance of inflation pressure can lead to tyre underinflation which is unsafe. This can be prevented by Tyre Pressure Monitoring Systems, however the user is required to take action and in that respect consumer awareness is very relevant. Additionally the air filling stations need to provide correct pressure indication not to confuse the driver. The major safety concern of inflation pressure is quick deflation that can lead to tyre blowout failure or vehicle instabilities. Tyre Pressure Monitoring Systems can detect such events, however the current regulation prescribes a detection time of 10 minutes while safety critical situation can take place over several seconds.

There are no accidents known to result of faulty user interaction with the Tyre Pressure Monitoring System (e.g. resetting). Consumer awareness in general seems to be relevant to improving inflation pressure maintenance on vehicles.

- Tyre damage and ageing
  The most important safety impact of tyre damage and ageing is that it can lead to tyre blowout failure. Only by visual inspection the condition of the tyre can be assessed for these aspects. A safety improvement can be achieved by more inspections between regular periodic vehicle inspections on the tyre condition, during which at the same time inflation pressure and tread depth can be checked. Introducing (dedicated) tyre inspections will increase consumer awareness.

In summary the following actions to improve safety on a European scale are proposed:

Proposed actions for policies (in order of cost effectiveness):

I. Increase efforts for campaigning and enforcement of current tread depth legislation
J. Increase efforts for campaigning of tyre inflation pressure maintenance
K. Provide sufficient access to calibrated air filling stations[37]
L. Define a unified Winter tyre with the requirement to have the 3PMS marking
M. Include a requirement for quick deflation detection in TPMS regulation with a short reaction time (e.g. several seconds rather than minutes)
N. Install a harmonized tread depth requirement for Winter tyres (e.g. 4 mm[38])
O. Increase efforts for enforcement of Winter tyre legislation
P. Depending on the occurrence of wintery road conditions and member state-specific mobility demand increase awareness campaigns or install Winter tyre legislation

Note: item G and H may not be cost effective as a policy option; however the estimated safety benefit corresponds to 3% reduction of the number of fatalities under wintery conditions

The following actions are not supported with a cost benefit analysis, but are expected to be beneficial:

K. Install a harmonized tread depth requirement for truck tyres (e.g. 1.6 mm)
L. Organise tyre inspections on a voluntary basis or regulated between periodic vehicle inspections

[37] CBA on introducing regulation for air filling stations is not carried out
[38] Insufficient data available to carry out CBA to define threshold value

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14 Signature

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A Legislation Winter tyres

AUSTRIA **Winter tyres** - for vehicles capable of carrying eight passengers or more the use of Winter tyres on the drive axle is compulsory between 1st November and 15th March. For vehicles with a Gross Vehicle Weight of 3500kg or less and during conditions of snow, sleet or ice - the use of Winter tyres on each axle is compulsory between 1st November and 15th April. Alternatively, snow chains may be used on the driving axles(s) provided the road is covered with a layer of snow or black ice. **Snow Chains** - are compulsory on roads where road signage indicates their usage. Chains must be fitted to both wheels on the same drive axle.
BELGIUM **Winter tyres -** The use of Winter tyres is not compulsory however, where used, the speed rating of the Winter tyres must be sufficient for the vehicle and cannot be used between 1st May and 30th September. **Snow Chains** - Are not compulsory but are acceptable only where roads have a covering of snow or black ice
BOSNIA HERZEGOVINA **Winter tyres** - Are compulsory between 15th November and 15th April. Snow chains can be used with Summer tyres as an alternative. **Snow Chains** - It is compulsory to carry snow chains and a shovel within the vehicle between 1st November and 15th April.
BULGARIA **Winter tyres** - Bulgaria does not have mandatory legislation regarding the use of Winter tyres. **Snow Chains** - It is compulsory to carry snow chains between 1st November and 31st March. Snow chains must be used where indicated on at least one set of driven wheels.
CROATIA **Winter tyres -** In sleet, snow and ice, the vehicle must have at least two winter type tyres fitted to the drive axle with a minimum tread depth of 4 mm. **Snow Chains -** It is compulsory to carry snow chains and a shovel. Chains must be used for black ice conditions or where a minimum of 5cm of snow is present. At least one set should be fitted to the drive axle.
CZECH REPUBLIC **Winter tyres -** The use of Winter tyres can be rendered compulsory by means of a roadside sign between 1st November and 1st April and must have a minimum of 4 mm of tread depth. **Snow Chains -** The use of snow chains can be rendered compulsory by means of a traffic sign. A set of chains must be fitted on the driving axle. Maximum speed 50 km/hr.

DENMARK

Winter tyres - Denmark does not have mandatory legislation regarding the use of Winter tyres.

Snow Chains - The use of chains is permitted where the conditions are appropriate.

ESTONIA

Winter tyres - Are compulsory between 1st December and the end of February. This period can be extended should the weather conditions warrant it. Please check before you visit.

Snow Chains - It is not compulsory to carry or use snow chains.

FINLAND

Winter tyres - Are compulsory with a minimum tread depth of 3 mm between 1st December and the end of February for all vehicles with a GVW not exceeding 3500kg.

Snow Chains - It is not compulsory to carry snow chains.

FRANCE

Winter tyres - are not compulsory. In the case of an accident however, the lack of Winter tyre fitment can constitute a decisive argument for determining the responsibility for the damage. Only on specific roads can roadside signage indicate the compulsory usage of winter.

Snow Chains - It is not compulsory to carry snow chains other than on the French access road to the Mont Blanc tunnel where it is compulsory to have snow chains aboard between 1 October and 30 April. Chains are allowed on snow-covered roads, regardless of the period.
Fitting of snow chains is compulsory on some mountain passes. This is indicated by means of traffic signs. The compulsory use of snow chains for vehicles of which at least two wheels of the driving axle are equipped with Winter tyres or tyres with spikes expires.
The number of chains has not been described precisely. Article 9 of the decree of 18 July 1985 states: removable anti-grid systems must guarantee the departure, the control and the braking of the vehicle.

GERMANY

Winter tyres - The law states: In the case of motor vehicles the equipment should be adapted to the weather conditions. This particularly includes suitable tyres. This regulation does not apply to trailers and caravans.
In the event unsuitable tyres are used, a driver is in violation and risks a fine. Moreover, involvement in a traffic accident beyond the own culpability may lead to joint liability as a result of which the civil liability insurance only covers 70 to 80% of the damage in some instances. Use of unsuitable tyres can moreover be considered gross negligence so that the all-risk insurance may become null and void.

Snow Chains - Chains must be fitted on the tyres of the driving axle of the towing vehicle if this is prescribed by means of a traffic sign (*regulation only applies to vehicles with more than two wheels*) with a maximum speed of 50 km/hr. Snow chains are allowed on trailers if the towing vehicle is equipped with the same.

GREECE **Winter tyres -** There is no mandatory legislation concerning the use of Winter tyres **Snow Chains** - are permitted for use should weather conditions dictate.
HUNGARY **Winter tyres** - There is no mandatory legislation regarding the use of Winter tyres in Hungary. **Snow Chains -** are compulsory to carry in the event of wintry conditions. Border controls will deny access to any vehicle without sufficient chains. Speed is restricted to 50km/hour when chains are fitted. Chains must be fitted across at least one drive axle and if used on dry roads will result in a fine to the driver.
ICELAND **Winter tyres** - are compulsory from 1st November through to 14th April. The specific dates may alter year to year. Please check with your travel agent prior to driving in the member state.
IRELAND **Winter tyres** - There is no mandatory regulation or legislation regarding the use of Winter tyres. **Snow Chains** - are permitted in the event of severe winter conditions.
ITALY **Winter tyres** – are compulsory from November 15^{th} until April 15^{th} (next year) and the use thereof is also presented through road signs. However, the period can be extended for certain roads or for specific weather conditions. **Snow Chains -** It is not compulsory to have chains aboard the vehicle, except in the Alps where it is compulsory to carry chains between 15th October and 30th April. In the rest of Italy a vehicle must be equipped with snow chains (***or Winter tyres all-round***) if this is indicated by traffic signs. Snow chains must always be fitted on the driving axle of the vehicle.
LATVIA **Winter tyres** - are compulsory for all vehicles with a GVW of less than 3500kg from 1st December to 1st March. **Snow Chains** - are not compulsory to carry or use.
LITHUANIA **Winter tyres -** are compulsory for all vehicles up to and including a maximum GVW of 3500kg from 10th November to 1st April and must have a tread depth of no less than 3 mm. **Snow Chains** - are not compulsory to carry or use.

LUXEMBOURG

Winter tyres - are not compulsory. However, in case unsuitable tyres are used in wintry conditions and other road users are consequently hindered you risk a fine. In case of an accident the lack of Winter tyres constitutes an important argument for the allocation of the responsibility for the damage.
Winter tyres cannot be used in the period from 1st April up to 30th October if the speed rating of the Winter tyres is insufficient for the speed of the car.

Snow Chains - Are only permissible in the event of snow or ice covered roads.

NORWAY

Winter tyres - In the event of wintry conditions (ice, sleet, snow), all vehicles must have Winter tyres fitted with no less than 3 mm of tread depth remaining. As an alternative, Summer tyres with chains fitted will suffice.

Snow tyres - The use of chains is prohibited between Easter Monday and the 31st October except in adverse weather conditions within this period.

In the regions Nordland, Troms and Finnmark the use is allowed between 15th October and 1st May.

Heavy Vehicle Requirements – *new rules for 2013*

Winter tyres

- For motor vehicles with a total permitted weight of more than 3 500 kg, Winter tyres are obligatory during the period from 15 November to 31 March. This requirement does not apply to lift axles.
- Winter tyres can be either studded tyres or so-called friction tyres (non-studded). These must be specially labelled M+S, MS, M&S, "mud and snow", 3PMS or «3 peak mountain snowflake» and must be specially designed for winter driving.

Tread design depth

- For vehicles with a total permitted weight of more than 3 500 kg (both towing vehicle and trailer), tyres are required to have at least 5 mm tread design depth from 15 October in Nordland, Troms and Finnmark, and from 1 November in the rest of Norway.
- This requirement is in force up to and including 30 April in Nordland, Troms and Finnmark and up to and including the first Monday after Easter Monday in the rest of Norway.
- Outside this period, the requirement is a tread design depth of at least 1.6 mm.

Important

The vehicle must have Winter tyres (studded or non-studded), chains or the equivalent outside the periods mentioned above if this is necessary in order to ensure sufficient road grip when road conditions are taken into account. If snow or sheets of ice can be expected on the roads, chains must be brought, whatever the time of year.

Studded tyres

- Studded tyres are permitted only during the period when it is required to use tyres with a 5 mm tread depth, unless road conditions require their use.
- If a motor vehicle with a total permitted weight of more than 3500 kg is equipped with studded tyres, it must have studded tyres on all wheels mounted on the same axle. For dual wheel assemblies, it is sufficient to mount studded tyres on one of the tandem wheels.

POLAND **Winter tyres** - There are no mandatory regulations regards the use of Winter tyres in Poland. However, article 66.1 of the Act on Road Traffic states that each and every vehicle must be constructed, equipped and maintained in a manner that the use thereof neither jeopardises the passengers nor other road users. **Snow Chains** - It is not compulsory to carry snow chains however, where traffic signs indicate there use is compulsory on certain roads; they must be fitted across a driven axle.
PORTUGAL **Winter tyres -** There are no mandatory requirements regarding the use of Winter tyres in Portugal. **Snow Chains** - are compulsory for all roads where signage indicates such. Chains must be fitted across a driven axle.
ROMANIA **Winter tyres** - There is no mandatory regulation regarding the use of Winter tyres other than where fitted, they must have no less than 2 mm of tread remaining. **Snow Chains -** While it is not compulsory to carry chains, the use of them may be rendered compulsory in the event of adverse weather conditions.
SLOVAKIA **Winter tyres** - There are no mandatory regulations regarding the fitment of Winter tyres in Slovakia but in the event of an accident or collision, the lack of fitment could constitute an important argument for the allocation of the responsibility for the damage **Snow Chains** - are not compulsory to carry or use snow chains.
SLOVENIA **Winter tyres** - Winter equipment is compulsory for all motor vehicles, also for foreign vehicles from 15th November to 15th March. During this period, if required by weather conditions, Winter tyres must be fitted, or the vehicle must carry and use snow chains. Winter tyres must have no less than 3 mm of tread remaining. **Snow Chains** - are compulsory to carry as well as a shovel. 4x4 vehicles must be equipped with chains to the rear axle.
SPAIN **Winter tyres/Snow Chains** - Are only compulsory or designated and signed roads. Please check your route before travelling.

SWEDEN

Winter tyres - are compulsory for vehicles up to and including a GVW of 3500kg from 1st December to 31st March during wintry conditions and with a tread depth of no less than 3 mm remaining. The regulation is not applicable to foreign cars but fitment is recommended to avoid liability issues in the event of accident or collision.

Snow Chains - can be fitted as an alternative to Winter tyres must be fitted to each road wheel.

Trucks, buses and campers – new rules for 2013

As from 1 January 2013, heavy trucks, heavy buses and private cars class II (campers) with a total weight of more than 3.5 metric tons, are to have Winter tyres or equivalent equipment on the vehicle's driven wheels when there are wintry conditions on the roads during the period from 1 December to 31 March. This requirement applies to all tyres on driven wheels. Please observe that front-wheel drive vehicles are to be fitted with Winter tyres or equivalent equipment on the vehicle's rear wheels as well.

Equivalent equipment refers to, among other things, snow chains, slip protection and certain tyres with solid-block elements. Block tyres with Winter tyre treads labelled M+S or tyres labelled with the symbol alpine peak/snowflake (3PMS) should be considered Winter tyres.

The depth of the tyre tread of all tyres on heavy vehicles is to be at least 5 millimetres during wintry road conditions. This requirement does not apply to tyres mounted on trailers.

SWITZERLAND

Winter tyres - can be rendered compulsory on very specific roads and will be clearly indicated as such via road signage. There are no general mandatory regulations for the use of Winter tyres otherwise but the lack of fitment can constitute an important argument in the event of accident or collision.

Snow Chains - are compulsory only on indicated roads. Chains must be fitted across a driven axle and must be constructed of metal or a comparably FRA approved material.

UNITED KINGDOM

Winter tyres - There is no mandatory regulation regarding the use of Winter tyres in the UK at present.

Snow Chains - are permitted only for use on snow or ice covered roads where the road surface would not be damaged.

B Stakeholder consultation

The list of attendees to the consultation meeting is displayed below.

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The stakeholder questionnaire is provided as a separate document.

C GIDAS ANALYSIS

In this appendix, the results of the GIDAS study are presented in more detail.

Tread depth influences

The tyre tread depth is affecting grip level only significantly on wet and snow covered surfaces, and therefore tread depth influences on accidents are only investigated for those conditions.

Passenger car tyres on wet road

The tread depth distribution for accidents with passenger cars on a wet road is shown in Figure 3.1. The results for the grip category (marked “G”) and corresponding reference category (marked “R”) are shown side by side. The temperature range and tyre type (ST = Summer tyre, WT = Winter tyre) are indicated below each histogram. In order to judge the results on the statistical relevance the magnitude of 1 accident resolution is indicated for each category (as the sample size varies between grip and reference categories).
Figure 3.1 shows the tread depth distribution of passenger car tyres on wet roads as found in the grip accident category to the reference category.

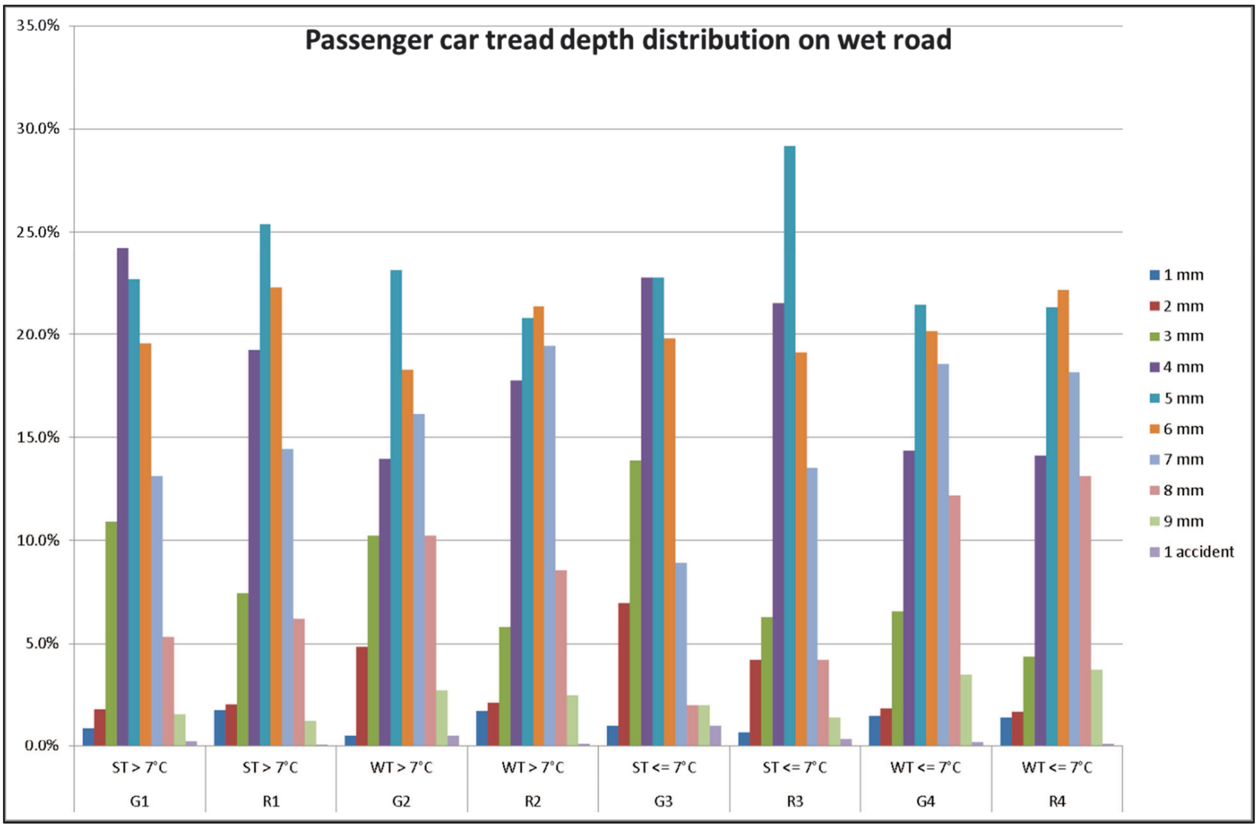

Figure 3.1: Tread depth distribution in passenger car accident records for a wet compared to reference data.

The results in Figure 3.1 for different categories are discussed in Table 3.1.

Table 3.1: Evaluation of tread depth results for passenger cars on wet roads.

Grip / reference category	Condition	Observation / assessment
G1 – R1 Summer tyre	WET T > 7 °C	There is a higher share of vehicles in the grip accident category that have a tread depth of 3-4 compared to the reference category, but for 1-2 mm the share is less than the reference. There is no indication that increasing the minimal tread depth for Summer tyres would reduce the number of grip accidents at higher temperatures.
G2 – R2 Winter tyre	WET T > 7 °C	There is a higher share of vehicles in the grip accident category that has a tread depth less than 4 mm compared to the reference category. There is an indication that an increase of the minimum tread depth for Winter tyres would reduce the number of grip accidents on wet roads at higher temperatures.
G3 - R3 Summer Tyre	WET T =< 7°C	There is a higher share of vehicles in the grip accident category that have a tread depth of 2-4 compared to the reference category, but for 1 mm the share is similar to the reference. There is an indication that increasing the minimal tread depth for Summer tyres would reduce the number of grip accidents on wet roads at lower temperatures, there seems to be a higher sensitivity for tread depth than at higher temperatures. However, the sample size for this category is quite low therefore no solid conclusions can be drawn.
G4 – R4 Winter tyre	WET T =< 7°C	There is a higher share of vehicles in the grip accident category that have a tread depth of 3 mm compared to the reference category, but for 1-2 mm the share is similar to the reference. There is limited indication that increasing the minimal tread depth for Winter tyres would reduce the number of grip accidents on wet roads at lower temperatures.

Passenger car tyres on snow

Figure 3.2 shows the tread depth distribution of passenger car tyres on snow covered roads as found in the grip accident category compared to the reference category. The results for Summer tyres are displayed, however the amount of data is found insufficient for further analysis.

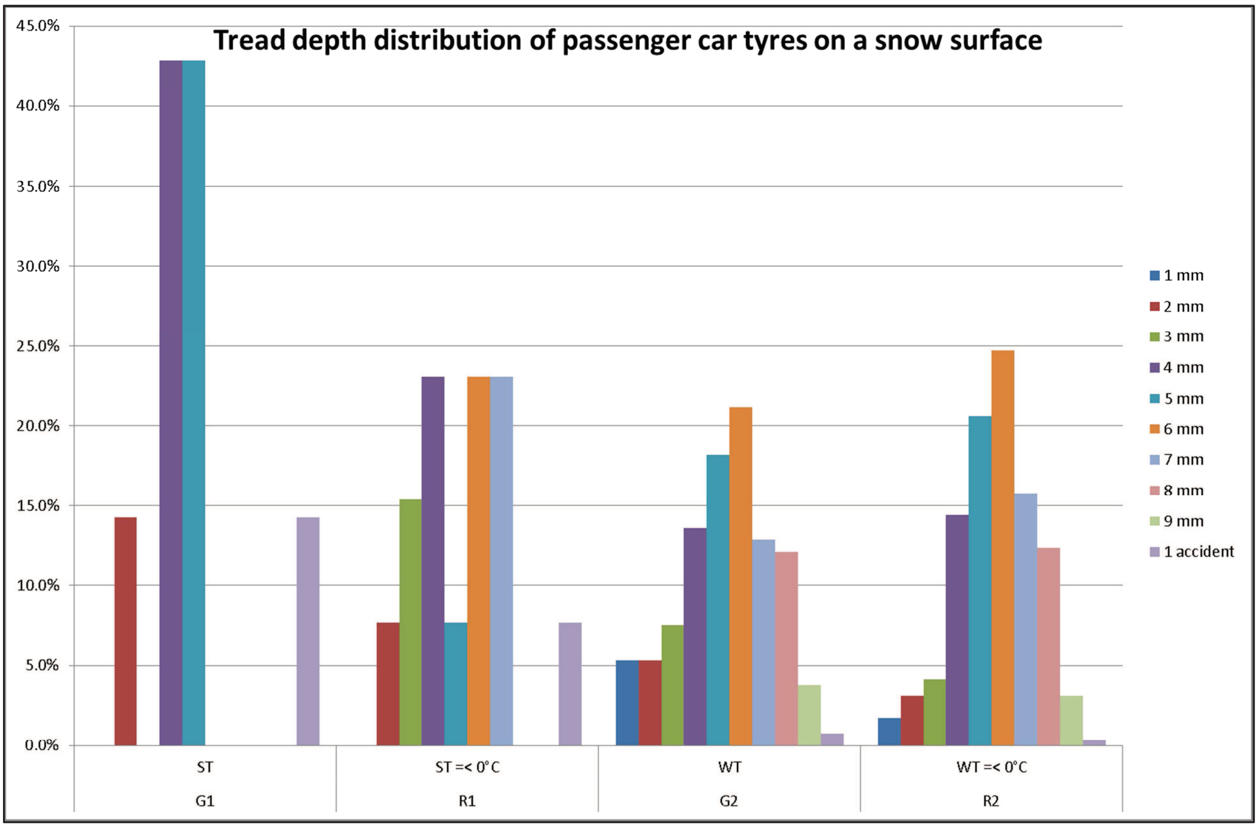

Figure 3.2: Tread depth distribution of passenger car tyres on a snow surface compared to reference data.

As can be seen in Figure 3.2, the distribution of tread depth in the grip accident category with Winter tyres on snow covered roads is different from the reference category. The grip accidents have a higher share of tread depth of less than 4 mm than the reference. This indicates that for Winter tyres an increase of the minimum tread depth could reduce the number of grip accidents on snow covered roads.

Truck tyres

The number of records in the database regarding grip accidents for trucks is quite limited, and furthermore no documentation is made on the use of Summer tyres and Winter tyres. The distribution of tread depth is very similar for high and low temperatures and therefor no further distinction is made for temperatures in the analysis. The amount of records for trucks on snow roads is found to be insufficient for analysis.

The distribution of tread depth in the grip accident category on wet roads found for trucks is compared to the reference category in Figure 3.3.

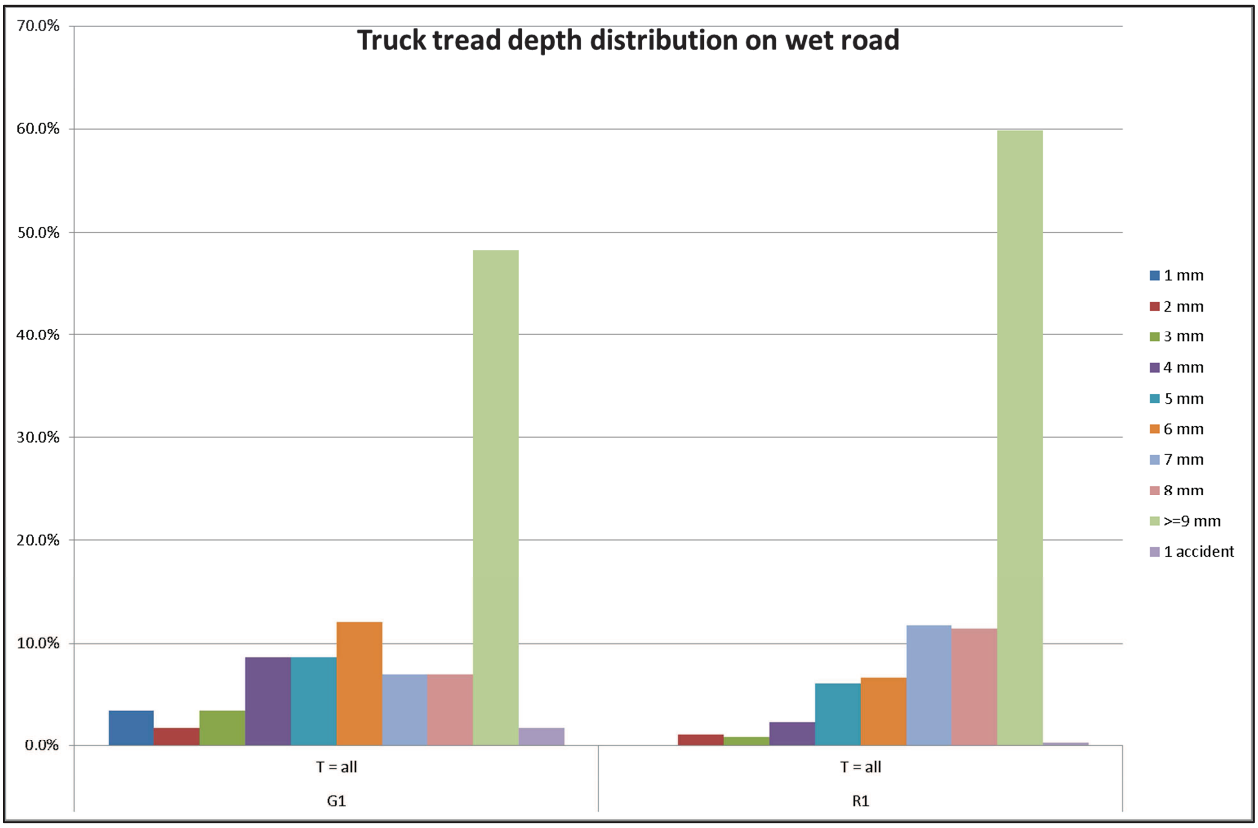

Figure 3.3: Tread depth distribution of truck grip accidents on a wet road compared to the reference.

As can be seen in Figure 3.3 the tread depth distributions of the grip accident category G1 is different from the reference category R1. Even though the sample size of the category data is small it is remarkable that very reduced tread depth only is found in the grip accident category, and that the share with tread depth larger than 9 mm is smaller than in the reference category. These results do indicate that tread depth is an influencing factor for grip accidents of trucks, and that setting a minimum requirement of tread depth for truck tyres could reduce the amount of grip accidents.

Tyre age influence

The influence of tyre age on grip accidents is studied for passenger car tyres only as the amount of data for truck tyres is insufficient for analysis. The results are discussed for the different road conditions below.

Passenger car tyres on dry road

The tyre age distribution is determined for dry road conditions for the grip accident category for three ranges of temperatures. The tyre age distribution in the grip accident category is compared to the reference category in Figure 3.4.

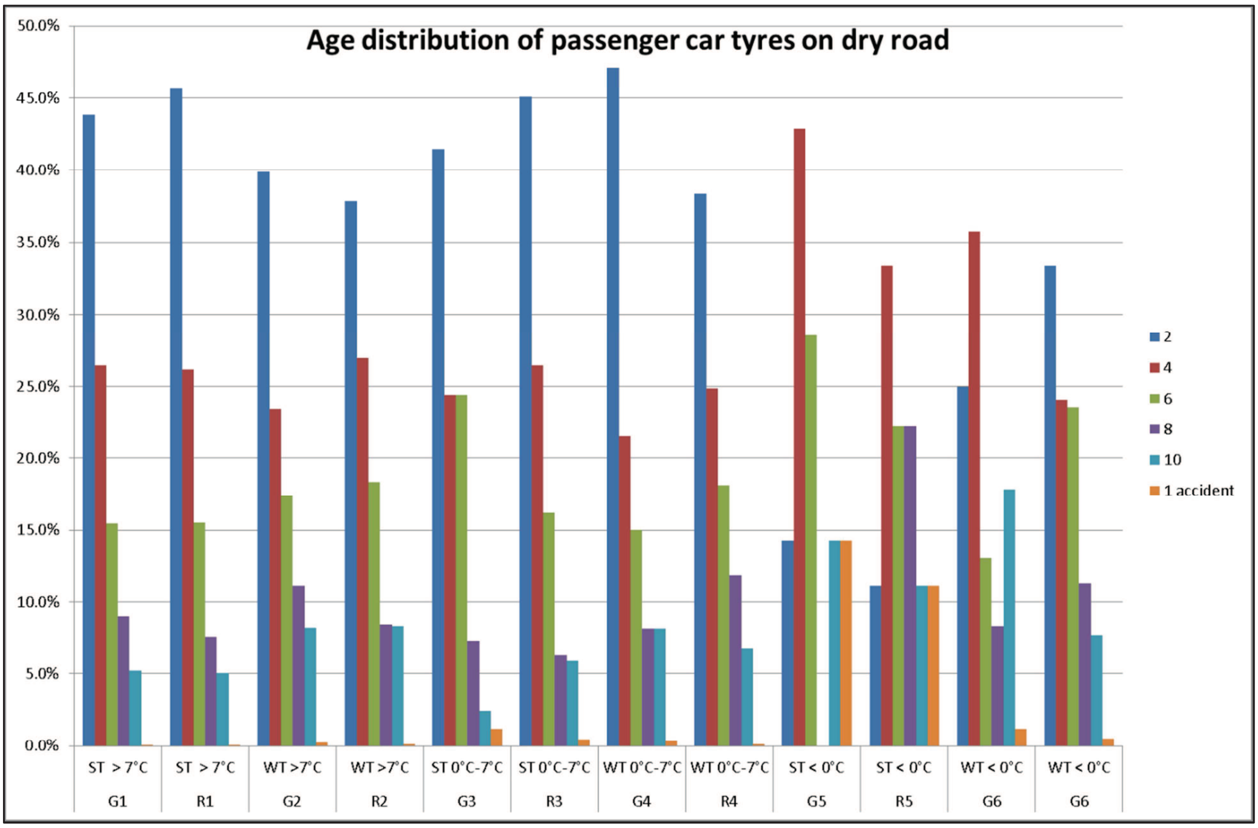

Figure 3.4: Distribution of tyre age for grip related accidents with passenger cars on dry road compared to reference data.

The results in Figure 3.4 are discussed in Table 3.2.

Table 3.2: Evaluation of tyre age distribution results for passenger cars tyres on dry roads.

Category / reference	Condition	Observation / assessment
G1 – R1 Summer tyre	DRY T > 7 °C	The distribution of tyre age in the grip accident category is very similar to the reference category. No influence of tyre age of Summer tyres is assessed for dry road conditions with temperature above 7 °C
G2 – R2 Winter tyre	DRY T > 7 °C	The distribution of tyre age in the grip accident category is very similar to the reference category. No influence of tyre age of Winter tyres is assessed for dry road conditions with temperature above 7 °C
G3 - R3 Summer Tyre	DRY T 0°C - 7°C	The distribution of tyre age in the grip accident category is different from the reference category; however there is no clear indication how the tyre age could affect grip accidents.
G4 – R4 Winter tyre	DRY T 0°C - 7°C	The distribution of tyre age in the grip accident category is different from the reference category; however there is no clear indication how the tyre age could affect grip accidents.
G5 – R5 Summer Tyre	DRY T =< 0°C	The sample sizes of the grip accident category and reference category are too small to conclude on tyre age influences.
G6 – R6 Winter tyre	DRY T =< 0°C	The distribution of tyre age in the grip accident category is different from the reference category, and indicates that more aged tyres are involved in grip accidents. This result indicates that tyre age is an influencing factor on the grip performance of Winter tyres for temperatures < 0°C.

Passenger car tyres on wet road

The tyre age distribution is discussed for wet road conditions for the grip accident categories in two ranges of temperatures. The tyre age distribution in the grip accident category is compared to the reference category in Figure 3.5.

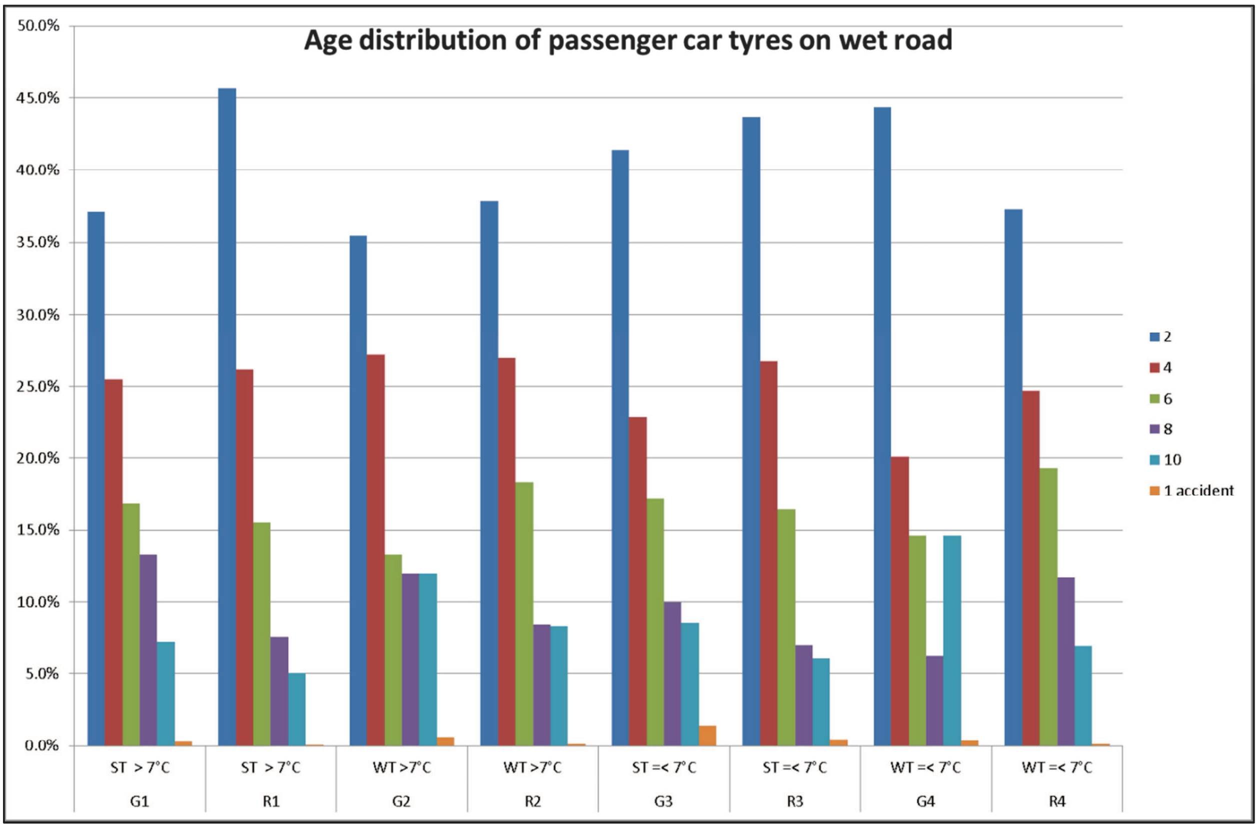

Figure 3.5: Distribution of tyre age for grip related accidents with passenger cars on wet road compared to reference data.

The results Figure 3.5 are discussed in Table 3.3.

Table 3.3: Evaluation of tyre age distribution results for passenger cars tyres on wet roads.

Category / reference	Condition	Observation / assessment
G1 – R1 Summer tyre	WET T > 7 °C	The distribution of tyre age in the grip accident category indicates a higher age of Summer tyres than the reference category. The results indicate that aging of Summer tyres increases the chance of a grip related accident on a wet road and temperature T > 7 °C.
G2 – R2 Winter tyre	WET T > 7 °C	The distribution of tyre age in the grip accident category indicates a higher age of Winter tyres than the reference category. Mainly Winter tyres aged 8 years or older are more found in grip accident data. The results indicate that aging of Winter tyres increases the chance of a grip related accident on a wet road and temperature T > 7 °C.
G3 - R3 Summer Tyre	WET T =< 7°C	The distribution of tyre age in the grip accident category indicates a higher age of Summer tyres than the reference category. The results indicate that aging of Summer tyres increases the chance of a grip related accident on a wet road and temperature T =< 7 °C.
G4 – R4 Winter tyre	WET T =< 7°C	The distribution of tyre age in the grip accident category is different from the reference category, and indicates that more aged Winter tyres are involved in grip accidents. This result indicates that tyre age an influencing factor on the grip performance of Winter tyres on a wet road for temperatures =< 7°C.

Passenger car tyres on snow and ice

The tyre age distribution in for grip related accidents is discussed for snow and ice road conditions. The tyre age distribution in the grip accidents category is compared to the reference category in Figure 3.6.

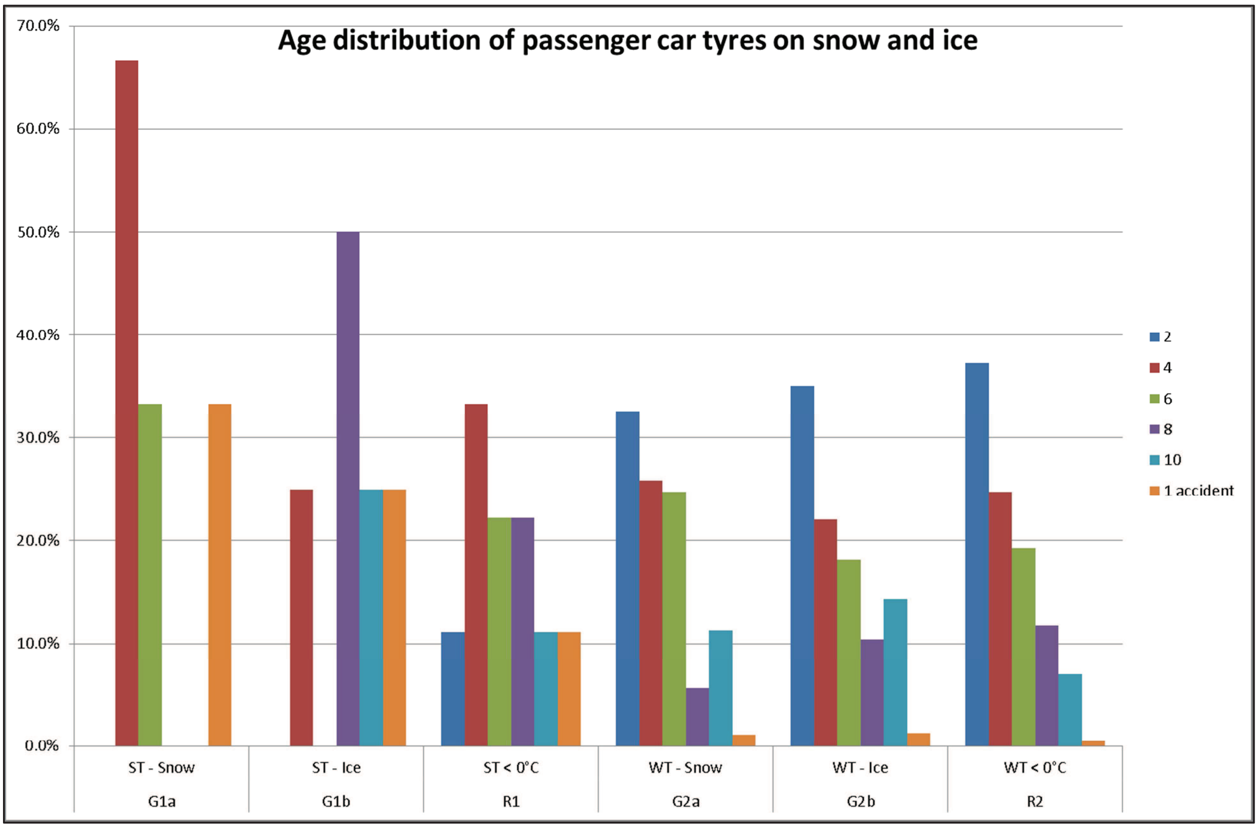

Figure 3.6: Distribution of tyre age for grip related accidents with passenger cars on snow and ice road compared to reference data.

The results in Figure 3.6 are discussed in Table 3.4.

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Table 3.4: Evaluation of tyre age distribution results for passenger cars tyres on snow and ice roads.

Category / reference	Condition	Observation / assessment
G1a/G1b – R1 Summer tyre	Snow/ice T =< 0 °C	The sample size in the Summer tyre categories is too small for analysis.
G2a – R2 Winter tyre	Snow T =< 0 °C	There is a different Winter tyre age distribution in the grip accident category compared to the reference category. The grip accident category shows fewer Winter tyres aged 2 years and a high population of very old tyres, which may indicate some influence of ageing. The small population of tyres aged 8 years cannot be explained.
G2b – R2 Winter tyre	Ice T =< 0 °C	The grip accident category shows a higher population of very winter old tyres compared to the reference category. This may be an indication of ageing influence of Winter tyres in grip accidents.

Tyre inflation pressure influence

The inflation pressure is measured on all tyres of a vehicle involved in an accident. The maximum deviation of the inflation pressure between the individual tyres of the investigated vehicle is used as a data point for creating distribution functions. Note that the inflation pressure is measured after the accident, and deflation of tyres can also be the result of the accident. Figure 3.7shows an overview of the share of vehicles in the grip accident categories and reference categories with an assumed correct tyre pressure (inflation pressure deviation < 0.2 bar), and the share of vehicles with at least one severely deflated tyre (inflation pressure deviation >1.8 bar).

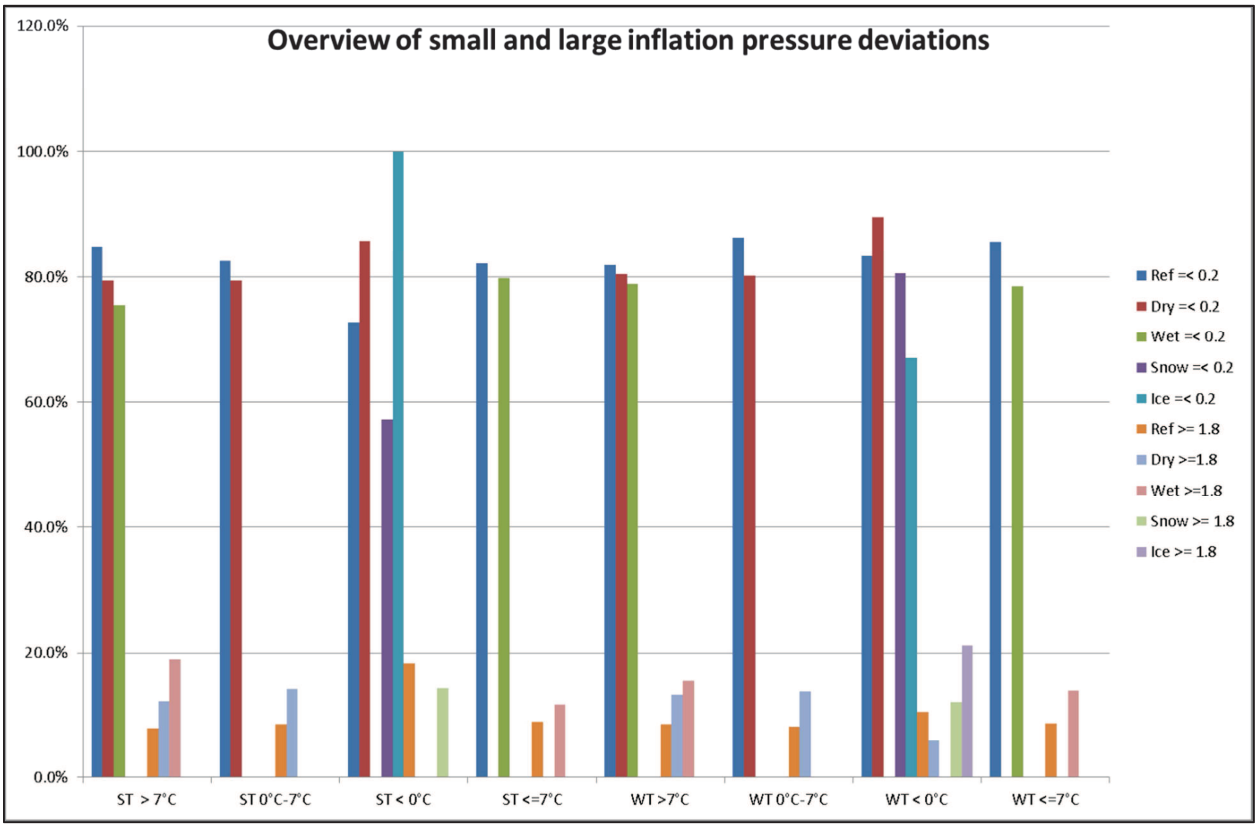


Figure 3.7: Inflation pressure differences of Summer and Winter tyres for different road and temperature conditions.

As can be seen in Figure 3.7 around 80% of the vehicles in the accident database seem to have a correct inflation pressure. It is however not possible to conclude the inflation pressure influence on grip accidents using the results in Figure 3.7, as it is not distinguished between what inflation pressure exists prior to the accident and what the result of the accident is.

A more detailed analysis is made on inflation deviations between 0.4 and 1.6 bar and the results for accident categories for dry road conditions are shown in Figure 3.8. For Summer tyres there is some indication that a higher deviation of inflation pressure could be present in the grip accident category, but only for temperatures above 7 degrees. For the other grip accident categories the results are definitively inconclusive. The same holds for results found on other road conditions, which are for that reason not further presented.

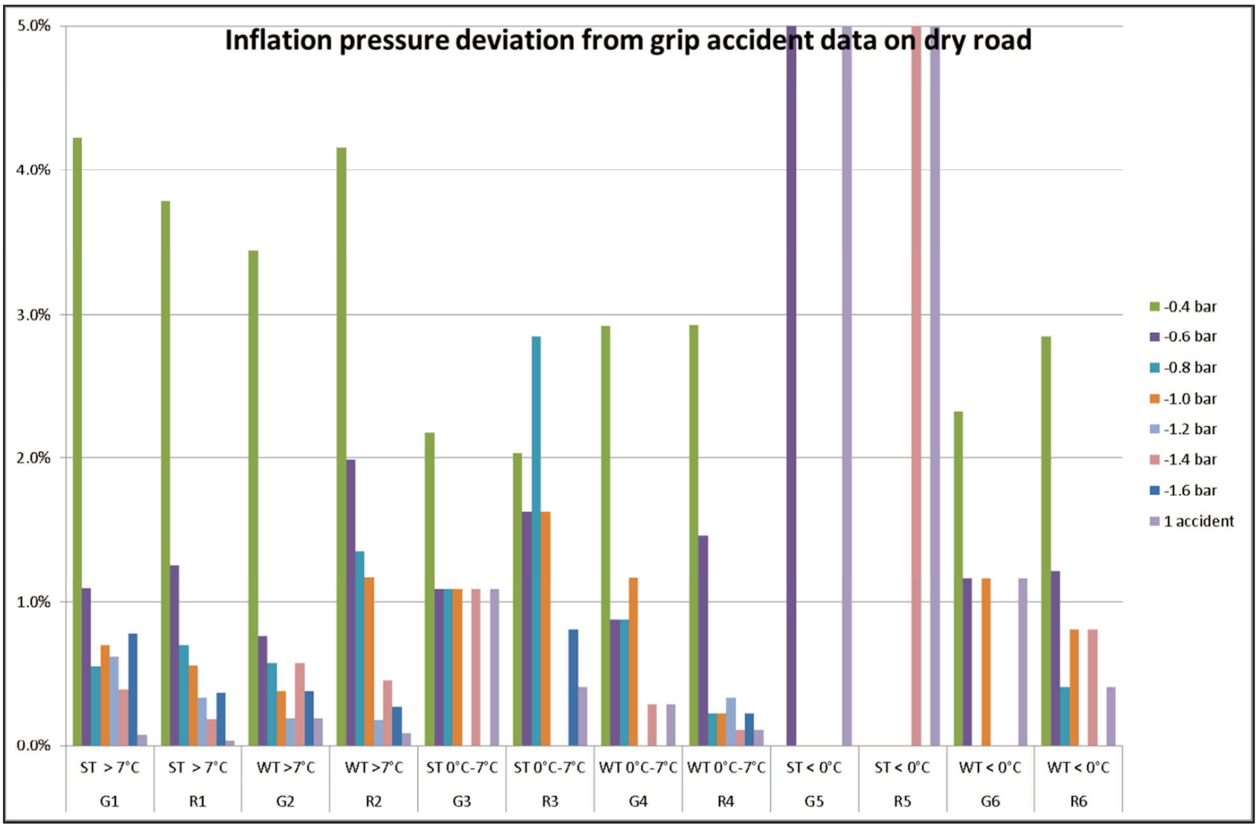
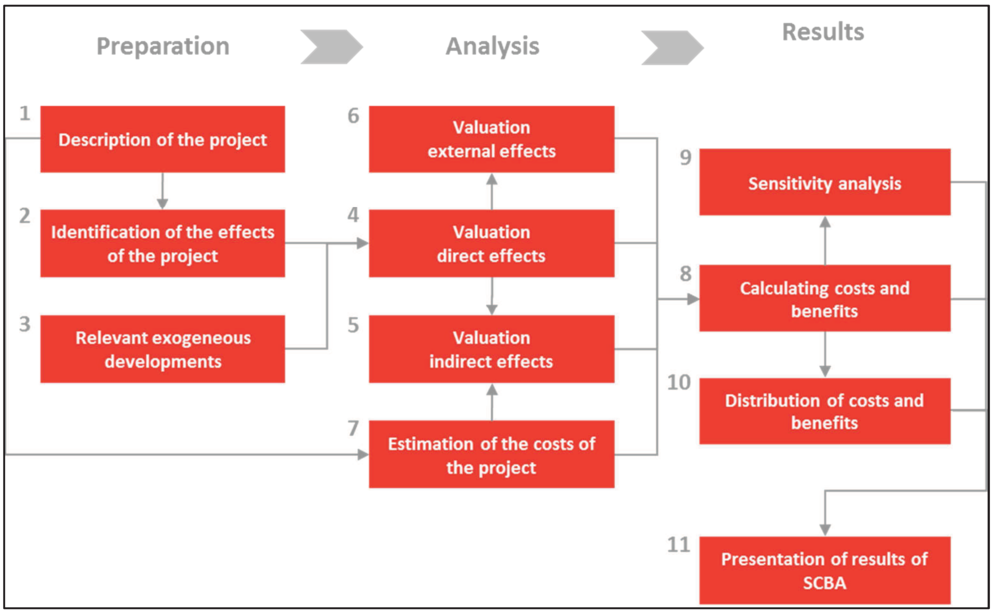


Figure 3.8: Detailed results for inflation pressure deviation found in accident categories for dry road conditions.

D General outline for a Social Cost Benefit Analysis

The figure below shows the different steps of a traditional social cost benefit analysis. This is the general framework for performing a SCBA, usually applied for infrastructure projects. In the case of a project which consists of a change of regulation, not all steps will be as relevant. This will be discussed in more detail in the paragraphs below.



Step 1: Description of the scenarios/project

The start of the SCBA is the description of the project alternatives. Important in this step is a good description of the reference alternative. The project alternatives are presented in Chapter 10. In first instance, a larger set of different possible scenarios is suggested and analysed. Based on the information available from previous chapters and the stakeholder meeting, a selection of a limited number of scenarios per topic is made.

For the reference scenario we assume that the regulation will remain as it is today. For example, this means that there is no general obligation within the European Union, but national legislation can oblige the use of Winter tyres. Given the current status in the European Union this also means that this analysis is in principle done on a member state-per-member state basis as the reference is different in each of the Member States. However, some assumptions may need to be made on a European level, and then translated to member state level.

Step 1 ‘project description’ leads to a list of project alternatives and a description of the reference alternative. The project alternatives are described, focusing on the differences between the alternatives and – if relevant – information needs for the next steps.

Step 2: Identification of the effects of the project

The goal of this step is to identify the differences between the reference scenario and the project alternatives. These differences are the effects of the project alternatives which will be quantified and evaluated in the next steps of the SCBA.

We can distinguish 4 groups of effects:
- The **direct effects** on the transport system which follow from the changes in the costs of transport, and if there are any, the changes in the amount of transport between the reference scenario and the project alternatives. These are the effects for the transport user himself and include the increase in the cost of driving due to the increase in fuel use.
- The **indirect effects** are the effects outside the road transport market. These are mainly the effects on other modes (e.g. modal shifts due to the increase in the cost of road transport), changes in government revenue (e.g. less excise duties if there is a decrease in road transport due to the increased cost, increase in enforcement costs, etc.) and the wider economic effects (the effect on the tyre centres, garages, etc.). In this case, it is expected that these effects will be negligible as the direct effect – the increase is the cost of road transport is small.
- The **external effects** are the effects on society for which there is no compensation. In this case we will focus on the effects of emissions (air quality and climate change) and traffic safety.
- The **costs of the project**. This equals the net investment costs and includes the purchase costs of the Winter tyres and rims, working hours, costs of storage, etc. and should for example also take into account the effect on the lifespan of the “normal tiers” (using Winter tyres implies that the regular tyres are not used at that moment).

Step 2 determines the different relevant effects which will be assessed further on. Depending on the expected magnitude of the effects, not all of the impacts mentioned above are assessed. The selection is based on the previous steps, the stakeholder consultation, etc. The list of effects forms the input for the main structure of the SCBA table.

Table 3.5: Example SCBA structure.

		Total
Direct effects road transport		
Direct effects passenger transport	Cost-induced change in vkm for passenger transport	
Indirect effects		
Effects rail	Differences in income	
Indirect effect government	Marginal cost of public funds	
	Changes in excise duties	
Indirect effect economy	Labour effect garages	
External effects		
Effects on society	Emissions	
	Accidents	
Project cost	Investment cost transport user	
	Changes in maintenance costs	
	Administrative and enforcement costs government	
TOTAL		

Step 3: Determining the relevant exogenous developments

Exogenous developments are the developments which can influence the project, but on which the regulator has no influence (for example the economic growth, growth in transport, etc.). For this project an important exogenous development is the weather and climate change.

It is not foreseen in the current evaluation that we will take climate changes into account. The current dataset includes monthly averages (temperature and precipitation) based on a 50-year dataset.

Another element within this step is the effect on transport flows. The proposed timeframe for this SCBA is 2012-2020. For the reference scenario we propose to use existing forecasts, assuming a moderate economic growth.

For the project alternatives we propose to use the expected changes in price and price elasticity in order to determine if the change in transport costs is large enough to change the demand for road transport. It is our expectation that the effect will be negligible. Given this expected small impact, we propose not to work with different economic growth scenarios.

Given the expected small impact on costs and hence on total transport demand we propose to work with 1 economic background scenario.

Step 4: Valuation direct effects

Step 4 consists of the valuation of the direct effects. These are the effects for the users of the project, hence- depending on the scenario – the road users (passengers and/or freight). The main direct effect is the increase in fuel use and hence the cost per km caused by Winter tyres, tyre tread depth or tyre (under)inflation.

This means that the generalized price, which is the sum of the monetary costs and the time costs, will increase. On the figure below this is de increase from P0 to P1 (on the vertical axis). This leads to a decrease in volume from Q0 to Q1 (on the horizontal axis). The direct loss for the users is then equal to the grey area: the loss for the remaining users (P0P1AB) and the loss for the users which disappear (ABC).

This is the standard calculation of the consumer surplus in SCBA

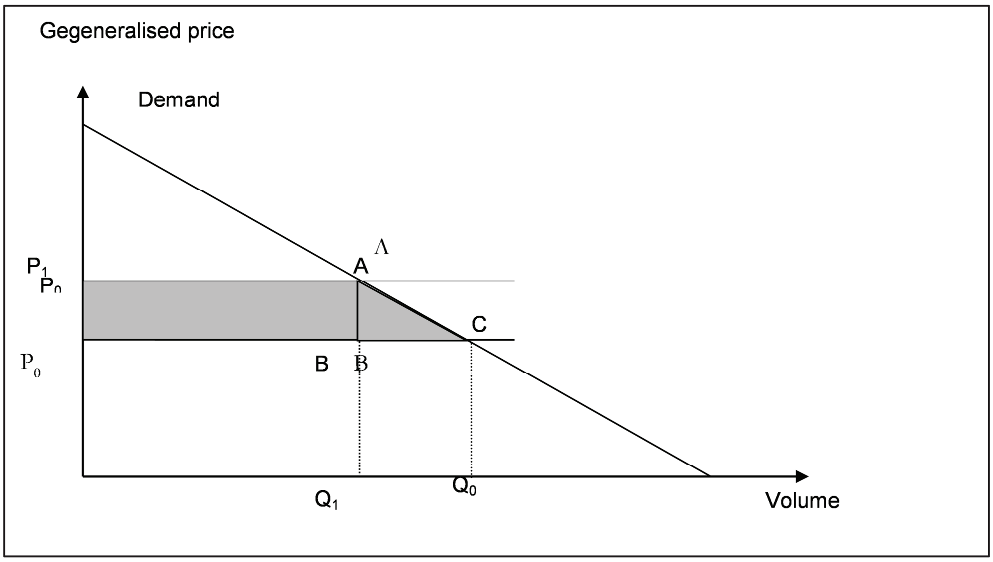


Figure 3.9: Graphical representation consumer surplus.

The traffic volumes and the changes in traffic (Q0 and Q1) are an input from the previous step. For the private costs of transport (purchase costs, insurance, fuel costs, and personnel costs) we propose to base ourselves on [59] . To come to monetary costs, the differences in time are valuated at the VOT. We propose to use the VOT as indicated in [60] and [61] .

Within the current project, we do not foresee high additional costs as a result of tyre changes or time loss (i.e. when people drive slower). As a result, the direct effects and indirect effects would be considered to be virtually non-existent.

Step 5: Valuation indirect effects

Indirect effects are the effects which are not directly caused by the project, but a consequence of the direct effects of the project on the transport costs. In this case we might distinguish:

- The effects on rail and inland waterways due to the modal shift effect. However, given the expected small effect on the transport road costs, we propose not to calculate this effect, but keep it as a “for the record” post.
- The effects on government revenue. Part of the administrative costs will happen with tax money. This money has a certain costs, called the marginal costs of public funds. The idea is that it is more expensive than 1 euro to collect 1 euro. As there is some discussion in the literature on the magnitude of this, we propose to take this into account as a “for the record” post.
- There might also be an effect on other sectors such as the transport supply industry. Ideally these types of effects are calculated using a general equilibrium model. Given that the expected effect will be small, this effect will only be taken up as a “for the record” post.

Step 6: Valuation external effects

External effects are those effects which are there, but for which no one pays directly via a market. In the end society pays as a whole. For this SCBA the most important external effects are emissions and safety.

In a first step we quantify the effects, in a second step these effects will be monetised by multiplying the effect with the valuations. The valuation of the external effects will be in line with the valuations used in [58] and [59].

Step 7: Project costs

This step summarizes the different project costs. The different categories of costs are:

- For the user
  - Purchase costs of material and costs of changing tyres
  - Increased maintenance costs or storage costs
  - Additional investment costs for companies (R&D)
- For the government
  - Increased administrative costs
  - Increased enforcement costs
- Campaign costs

These costs are net costs. Input information comes from Chapters 5 to 9.

Step 8: Sum of costs and benefits

In the previous steps the different costs and benefits were quantified and monetised. In this step all these costs and benefits are summed to obtain one number which will express the social benefit or cost of the project. This will be done by calculating the net constant value.

For this calculation we propose to use a discount rate of 4% and an expected tyre lifespan of 4 years (4 years, 51 weeks).

Step 9: Risks and uncertainties

This is the sensitivity analysis. The idea is to capture the main uncertainties in the calculation by allowing some parameters to vary. For this project we propose to do a sensitivity analysis on (not limitative):

- Discount rate
- Life span
- Investment costs
- Outcome Safety effects

Discount rate and life span sensitivity analyses took place in the first round of calculations. The impact of changes in discount rate was limited since few future investments needed to be taken into account. The impact of tyre life span was limited since overall wear-effects from wrongful tyre use was relatively low (either in direct effect, or from the percentage of very wrongful use such as severe tyre under inflation).

Step 10: Distribution of costs and benefits

In this step the costs and benefits can be distributed over different groups, geographical regions, etc.

Step 11: Presentation of the results of the SCBA

The presentation of the results of the SCBA is crucial for both the understanding and the acceptability of the results. Hence the summary of the SCBA should include in a structural way:

- A description of the project alternatives, reference alternative and background scenarios (weather)
- A qualitative description of the project effects
- An overview of the different input parameters
- The final tables and graphs.

E Calculations for SCBA

A number of calculation steps were undertaken in the current project in relation to the estimation of costs and benefits related to the different identified scenarios. In order to present these calculations as clearly as possible, the current annex is split into different sections:

- General input data and baseline calculation
  - Vehicle usage data
  - Passenger car data
  - Road safety data
  - Weather data
- Additional information for scenario-specific calculations
  - Interest rate
  - Discount rate
  - Cost prices (various elements)
- Scenario-specific calculation
  - General methodology
  - Harmonized Winter tyres
  - Tyre tread depth requirements
  - TPMS and tyre pressure

<u>General input data and baseline calculation</u>

In this section, we present information on the general input data insofar vehicle usage, passenger car data, road safety data and weather data are concerned. These are the four types of information for which extensive preparations and calculations were required based on different datasets and databases.

The combination of these databases and the result of the calculations resulted in information for the estimation of a baseline for the years 2012 up to 2030 for: vehicle usage, number of registered passenger cars and road safety.

Vehicle usage data

For each of the EU Member States, the vehicle usage data for passenger cars was estimated for the time period 2012 to 2030. The base data for this calculation is available through Eurostat (road_tf_vehmov: Motor vehicle movements on national territory, irrespective of registration member state) in the form of millions of vehicle kilometres for the time period 2003 to 2012. Missing member state values for the period 2003 to 2012 were estimated based on relative proportions for existing years, compared to the EU total.

The extrapolation from 2012 to 2030 is based on an exponential regression analysis for member states, based on the EU-total. Although this method is not as detailed as for example a member state-by-member state analysis, it still offers a relatively good fit with existing data.

The resulting vehicle kilometres data table is presented below. This information is used for further estimation of:
- The number of vehicle kilometres ran by passenger cars under specific meteorological conditions (for the scenarios on the harmonised used of Winter tyres).
- The number of vehicle kilometres ran by passenger cars with different tread depths (for the scenarios on the tyre tread depth requirements).
- The number of vehicle kilometres ran by passenger cars with different levels of tyre inflation/deflation (for the scenarios on TPMS).
- The estimation of the sub-optimal use of tyres in different conditions.

Table 3.6: Predicted vehicle kilometres for different member states

GEO/TIME	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	78.1	78.7	79.6	80.6	81.5	82.4	83.3	84.2	85.2	86.1	87.0	87.9	88.8	89.7	90.7	91.6	92.5	93.4	94.3
Bulgaria	9.8	9.9	10.0	10.1	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.1	11.2	11.3	11.4	11.5	11.6	11.8	11.9
Czech Republic	37.4	37.7	38.1	38.5	39.0	39.4	39.9	40.3	40.7	41.2	41.6	42.1	42.5	42.9	43.4	43.8	44.3	44.7	45.1
Denmark	40.2	40.5	40.9	41.4	41.9	42.3	42.8	43.3	43.8	44.2	44.7	45.2	45.6	46.1	46.6	47.1	47.5	48.0	48.5
Germany	604.0	608.5	615.6	622.7	629.8	636.9	644.0	651.1	658.2	665.3	672.4	679.5	686.6	693.7	700.8	707.9	715.0	722.1	729.1
Estonia	7.9	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5
Ireland	27.1	27.3	27.7	28.0	28.3	28.6	28.9	29.3	29.6	29.9	30.2	30.5	30.8	31.2	31.5	31.8	32.1	32.4	32.8
Spain	198.8	200.3	202.6	204.9	207.3	209.6	211.9	214.3	216.6	218.9	221.3	223.6	225.9	228.3	230.6	233.0	235.3	237.6	240.0
France	452.1	455.5	460.8	466.1	471.4	476.7	482.0	487.3	492.6	497.9	503.2	508.6	513.9	519.2	524.5	529.8	535.1	540.4	545.7
Croatia	18.0	18.1	18.3	18.6	18.8	19.0	19.2	19.4	19.6	19.8	20.0	20.2	20.5	20.7	20.9	21.1	21.3	21.5	21.7
Italy	515.6	519.5	525.6	531.6	537.7	543.7	549.8	555.9	561.9	568.0	574.0	580.1	586.1	592.2	598.3	604.3	610.4	616.4	622.5
Cyprus	3.9	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7
Latvia	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4
Lithuania	7.8	7.9	8.0	8.1	8.2	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.4
Luxembourg	4.6	4.6	4.7	4.8	4.8	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.2	5.3	5.3	5.4	5.5	5.5	5.6
Hungary	26.7	26.9	27.2	27.6	27.9	28.2	28.5	28.8	29.1	29.4	29.8	30.1	30.4	30.7	31.0	31.3	31.6	32.0	32.3
Netherlands	109.3	110.1	111.4	112.7	114.0	115.3	116.5	117.8	119.1	120.4	121.7	123.0	124.2	125.5	126.8	128.1	129.4	130.7	131.9
Austria	63.9	64.3	65.1	65.8	66.6	67.3	68.1	68.8	69.6	70.3	71.1	71.8	72.6	73.3	74.1	74.8	75.6	76.3	77.1
Poland	165.6	166.9	168.8	170.8	172.7	174.7	176.6	178.6	180.5	182.5	184.4	186.3	188.3	190.2	192.2	194.1	196.1	198.0	200.0
Portugal	59.2	59.7	60.4	61.1	61.8	62.5	63.2	63.8	64.5	65.2	65.9	66.6	67.3	68.0	68.7	69.4	70.1	70.8	71.5
Romania	33.4	33.7	34.1	34.5	34.9	35.3	35.6	36.0	36.4	36.8	37.2	37.6	38.0	38.4	38.8	39.2	39.6	40.0	40.4
Slovenia	15.6	15.8	15.9	16.1	16.3	16.5	16.7	16.9	17.0	17.2	17.4	17.6	17.8	18.0	18.1	18.3	18.5	18.7	18.9
Slovakia	25.4	25.6	25.9	26.2	26.5	26.8	27.0	27.3	27.6	27.9	28.2	28.5	28.8	29.1	29.4	29.7	30.0	30.3	30.6
Finland	46.8	47.1	47.7	48.2	48.8	49.3	49.9	50.4	51.0	51.5	52.1	52.6	53.2	53.7	54.3	54.8	55.4	55.9	56.5
Sweden	63.5	64.0	64.7	65.5	66.2	67.0	67.7	68.5	69.2	69.9	70.7	71.4	72.2	72.9	73.7	74.4	75.2	75.9	76.7
United Kingdom	386.7	389.6	394.1	398.7	403.2	407.8	412.3	416.8	421.4	425.9	430.5	435.0	439.5	444.1	448.6	453.2	457.7	462.3	466.8
TOTAL (billion vkm)	**3 010.1**	**3 032.7**	**3 068.1**	**3 103.4**	**3 138.8**	**3 174.1**	**3 209.5**	**3 244.8**	**3 280.2**	**3 315.6**	**3 350.9**	**3 386.3**	**3 421.6**	**3 457.0**	**3 492.3**	**3 527.7**	**3 563.1**	**3 598.4**	**3 633.8**

Passenger car data

For each of the EU Member States, the number of registered passenger cars is estimated for the time period 2012 to 2030. The base data for this calculation is available through Eurostat (road_eqs_carmot: Number of motor vehicles in different members states, by vehicle registration) in the form of thousands of vehicles for the time period 2003 to 2012. Missing member state values for the period 2003 to 2012 were estimated based on relative proportions for existing years, compared to the EU total. The extrapolation from 2012 to 2030 is based on an exponential regression analysis for member states, based on the EU-total.

This information is used for (double-checking) the estimation of the number of tyre purchases for the different scenarios.

Road safety data

For each of the EU Member States, the number of fatalities resulting from accidents where passenger cars were involved was estimated for the time period 2012 to 2030. The base data for this calculation is available the CARE (and/or CADaS) database and presents information from the year 2000 to 2012. This data was made available by DG MOVE. Missing member state values for the period 2000 to 2012 were estimated based on relative proportions for existing years, compared to the EU total. (Note: for Bulgaria, information is missing for the entire timeframe)

This information is used for further estimation of:
- The number of fatalities from accidents involving passenger cars under specific meteorological conditions (for the scenarios on the harmonised used of Winter tyres).
- The number of fatalities from accidents involving passenger cars with different tread depths (for the scenarios on the tyre tread depth requirements).
- The number of fatalities from accidents involving passenger cars with different levels of tyre inflation/deflation (for the scenarios on TPMS).

The extrapolation on the number of fatalities from accidents where passenger cars are involved from 2012 to 2030 for each of the Member States for the different scenarios is based on an exponential regression analysis for member states, based on the EU-total of registered fatalities in the time period 2000 to 2012. Although this method is not as detailed as for example a member state-by-member state analysis, it offers a good fit with existing data.

In the case of the extrapolation of the number of fatalities from accidents involving passenger cars under specific meteorological conditions (for use in the scenarios on the harmonised use of Winter tyres) and specific tyre use cases (for use in the scenarios on tread depth), this data is first further enriched with the relative portion of preponderance of (1) relevant temperature conditions based on the EFSA database and (2) road and precipitation condition information available in the CARE database. The relevant meteorological conditions for the scenarios on harmonised Winter tyre use were identified through the analysis of the GIDAS database as being: <0°C and dry. For the scenarios on tread depth these were: passenger cars using Winter tyres with a tread depth lower than 4 mm, being used during warm and wet conditions.

In the case of the extrapolation of the number of fatalities from accidents involving passenger cars with underinflated tyres (for use in the scenarios on TPMS and tyre pressure), this data is first further enriched with estimates on the current preponderance of different levels of tyre inflation based on literature (ETRMA & EIB studies) and statistics from Poland, Czech Republic and the Netherlands.

The different resulting tables are presented below:

Table 3.7: The number of persons killed per member state under relevant meteorological conditions for the scenarios on harmonised Winter tyre use and 3PMS. (2000-2015).

GEO/TIME	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Belgium	9	14	6	6	10	12	7	7	6	12	13	4	4	4	4	4
Bulgaria																
Czech Republic	83	82	83	86	85	76	62	64	54	52	49	43	38	41	39	37
Denmark	20	23	19	21	14	17	10	13	12	12	16	11	6	7	6	6
Germany	233	236	195	195	185	176	153	124	117	117	137	98	92	100	94	89
Estonia	18	20	17	17	17	17	17	20	10	10	10	10	10	11	10	10
Ireland	2	4	1	3	1	3	3	2	3	4	4	4	4	4	4	4
Spain	19	22	16	17	19	14	15	10	11	10	11	4	4	4	4	4
France	39	58	20	35	33	38	26	26	25	30	52	17	20	22	20	19
Croatia	5	5	4	4	4	4	4	4	2	3	5	3	3	3	3	3
Italy	51	74	57	46	43	55	38	33	28	22	32	22	25	27	26	24
Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	44	48	41	42	41	33	28	29	25	19	15	11	15	16	15	14
Luxembourg	0	3	1	1	0	1	2	0	0	0	2	1	0	0	0	0
Hungary	48	53	45	46	48	48	42	33	24	26	26	18	20	22	20	19
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	6	9	2	5	4	4	2	2	5	3	6	1	4	4	4	4
Austria	63	71	59	62	62	57	45	43	44	42	38	31	33	36	34	32
Poland	302	301	285	304	291	303	261	278	259	252	220	205	139	151	142	134
Portugal	8	4	4	5	2	6	3	2	2	2	1	1	2	2	2	2
Romania	89	95	90	79	93	114	102	105	120	109	102	80	73	79	75	70
Slovenia	8	10	9	7	9	10	7	8	5	4	3	3	3	3	3	3
Slovakia	41	45	38	39	38	39	32	30	30	24	20	20	20	22	20	19
Finland	51	61	64	50	56	51	42	53	41	35	37	39	35	38	36	34
Sweden	56	59	62	57	45	43	43	44	36	35	26	26	26	28	27	25
United Kingdom	14	25	12	13	20	16	11	13	20	22	28	10	12	13	12	12
Total EU (Est)	**1209**	**1322**	**1130**	**1140**	**1120**	**1137**	**955**	**943**	**879**	**845**	**853**	**662**	**588**	**637**	**601**	**567**

Table 3.8: The number of persons killed per member state under relevant meteorological conditions for the scenarios on harmonised Winter tyre use and 3PMS. (2016-2030).

GEO/TIME	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2
Bulgaria															
Czech Republic	35	33	31	29	27	26	24	23	22	21	19	18	17	16	15
Denmark	5	5	5	5	4	4	4	4	3	3	3	3	3	3	2
Germany	84	79	75	70	66	63	59	56	53	50	47	44	42	39	37
Estonia	9	9	8	8	7	7	6	6	6	5	5	5	5	4	4
Ireland	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2
Spain	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2
France	18	17	16	15	14	14	13	12	11	11	10	10	9	9	8
Croatia	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1
Italy	23	21	20	19	18	17	16	15	14	14	13	12	11	11	10
Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	14	13	12	11	11	10	10	9	9	8	8	7	7	6	6
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	18	17	16	15	14	14	13	12	11	11	10	10	9	9	8
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2
Austria	30	28	27	25	24	22	21	20	19	18	17	16	15	14	13
Poland	127	119	113	106	100	95	89	84	80	75	71	67	63	60	56
Portugal	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
Romania	66	63	59	56	53	50	47	44	42	39	37	35	33	31	30
Slovenia	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1
Slovakia	18	17	16	15	14	14	13	12	11	11	10	10	9	9	8
Finland	32	30	28	27	25	24	23	21	20	19	18	17	16	15	14
Sweden	24	22	21	20	19	18	17	16	15	14	13	13	12	11	11
United Kingdom	11	10	10	9	9	8	8	7	7	6	6	6	5	5	5
Total EU (Est)	535	505	477	450	425	401	378	357	337	318	300	283	267	252	238

Table 3.9: The number of persons killed per member state for the scenarios on tyre tread depth (regular tyres, 1.6 mm) (2000-2015).

GEO/TIME	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Belgium	154	136	109	72	83	83	86	72	62	59	64	48	48	50	47	43
Bulgaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Czech Republic	106	125	117	108	108	110	87	86	80	79	61	60	46	48	45	42
Denmark	46	44	40	37	36	30	19	24	31	21	26	18	14	14	13	12
Germany	705	722	651	482	557	472	428	419	364	348	287	272	262	271	252	234
Estonia	20	20	19	15	16	15	15	17	7	7	7	7	7	7	7	6
Ireland	45	44	41	25	31	37	34	26	34	33	29	29	29	30	28	26
Spain	308	286	312	286	240	184	168	143	125	110	102	82	61	63	59	55
France	657	655	572	344	404	324	318	305	267	232	260	215	217	225	209	195
Croatia	0	0	0	0	0	0	0	34	30	29	35	21	19	19	18	17
Italy	362	394	423	303	332	317	266	228	216	188	228	155	159	165	153	143
Cyprus	1	1	1	1	1	0	1	2	0	1	0	0	0	0	0	0
Latvia	55	55	53	42	45	34	26	32	30	20	14	13	14	15	14	13
Luxembourg	10	10	11	5	4	6	5	4	4	6	4	5	4	4	4	4
Hungary	79	79	76	60	76	83	67	60	47	48	45	33	31	32	30	28
Malta	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	89	65	62	54	56	44	44	39	41	31	28	20	22	23	21	20
Austria	70	81	75	59	65	60	47	47	48	47	42	28	40	41	38	35
Poland	396	416	383	360	415	372	359	404	390	372	295	275	275	285	265	246
Portugal	88	78	97	83	56	44	37	32	42	44	58	42	33	34	32	30
Romania	47	52	72	48	58	128	114	132	152	142	131	95	68	70	65	61
Slovenia	10	13	14	12	20	17	9	14	8	8	4	5	5	5	5	4
Slovakia	56	56	54	42	46	42	35	40	43	29	25	25	25	26	24	22
Finland	42	52	49	38	34	33	33	41	36	25	24	30	29	30	28	26
Sweden	69	67	60	62	48	48	42	50	43	38	25	25	25	26	24	22
United Kingdom	338	337	336	290	331	307	296	262	234	213	151	135	150	156	145	135
Total EU (Est)	3755	3790	3628	2830	3063	2790	2536	2512	2334	2130	1946	1638	1584	1642	1526	1419

Table 3.10: The number of persons killed per member state for the scenarios on tyre tread depth (regular tyres, 1.6 mm) (2000-2015).

GEO/TIME	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	40	37	35	32	30	28	26	24	22	21	19	18	17	16	15
Bulgaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Czech Republic	39	36	33	31	29	27	25	23	22	20	19	17	16	15	14
Denmark	11	11	10	9	8	8	7	7	6	6	5	5	5	4	4
Germany	218	202	188	175	163	151	141	131	121	113	105	98	91	84	78
Estonia	6	6	5	5	4	4	4	4	3	3	3	3	2	2	2
Ireland	24	23	21	20	18	17	16	15	14	13	12	11	10	9	9
Spain	51	47	44	41	38	35	33	31	28	26	25	23	21	20	18
France	181	168	156	145	135	126	117	108	101	94	87	81	75	70	65
Croatia	16	15	14	13	12	11	10	9	9	8	8	7	7	6	6
Italy	133	123	115	106	99	92	86	80	74	69	64	59	55	51	48
Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	12	11	10	10	9	8	8	7	7	6	6	5	5	5	4
Luxembourg	3	3	3	3	2	2	2	2	2	2	2	1	1	1	1
Hungary	26	24	22	21	19	18	17	15	14	13	12	11	11	10	9
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	18	17	16	15	14	13	12	11	10	9	9	8	8	7	7
Austria	33	31	28	26	25	23	21	20	18	17	16	15	14	13	12
Poland	229	213	198	184	171	159	148	137	128	119	110	103	95	89	82
Portugal	28	26	24	22	21	19	18	17	15	14	13	12	12	11	10
Romania	56	52	49	45	42	39	36	34	31	29	27	25	23	22	20
Slovenia	4	4	3	3	3	3	3	2	2	2	2	2	2	2	1
Slovakia	21	19	18	17	15	14	13	12	12	11	10	9	9	8	7
Finland	24	23	21	20	18	17	16	15	14	13	12	11	10	9	9
Sweden	21	19	18	17	15	14	13	12	12	11	10	9	9	8	7
United Kingdom	125	116	108	101	94	87	81	75	70	65	60	56	52	48	45
Total EU (Est)	1319	1226	1140	1060	985	916	851	791	736	684	636	591	549	511	475

Table 3.11: the number of persons killed per member state involving passenger cars with underinflated tyres (2012-2013).

GEO/TIME	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	455	378	355	332	312	292	274	257	241	226	212	198	186	174	164	153	144	135	126
Bulgaria																			
Czech Republic	368	375	351	328	307	288	270	252	236	221	207	194	182	170	159	149	140	131	122
Denmark	81	99	92	85	79	73	67	62	58	54	50	46	43	39	37	34	31	29	27
Germany	1791	1587	1466	1354	1250	1155	1067	985	910	840	776	717	662	611	564	521	481	445	411
Estonia	54	50	46	43	40	37	34	32	30	28	26	24	22	21	19	18	16	15	14
Ireland	129	120	114	108	102	96	91	86	81	77	73	69	65	61	58	55	52	49	46
Spain	474	499	476	454	432	412	393	375	357	340	325	309	295	281	268	256	244	232	221
France	866	820	727	644	571	507	449	398	353	313	278	246	218	193	172	152	135	120	106
Croatia	1881	1544	1408	1284	1170	1067	973	887	808	737	672	612	558	509	464	423	386	352	320
Italy	186	187	173	160	149	138	128	118	110	102	94	87	81	75	70	64	60	55	51
Cyprus	1644	1440	1327	1223	1127	1039	957	882	813	749	691	636	587	541	498	459	423	390	359
Latvia	18	16	14	13	12	11	10	9	8	8	7	6	6	5	5	4	4	4	3
Luxembourg	72	73	65	57	51	45	40	35	31	28	25	22	19	17	15	14	12	11	9
Hungary	22	18	16	15	14	13	12	11	10	10	9	8	8	7	6	6	6	5	5
Malta	253	265	242	221	202	184	169	154	141	128	117	107	98	90	82	75	68	62	57
Netherlands	9	8	8	7	7	6	6	5	5	5	4	4	4	3	3	3	3	3	2
Austria	218	190	175	162	149	138	127	117	108	100	92	85	78	72	67	62	57	52	48
Poland	282	255	239	224	210	197	184	173	162	152	142	133	125	117	110	103	96	90	84
Portugal	1615	1829	1769	1712	1656	1602	1550	1500	1451	1404	1359	1314	1272	1230	1191	1152	1114	1078	1043
Romania	255	246	226	208	191	175	161	148	136	125	115	106	97	89	82	76	69	64	59
Slovenia	798	741	688	639	594	551	512	476	442	410	381	354	329	305	283	263	244	227	211
Slovakia	46	45	41	37	34	31	28	26	24	21	20	18	16	15	14	12	11	10	9
Finland	171	156	145	134	124	115	106	98	91	84	78	72	67	62	57	53	49	45	42
Sweden	147	153	146	140	135	129	124	119	114	109	105	100	96	92	88	85	81	78	75
United Kingdom	151	139	128	117	108	99	90	83	76	70	64	59	54	49	45	42	38	35	32
Total EU (Est)	829	841	782	727	676	629	584	543	505	470	437	406	378	351	326	303	282	262	244

Weather data

For each of the EU Member States, the relative preponderance of temperature conditions was estimated based on data available in the EFSA database. This database is made available by the European Food Safety Authority and contains, among others, meteorological datasets (Mean monthly temperature (12 maps, each per month), Mean annual temperature, Arrhenius weighted mean annual temperature, Mean monthly precipitation (12 maps, each per month), Mean annual precipitation). The data is presented in the format of a geo-mapped dataset, effectively making the data extractable through normal GIS applications. After a careful analysis of the available data, it was decided to only make use of the mean monthly temperatures (for each month).

As a result of the data extraction through a GIS application, average monthly temperatures (as well as local minimum, local maximum and standard deviation) for all EU NUTS1 regions could be calculated. Based on this, a relative preponderance of temperatures (compared to a cut-off point) was estimated for each of the NUTS1 regions. These averages were then weighted based on surface size and compounded for the individual member states.

A graphical presentation of a selection of the NUTS1- information, compared to different temperature cut-off points is presented below. (Colour scale from light to dark: 0-25%, 25-50%, 50%-75%, 75-100%).

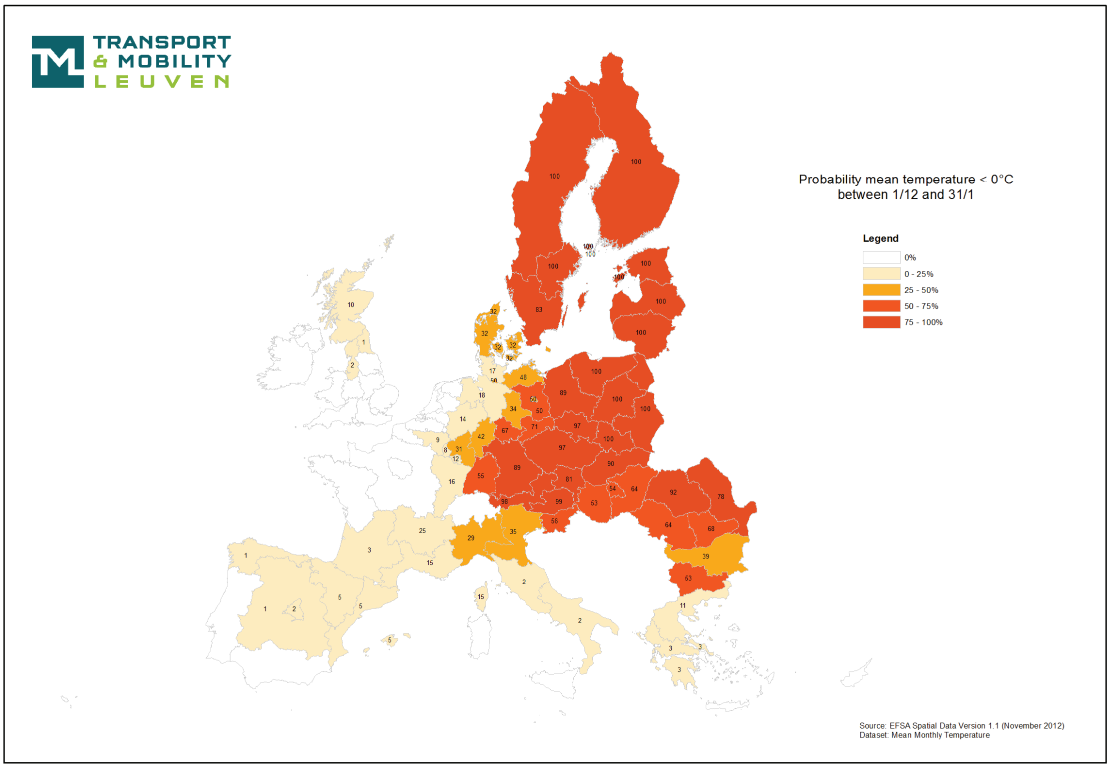


Figure 3.10: Probability of mean temperature <0°C between 1-12 and 31-01.

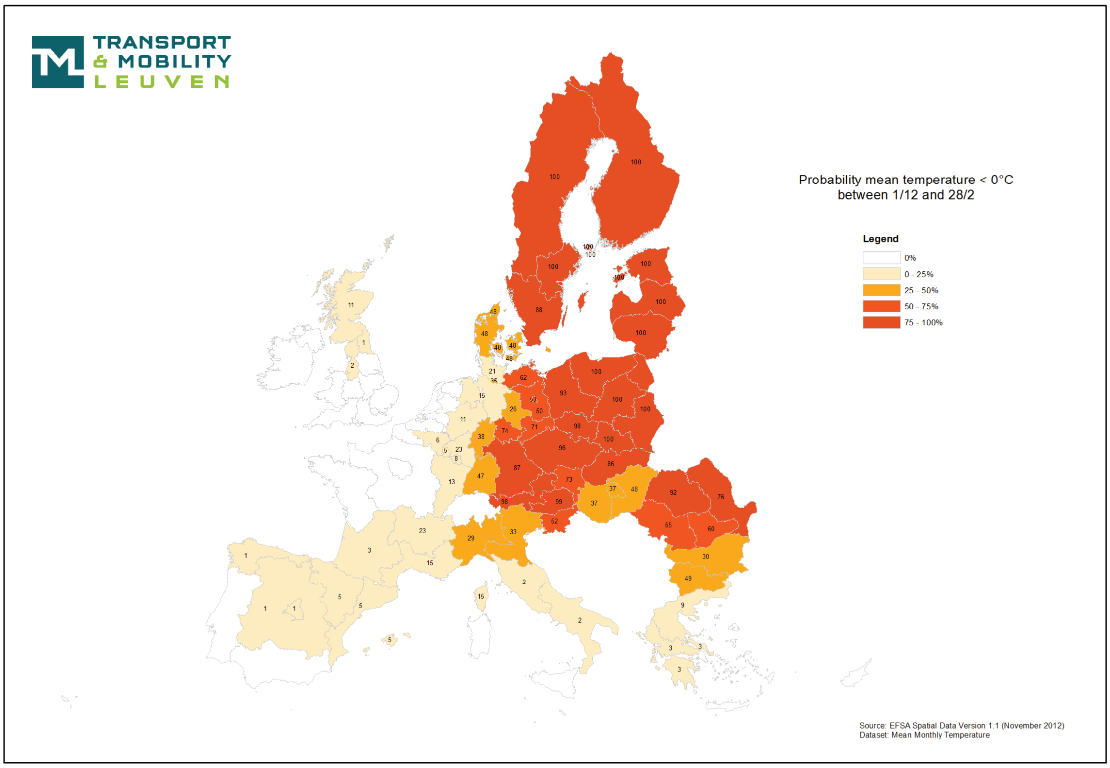


Figure 3.11: Probability of mean temperature <0°C between 1-12 and 26-02.

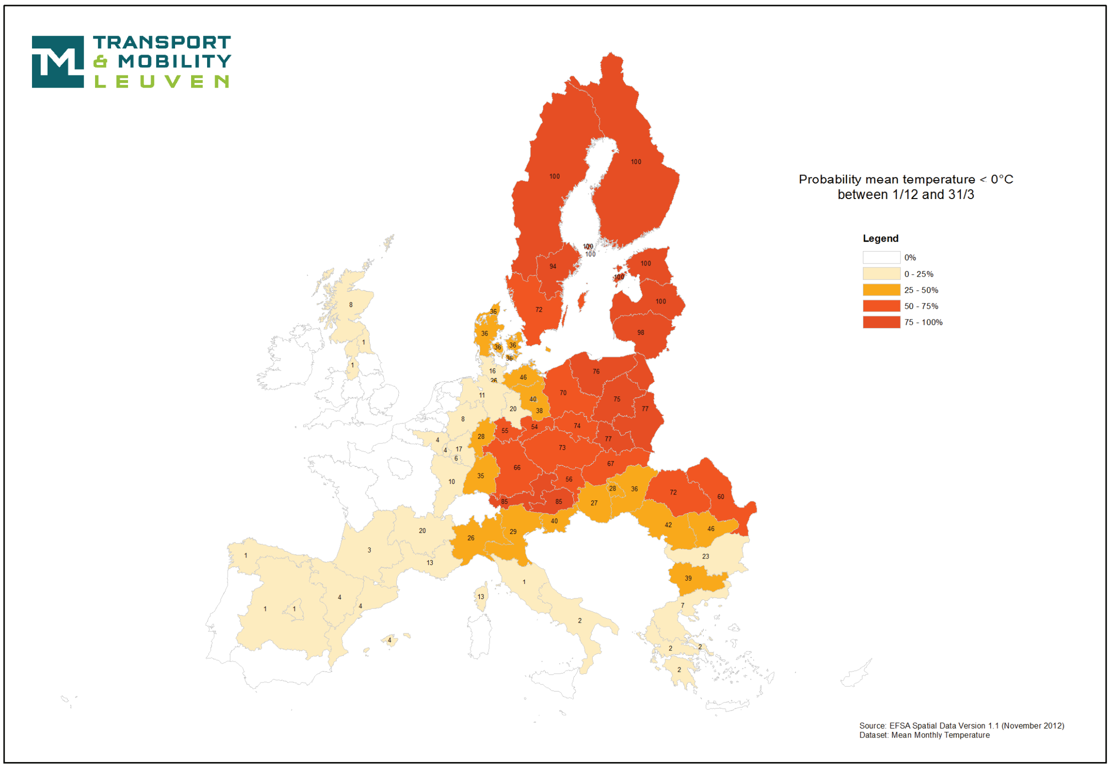


Figure 3.12: Probability of mean temperature <0°C between 1-12 and 31-03.

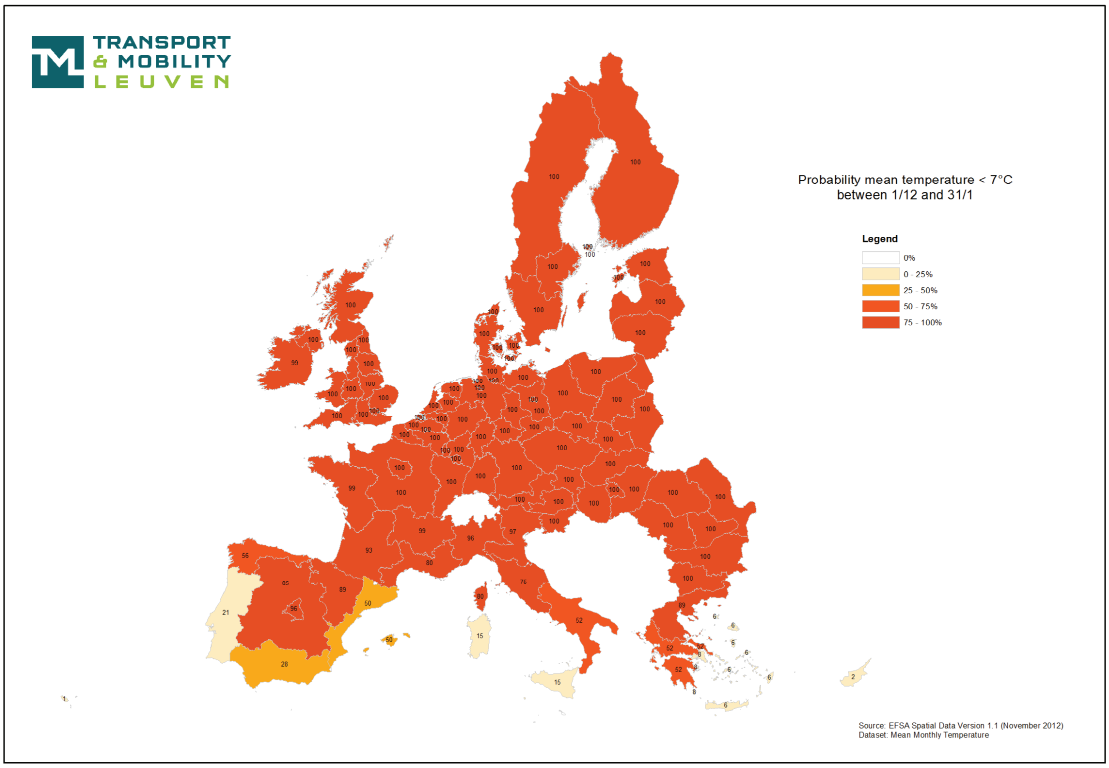


Figure 3.13: Probability of mean temperature <7°C between1-12 and 31-01.

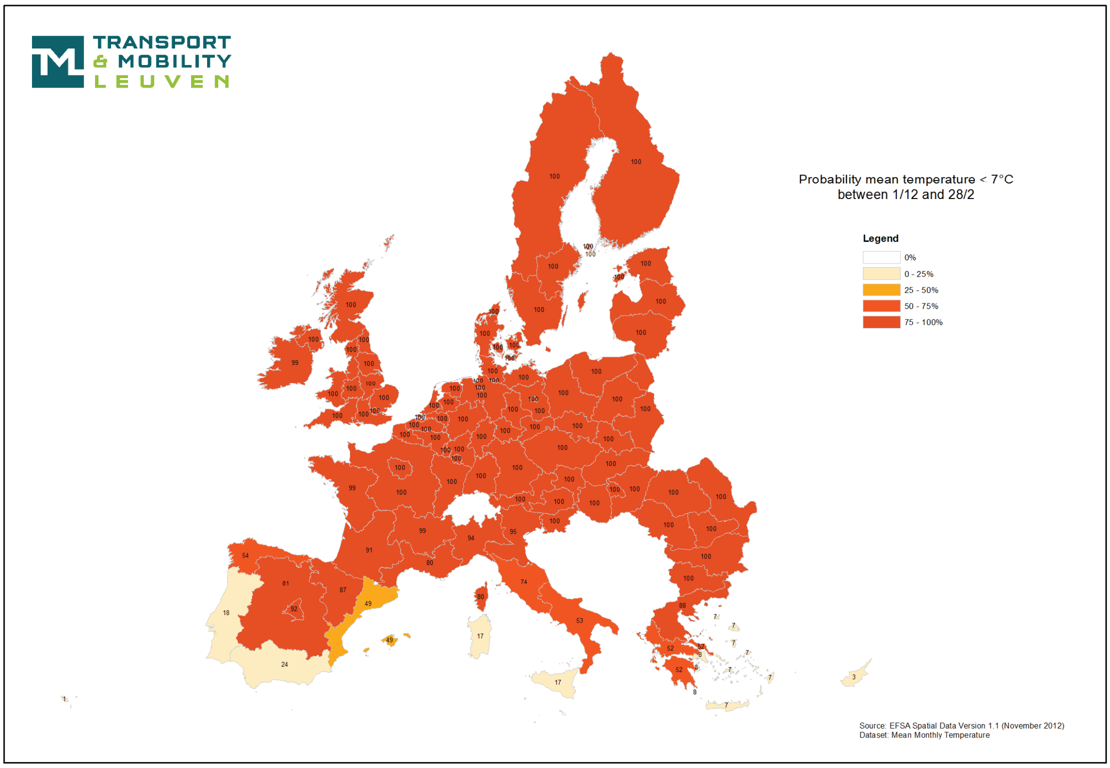


Figure 3.14: Probability of mean temperature <7°C between 1-12 and 26-02.

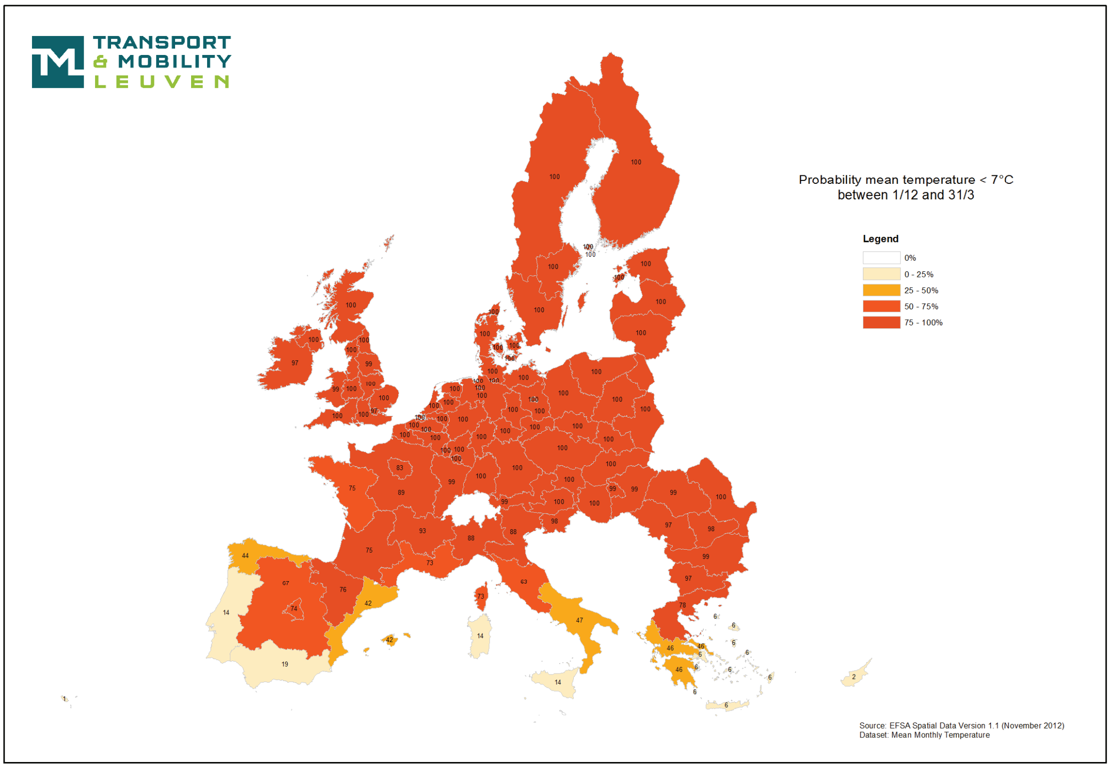


Figure 3.15: Probability of mean temperature <7°C between 1-12 and 13-03.

This information is used for further estimation of:

- The number of fatalities from accidents involving passenger cars under specific meteorological conditions (for the scenarios on the harmonised used of Winter tyres).
- The number of fatalities from accidents involving passenger cars with different tread depths (for the scenarios on the tyre tread depth requirements).

A tabular excerpt of this information is presented in the two tables below containing relative percentages of temperature preponderances for the cut-off temperatures of 7°C and 0°C, merged for member states.

Table 3.12: Probability of <7°C mean monthly temperatures and on yearly basis (Project calculations based on EFSA data).

	<7°c													
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total days	Portion da
Belgium	31.00	28.00	27.78	1.40	0.00	0.00	0.00	0.00	0.00	0.00	20.99	31.00	140	38%
Bulgaria	31.00	28.00	28.70	2.58	0.00	0.00	0.00	0.00	0.00	0.00	19.87	31.00	141	39%
Czech Republic	31.00	28.00	31.00	14.63	0.00	0.00	0.00	0.00	0.00	9.04	30.00	31.00	175	48%
Denmark	31.00	28.00	31.00	21.58	0.00	0.00	0.00	0.00	0.00	0.80	30.00	31.00	173	48%
Germany	31.00	28.00	31.00	8.69	0.00	0.00	0.00	0.00	0.00	2.13	29.10	31.00	161	44%
Estonia	31.00	28.00	31.00	28.90	0.00	0.00	0.00	0.00	0.00	20.94	30.00	31.00	201	55%
Ireland	31.00	28.00	31.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	16.56	31.00	138	38%
Greece	21.13	16.08	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	13.33	56	15%
Spain	23.61	13.46	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.55	12.99	53	15%
France	31.00	28.00	15.82	1.02	0.00	0.00	0.00	0.00	0.00	0.00	15.73	31.00	123	34%
Croatia (~Italy)	27.50	22.81	14.02	1.06	0.00	0.00	0.00	0.00	0.00	0.00	11.15	19.31	96	26%
Italy	27.50	22.81	14.02	1.06	0.00	0.00	0.00	0.00	0.00	0.00	11.15	19.31	96	26%
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Latvia	31.00	28.00	31.00	24.73	0.00	0.00	0.00	0.00	0.00	17.14	30.00	31.00	193	53%
Luxembourg	31.00	28.00	31.00	7.51	0.00	0.00	0.00	0.00	0.00	1.69	30.00	31.00	160	44%
Hungary	31.00	28.00	23.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.86	31.00	137	38%
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Netherlands	31.00	28.00	31.00	10.47	0.00	0.00	0.00	0.00	0.00	0.00	19.62	31.00	151	41%
Austria	31.00	28.00	31.00	20.63	2.16	0.00	0.00	0.00	0.00	16.70	30.00	31.00	190	52%
Poland	31.00	28.00	31.00	9.68	0.00	0.00	0.00	0.00	0.00	5.44	30.00	31.00	166	46%
Portugal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Romania	31.00	28.00	30.19	3.85	0.00	0.00	0.00	0.00	0.00	1.50	27.73	31.00	153	42%
Slovenia	31.00	28.00	31.00	6.54	0.00	0.00	0.00	0.00	0.00	0.42	30.00	31.00	158	43%
Slovakia	31.00	28.00	31.00	10.17	0.00	0.00	0.00	0.00	0.00	6.40	30.00	31.00	168	46%
Finland	31.00	28.00	31.00	30.00	16.22	0.00	0.00	0.00	10.29	30.99	30.00	31.00	239	65%
Sweden	31.00	28.00	31.00	28.55	4.13	0.00	0.00	0.00	2.57	17.15	30.00	31.00	203	56%
United Kingdom	31.00	28.00	28.48	6.57	0.00	0.00	0.00	0.00	0.00	0.61	21.09	31.00	147	40%

Table 3.13: Probability of <0°C mean monthly temperatures and on yearly basis (Project calculations based on EFSA data).

	<0°c													
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total days	Portion da
Belgium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Bulgaria	28.27	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	33	9%
Czech Republic	31.00	24.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.57	80	22%
Denmark	31.00	18.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49	14%
Germany	18.57	6.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.14	29	8%
Estonia	31.00	28.00	27.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.99	31.00	128	35%
Ireland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Greece	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Spain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
France	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Croatia (~Italy)	3.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	1%
Italy	3.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	1%
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Latvia	31.00	28.00	23.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.04	31.00	119	33%
Luxembourg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Hungary	31.00	4.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.77	43	12%
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Netherlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Austria	31.00	23.89	8.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.93	26.74	97	27%
Poland	31.00	26.99	2.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.88	86	24%
Portugal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%
Romania	31.00	21.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.97	70	19%
Slovenia	31.00	16.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.12	53	15%
Slovakia	31.00	25.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.14	82	23%
Finland	31.00	28.00	30.98	15.48	0.00	0.00	0.00	0.00	0.00	3.64	29.93	31.00	170	47%
Sweden	31.00	28.00	15.58	3.16	0.00	0.00	0.00	0.00	0.00	1.09	6.25	26.38	111	31%
United Kingdom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0%

Additional information for scenario-specific calculations

Interest rate

The interest rate that was used for the forward-calculation of cost prices is based on the average historic harmonised inflation in Europe. This can be found through Eurostat for the period of 1997 up to 2013. An easy to use excerpt can be found here: http://www.inflation.eu/inflation-rates/europe/historic-inflation/hicp-inflation-europe.aspx

The average yearly interest rate is 1.97%.

Discount rate

The discount rate that was used for the back-calculation of future costs to the 2012 base-year is 4%. This percentage includes opportunity costs, etc.

Cost prices (various elements)

Throughout the calculations, various cost prices were collected for relevant goods, services, etc. These are presented in the table below (including references).

Table 3.14: Overview of cost prices used in the calculations.

Item, good, service, etc.	Cost price (€, 2012)	Reference/data source
Winter/Summer tyres	500€ / set of 4 tyres	Search of 3 main online tyre retailers and direct comparison of main tyre retailers (July 2014)
Rims	200€ / set of 4 rims	Comparison of online retailers (July 2014)
Tyre change	66€ including mounting of tyres on rims; 20€ without mounting of tyres on rims	Direct comparison of tyre service centres (July 2014)
Tyre storage	24€	Direct comparison of tyre service centres (July 2014)
Tyre mould	50.000-100.000 US$	[62]
Air pressure pumps (petrol stations), including maintenance	3000-6500€ for installation and yearly service (over 5-year period)	Information collected from air compressor retailers
TPMS systems	100-250€ (no distinction made between direct vs indirect TPMS system)	Stakeholder information
TPMS maintenance	100€/sensor every 5 years	Stakeholder information
Consumer awareness campaign	180.000€/year (German tyre information campaign practice)	Stakeholder information
Enforcement (police)	23.2€/labour hour EU average (detailed information per member state available)	Eurostat (lc_lci_lev) Labour cost education, human health and social work activities, arts, entertainment and recreation, other service activities
Enforcement (vehicle inspection)	23.7€/labour hour EU average (detailed information per member state available)	Eurostat (lc_lci_lev) Labour cost industry, construction and services.
CO2-ton avoided	20€/ton	GHG-TransPoRD

Insofar the monetisation of fatalities is concerned we make use of the information presented in the update of the handbook on external costs of transport.

This presents us with the following table:

Table 3.15: Estimated social cost for fatalities and injuries.

Member state	Fatality	Severe injury	Slight injury
Belgium	2 178 000.00	330400	21300
Bulgaria	984 000.00	127900	9800
Czech Republic	1 446 000.00	194300	14100
Denmark	2 364 000.00	292600	22900
Germany	2 220 000.00	307100	24800
Estonia	1 163 000.00	155800	11200
Ireland	2 412 000.00	305600	23300
Spain	1 913 000.00	237800	17900
France	2 070 000.00	289200	21600
Croatia	1 333 000.00	173300	13300
Italy	1 916 000.00	246200	18800
Cyprus	1 234 000.00	163100	11900
Latvia	1 034 000.00	140000	10000
Luxembourg	3 323 000.00	517700	31200
Hungary	1 225 000.00	164400	11900
Malta	2 122 000.00	269500	20100
Netherlands	2 388 000.00	316400	25500
Austria	2 395 000.00	327000	25800
Poland	1 168 000.00	156700	11300
Portugal	1 505 000.00	201100	13800
Romania	1 048 000.00	136200	10400
Slovakia	1 593 000.00	219700	15700
Slovenia	1 989 000.00	258300	18900
Finland	2 213 000.00	294300	22000
Sweden	2 240 000.00	328700	23500
Great Britain	2 170 000.00	280300	22200
EU average	1 870 000.00	243100	18700

The average tyre life span is estimated at 50.000km (stakeholder information).
The average vehicle age is estimated at 8 years (TREMOVE v3.4).
The average vehicle life span is estimated at 14 years (TREMOVE v3.4)

Scenario-specific calculation

In this section, we present the general calculation methodology, the main assumptions for each scenario and the overview of estimated cost-benefit ratios.

General methodology

The general working principles for the making of SCBAs is presented in the previous annex. Insofar the specific calculation method is concerned, the following steps are taken.

After the identification of the different relevant costs and benefits, each of the costs and benefits is estimated through the following of this rationale:

1 Estimation of effect sizes
   a) Road safety: the differences in the relevant variables between the baseline condition and the measures are estimated based on the direct estimation of the avoidance of fatalities under relevant conditions.
   b) Equipment purchases (tyres, moulds, etc.): the differences in the equipment costs between the baseline condition and the measures are estimated based on the difference in the number of vehicle kilometres that are ran under specific meteorological conditions.
   c) Fuel efficiency and CO2 emission reduction: the differences in the equipment costs between the baseline condition and the measures are estimated based on the difference in the number of vehicle kilometres that are ran.
   d) Awareness campaigns: the working assumption is that currently, no information campaigns are foreseen (with the exception of Germany). The German example is transposed to other member states based on the number of registered vehicles. For some of the scenarios, a difference with the baseline in terms of working time can be estimated.
   e) Enforcement activities: the working assumption is that currently, no specific enforcement activities are executed. For some of the scenarios, a difference with the baseline in terms of working time can be estimated.

2 Monetisation
   a) For each of the variables, the relevant cost (presented above) is attributed to a single unit (fatality, tyre set, mould, working hour, etc.).

Harmonized Winter tyres

General assumptions:

- For Winter tyre use, the expert opinion on appropriate use is “4 tyres, maximum 4 years old, minimum 4 mm tread depth”. The “4 years old” rule is interpreted as “4 years and 51 weeks”. Maximum mileages for Winter tyre use are accordingly estimated for different member states and meteorological conditions.

– The safety effect is estimated based on the GIDAS data and current winter tyre use in Germany (90%). With each % of increased appropriate winter tyre use, With each % of reduced inappropriate winter tyre use (<4mm), we estimate a reduction of 0.72% (in member states with no relevant legislation), 0.85% (in member states with conditional legislation) and 1.15% (in member states with absolute legislation) (<0°c and dry).

Effect assumptions:

- Soft behavioural change
  - A behavioural change between 5% and 20% is considered in tyre purchase behaviour for those member states with no existing legislation
  - A behavioural change between 5% and 10% is considered in tyre purchase behaviour for those member states with any format of existing legislation.
- Behavioural change with enforcement
  - A behavioural change between 10% and 20% is considered in tyre purchase behaviour for all member states.
- Conditional Winter tyre use legislation
  - A behavioural change for those member states with no existing legislation to the level of tyre use of member states with conditional legislation is supposed (60% use of Winter tyres in winter period)
  - No behavioural change for member states with the strictest, absolute Winter tyre use legislation.
- 3PMS as standard for Winter tyres
  - No behavioural change
  - Tyre quality change for at most 15% of tyres that are currently presented to the market that are not marked with 3PMS. This percentage is assumed to also be the market penetration ratio.
  - An investment from the part of tyre manufacturers over a period up to 2020 is considered. The investment cost is 15 million €.
  - A user awareness campaign and enforcement actions aimed at phasing out non-3PMS Winter tyres is upheld until 2020.

The overview of effects is shown in the tables below.

Soft behavioural change

Low estimation

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	51.48	53.93	55.55	57.22	58.93	60.69	62.49	64.34	66.24	68.19	70.19	72.24	74.35	76.51	78.73	81.00	83.33	85.73	88.18
	tyre change	31.22	32.07	33.09	34.13	35.19	36.29	37.42	38.58	39.77	40.99	42.24	43.53	44.85	46.20	47.59	49.02	50.49	52.00	53.54
	storage	1.97	2.03	2.09	2.16	2.22	2.29	2.36	2.44	2.51	2.59	2.67	2.75	2.83	2.92	3.01	3.10	3.19	3.28	3.38
administration	campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
Society	safety	71.45	78.96	75.98	73.11	70.35	67.69	65.14	62.68	60.31	58.03	55.84	53.73	51.71	49.75	47.87	46.07	44.33	42.65	41.04
benefit to cost ratio	costs	85.66	89.04	91.76	94.56	97.42	100.4	103.4	106.5	109.7	113	116.3	119.8	123.3	126.9	130.6	134.5	138.4	142.4	146.5
	benefits	71.45	78.96	75.98	73.11	70.35	67.69	65.14	62.68	60.31	58.03	55.84	53.73	51.71	49.75	47.87	46.07	44.33	42.65	41.04
	ratio	0.83	0.89	0.83	0.77	0.72	0.67	0.63	0.59	0.55	0.51	0.48	0.45	0.42	0.39	0.37	0.34	0.32	0.3	0.28

High estimation

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	170.62	178.48	183.88	189.42	195.10	200.94	206.93	213.08	219.39	225.86	232.51	239.33	246.32	253.50	260.87	268.43	276.19	284.14	292.30
	tyre change	96.98	99.63	102.78	106.01	109.33	112.74	116.24	119.84	123.53	127.32	131.22	135.21	139.32	143.53	147.85	152.29	156.85	161.53	166.33
	storage	6.12	6.29	6.49	6.70	6.91	7.12	7.34	7.57	7.80	8.04	8.29	8.54	8.80	9.06	9.34	9.62	9.91	10.20	10.50
administration	campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
Society	safety	200.78	221.88	213.50	205.44	197.68	190.22	183.04	176.12	169.47	163.07	156.92	150.99	145.29	139.80	134.53	129.45	124.56	119.85	115.33
benefit to cost ratio	costs	274.7	285.4	294.2	303.2	312.4	321.9	331.6	341.6	351.9	362.4	373.2	384.3	395.7	407.4	419.4	431.7	444.3	457.3	470.6
	benefits	200.8	221.9	213.5	205.4	197.7	190.2	183	176.1	169.5	163.1	156.9	151	145.3	139.8	134.5	129.5	124.6	119.9	115.3
	ratio	0.73	0.78	0.73	0.68	0.63	0.59	0.55	0.52	0.48	0.45	0.42	0.39	0.37	0.34	0.32	0.3	0.28	0.26	0.25

Behavioural change with enforcement

Low estimation

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	35.29	37.24	38.34	39.47	40.63	41.82	43.04	44.30	45.58	46.90	48.26	49.65	51.07	52.53	54.03	55.57	57.15	58.76	60.42
	tyre change	27.89	28.66	29.56	30.49	31.45	32.43	33.43	34.47	35.53	36.62	37.74	38.89	40.07	41.28	42.52	43.80	45.11	46.46	47.84
	storage	1.76	1.81	1.87	1.93	1.99	2.05	2.11	2.18	2.24	2.31	2.38	2.46	2.53	2.61	2.69	2.77	2.85	2.93	3.02
administration	Monitoring (veh. Insp.)	12.53	12.96	13.36	13.77	14.20	14.63	15.08	15.54	16.01	16.50	17.00	17.51	18.03	18.57	19.12	19.69	20.27	20.87	21.48
	Enforcement	4.00	4.14	4.26	4.40	4.53	4.67	4.81	4.96	5.11	5.27	5.43	5.59	5.76	5.93	6.10	6.28	6.47	6.66	6.86
Society	safety	85.03	93.97	90.42	87.00	83.72	80.56	77.52	74.59	71.77	69.06	66.45	63.95	61.53	59.21	56.97	54.82	52.75	50.76	48.84
benefit to cost ratio	costs	81.47	84.8	87.39	90.06	92.79	95.6	98.48	101.4	104.5	107.6	110.8	114.1	117.5	120.9	124.5	128.1	131.9	135.7	139.6
	benefits	85.03	93.97	90.42	87	83.72	80.56	77.52	74.59	71.77	69.06	66.45	63.95	61.53	59.21	56.97	54.82	52.75	50.76	48.84
	ratio	1.04	1.11	1.03	0.97	0.9	0.84	0.79	0.74	0.69	0.64	0.6	0.56	0.52	0.49	0.46	0.43	0.4	0.37	0.35

High estimation

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	70.58	74.48	76.68	78.94	81.26	83.64	86.09	88.60	91.17	93.81	96.51	99.29	102.14	105.06	108.06	111.14	114.29	117.53	120.85
	tyre change	55.78	57.31	59.12	60.98	62.89	64.85	66.87	68.93	71.06	73.24	75.48	77.78	80.14	82.56	85.05	87.60	90.22	92.91	95.67
	storage	3.52	3.62	3.73	3.85	3.97	4.10	4.22	4.35	4.49	4.63	4.77	4.91	5.06	5.21	5.37	5.53	5.70	5.87	6.04
administration	Monitoring (veh. Insp.)	12.53	12.96	13.36	13.77	14.20	14.63	15.08	15.54	16.01	16.50	17.00	17.51	18.03	18.57	19.12	19.69	20.27	20.87	21.48
	Enforcement	4.00	4.14	4.26	4.40	4.53	4.67	4.81	4.96	5.11	5.27	5.43	5.59	5.76	5.93	6.10	6.28	6.47	6.66	6.86
Society	safety	170.06	187.93	180.84	174.01	167.44	161.12	155.03	149.18	143.54	138.12	132.91	127.89	123.06	118.41	113.94	109.64	105.50	101.52	97.68
benefit to cost ratio	costs	146.4	152.5	157.2	161.9	166.9	171.9	177.1	182.4	187.8	193.4	199.2	205.1	211.1	217.3	223.7	230.2	237	243.8	250.9
	benefits	170.1	187.9	180.8	174	167.4	161.1	155	149.2	143.5	138.1	132.9	127.9	123.1	118.4	113.9	109.6	105.5	101.5	97.68
	ratio	1.16	1.23	1.15	1.07	1	0.94	0.88	0.82	0.76	0.71	0.67	0.62	0.58	0.54	0.51	0.48	0.45	0.42	0.39

Conditional Winter tyre use legislation

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	225.55	235.40	242.56	249.91	257.45	265.19	273.14	281.30	289.67	298.26	307.08	316.13	325.42	334.95	344.73	354.77	365.06	375.63	386.47
	tyre change	115.14	118.30	122.03	125.87	129.81	133.86	138.02	142.29	146.67	151.17	155.80	160.54	165.41	170.41	175.55	180.82	186.23	191.78	197.48
	storage	7.27	7.47	7.71	7.95	8.20	8.45	8.72	8.99	9.26	9.55	9.84	10.14	10.45	10.76	11.09	11.42	11.76	12.11	12.47
administration	Campaign	0.29	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.42
	Monitoring (veh. Insp.)	5.36	5.54	5.71	5.89	6.07	6.26	6.45	6.64	6.85	7.05	7.27	7.48	7.71	7.94	8.17	8.42	8.66	8.92	9.18
	Enforcement	1.69	1.75	1.81	1.86	1.92	1.98	2.04	2.10	2.16	2.23	2.30	2.37	2.44	2.51	2.58	2.66	2.74	2.82	2.90
Society	safety	192.92	213.19	205.14	197.39	189.94	182.77	175.87	169.23	162.84	156.69	150.77	145.08	139.60	134.33	129.26	124.38	119.68	115.16	110.81
benefit to cost ratio	costs	355.3	368.8	380.1	391.8	403.8	416.1	428.7	441.7	455	468.6	482.6	497	511.8	527	542.5	558.5	574.9	591.7	608.9
	benefits	192.9	213.2	205.1	197.4	189.9	182.8	175.9	169.2	162.8	156.7	150.8	145.1	139.6	134.3	129.3	124.4	119.7	115.2	110.8
	ratio	0.54	0.58	0.54	0.5	0.47	0.44	0.41	0.38	0.36	0.33	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.19	0.18

3PMS as standard for Winter tyres

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	tyre purchase	196.64	206.65	212.83	219.17	225.68	232.35	239.21	246.24	253.45	260.86	268.46	276.25	284.25	292.46	300.87	309.51	318.37	327.46	336.78
	tyre change	134.79	138.48	142.86	147.35	151.96	156.70	161.57	166.57	171.70	176.97	182.38	187.93	193.64	199.49	205.50	211.67	218.01	224.51	231.18
Tyre manufacturer	R&D	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00										
administration	Campaign	0.59	0.60	0.61	0.62	0.64	0.65	0.66	0.67	0.69										
	Monitoring (veh. Insp.)	12.53	12.96	13.36	13.77	14.20	14.63	15.08	15.54	16.01										
	Enforcement	4.00	4.14	4.26	4.40	4.53	4.67	4.81	4.96	5.11										
Society	safety	681.08	681.38	649.13	618.40	589.13	561.25	534.68	509.37	485.26	462.29	440.41	419.56	399.70	380.78	362.76	345.59	329.23	313.64	298.80
benefit to cost ratio	costs	363.6	377.8	388.9	400.3	412	424	436.3	449	462	437.8	450.8	464.2	477.9	492	506.4	521.2	536.4	552	568
	benefits	681.1	681.4	649.1	618.4	589.1	561.3	534.7	509.4	485.3	462.3	440.4	419.6	399.7	380.8	362.8	345.6	329.2	313.6	298.8
	ratio	1.87	1.8	1.67	1.54	1.43	1.32	1.23	1.13	1.05	1.06	0.98	0.9	0.84	0.77	0.72	0.66	0.61	0.57	0.53

Tyre tread depth requirements

General assumptions:

- The safety effect is estimated based on the GIDAS data and current regular tyre use in the EU (~10% of vehicles running with tyres below 1.6 mm tread depth). With each % of reduced tyre use, we expect a 3.772% decrease in the number of fatalities under the identified critical conditions.

Effect assumptions:

- Behavioural change through voluntary pick-up:
  - A behavioural change between 10% and 20% is considered in reduced suboptimal use of tyres for all member states with Winter tyre legislation.
- Forced renewal of tyres, depending on the tyre tread depth, through enhanced enforcement:
  - A behavioural change between 10% and 40% is considered in reduced suboptimal use of tyres for all member states with Winter tyre legislation.

The overview of effects is shown in the tables below.

Behavioural change through voluntary pick-up

Low behavioural change

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
End user	Tyre Purchase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	Campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
Society	safety	33.99	35.93	34.06	32.28	30.60	29.01	27.50	26.07	24.71	23.42	22.20	21.04	19.95	18.91	17.92	16.99	16.11	15.27	14.47
benefit to cost ratio	costs	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
	benefits	33.99	35.93	34.06	32.28	30.60	29.01	27.50	26.07	24.71	23.42	22.20	21.04	19.95	18.91	17.92	16.99	16.11	15.27	14.47
	ratio	34.21	35.46	32.97	30.65	28.49	26.48	24.62	22.89	21.27	19.78	18.38	17.09	15.89	14.77	13.73	12.76	11.86	11.03	10.25

High behavioural change

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
End user	Tyre Purchase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	Campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
Society	safety	67.99	71.86	68.12	64.57	61.20	58.02	54.99	52.13	49.41	46.84	44.40	42.09	39.90	37.82	35.85	33.98	32.21	30.53	28.94
benefit to cost ratio	costs	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
	benefits	67.99	71.86	68.12	64.57	61.20	58.02	54.99	52.13	49.41	46.84	44.40	42.09	39.90	37.82	35.85	33.98	32.21	30.53	28.94
	ratio	68.43	70.93	65.93	61.29	56.98	52.97	49.24	45.77	42.55	39.55	36.77	34.18	31.77	29.54	27.46	25.53	23.73	22.06	20.50

Forced renewal of tyres, depending on tyre tread depth, through enhanced enforcement

Low enforcement effect

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
End user	Tyre Purchase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	Campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
	Monitoring (Veh. Insp.)	49.46	51.15	52.74	54.38	56.05	57.77	59.54	61.36	63.22	65.13	67.10	69.11	71.18	73.31	75.49	77.73	80.02	82.38	84.80
	Police Enforcement	14.24	14.85	15.41	15.96	16.25	16.55	17.02	17.57	18.16	18.58	19.22	19.81	20.43	21.06	21.70	22.37	23.05	23.75	24.47
Society	safety	169.96	179.64	170.29	161.42	153.01	145.04	137.49	130.33	123.54	117.10	111.00	105.22	99.74	94.55	89.62	84.95	80.53	76.33	72.36
benefit to cost ratio	costs	64.69	67.01	69.18	71.38	73.38	75.42	77.68	80.07	82.55	84.90	87.52	90.16	92.87	95.65	98.50	101.43	104.43	107.51	110.68
	benefits	169.96	179.64	170.29	161.42	153.01	145.04	137.49	130.33	123.54	117.10	111.00	105.22	99.74	94.55	89.62	84.95	80.53	76.33	72.36
	ratio	2.63	2.68	2.46	2.26	2.09	1.92	1.77	1.63	1.50	1.38	1.27	1.17	1.07	0.99	0.91	0.84	0.77	0.71	0.65

High enforcement effect

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
End user	Tyre Purchase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	Campaign cost	0.99	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.38	1.41
	Monitoring (Veh. Insp.)	49.46	51.15	52.74	54.38	56.05	57.77	59.54	61.36	63.22	65.13	67.10	69.11	71.18	73.31	75.49	77.73	80.02	82.38	84.80
	Police Enforcement	14.24	14.85	15.41	15.96	16.25	16.55	17.02	17.57	18.16	18.58	19.22	19.81	20.43	21.06	21.70	22.37	23.05	23.75	24.47
Society	safety	339.93	359.29	340.58	322.84	306.02	290.08	274.97	260.65	247.07	234.21	222.01	210.44	199.48	189.09	179.24	169.91	161.06	152.67	144.72
benefit to cost ratio	costs	64.69	67.01	69.18	71.38	73.38	75.42	77.68	80.07	82.55	84.90	87.52	90.16	92.87	95.65	98.50	101.43	104.43	107.51	110.68
	benefits	339.93	359.29	340.58	322.84	306.02	290.08	274.97	260.65	247.07	234.21	222.01	210.44	199.48	189.09	179.24	169.91	161.06	152.67	144.72
	ratio	5.25	5.36	4.92	4.52	4.17	3.85	3.54	3.26	2.99	2.76	2.54	2.33	2.15	1.98	1.82	1.68	1.54	1.42	1.31

TPMS and tyre pressure

General assumptions:

- The safety effect is estimated based on the GIDAS data and current tyre use. With each % of decreased severe tyre under inflation use (>20% underinflated), we expect a decrease in the number of fatalities between 0.0015% and 0.05% under the identified critical conditions.

Effect assumptions:

- TPMS improved detection rate:
  - Current TPMS effectiveness is estimated at 55%. Within this scenario, we assume an 80% detection rate is achieved.
- Air pump at petrol stations
  - A behavioural change between 10% and 20% in reduced under inflation rates for all road users is assumed, under the condition of the use of user information campaigns.

The overview of effects is shown in the tables below.

TPMS improved detection rate

Low equipment cost

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	TPMS cost	299.66	309.89	319.52	329.42	339.58	350.01	360.72	371.71	383.00	394.60	406.49	418.71	431.25	444.11	457.32	470.88	484.79	499.07	513.73
	Avoided tyre purchase	27.03	27.96	28.83	29.72	30.64	31.58	32.54	33.53	34.55	35.60	36.67	37.77	38.91	40.07	41.26	42.48	43.74	45.02	46.35
	Fuel cost reduction	369.49	376.05	382.55	389.09	411.90	433.97	456.21	477.60	498.33	505.67	512.61	519.78	527.22	534.08	532.44	532.74	534.14	536.29	538.58
Society	safety	35.00	34.82	34.62	34.42	33.89	33.35	32.79	32.22	31.63	31.21	30.83	30.50	30.20	29.81	29.41	29.06	28.75	28.47	28.33
	CO2 emission reduction	51.77	51.35	48.56	45.94	43.47	41.16	38.99	36.96	35.04	33.24	31.54	29.94	28.44	27.03	25.70	24.44	23.26	22.14	21.09
benefit to cost ratio	costs	299.7	309.9	319.5	329.4	339.6	350	360.7	371.7	383	394.6	406.5	418.7	431.3	444.1	457.3	470.9	484.8	499.1	513.7
	benefits	483.3	490.2	494.6	499.2	519.9	540.1	560.5	580.3	599.6	605.7	611.7	618	624.8	631	628.8	628.7	629.9	631.9	634.3
	ratio	1.61	1.58	1.55	1.52	1.53	1.54	1.55	1.56	1.57	1.54	1.5	1.48	1.45	1.42	1.37	1.34	1.3	1.27	1.23

High equipment cost

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	TPMS cost	749.14	774.73	798.81	823.54	848.94	875.02	901.80	929.29	957.51	986.49	#####	#####	#####	#####	#####	#####	#####	#####	#####
	Avoided tyre purchase	27.03	27.96	28.83	29.72	30.64	31.58	32.54	33.53	34.55	35.60	36.67	37.77	38.91	40.07	41.26	42.48	43.74	45.02	46.35
	Fuel cost reduction	369.49	376.05	382.55	389.09	411.90	433.97	456.21	477.60	498.33	505.67	512.61	519.78	527.22	534.08	532.44	532.74	534.14	536.29	538.58
Society	safety	35.00	34.82	34.62	34.42	33.89	33.35	32.79	32.22	31.63	31.21	30.83	30.50	30.20	29.81	29.41	29.06	28.75	28.47	28.33
	CO2 emission reduction	200.40	189.62	179.22	169.46	160.30	151.71	143.65	136.07	128.96	122.27	115.99	110.08	104.52	99.29	94.37	89.74	85.37	81.26	77.38
benefit to cost ratio	costs	749.1	774.7	798.8	823.5	848.9	875	901.8	929.3	957.5	986.5	1016	1047	1078	1110	1143	1177	1212	1248	1284
	benefits	631.9	628.5	625.2	622.7	636.7	650.6	665.2	679.4	693.5	694.8	696.1	698.1	700.9	703.3	697.5	694	692	691.1	690.6
	ratio	0.84	0.81	0.78	0.76	0.75	0.74	0.74	0.73	0.72	0.7	0.68	0.67	0.65	0.63	0.61	0.59	0.57	0.55	0.54

Air pump at petrol station

Low equipment cost

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	Tyre pump	36.83	37.55	38.29	39.05	39.82	40.60	41.40	42.22	43.05	43.90	44.76	45.64	46.54	47.46	48.39	49.35	50.32	51.31	52.32
	Avoided tyre purchase	10.81	11.18	11.53	11.89	12.25	12.63	13.02	13.41	13.82	14.24	14.67	15.11	15.56	16.03	16.50	16.99	17.49	18.01	18.54
	Fuel cost reduction	147.80	150.42	153.02	155.64	164.76	173.59	182.48	191.04	199.33	202.27	205.04	207.91	210.89	213.63	212.97	213.10	213.66	214.52	215.43
Administration	Campaign cost	5.04	5.14	5.24	5.34	5.45	5.56	5.67	5.78	5.89	6.01	6.13	6.25	6.37	6.49	6.62	6.75	6.89	7.02	7.16
Society	safety	14.00	13.93	13.85	13.77	13.56	13.34	13.11	12.89	12.65	12.48	12.33	12.20	12.08	11.92	11.77	11.63	11.50	11.39	11.33
	CO2 emission reduction	19.20	18.48	17.51	16.60	15.75	14.96	14.21	13.50	12.84	12.22	11.64	11.09	10.57	10.08	9.62	9.19	8.78	8.39	8.03
benefit to cost ratio	costs	41.87	42.69	43.53	44.39	45.27	46.16	47.07	47.99	48.94	49.9	50.89	51.89	52.91	53.95	55.02	56.1	57.21	58.33	59.48
	benefits	191.8	194	195.9	197.9	206.3	214.5	222.8	230.9	238.7	241.2	243.7	246.3	249.1	251.7	250.9	250.9	251.4	252.3	253.3
	ratio	4.58	4.54	4.5	4.46	4.56	4.65	4.73	4.81	4.88	4.83	4.79	4.75	4.71	4.66	4.56	4.47	4.4	4.33	4.26

High equipment cost

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
end user	Tyre pump	79.79	81.37	82.97	84.60	86.27	87.97	89.70	91.47	93.27	95.11	96.98	98.89	100.84	102.83	104.85	106.92	109.03	111.17	113.36
	Avoided tyre purchase	21.63	22.37	23.06	23.78	24.51	25.26	26.03	26.83	27.64	28.48	29.34	30.22	31.12	32.05	33.01	33.98	34.99	36.02	37.08
	Fuel cost reduction	295.59	300.84	306.04	311.28	329.52	347.17	364.97	382.08	398.66	404.54	410.09	415.83	421.77	427.26	425.95	426.19	427.31	429.03	430.86
Administration	Campaign cost	5.04	5.14	5.24	5.34	5.45	5.56	5.67	5.78	5.89	6.01	6.13	6.25	6.37	6.49	6.62	6.75	6.89	7.02	7.16
Society	safety	28.00	27.86	27.70	27.53	27.11	26.68	26.23	25.77	25.30	24.96	24.67	24.40	24.16	23.84	23.53	23.25	23.00	22.78	22.66
	CO2 emission reduction	145.07	139.61	132.30	125.46	119.04	113.01	107.35	102.04	97.04	92.34	87.93	83.77	79.86	76.17	72.70	69.42	66.33	63.42	60.66
benefit to cost ratio	costs	84.83	86.51	88.21	89.95	91.72	93.53	95.37	97.25	99.16	101.1	103.1	105.1	107.2	109.3	111.5	113.7	115.9	118.2	120.5
	benefits	490.3	490.7	489.1	488	500.2	512.1	524.6	536.7	548.7	550.3	552	554.2	556.9	559.3	555.2	552.9	551.6	551.3	551.3
	ratio	5.78	5.67	5.54	5.43	5.45	5.48	5.5	5.52	5.53	5.44	5.35	5.27	5.19	5.12	4.98	4.86	4.76	4.66	4.57