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Memorandum

Earth, Life & Social Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10

To
Ministry of Infrastructure and Environment, the Netherlands
Attn. Johan Sliggers

From
Uilke Stelwagen (TNO)
Michael Dittrich (TNO)
Peter Ruijs (TNO)
Stephan van Zyl (TNO)

Subject
Potential benefits of Triple-A tyres in Rotterdam city

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Summary

In two previous studies performed by TNO and M+P, it has been shown that Triple-A tyres can have a large effect on the fuel consumption of Dutch and EU road transport. Apart from energy-efficient tyres (as indicated by the tyre label), correct tyre pressure maintenance can have a large impact on fuel consumption. In this study, the potential benefits of both, Triple-A tyres and correct tyre pressure maintenance are quantified for the city of Rotterdam.

The studied area of Rotterdam city holds a land surface of 210 km^2, a cumulative road length of 1100km and roughly 625500 inhabitants. The cumulative annual mileage of road transport in Rotterdam amounts to nearly 5 billion kilometres, of which 4.5 billion kilometres are driven by light duty vehicles only (cars and vans).

The results from this study show that the use of Triple-A tyres and correct tyre pressure maintenance have a large savings potential. The use of Triple-A tyres and correct tyre pressure maintenance in Rotterdam could annually **save up to 28 million litres of fuel and reduce CO_2 emissions by roughly 69 kton**, 5% of the annual CO_2 emissions from road transport in Rotterdam. Yearly, the number of **serious injuries would be reduced by 3** and **the number of slight injuries would be reduced by 6**. Due to the favourable noise characteristics of Triple-A tyres, the **number of annoyed and highly annoyed people by road traffic would be reduced by 7400 and 4300 respectively**. The **number of sleep-disturbed and highly sleep-disturbed people would be reduced by 5700 and 3700 respectively**. From a **societal perspective, the associated annual cost savings are estimated to amount to 25 million Euros**. For the end-user, annual fuel cost savings would range from 150 Euros for passenger cars to 3000 Euros for heavy duty vehicles with long haul mission profile.

Given the large potential benefits of high-perfomance tyres, an accelerated market uptake could help in making road transport more environmentally friendly, safer and quieter. Whether the full potential can be realized in practice largely depends on the vehicle’s driving behaviour and the degree to which advertised tyre label

values comply with EU-mandated values. The calculated savings potential of energy-efficient tyres is in the same order-of-magnitude of on-road measurements performed by TNO for light-duty and heavy-duty vehicles.

1. Introduction

In two previous studies performed by TNO and M+P it was determined that large cost savings and CO_2 reductions can be achieved in the Netherlands and the EU by switching Triple-A tyres [TNOa, 2014][TNOb, 2014]. Apart from the choice of the tyre, correct tyre pressure maintenance plays a significant role for optimized fuel consumption. The Dutch government has a clear vision for sustainable transport in 2020 and 2030 [BSV, 2015]. Energy-efficient tyres as well as correct tyre pressure maintenance can contribute to this vision and are considered low hanging fruit with little extra costs and large impact. Based on these insights, a number of governmental and municipal fleet owners have shown interest in the implementation of tyre-related measures.

Aim and scope
This report documents the potential benefits of Triple-A tyres and correct tyre pressure maintenance for the annual road transport activities in and around Rotterdam.

Benefits are calculated for the following measures:
A. Switching from average (DCB-label) tyres to Triple-A tyres;
B. Correct tyre pressure maintenance.

Benefits are expressed in terms of:
- Fuel savings: reduced fuel consumption (in litres), societal and end-user fuel cost savings (in Euros) and CO_2 reduction (in tons);
- Safety improvement potential: reduced numbers of traffic casualties and costs;
- Noise reduction potential: reduced numbers of annoyed and sleep-disturbed people and the associated health and sound isolation costs.

Approach
The savings potential of Triple-A tyres is determined based on the average distribution of tyre labels in the Netherlands. The savings potential of correct tyre pressure maintenance is determined based on the average tyre pressure distribution of vehicles on Dutch and European roads.

Structure
This report is structured in the following way: In chapter 2, an overview is given of the methodology and assumptions made to determine the savings potential. Results are displayed and discussed in chapter 3. Items for conclusion, discussion and recommendations are documented in the final chapter 4.

2. Methodology and assumptions

The core research question to be answered in this study is: What are potential benefits of Triple-A tyres and correct tyre pressure maintenance in Rotterdam? The methodology and assumptions required for the calculation of this benefit are discussed in this chapter.

Triple-A tyres refer to A-labelled tyres for energy efficiency, wet grip and noise. The methodology of this study is to a large extend copied from a previous study on the benefits of Triple-A tyres [TNO, 2014a]. The potential benefits are calculated for the following items:

- Fuel savings potential expressed in reduced amount of fuel consumption, costs and CO_2 emissions;
- Safety improvement potential expressed in reduced numbers of traffic casualties and costs;
- Noise reduction potential expressed in reduced numbers of annoyed and sleep-disturbed people and the associated health and sound isolation costs.

Assumptions on the fleet composition and traffic statistics are specified for the Rotterdam situation. Only if no specific data is available, Dutch average numbers are used, e.g. for the average fuel consumption of vehicles. The scope of this study is to provide an order-of-magnitude estimate of the annual associated cost savings for Rotterdam if the entire fleet was to switch to Triple-A tyres and if the tyre pressure is to be maintained at the prescribed value. It is not a full-scale impact assessment, however gives an indication of the potential benefits of quality tyres on vehicles. The area of interest is depicted in red in Figure 1.

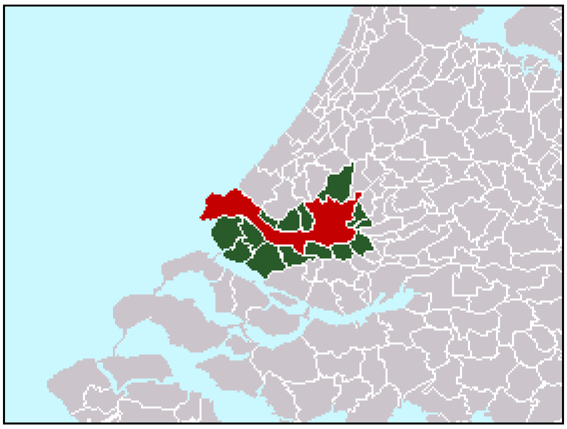

Figure 1: Area of interest: Rotterdam, city (red); excluded: Rotterdam, region (green)

This memorandum is limited to documenting the essential differences in the calculation of savings potentials for Rotterdam in comparison to the whole of the Netherlands. For the more detailed insights to the calculation and methodology used in the Dutch study, it is referred to [TNO, 2014a].

An overview of the assumptions for Rotterdam versus NL are provided in Table 1. The most important assumption in this study is that the current tyre distribution in Rotterdam is identical to the tyre distribution in the Netherlands: The average end-user is assumed to drive the following tyres:

- Energy-efficiency: D-label[1]

[1] D-labels do not exist for C1 and C2 tyres, however statistically the average label lies in between a C-label and a E-label.

- Wet grip: C-label
- Noise: B-label[2]

Table 1: Assumptions made in the Triple-A study for the Netherlands in comparison to the current study for Rotterdam.

	Same assumptions as in NL	Adapted assumptions to the total fleet of Rotterdam
General	• NL tyre label distribution	
Fuel savings	• NL driving patterns • NL share of vehicle technologies • NL fuel consumption	• Rotterdam road transport activities in vehicle-kilometres
Safety improvement	• NL accident causation • NL weather conditions • Calculations for car van and truck occupants	• Entire Rotterdam road network
Noise reduction	• NL road surface characteristics • NL driving speeds	• Rotterdam number of annoyed and sleep-disturbed people

The following paragraphs further elaborate on the underlying assumptions.

2.1. Assumptions for fuel savings potential

The fuel savings of energy-efficient A-label tyres and correct tyre pressure maintenance are calculated separately and in combination. Apart from the knowledge of the impact of tyre choice and tyre pressure (as determined in the previous chapter), the following knowledge is required:

- fleet composition (annual mileage, average fuel consumption)
- distribution of tyre labels across the fleet;
- distribution of tyre pressure across the fleet;
- savings potential of energy-efficient A-label tyres;
- savings potential of correct tyre pressure maintenance;
- combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance;
- fuel costs.

Below, the available information of Rotterdam is discussed. Where specific data is not available, explicit assumptions are made based on national default values.

Fleet composition

The annual mileage of different vehicle categories in Rotterdam is determined from URBIS III data for different vehicle groups, see Table 2. The cumulative length of all road types amounts to roughly 1100 km. The fuel consumption is assumed to be the same as for the average Dutch fleet.

[2] B-label is indicated by two black waves. Three waves are the loudest label-value.

Table 2: Estimates for the annual cumulative mileage of the vehicles of the total fleet in Rotterdam and their fuel consumption.

Tyre class	Vehicle group	Annual mileage	Fuel consumption
		[Mkm]	[l/100 km]
C1	Cars and vans (petrol/diesel)	4441	7
C2	Distribution truck (diesel)	273	20
C3	Heavy duty (diesel)	237	32

TOTAL	4951

Distribution of tyre labels across the fleet
The same distribution is assumed as in the Netherlands, see [TNO, 2014a].

Distribution of tyre pressure across the fleet
The distribution of tyre pressure in the Amsterdam fleet was assumed to be the same as for the Dutch fleet (light duty) and EU fleet (heavy duty), unless more specific knowledge was available. The tyre pressure distribution for Dutch passenger cars is reported in [GRRF, 2008] and shown in Figure 2 as a function of the difference between recorded pressure and recommended pressure. Based on this data, approximately 30% of the cars on the road drive with an under-inflation of up to 10%. The tyre pressure distribution heavy duty trucks was assumed to be the same as reported in [TPMS, 2013] and is also shown in Figure 2.

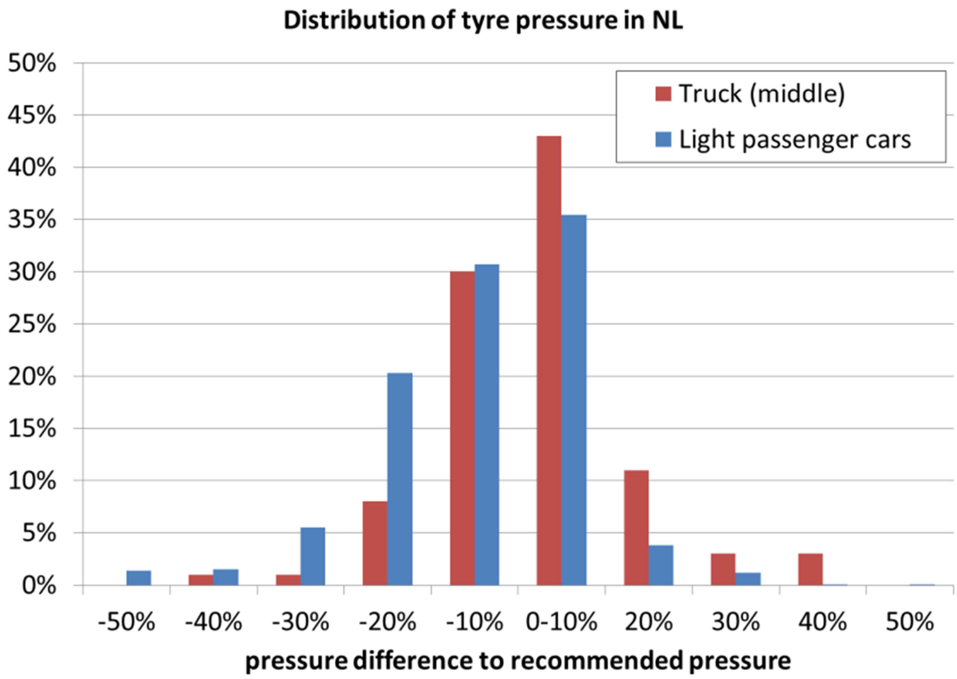

Figure 2: Distribution of tyre pressure in Rotterdam [GRRF, 2008][TPMS, 2013]

Savings potential of energy-efficient A-label tyres
The fuel savings potential of energy-efficient A-label tyres is determined using the same methodology as in [TNOa, 2014]. The basis of all calculations is the coefficient of rolling resistance (RRC) as documented in regulation EC 1222 [EC1222, 2009] and UNECE R117. This table documents the range of rolling resistances of each tyre class and different vehicle categories.

Table 3: Coefficient of rolling resistance (RRC) in kilograms per ton in % [EC1222, 2009]

Tyre label	Coefficient of rolling resistance (RRC) [in kilograms per ton in %]		
	C1 (Passenger car)	C2 (Light Truck)	C3 (Heavy truck & bus)
A	RRC ≤ 6.5	RRC ≤ 5.5	RRC ≤ 4.0
B	6.6 ≤ RRC ≤ 7.7	5.6 ≤ RRC ≤ 6.7	4.1 ≤ RRC ≤ 5.0
C	7.8 ≤ RRC ≤ 9.0	6.8 ≤ RRC ≤ 8.0	5.1 ≤ RRC ≤ 6.0
D	None	None	6.1 ≤ RRC ≤ 7.0
E	9.1 ≤ RRC ≤ 10.5	8.1 ≤ RRC ≤ 9.2	7.1 ≤ RRC ≤ 8.0
F	10.6 ≤ RRC ≤ 12.0	9.3 ≤ RRC ≤ 10.5	RRC ≥ 8.1
G	None	None	None

The fuel savings potential is calculated by multiplication of the difference in RRC (due to a switch from tyre label B, C D, E or F to tyre label A) with the share of rolling resistance in the overall driving resistances (as a function of the driving behaviour). Based on fleet-specific shares of the driving pattern (equal to Dutch average), the savings potential is recalculated for and presented in Table 4. On average, the savings fuel potential varies between 4 and 5.3%. It is assumed that tyres are replaced at the end of their lifetime and at the moment of new vehicle purchase. The presented savings potential is therefore not instantly achieved for the entire fleet.

Table 4: Fuel savings potential of energy-efficient A-label tyres in Rotterdam

Tyre class	Vehicle segment	Driving Pattern	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Cars and vans (petrol/diesel)	39 / 61	4.8%	5.7%	5.3%
C2	Distribution truck (diesel)	32 / 68	3.5%	4.4%	3.9%
C3	Heavy duty (diesel)	17 / 83	4.1%	4.1%	4.1%

Savings potential of correct tyre pressure maintenance
For the calculation of the impact of correct tyre pressure maintenance, the relation between tyre pressure and rolling resistance is required. This relation has been extensively studied by several tyre manufacturers and is described by [Exxon, 2008]:

$$RR \sim (p_{reference}/p_{test})^{0.5\text{-}0.7}$$

The effect of tyre pressure on RRC is thus equal for all vehicles for the same relative difference from the recommended tyre pressure.

Table 5: Fuel savings potential of correct tyre pressure maintenance in Rotterdam

Tyre class	Vehicle segment	Driving Pattern	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Cars and vans (petrol/diesel)	39 / 61	1.5%	1.5%	1.5%
C2	Distribution truck (diesel)	32 / 68	0.9%	0.9%	0.9%
C3	Heavy duty (diesel)	17 / 83	1.0%	1.0%	1.0%

The savings potential of correct tyre pressure maintenance is determined by reducing all under-inflation to zero. It is assumed that over-inflation remains unchanged with correct tyre pressure maintenance. The resulting savings potential is shown in Table 5.

Combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance

The combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance is shown in Table 6. It is determined through multiplication of the savings potentials in the following way: $\%_c = 1 - (1-\%_a)*(1-\%_b)$, where $\%_a$, $\%_b$ and $\%_c$ represent the savings potentials of measures A and B and the combined savings potential of measure C.

Table 6: Fuel savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance in Rotterdam

Tyre class	Vehicle category	Driving Behaviour	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Cars and vans (petrol / diesel)	39 / 61	6.3%	7.1%	6.7%
	Distribution truck (diesel)	32 / 68	4.3%	5.2%	4.8%
	Heavy duty (diesel)	17 / 83	5.0%	5.0%	5.0%

Fuel costs

Fuel costs savings are calculated from a societal perspective. For reasons of consistency, the same fuel prices are used as in the Triple-A tyre study for the Netherlands (see Table 7). It is acknowledged however, that fuel costs vary over time and are currently lower than one year ago.

Table 7: Average fuel prices used in the calculation of the societal cost savings [BSP, 2014]

	Fuel price, end-user perspective (incl. excise duty, incl. VAT)	Fuel price, societal perspective (excl. excise duty, excl. VAT)
	[€/l]	[€/l]
Petrol	1.75	0.68
Diesel	1.50	0.76

Additional investment costs and operational costs of energy-efficient A-label tyres and correct tyre pressure maintenance have been assumed to be zero. In [Geluid, 2015], it was determined that high-performance tyres do not necessarily cost more than standard tyres. In fact, there seems to be little of no correlation between additional costs and high-performance tyres. This is of course only applicable, if the appropriate tyres are chosen at the point of new vehicle sales or effectively when the tyre need to be replaced because they have reached the end of their lifetime. Additionally, large vehicle fleets often have their own pumping station or maintenance costs are included in the lease contract. Extra pumping costs are therefore excluded.

2.2. Assumptions for safety improvement potential

The study for safety improvement regarding the wet grip performance is based on the assumption that collision speed is reduced for tyres with better grip, and as a result injuries of victims will be less severe. The same methodology is used as in [TNOa, 2014]. A short overview of this methodology follows below.

Only accidents on wet roads are considered, and the type of accidents is related to the road type infrastructure and typical driving speed. Furthermore, improvements were assessed for different road user groups (i.e. car, truck, cyclists and pedestrians) in the Netherlands. In the previous study, the methodology has been developed for a detailed assessment, namely for four different scenarios on wet roads:

A. Car-car accidents on city roads (50km/h);
B. Car-car accidents on rural roads (80km/h);
C. Car-car accidents on motorways (120km/h);
D. Car-pedestrian accidents.

The calculations are made with the same distribution of tyre labels as for the whole Netherland. Accident data has been derived from the Dutch accident database BRON of the year 2009 (corresponding to the previous studies). The region of interest is Rotterdam has a different distribution of road types compared to the whole of Netherland. As a result, the number of casualties are low and mainly for available for two accident scenarios: car-car urban roads and car-pedestrian (see Table 8). Note that all fatalities are found in car-pedestrian accidents.

Table 8: Number of casualties of car occupants and pedestrians in accidents on wet roads in Rotterdam (BRON 2009)

Accident scenario	Fatalities	Severely injured	Slight injured
Car-car urban roads	0	8	32
Car-car rural roads	0	1	2
Car-car motorways	0	0	0
Car-pedestrian	2	5	11
Total	**2**	**14**	**45**

2.3. Assumptions for noise reduction potential

The method for computation of noise benefits is based on the European VENOLIVA computation method for numbers of (highly) annoyed and sleep-disturbed people [VENO, 2011], and more recent studies including effects of road surface [BIGW, 2015] in combination with tyres.

This method distinguishes 8 road type / traffic combinations. For the EU reference scenario, i.e. the current situation with the current tyre distribution, the VENOLIVA reference is used. Per road type / traffic combination the reductions of (highly) annoyed and sleep disturbed people are extrapolated using the EU reference numbers multiplied by the reduction factors, as determined in the previous study [TNOa, 2014]. The EU reduced numbers of (highly) annoyed and sleep disturbed people are obtained by summation of reductions per road type / traffic combination.

An essential assumption is that the average reduction factors of annoyed and sleep-disturbed people are assumed to be equal to the reduction factors for the Netherlands. Assessment of the monetary benefits is done by linear extrapolation of the results for all of the Netherlands.

3. Results

In this chapter the overall benefits of Triple-A tyres are discussed. The savings potential of energy, safety and noise are dealt with independently in the following three sections. The overall benefits are summarized in chapter 3.4.

3.1. Fuel savings potential in Rotterdam

Below the fuel savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance are calculated separately and in combination.

Fuel savings potential of energy-efficient A-label tyres

Table 9 shows the fuel savings potential (societal perspective) of energy-efficient A-label tyres in Rotterdam. A-label tyres could save Rotterdam up to 22 million litres of fuel and 54 thousand tons of CO_2. This is equivalent to nearly 16 million Euros.

Table 9: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of energy-efficient A-label tyres in Rotterdam (societal perspective)

Tyre class	Vehicle group	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[kl]	[k€]	[ktCO_2]
C1	Cars and vans (petrol/diesel)	5.3%	17130	12200	41
C2	Distribution truck (diesel)	3.9%	2180	1660	6
C3	Heavy duty truck (diesel)	4.1%	3130	2380	8
		TOTAL	22440	16240	54

Fuel savings potential of correct tyre pressure maintenance

Table 10 shows the fuel savings potential (societal perspective) of correct tyre pressure maintenance in Rotterdam. Tyre pressure maintenance could save

Rotterdam up to 6 million litres of fuel and 15 thousand tons of CO_2. This is equivalent to nearly 4.5 million Euros.

Table 10: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of correct tyre pressure monitoring in Rotterdam (societal perspective)

Tyre class	Vehicle group	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[kl]	[k€]	[ktCO_2]
C1	Cars and vans (petrol/diesel)	1.5%	4950	3520	12
C2	Distribution truck (diesel)	0.9%	480	360	1
C3	Heavy duty truck (diesel)	1.0%	770	580	2
		TOTAL	6200	4460	15

Combined fuel savings of energy-efficient A-label tyres and correct tyre pressure maintenance

Table 11 shows the fuel savings potential (societal perspective) of energy-efficient A-label tyres in combination with tyre pressure maintenance in Rotterdam. Energy-efficient tyres and tyre pressure maintenance could save Rotterdam up to 28 million litres of fuel and 70 thousand tons of CO_2. This is equivalent to nearly 20 million Euros.

Table 11: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of energy-efficient A-label tyres and correct tyre pressure maintenance in Rotterdam (societal perspective)

Tyre class	Vehicle group	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[kl]	[k€]	[ktCO_2]
C1	Passenger cars (petrol/diesel)	6.7%	21820	15540	52
C2	Distribution (diesel)	4.3%	2630	2000	7
C3	Heavy duty (diesel)	5.0%	3860	2940	10
		TOTAL	28310	20480	69

Table 12 shows the combined fuel savings of energy-efficient A-label tyres and correct tyre pressure maintenance from an end-user perspective. For this purpose several mission profiles are considered in analogy to the previous studies [TNOa, 2014]. The highest savings potential is achieved for passenger cars, however long haul vehicles achieve the highest annual fuel and cost savings due to their high amount of fuel consumptions and annual mileage.

Table 12: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of energy-efficient A-label tyres and correct tyre pressure maintenance in Rotterdam

Tyre class	Vehicle group	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[kl]	[k€]	[ktCO_2]
C1	Passenger cars (family, petrol)	6.71%	86	150	0.2
	Passenger cars (lease, diesel)	6.71%	147	220	0.4
	Service delivery (diesel)	6.71%	376	564	1.0
	Urban delivery/collection (diesel)	6.71%	564	846	1.5
C2	Municipal utility (diesel)	4.76%	657	986	1.7
	Regional delivery/collection (diesel)	4.76%	723	1084	1.9
C3	Long haul (diesel)	5.02%	1997	2996	5.2
	Construction (diesel)	5.02%	673	1009	1.8
	Bus (diesel)	5.02%	904	1356	2.4
	Coach (diesel)	5.02%	723	1085	1.9

3.2. Safety improvement potential in Rotterdam

The study for the Netherlands indicates that 40% of accidents on wet roads are less severe when tyres with better grip are used. In this study of the City of Rotterdam it is found that 2 fatalities, 14 severe injuries and 45 slight injuries are recorded in the Dutch accident database BRON for accidents on a wet roads in Rotterdam in 2009. The calculated casualty reduction when using tyres with better wet grip (A-label) is between zero and 20% depending on the injury level. This is explained by the distribution of road types in Rotterdam. The main reduction of better wet grip tyres can be achieved in accidents on rural roads and motorways because of the higher reduction of the impact speed. In Rotterdam most casualties on wet roads appear on urban roads where the calculated impact speed reduction with better wet grip tyres is limited. Table 13 shows the casualties considered in Rotterdam, Netherland and Europe.

Table 13: Overview of accident injuries on wet roads for passenger car vehicles for Rotterdam in comparison to the whole of Netherlands and Europe.

Countries	Fatalities	Severely injured	Slight injured
Rotterdam (2009)	2	14	45
Netherlands (2009)	89	627	2,773
EU-19 (2010)	5,125	29,562	141,350
EU-28 (2010)	6,355	36,657	175,274

For conversion towards monetary benefits, Table 14 lists the conversion amounts used and the calculation results of Rotterdam with respect to the reduction of casualties and the financial benefit. In total, nearly 900 thousand Euros could be saved in Rotterdam with A-label tyres for wet grip.

Table 14: Benefits of introducing A-label tyres with wet-grip performance in Rotterdam

Injury level	Reduction of casualties [n]	Conversion amount (k€/n)	Financial benefit (M€)
Fatalities	0	2,500	0,000
Severe injury	3	280	0,840
Slight injury	6	9	0,054
Total			**0,894**

3.3. Noise reduction potential in Rotterdam

In two computational steps, the average reduction of the tyre rolling noise as well as the effective in-traffic reductions of vehicle noise emissions was determined. These average reductions were taken from the previous study [TNOa, 2014] and updated with an improved model [BIGW, 2015]. The average reductions of the tyre rolling noise are determined for each tyre class at a transition from the current tyre mix to the best-performing low-noise tyre. The effective reductions of in-traffic vehicle noise emissions are computed as a function of the following road and traffic characteristics:

- Vehicle category: Light Vehicles (LV), Medium Vehicles (MV) and Heavy Vehicles (HV)
- Operating condition: Accelerating or Free flowing (= constant speed)
- Driving speed: 30, 40, 50, 80, 100 and 120 km/h
- Type of road surface:
    - Dense Asphalt Concrete (DAC),
    - Porous Asphalt Concrete (PAC),
    - 2-layer PAC,
    - 2-layer PAC with fine grading of the top layer (2/4 mm)
    - Thin noise-reducing surface layer (porous or semi-porous)

In the third step, the reduction of the characteristic noise impact of a traffic flow is calculated for 8 different road / traffic combinations and is based on the vehicle noise emission values from the Dutch statutory noise impact calculation method [RMV, 2012]. The reduction of the numbers of (highly) annoyed and (highly) sleep-disturbed people are determined from the changes of the traffic flow noise impact. These computations are carried out using the dose-effect relationships for road traffic noise as recommended in the position paper published by the EC [Annoy, 2002]. The results in terms of the changes of the numbers and percentages are given in Table 15.

Table 15: Reductions of numbers of (highly) annoyed and (highly) sleep-disturbed people in Rotterdam, resulting from a shift from an average tyre mix to the best-performing low-noise tyres.

Annoyance	**Number Highly Annoyed [HA]**	**Number Annoyed [MA]**	**Differ-ences HA**	**Differ-ences Ann.**	**Relative Differ-ences HA**	**Relative Differ-ences Ann.**
Reference 2013	38.362	88.835				
Most quiet tyres	34.041	81.403	4320	7431	11,3%	8,4%
Sleep disturbance	**Number Highly Sleep Disturbed [HSD]**	**Number Sleep Disturbed [SD]**	**Differ-ences HSD**	**Differ-ences SD**	**Relative Differ-ences HSD**	**Relative Differ-ences SD**
Reference 2013	42.296	81.967				
Most quiet tyres	38.588	76.227	3708	5740	8,8%	7,0%

For the assessment of monetary benefits due to the widespread introduction of low-noise tyres a methodology is used similar to that applied in the VENOLIVA study [VENO, 2011], but with an updated approach for health benefits.

Table 16: Hedonic Pricing (= property valuation), health and total benefits in millions of Euros for the full introduction of low-noise tyres in Rotterdam, expressed as a maximum annual value, as an annual average and as accumulated benefits over the appraisal period 2015-2025.

	Hedonic Pricing benefits (M€)	**Health benefits (M€)**	**Total benefits (M€)**
Annual benefit for immediate implementation	0,26	0,14	0,40
Annual average	0,21	0,11	0,32
Accumulated 2015 - 2025	2,09	1,09	3,18

3.4. Overall benefits of Triple-A tyres and correct tyre pressure maintenance in Rotterdam

The potential benefit of Triple-A tyres and correct tyre pressure maintenance in Rotterdam is determined as the sum of all societal benefits for energy, safety and noise as discussed in the previous chapters. The results are shown in Table 17.

The benefits are shown separately for A-label performance of each aspect, as well as in combination.

Table 17: Potential benefits of A-rated tyres and correct tyre pressure maintenance in Rotterdam

Potential benefits	Energy	Safety	Noise	TOTAL
Annual fuel savings [in million l]	28	-	-	28
Annual CO_2 reduction [in $ktCO_2$]	69	-	-	69
Reduced number of fatalities	-	0	-	0
Reduced number of serious injuries	-	3	-	3
Reduced number of slight injuries	-	6	-	6
Reduced number of highly annoyed people [in thousands]	-	-	4.3	4.3
Reduced number of annoyed people [in thousands]	-	-	7.4	7.4
Reduced number of highly sleep disturbed people [in thousands]	-	-	3.7	3.7
Reduced number of sleep disturbed people [in thousands]	-	-	5.7	5.7
Annual cost savings [in million Euro]	20.5	0.9	3.2	24.6

4. Discussion and Recommendation

In above chapters the fuel savings potential of energy-efficient tyres and correct tyre pressure maintenance are quantified and discussed for the transport activity of Rotterdam. It is concluded that both measures have a large potential and come at little or no costs. It is therefore advisable to apply both measures, for as far as this is practical.

Below several notes are made on the accuracy and specific boundary conditions of the above calculation. Furthermore, recommendations for improvement are made.

Tested tyre label values and real-world performance
Tyre label values for fuel-efficiency refer to a specific rolling resistance value that has been measured using the harmonized testing method UNECE R117.02, referring to ISO standard 28580. The measured value is corrected according to the alignment procedure as described by EU regulation 1235/2001, amending EU Regulation 1222/2009 [ETRMA, 2012].

It is acknowledged that several sources indicate an incoherence between the labelled performance and the measured performance of tyres ([IN2, 2013][ADAC, 2015]). In both [IN2, 2013] and [ADAC, 2015] on average a clear correlation is observed between rolling resistance (RRC) and the tyre label, however the variance of the measured rolling resistance is large within one label. As a result, there is overlap between RRC and label values. In [ADAC, 2015], B label tyres perform best on average, A label tyres have not been tested. Except for two outliers in the measurement (Pirelli Cinturato P1 Verde and Nokian Line), a downward trend is observed towards reduced RRC with improved tyre label. From the test specifications defined in [ADAC, 2015], it remains unclear what the reasons are for this deviation. Fuel consumption is measured at a constant speed of 100 km/h over a distance of 2 km and measurements are repeated at least three times. At this test condition, the external influences of wind and other must not be neglected.

Generally, stakeholders have questioned the accuracy of the tyre RRC test. Tyre manufacturers have shown that the R117 test is reproducible and repeatable across the different laboratories with an accuracy which is much smaller that the width of a tyre label class as described in Table 3. The relevance of the test for on-road performances of tyres is as yet an open question. The test is performed on a smooth steel drum (unlike the noise test) at a fixed velocity, and tyre manufacturers suggest that the additional rolling resistance due to the radius of the drum is about 10%-20% which should be comparable to a 10%-20% increase from the road surface texture. This would make the R117 absolute value relevant for on-road performances. Aspects at turning, toe-in and road undulation are not covered by this tests. Alternative test procedures may produce a large variation in test results, which may however, lie outside the control of the tyre manufacturer. The test procedure R117 is designed to provide a standard value, which may have is drawbacks but is the best available, comparable and relevant number at present.

TNO tests of low-rolling resistance tyres have shown on light-duty as well as heavy-duty vehicles that fuel savings in the order of 3 to 4 % can be achieved [TvdT, 2013][WLTP, 2014]. Such evaluation requires large monitoring programs. On road testing is affected by many external circumstances for which must be corrected, and the tests must be performed with exact identical vehicle state, to exclude unwanted variations. Two aspects in particular are important. First, the warm tyre pressure is the result of the conditioning due to driving, this varies greatly from tests to test, by up to 12% variation in warm tyre pressure. Secondly, wind will affect the results, and is almost impossible to correct for as wind gustiness may vary from location to location, and time to time.

Availability of energy-efficient A-label winter tyres
While there is a large abundance of energy-efficient A-label summer tyres, the choice for winter tyres is limited. In practise, this could result in a lower savings potential for winter tyres simply because the end-user cannot buy the tyre of choice.

Tyre conditioning
It is known that the rolling resistance of a tyre depends on its stiffness. Since the stiffness of rubber is to a large degree dependent on the tyre temperature, the

rolling resistance changes over the drive time and generally leads to a lower rolling resistance after a few minutes of driving. Once the tyre is conditioned, the rolling resistance does not decrease any further. In this study, the hysteresis of tyre stiffness is not taken into account, thus calculations are based on a warm conditioned tyre. The different hysteresis of tyres and tyre labels can be relevant if an existential share of the fleet only travel very short distances.

Emissions of particulate matter (PM)
Several sources are of influence to emissions of particulate matter (PM): the engine, after-treatment technologies, abrasive wear of brakes and abrasive wear of tyres. Tyre wear is not part of the tyre label and yet little research has been done to document the difference in PM emissions between tyre labels. In [ADAC, 2015], tyre wear has been quantified with a grade however no numbers of particulate numbers, nor amount of grams, have been published. In order to compare the different performance of tyres on particulate matter emissions, it is recommended to perform further research.

Distribution of tyre labels across the Rotterdam fleet
The tyre label distribution across the Rotterdam fleet was assumed to be the same as in the Netherlands. The calculation of the savings potential could be further improved if more information is available on the specific tyre labels distribution within Rotterdam.

Distribution of tyre pressure across the Rotterdam fleet
The distribution of tyre pressures across the Rotterdam fleet is to a large extend unknown. Therefore, the Dutch average tyre pressure distribution has been used based on information from [GRRF, 2008] and [TPMS, 2013].

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