THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2010
5(3): 169–176

ANALYSIS AND EVALUATION OF THE EFFECT OF STUDDED TYRES ON ROAD PAVEMENT AND ENVIRONMENT (III)

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Abstract. In the economic evaluation of studded tyres their benefit and damage to the public was analyzed. Such aspects as the price of studded tyres, their effect on braking distance, fuel costs, road pavement, pavement marking, initiation of particulate mater and the increase in noise emisions were compared and analyzed. Based on the inquiry of tyre sellers and executed calculations, it was determined that in Lithuania, in winter season about 15% of passenger cars use winter tyres with studs, therefore due to the reduced number of road accidents (reduced number of people killed and injured) the public receives the benefit of 1.81 mln EUR. However, due to the more expensive tyres, increased fuel consumption, damages to horizontal pavement marking, negative impact of particulate matter on human health the public incur considerably higher losses amounting even to 38.43–39.07 mln EUR.

Keywords: studded tyres, economic evaluation, fuel costs, road pavement marking, human health, particulate mater (PM), noise emissions.

1. Introduction

In the last several years a number of passenger cars using studded winter tyres on Lithuanian roads have been gradually decreasing. This fact is also confirmed by the tyre sellers. Based on their data, 5–7 years ago the sales of studded tyres for passenger cars made 40–60%, whereas, in the last winter season of 2008 the sales of studded tyres (and of those prepared for studding) made only 4–8% of the total sales of winter tyres. Such a low percent of the sales of studded tyres was influenced by the newly accepted legal acts providing for a future prohibition of the use of studded tyres on Lithuanian roads. Besides, the car owners who travel or plan to travel by car to the European Union (EU) member-states (starting with Poland and further to the south) choose to buy non-studded winter tyres since the use of studded tyres in those countries is prohibited.

Based on the above statistical data, it was assumed in the calculations that in winter 15% of passenger cars use studded winter tyres. Thus, in the economic evaluation of studded tyres the analysis of their benefit and damage was carried out, i.e. the following aspects were analyzed and compared: the price of studded tyres; their effect on braking distance, fuel costs, road pavement, pavement marking, initiation of particulate matter (PM) and on the increase in noise emissions (Laurinavičius *et al.* 2009; Vaiškūnaitė *et al.* 2009).

2. Accident losses caused by passenger cars using non-studded and studded tyres

Based on data of the *Association of Companies for Road Vehicle State Technical Inspection Transeksta,* according to the number of road vehicles presented for the initial technical inspection Lithuania has ~1100000 of the used passenger cars use, of which 15% (~165 000 units) are equipped with winter tyres having studs. The driver, having acquired winter tyres, uses them on the average for 4 years. Thus, the additional costs for the Lithuanian drivers (between studded and non-studded winter tyres) will average to 1.91–2.39 mln EUR/year:

$$K_{\Delta P} = \frac{\Delta K_{ZD} \times T_{ZD}}{P_T} =$$

$$\frac{(46.34-57.92)\times 165000}{4} = 1.91-2.39 \text{ mln EUR/year}, \quad (1)$$

where $K_{\Delta P}$ – additional annual costs for the Lithuanian drivers having acq uired studded winter tyres, mln EUR/year;

ΔK_{ZD} – difference between the prices of studded and non-studded winter tyres, EUR; T_{ZD} – number of passenger cars equipped with studded winter tyres, units; P_T – average service life of studded winter tyres, years.

If a theoretical assumption is made that the use of studded tyres in winter is obligatory, the additional costs for the drivers ($K_{\Delta PT}$) (between studded and non-studded winter tyres) would amount to 12.74–15.93 mln EUR/year:

$$K_{\Delta P} = \frac{(46.34 - 57.92) \times 1100000}{4} =$$

$$12.74 - 15.93 \text{ mln EUR/year.} \quad (2)$$

Many of world-wide investigations to determine a percentage difference in road accidents using studded and non-studded winter tyres showed that when using passenger cars with studded tyres on snowy or icy road pavement the accident risk is reduced by 5%, on dry and wet pavement – by 2%. When using passenger cars with studded tyres under various (all) traffic conditions the accident risk is reduced by up to 4%.

Having calculated the average of accidents of 2005–2008 winter seasons and the distribution of accident victims according to pavement condition, it could be stated that in this period the average number of accidents was 2329 where 267 people were killed and 2757 were injured. Since no data is available on the type of winter tyres (studded or non-studded), it was assumed in the calculations that 15% of accident-involved passenger cars were using studded tyres and 85% – non-studded tyres. Correspondingly, accidents were calculated where the passenger cars with studded tyres were damaged. In the calculations the effect of studded tyres on the accident risk was taken into consideration (i.e. the accident risk is reduced by 4% on the average).

It was calculated that 15% of the Lithuanian road users used studded tyres in winter, therefore, on the average 1.6 lives were saved and 16.54 less people were injured every year compared to the case if all passenger cars had used non-studded tyres. If accident costs are multiplied by these reductions it is obtained that due to the use of studded tyres in Lithuania the damage caused by road accidents is reduced by 1.81 mln EUR/year on the average. In the further analysis of this research, when calculating damage caused by road accidents, the damage (theoretical) caused by vehicles with studded tyres (from 1 November to 1 April) was compared to that with non-studded tyres. Definitely, this calculation is more theoretical since in this case a legal act would be necessary prohibiting the use of winter non-studded tyres. Accident-caused damage when using passenger cars with non-studded and studded tyres is given in Fig. 1.

Though, when using passenger cars with studded tyres under various traffic conditions, the risk of accidents is reduced only by 4%, a number of people killed and injured on the Lithuanian roads in the recent 4 years shows that the average theoretical difference in the use of passenger cars with non-studded and studded tyres makes 12.86 mln EUR per year (Elvik, Vaa 2004; Kapski *et al.* 2008; Tampère *et al.* 2009).

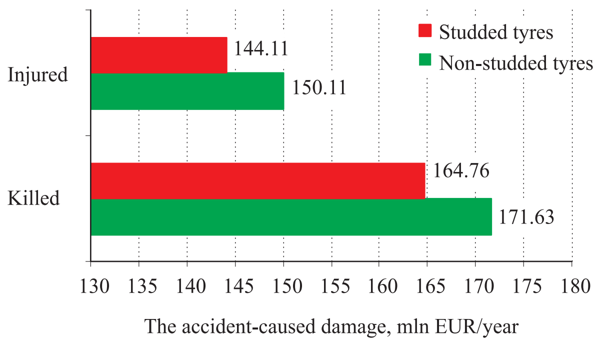

Fig. 1. Determination of accident-caused theoretical damage when using passenger cars with non-studded and studded tyres (Accumulation and renewal of traffic data of the roads of national significance, 2008)

3. The effect of winter tyres on fuel costs

Vehicle fuel costs are increased by 15% on icy and snowy road pavements compared to dry roads. It was determined in the foreign researches that when using a passenger car with studded tyres the fuel costs increase from 1.2% to 2% compared to non-studded tyres (Scheibe 2002; Zubeck *et al.* 2004) and according to some sources – even from 4% to 8%. Fuel costs in winter depend not only on the type of tyres (studded or non-studded) but also on road maintenance, driving speed, mode of driving, etc. The Vehicle Operating Costs (VehOC's) of a passenger car (EUR/1000 veh-km) under different pavement roughness in the year 2008 are given in Fig. 2.

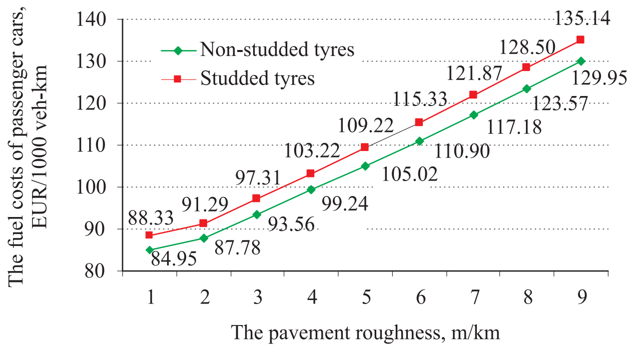

Fig. 2. Evaluation of the fuel costs of passenger cars using non-studded and studded tyres (Accumulation and renewal of traffic data of the roads of national significance, 2008)

With the help of Highway Development and Management model-4 (HDM-4) the VehOC's under different pavement roughness were calculated. In the model the fuel costs of passenger cars make 30–40% of the total transport expenditures. In the calculations of this research it was assumed that the fuel costs of a passenger car make 35% of its total operating costs.

The annual average daily traffic (AADT) and its composition on the roads of different groups by the different class of vehicles in 2008 are given in Table 1. The AADT on all the roads of national significance is 1414 vehicles per day, of which 1087 are passenger cars.

The AADT of passenger cars in the different group of roads (Accumulation and renewal of traffic data of the roads of national significance, 2008) is given in Fig. 3.

The annual mileage by vehicles is the total amount of vehicle kilometres per year on the considered road or its section. This index reflects the size of the national vehicle fleet and the volume of its use. The annual mileage *AM* is calculated by the Eq (3):

$$AM = AADT \times L \times 365; \quad (3)$$

where *AM* – the annual mileage of the vehicle kilometres per year, veh-km/year; *AADT* – annual average daily traffic of the road section per day, vpd; *L*– length of the road section, km.

The annual mileage by vehicles per a group of roads is calculated as the sum of annual mileage on the separate sections of this group of roads *AM*. Based on the previously analyzed statistical traffic data and the length of Lithuanian roads of national significance, the annual mileage was calculated for the main and national roads in 2006–2008 (Fig. 4).

Having made the analysis of traffic volume of the roads of national significance, it was calculated that from 1 November to 1 April the annual mileage by passenger cars makes 35.80% of the total annual mileage.

Based on the statistical traffic data, traffic composition and the calculated annual mileage, it is possible to calculate how many kilometres in the different group of roads are travelled by passenger cars per year, how many kilometres are travelled in winter and how many kilometres are travelled by passenger cars with studded tyres.

In the beginning of 2009 the average pavement roughness on the main roads was 2.27 m/km, on national roads – 3.16 m/km, and on regional roads – 4.50 m/km. Based on the calculated annual mileage by passenger cars with studded tyres in winter (Fig. 5), the average pavement roughness and the difference in fuel costs under the existing pavement roughness (Fig. 2), it is possible to calculate

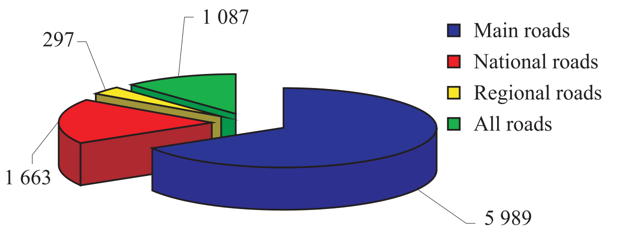

Fig. 3. The AADT of passenger cars in the different group of roads (Accumulation and renewal of traffic data of the roads of national significance, 2008)

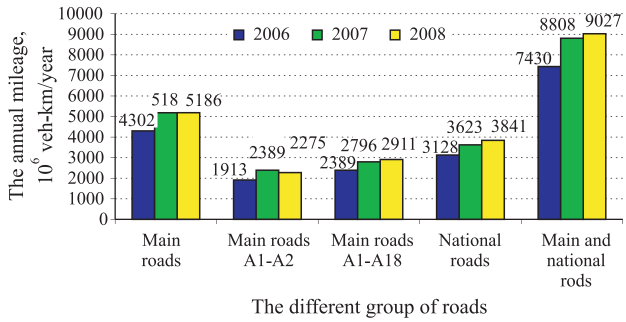

Fig. 4. The calculated annual mileage in the different group of roads depending on traffic volume and length of road sections

what is the increase in the annual fuel costs for the road users travelling by passenger cars with studded tyres:

$$C_F = AM_{PC} \times RV_{PRFC}; \quad (4)$$

where C_F – the annual fuel costs for the road users travelling by passenger cars with studded tyres, mln EUR/year; AM_{PC} – the annual mileage by passenger cars with studded tyres in winter per year, veh-km/year; RV_{PRFC} – the ratio between values of the average pavement roughness and of the difference in fuel costs under the existing pavement roughness per kilometer, EUR/km.

Table 1. The AADT of all the classes of vehicles in the different group of roads (Accumulation and renewal of traffic data of the roads of national significance, 2008)

Road group	AADT, vpd												
	Total	Motorcycle	Passenger car (PC)	Minibus	Bus	Light truck	Medium truck1	Medium truck2	3-axle	4-axle	5-axle	Tractor	Light (motorcycle, PC, minibus, light truck)	Heavy
Main roads	8 100	11	5 989	288	66	369	90	198	77	131	864	17	6 657	1 443
National roads	2 092	0	1 663	80	19	102	28	51	21	19	95	14	1 846	246
Regional roads	375	2	297	17	4	17	9	9	6	4	7	3	333	42
All roads	1 414	2	1 087	54	13	66	20	34	15	18	98	7	1 209	205

It is possible to calculate by the Eq (4):
On main roads:

$$205.90 \times 10^6 \times 3.51 \times 10^{-9} = 0.72 \text{ mln EUR/year};$$

On national roads:

$$164.00 \times 10^6 \times 3.72 \times 10^{-9} = 0.61 \text{ mln EUR/year};$$

On regional roads:

$$82.91 \times 10^6 \times 4.22 \times 10^{-9} = 0.35 \text{ mln EUR/year};$$

Total: 1.68 mln EUR/year.

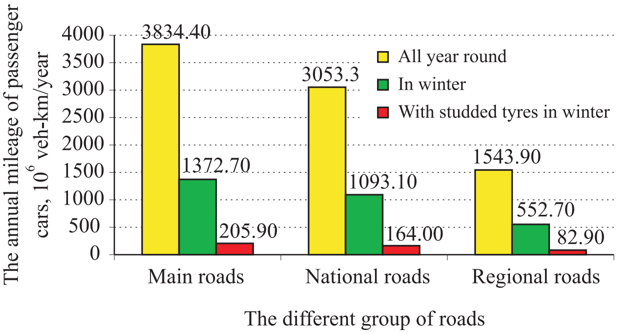

Fig. 5. The calculated annual mileage in the different group of roads depending on the season of the year

It was determined that when using passenger cars with studded tyres their fuel costs are increased by 4%, the road users (owners or managers of vehicles), solely on the roads of national significance, incur the additional fuel costs of 1.68 mln EUR/year.

Theoretical damage to the road users due to the increased fuel costs, if all passenger cars had to obligatory use studded tyres in winter, solely on the roads of national significance, would make 11.24 mln EUR/year of additional fuel costs. It is possible to calculate:

$$C_{TF} = AM_{TPC} \times RV_{PRFC}; \quad (5)$$

where C_{TF} – the annual fuel costs for the road users travelling by passenger cars with studded tyres (if all passenger cars had to obligatory use studded tyres in winter), mln EUR/year; AM_{TPC} – the annual mileage by passenger cars with studded tyres in winter per year (if all passenger cars had to obligatory use studded tyres in winter, from 1 November to 1 April), veh-km/year; RV_{PRFC} – the ratio between values of the average pavement roughness and of the difference in fuel costs under the existing pavement roughness per kilometer, EUR/km.

It is possible to calculate by the Eq (5):
On main roads:

$$1372.70 \times 10^6 \times 3.52 \times 10^{-9} = 4.83 \text{ mln EUR/year};$$

On national roads:

$$1093.10 \times 10^6 \times 3.73 \times 10^{-9} = 4.08 \text{ mln EUR/year};$$

On regional roads:

$$552.70 \times 10^6 \times 4.22 \times 10^{-9} = 2.33 \text{ mln EUR/year};$$

Total: 11.24 mln EUR/year.

4. Damage to the environment due to the initiation of particulate matter and noise from winter tyres

Global changes affecting climate change are greenhouse effect and the depletion of the ozone layer. Lithuania, having ratified the Kyoto Protocol in 2002, like other EU countries committed itself in 2008–2012 to reduce its greenhouse gas emissions by 8% compared to the year 1990 (Environmental Impact Assessment of the Reconstruction of the Road A5 Kaunas-Marijampolė-Suwalki 22.0–56.5 km section; Environmental Impact Assessment of the Vilnius City Southern By-pass Between the Roads A1 Vilniaus-Kaunas-Klaipėda and A3 Vilnius-Minsk 0.0–7.6 km section). Gases, exhaust from road vehicles and affecting regional pollution, are as follows: nitrous oxide (NOx), sulphur oxide (SO_2), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter ($PM_{2.5}$). The amount and composition of pollutants exhaust from road vehicles into the ambient air depend on the annual average daily traffic, share of heavy traffic, annual mileage, fuel quality, technical characteristics of vehicles, number of stops and starts, traffic congestions, etc. (Gustafsson *et al.* 2008; Ketzel *et al.* 2007; Kupiainen 2007; Schmit, Schlender 2003; Vallius 2005).

Taking into consideration the impact of one of vehicle-generated pollution sources, i.e. studded tyres, on the environment, the analysis was focused only on particulate matter. Particulate matter is a mixture of particles and liquid droplets (aerosols) suspended in the ambient air and consisting of different components – acids, sulphates, nitrates, metals, organic compounds, soil particles, dust, smut. In winter road vehicles, especially those using studded tyres, cause also a secondary pollution with particulate matter. This means that the studded winter tyres destroy road pavement, lift into the ambient air the remnants of destroyed pavement, the spread sand and salt mixture and uncollected mud, and when using such tyres on "bare" road pavement (without ice or snow) – fine and very dangerous micro elements initiated during traction. The Swedish researchers have determined that a passenger car with studded tyres having travelled 1 km "mills out" about 5–12 g of asphalt particles on a rural road and about 2–5 g on a city street. In cities the wear of asphalt pavements is slower due to a lower driving speed (Hääl *et al.* 2008; Norman, Johansson 2006; Räisänen *et al.* 2005).

It was assumed in the calculations that one vehicle with studded tyres having travelled one kilometre on a rural road "mills out" 2 g of asphalt particles.

When assessing the effect of studded tyres on the initiation of particulate mater it was assumed that 15% of the total number of passenger cars in winter (i.e. 5 months per year) uses studded tyres. Having made the analysis of traffic volume on the roads of national significance it was calculated that from 1 November to 1 April the passenger cars travel 35.8% on he average of the total annual mileage. Based on the calculated annual mileage by passenger cars with studded tyres per year (Fig. 6) it is possible to calculate how much particulate matter is "milled out" from the road pavement by the studs of winter tyres on the roads of national significance:

$$Q_T = AM_{PC} \times Q_G; \quad (6)$$

where Q_T – the total quantity of asphalt particles, which "milled out" from the road pavement passenger cars with studded tyres per year on the roads of national significance, t/year; AM_{PC} – the annual mileage by passenger cars with studded tyres in winter per year, veh-km/year; Q_G – the quantity of asphalt particles, which "mills out" from the road pavement one vehicle with studded tyres having travelled one kilometre, g/km.

It is possible to calculate by the Eq (6):

On main roads:

$205.9 \times 10^6 \times 2 = 411.80$ t/year;

On national roads:

$164.0 \times 10^6 \times 2 = 328.00$ t/year;

On regional roads:

$82.9 \times 10^6 \times 2 = 165.80$ t/year;

Total: 905.60 t/year.

The cost of ambient air pollution is given in Fig. 6 (Feasibility Study for the Need of Repair Works of the Roads and Bridges of National Significance).

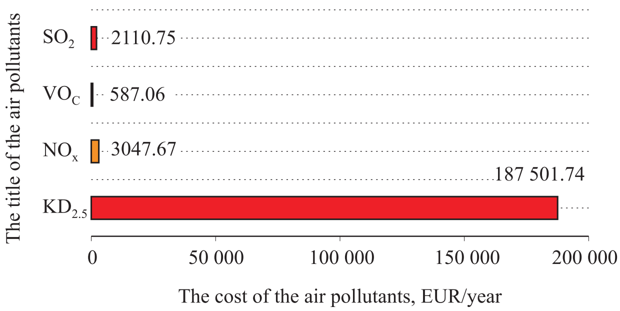

Fig. 6. The cost (EUR) of air pollutants within the urban territory (Accumulation and renewal of traffic data of the roads of national significance, 2008)

Based on a number of asphalt particles "milled out" by the studs of winter tyres from the asphalt pavement on main, national and regional roads and the cost of particulate matter pollution in a rural territory (Fig. 6), the damage from the studs was calculated:

$$D_{TS} = Q_T \times C_{RT}; \quad (7)$$

where D_{TS} – the damage of the tyres studs on the roads national significance per year, mln EUR/year; Q_T – the total quantity of asphalt particles, which "milled out" from the road pavement passenger cars with studded tyres per year on the roads of national significance, t/year; C_{RT} – the cost of particulate matter pollution in a rural territory, EUR/t.

It is possible to calculate by the Eq (7):

On main roads:

$411.80 \times 37500.29 = 15.44$ mln EUR/year;

On national roads:

$328.00 \times 37500.29 = 12.30$ mln EUR/year;

On regional roads:

$165.80 \times 37500.29 = 6.22$ mln EUR/year;

Total: 33.96 mln EUR/year.

In Lithuania, in a period of winter season almost 15% of passenger cars use studded winter tyres which exhaust into the ambient air particulate matter and negatively affect human health. It was determined that this damage, solely on the roads of national significance, amounts to 33.96 mln EUR/year.

Taking into consideration the use of studded tyres on the local roads (also in a residential area, especially in city streets), damage to the public would be increased even more. Due to the lack of statistical data on a number of kilometres travelled on these roads, damage to the public due to the increased particulate matter was not assessed.

For this purpose a theoretical damage was calculated which would be caused by particulate matter if all passenger cars in a winter season (from 1 November to 1 April) had to obligatory use only studded tyres. A theoretical amount of asphalt particles "milled out" from the pavement of the roads of national significance, if all passenger cars used only studded tyres in winter, would amount to 6037.00 t/year:

$$T_{PM} = AM_{TPC} \times Q_G; \quad (8)$$

where T_{PM} – the theoretical damage of particulate matter from the tyres studs on the roads national significance per year (if all passenger cars in a winter season (from 1 November to 1 April) had to obligatory use only studded tyres), t/year; AM_{TPC} – the annual mileage by passenger cars with studded tyres in winter per year (if all passenger cars had to obligatory use studded tyres in winter, from 1 November to 1 April), veh-km/year; Q_G – the quantity of asphalt particles, which "mills out" from the road pavement one vehicle with studded tyres having travelled one kilometre, g/km.

It is possible to calculate by the Eq (8):

On main roads:

$1372.7 \times 10^6 \times 2 = 2745.40$ t/year;

On national roads:

$1093.1 \times 10^6 \times 2 = 2186.20$ t/year;

On regional roads:

$552.7 \times 10^6 \times 2 = 1105.40$ t/year;

Total: 6037.00 t/year.

A theoretical damage to the public due to particulate matter "milled out" and exhaust into the ambient air would amount to 226.42 mln EUR.

Noise is a disorderly mixture of sound waves of various strength and frequency, unusual to human ear and causing unpleasant sensations. Noise damages hearing, irritates the central nervous system, changes human character and behaviour, induce crudity and aggression of an individual. All over the world road transport is recognised as the main source of noise.

When a studded tyre rolls over the road surface the increased tyre vibration causes noise. A higher traction of studded tyres and road pavement, compared to that of non-studded tyres, increases noise emission by 3–5 dBA (Kropp *et al.* 2007; Peeters, Blokland 2007).

In Sweden, when the use of studded tyres was reduced by 20% the noise emissions decreased by 1.0–1.5 dBA. In Lithuania, in the last two winter seasons studded tyres were used by about 15% of all passenger cars. Based on the Swedish research data it could be stated that having prohibited the use of studded tyres in Lithuania the general noise level would be decreased by 0.75–1.13 dBA. The specialists have calculated the damage to the human health caused by the equivalent noise level in a day. The cost of noise emissions are given in Fig. 7 (Environmental Impact Assessment of the Reconstruction of the Road A5 Kaunas-Marijampolė-Suwalki 22.0–56.5 km section).

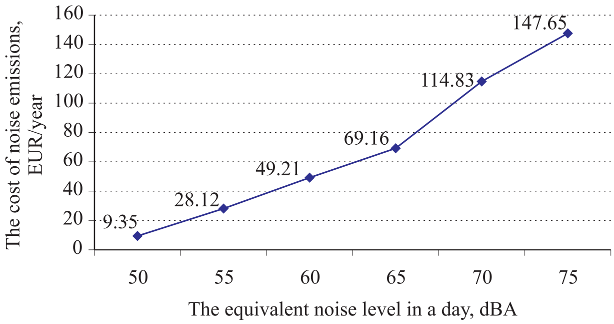

Fig. 7. The cost (EUR) of noise emissions per year (Accumulation and renewal of traffic data of the roads of national significance, 2008)

The cost of noise emissions shows that with the increased equivalent noise level only by 5 dBA the damage to the human health has been significantly increasing. It is almost impossible to determine the noise-caused damage to the public, since in the different noise diapasons the damage to the human health varies unevenly, besides, people use to live at a different distance from the main transport arteries and no exact data is available on what is a number of residents living close to them.

5. The effect of studded tyres on road pavement marking

Studded tyres intensively damage road pavement surface. The wear of road pavement is considerably larger compared to the use of the other type of tyres. At present horizontal marking of Lithuanian roads is carried out with paint or polymer materials. The service life and warranty of horizontal marking are dependent on the designation of lines and the materials used. Using polymer materials the marking can have a thin layer or a full thickness. When a continuous edge line is marked with paint the service life of marking is two years. When the centre road line is marked with paint and other horizontal marking is carried out the service life is one year. When horizontal marking is made by polymer materials the service life of the marking is twice as long, i.e. when using polymer materials the service life of full-thickness marking is four years, while the service life of the above mentioned thin-layer marking materials – two years. Certainly, the use of polymer materials for horizontal marking generates higher costs. Comparison of the costs is given in Fig. 8.

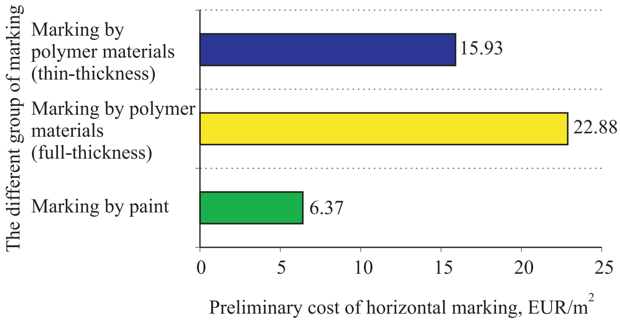

Fig. 8. Preliminary cost of horizontal marking (Accumulation and renewal of traffic data of the roads of national significance, 2008)

Studded tyres cause the wear of all types of horizontal marking at pedestrian crossings, of continuous and discontinuous marking lines on the carriageway. In a day time horizontal marking can visually look as of sufficiently good quality, though in a dark period of the day it does not serve the main function, i.e. to reflect light, since a specific density of light in darkness is too low. The main reason – the marking surface is polluted with unreflecting materials. Horizontal marking is mostly damaged by studded tyres when it is polluted with the "milled out" bitumen particles from asphalt pavement in winter and becomes poorly visible in a dark time of the day. When a marking line is passed by studded tyres the studs stick into the line and leave small depressions with the remnants of bitumen particles.

We did not succeed to find any accurate scientific investigations on how much the service life of horizontal marking would be extended if the vehicles used no studded tyres. However, all the road specialists unanimously admit that studded tyres reduce the durability of horizontal marking. A very cautious forecast was assumed in the calculations that with the use of studded tyres the wear of horizontal marking is 10% faster. Correspondingly, it could be apparently stated that in a year due to the use of studded tyres the wear of horizontal marking is faster and the public looses ~10% of funds allocated to the marking. In the last two years 8.69–10.14 mln EUR was allocated each year to the renovation of marking on the roads of national significance. Besides, additional horizontal marking was implemented on the repaired and reconstructed road sections.

Based on the above, it could be stated that due to a faster wear of horizontal marking the public looses 0.87–1.01 mln EUR every year.

6. Economic evaluation of winter tyres (studded and non-studded)

Having made a comparative cost-benefit analysis, a comparison of studded and non-studded winter tyres and their benefit (additional costs) for the public, it was determined that it is more cost-effective for the road users to use non-studded tyres. A comparative cost-benefit analysis is given in Fig. 9 and Table 2 where positive and negative factors (pluses and minuses) for the use of studded and non-studded winter tyres are described.

In winter almost 15% of the road users in Lithuania use studded tyres on their passenger cars, therefore due to the reduced number of road accidents (reduced number of people killed and injured) the public receives the benefit of 1.81 mln EUR. However, due to the more expensive tyres, increased fuel consumption, damages to horizontal pavement marking, negative impact of particulate matter on human health the public incur considerably higher losses amounting even to 38.43–39.07 mln EUR (Baltrėnas *et al.* 2007; 2008; Lama *et al.* 2007; Radziszewski 2007; Ziari *et al.* 2007; Zubeck *et al.* 2004).

7. Conclusions

Based on the inquiry of tyre sellers it was determined that in Lithuania, in winter season about 15% of passenger cars use winter tyres with studs.

It was identified that additional costs for the drivers (between studded and non-studded winter tyres) will amount to 1.91–2.39 mln EUR/year on average.

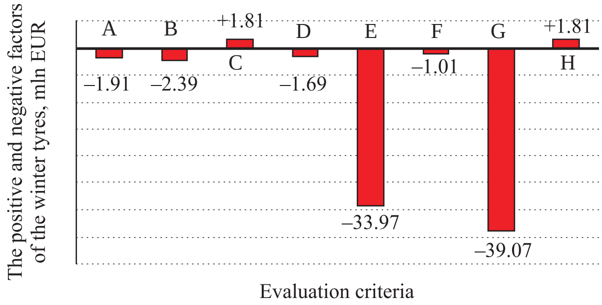

Fig. 9. Economic evaluation of winter tyres (studded and non-studded) (A – additional costs for the drivers due to studded tyres; B – additional costs for the drivers due to non-studded tyres; C – damage due to road accidents; D – effect of tyres on fuel costs; E – effect of studded tyres on the initiation of particulate matter; F – damage due to tyre-generated noise; G – effect of tyres on pavement marking; H – total damage)

Taking into consideration a number of people killed and injured during road accidents on the roads of Lithuania in 2005–2008, it was calculated that due to the use of studded tyres the accident-caused damage is reduced by 1.81 mln EUR/year on average.

When using passenger cars, equipped with studded tyres, the fuel consumption of these cars is increased by 4%, thus, the road users (owners or managers of cars) solely on the roads of national significance incur the additional fuel costs of 1.68 mln EUR/year.

Table 2. Economic evaluation of winter tyres (studded and non-studded)

Evaluation criteria	Factors		Notes
	Negative	Positive	
Difference in the price of studded and non-studded tyres	Negative −(1.91–2.39) mln EUR	–	The difference between one studded and non-studded winter tyre is 11.58–14.48 EUR; for 4 tyres 46.34–57.92 EUR. Additional costs for the drivers (between studded and non-studded winter tyres) will amount to 1.91–2.39 mln EUR/year on the average.
Damage due to road accidents	–	Positive +1.81 mln EUR	Due to the use of studded tyres in Lithuania the damage caused by road accidents is reduced by 1.81 mln EUR/year on the average.
Effect of tyres on fuel costs	Negative −1.68 mln EUR	–	The use of passenger cars equipped with studded tyres increases fuel consumption by 4%, therefore the road users (the owners and managers of passenger cars), solely on the roads of national significance, incur 1.68 mln EUR of additional fuel costs per year.
Effect of studded tyres on the initiation of particulate matter	Negative −33.96 mln EUR/year	–	Passenger cars with studded tyres lift particulate matter which negatively affects human health. During the whole winter season 15% of passenger cars use studded winter tyres which lift particulate matter and negatively affect human health. This damage, solely on the roads of national significance, amounts to 33.96 mln EUR/year.
Damage due to tyre-generated noise	Large	Small	It is possible to calculate damage caused by studded tyres for the public only for a certain road (street) section but even in this case the special investigations are necessary.
Effect of tyres on pavement marking	Negative −(0.87–1,01) mln EUR	−z	Due to the wear of horizontal marking the public looses 0.87–1.01 mln EUR of additional costs every year.
TOTAL	−(38.43–39.07) mln EUR/year	+1.81 mln EUR/year	When using studded winter tyres the public incurs more damage than benefit.

In Lithuania, in a period of winter season about 15% of passenger cars use studded winter tyres which lift particulate matter and negatively affect human health. This damage, solely on the roads of national significance, amounts to 33.96 mln EUR/year.

It was determined that due to the use of studded tyres and faster wear of horizontal marking the public incur 0.87–1.01 mln EUR of additional costs every year.

In winter about 15% of the road users in Lithuania use studded tyres on their passenger cars, therefore due to the reduced number of road accidents (reduced number of people killed and injured) the public receives the benefit of 1.81 mln EUR. However, due to the more expensive tyres, increased fuel consumption, damages to horizontal pavement marking, negative impact of particulate matter on human health the public incur considerably higher losses amounting even to 38.43–39.07 mln EUR.

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Received 21 October 2009; accepted 03 August 2010