Analysis of the tire contact area pressure on the road

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Summary: The scientific article is dedicated to tires and the pressure they exert on the road surface. In the paper, we have defined the main structural elements of a tire. We analysed the dimensions of the contact areas and compared the measured values with the calculated ones. The article also deals with legislative conditions in road construction. In the next section we compare the design axle with the contact surfaces of the most frequently used tires. The results are summarized in tables and with a percentage difference. Based on this analysis, we came to the conclusion which tires have an impact on the road. At the end of the article we present possible solutions to the problem with their advantages and disadvantages.

Key words: tire, pressure, design axle, contact area

INTRODUCTION

This article deals with the designing of roadways from the point of view of the pressure the tires have on the road. The tire is a geometrically closed ring called toroid. According to Slovak technical standards 64001, a tire is a term for a tire or tube with a rim-mounted liner and filled with pressure medium. Tires have undergone many changes since they were invented. The largest structural change of tires occurred in the post-war period in 1948. Michelin bring, the first radial tire to the market. (1) Today's modern technologies already allow to build in various chips or sensors that influence the safety of the vehicle, tire wear and many other factors. The tires and brakes are the most important structural elements of the vehicle. Tires are a little more important because the braking effect depends directly on them. In the figure 1, can be seen the structural elements of the tire. (2)

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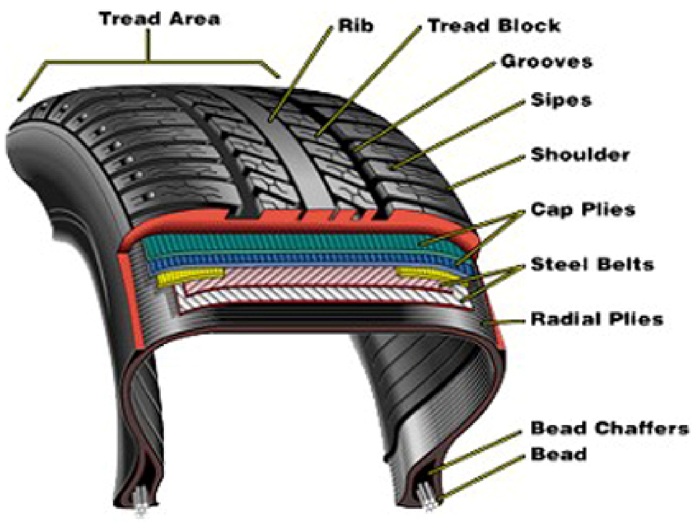


Source: (8)

Fig. 1 - Structural elemnts of the tire

The tires can be divided in several ways according to size, type, tread pattern, construction. In this article, we focused on tires used in N3, N3G and O4 vehicles. The tire, as the only connection point between the road and the vehicle, must capture all the state changes in the movement of the vehicle. Such as centrifugal forces, gravity and rolling resistance. The basic tire requirements are:

- transmit normal forces (vehicle weight)
- transfer driving and braking forces
- transmit lateral forces for steering and directional stability
- do not cause excessive noise
- do not adversely affect the environment
- dampen the transmission of uneven paths to the vehicle
- change the rotational movement of the shafts to the sliding movement of the vehicle,
- have a low rolling resistance
- at a low price, have a long mileage,
- have a low weight. (3)

In order to achieve the best possible tire properties, geometric patterns, professionally called tread, are formed on the tread surface made of sipes and grooves. The tread pattern is specially designed to provide the tires with all the necessary features such as traction, good water drainage, comfort, elimination of bumps, low rolling resistance and others. The arrangement of the figures, parts that provide contact between the vehicle and the road can be transverse and longitudinal. In the transverse arrangement, the tires are mainly focused on traction. The longitudinal arrangement provides good side force transfer properties to the vehicle. In practice, a combination of these two arrangements is most commonly used. The tire is the only point of contact between the vehicle and the ground. Shape of the tread is closely related to the size of the contact area. The tread fullness is a characteristic of the tread pattern.

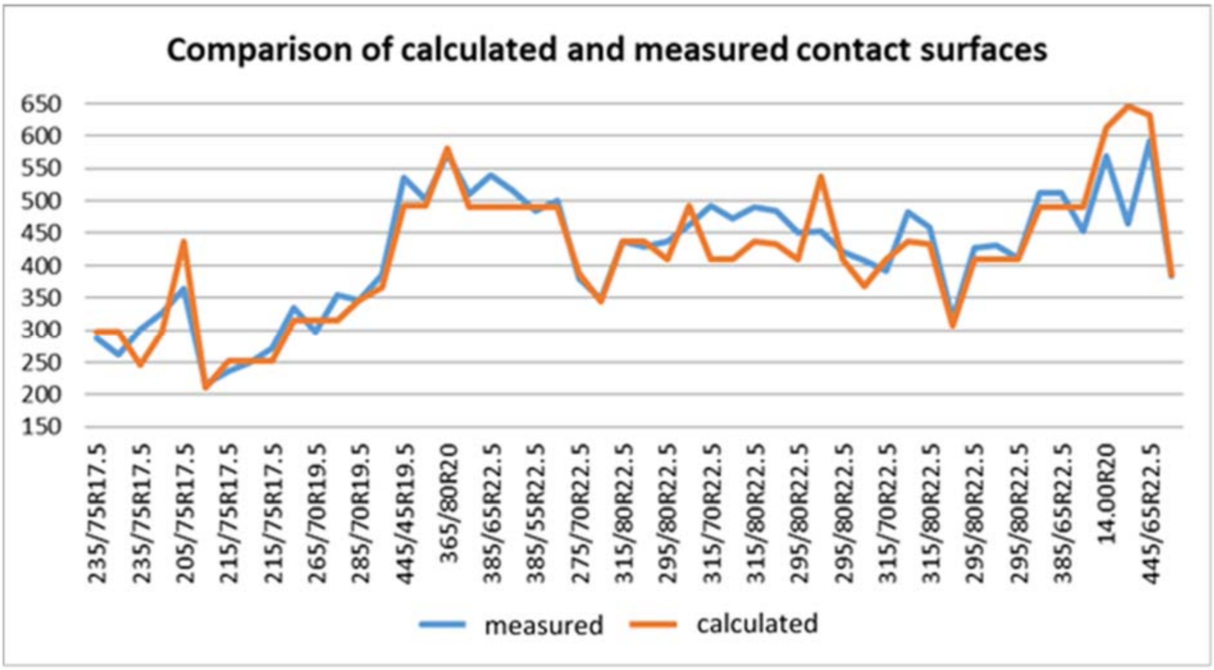
It is referred to as the Greek letter epsilon (ε). It gives us the ratio of the net and gross contact area between the vehicle and the road.

$$\varepsilon = \frac{A_s}{A_c} [\%] \quad (1)$$

To determine the contact area is most often used one of the following methods:

- ink method
- electronic method
- optical method.

It is also possible to calculate a theoretical contact area based on a simplified model. We would have to think of a tire as a homogeneous treadless body that would create pressure concentrations due to its unevenness. Then, based on Pascal's law, we would get a contact area. The following diagram shows the calculated and measured values of the contact surfaces.



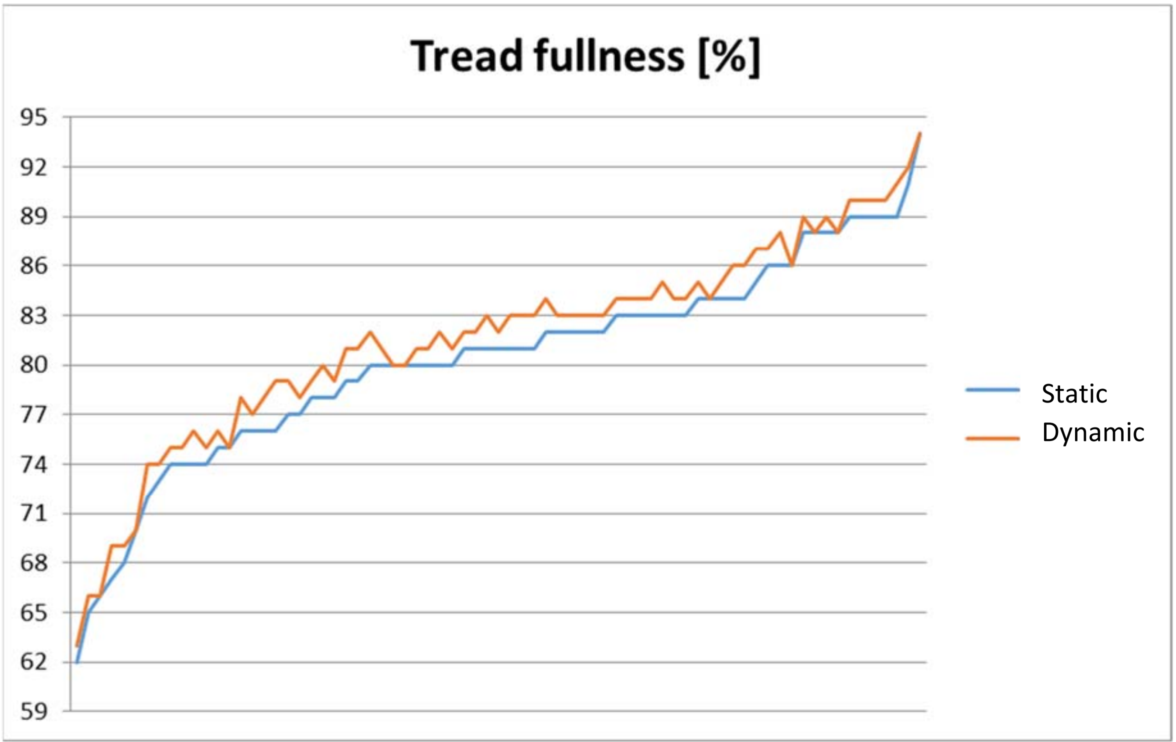
Source: Authors

Fig 2 - Comparsion of calculated and measured contact surfaces

Based on the graph above, I can say that the curves more or less follow their shape. The variation ranges of the deviation between the measured and calculated values is 0.2 to 28%. The biggest deviations occurred in tires for construction use. These tires have a block shape, deep and wide groove treads that make this a more significant difference. The average deviation was 7%.

TIRE CONTACT AREA

The tire contact area can be presented in two variants. Either as a net area where tread gaps are not included or as a gross area where tread gaps are included. In addition, tire contact surface measurements can be made in two ways, either as static or as dynamic. In the static detection of the contact area, the tire is pressed against the pad to form a footprint. In dynamic detection, it is possible to let the vehicle run on the pad at a certain speed, roll the tire over the drum or make a half-turn (180 °) on the tire over the pad. [4] The data in this section was obtained by the half-turn method. According to experimental measurements, (Jiří Marcín et al.), It can be stated that the contact surface of the tire increases with increasing speed. The shape or deformation size itself and the associated change in the contact surface is then reflected from the construction of the tire. Based on available information, I was unable to determine how much dependence is between speed and magnification of the contact area. However, it can be shown that in 98% of cases the contact area obtained in a dynamic state was greater than in the static one. The data is shown in the figure below.



Source: Authors

Fig. 3 - Static and dynamic comparison of tread fullness

One of the main factors affecting the size of the contact area is tire pressure. There is an indirect proportion, if there is greater pressure in the tire, then contact area is smaller. This proportion, with specific values, can be seen in Table 1.

Tab. 1 - Values measured at pressure change

Pressure [bar]	Gross contact area [cm^2]	Net contact area [cm^2]	Tread fullness [%]
5,5	633	504	80
6,5	573	458	80
9,5	486	390	80
10,5	469	375	80

Source: Authors

How to inflate the tires correctly is indicated on the vehicle or on the tire is stated maximum permissible pressure. To set or measure tire pressures, should be always done before driving. Tire pressures not only affect tire wear but also drive safety, fuel consumption, vehicle performance and driveability.

Possible consequences of over inflated tire are:

- braking distance extension,
- reduced driving comfort,
- increased risk of cracks.

Possible consequences of under inflated tire are:

- increased consumption,
- increased risk of defect,
- reduces performance.

The most common consequence that is common to over-inflated and under-inflated tires is a reduction in lifetime of tire. (5) The reason for the reduced tire life is the uneven tread wear. Proper tire inflation depends on the tire size and design, but also on the axle load. It is correct to say that the optimum tire pressure can only be determined after the goods have been loaded and the axle load has been measured. For this reason, we are now increasingly seeing tire pressure monitoring automatically. Today, smart tires are being developed that are able to change their pressure depending on the vehicle load. (6)

DIMENSIONING OF ROADS

The road traffic load is characterized by the number of vehicles passing through the transverse road profile, usually within 24 hours, the composition of the traffic flow and the vehicle axle parameters taking into account their future development. Due to the size of the destructive effects of each type of vehicle on the road, only trucks and buses are taken into account when designing roads. The lorry is transferred to a number of fictitious repetitive design axle loads during the proposed period on the planned route segment. [7] The design of roads is carried out according to the Act no. 135/1961 statute. The law states that the design of roads is carried out according to the applicable Slovak technical standards, technical regulations and objectively identified results of research and development for road infrastructure. The following rules currently apply to the design and assessment of asphalt roads:

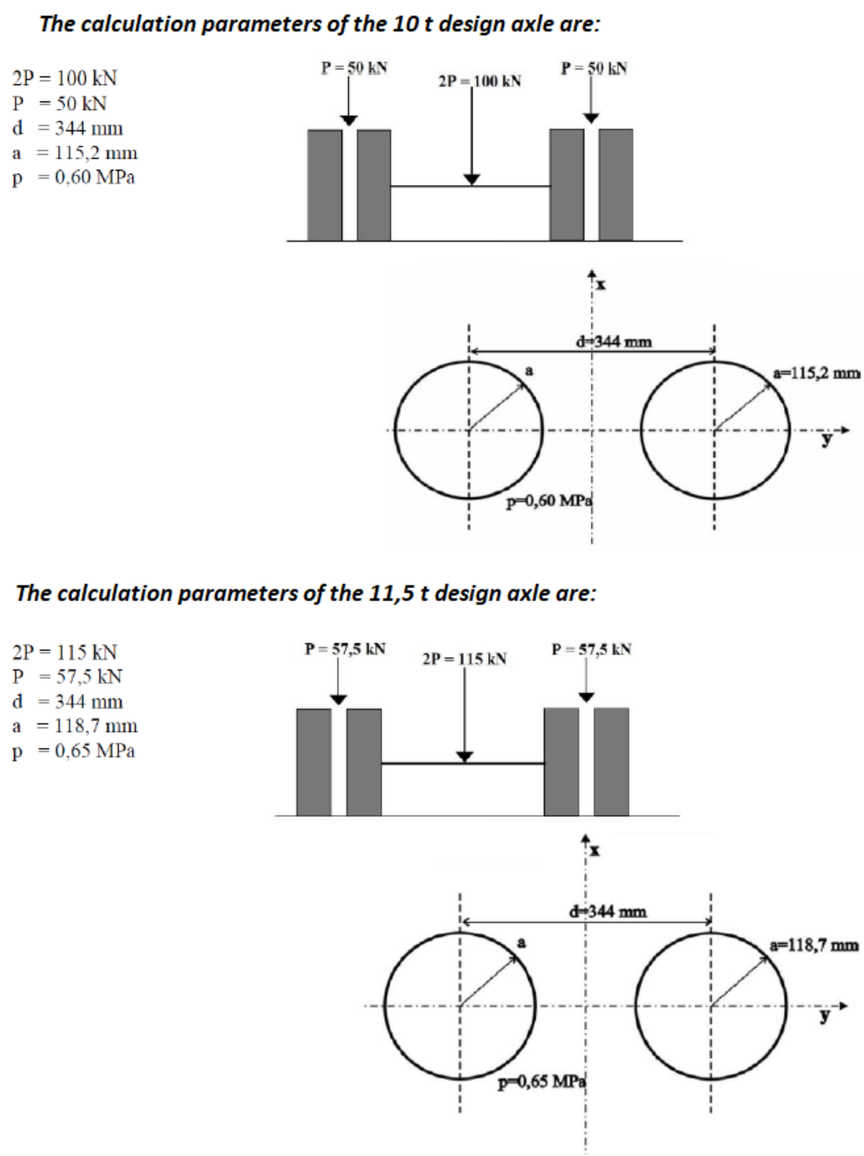
- STN 73 6114 Road pavements. Basic provisions for design, 1997
- TP 033/2009 Design of non-rigid and semi-rigid roads, Ministry of Transport of Post and Telecommunications of the SR, 2009

In Slovakia, most of the roads are asphalt, from the mechanical point of view the road construction is called non-rigid and semi-rigid roads, the most important document will be the above mentioned TP 033/2009. These are in compliance with the basic provisions for road design (STN 73 6114) and similar foreign regulations. Road traffic load is the number of passes of each type of vehicle. The effect of different types of axles on road damage is very different. That is why it is most often expressed by the conversion of individual axles into a design axle.

The design axle is defined by the parameters to which the axles of each type of truck are recalculated. The design axle is characterized by:

- Axle load
- pressure applied at the interface between the ground and the vehicle,
- the number and shape of the loaded areas and their geometric arrangement.

The actual road load of the vehicle wheels shall be replaced by the wheels of the design axle (10t) and the axle of maximum permissible mass (11,5t). In the Slovakia today the following calculation parameters of the design axle are valid within TP 033:



Source: TP033

Fig. 4 - Schematic view of design axle

The traffic load is expressed by the number of repeated design axle loads during the proposed period of time on the road site. This is equivalent to driving all trucks. The basis for calculating road traffic loads may be:

- periodic road traffic counting
- special traffic census
- transport-engineering research
- information obtained from weighing axles of trucks

There is currently no legislation to clearly define minimum road sizing requirements. Each road construction is accessed separately and a separate calculation is made for each roadway proposed. There is one more option when construction is done without calculations. At that time, we are talking about catalogues which, based on average values and with all the conditions with the same calculation principles as mentioned above, give us the specific values to which the roadway is to be dimensioned. The road construction according to the data sheets is governed by the technical conditions TP 002/2017. Using Pareto analysis, I have determined the most common tire sizes. I compared their contact areas with the contact area of the design axle. The contact area of the design axle tire is, after mathematical rounding at a load of 100kN, 834cm2 and at a load of 115kN 885cm2, which corresponds to the sum of the surfaces of the two wheels in the original design axle. The following table shows the selected tire dimensions according to the Pareto analysis together with their contact surfaces compared with the design axle contact surface loaded at 100kN.

Tab. 2 - Comparison of contact area of selected tire sizes with design axle contact area

N3G				
Tire	Gross contact area	Net contact area	% difference between gross contact area and design axle	% difference between net contact area and design axle
315/80R22.5	602	485	-28%	-42%
	592	452	-29%	-46%
	634	466	-24%	-44%
	582	429	-30%	-49%
385/65R22.5	740	578	-11%	-31%
11.00R20	520	384	-38%	-54%
	515	430	-38%	-48%
	502	410	-40%	-51%
	503	446	-40%	-47%
N3				
Tire	Gross contact area	Net contact area	% difference between gross contact area and design axle	% difference between net contact area and design axle
315/70R22.5	575	492	-31%	-41%
	568	473	-32%	-43%
	496	407	-41%	-51%
	542	391	-35%	-53%
315/60R22.5	533	431	-36%	-48%
	531	403	-36%	-52%
	522	465	-37%	-44%
	512	426	-39%	-49%

385/55R22.5	685	463	-18%	-44%
	630	513	-24%	-38%
	615	487	-26%	-42%
	595	502	-29%	-40%
O4				
Tire	Gross contact area	Net contact area	% difference between gross contact area and design axle	% difference between net contact area and design axle
385/65R22.5	598	545	-28%	-35%
	667	562	-20%	-33%
	649	540	-22%	-35%
	641	516	-23%	-38%
445/45R19.5	619	518	-26%	-38%
	609	534	-27%	-36%
	646	535	-23%	-36%
	630	503	-24%	-40%
435/50R19.5	629	501	-25%	-40%
	589	552	-29%	-34%
	636	549	-24%	-34%
	593	506	-29%	-39%

Source: Authors

With the table, we can see that gross area is more similar to the dimensions of the design axle tire with its dimensions. Accordingly, it can be concluded that the contact surface of the design axle tire in TP is understood as the gross area. We know from the table that none of the selected tires exceeds the surface area of the design axle tire. This fact forces us to consider if contact area of the design axle is unnecessarily large. Considering only contact surfaces, the results tell us that the contact areas of the most widely used tire sizes are on average several tens of percent smaller than the design axle tire contact area. This means that, with the same vertical force, these tires would exert more pressure on the road than the design axle tires, thus causing more damage to the road.

PRESSURE ON THE ROAD

The decisive factor for assessing axle loads and their impact on the road is pressure. The design axle has a defined pressure of 600 kPa for 10t axle and 650kPa for 11.5t axle. According to all materials available to us, the design of asphalt pavements is based solely on the design axle loaded at 10 tons. I did not consider other types of roads because 99% of roads are asphalt in Slovakia. At present, shall apply the Government of the Slovak Republic Regulation No. 349/2009 statue the maximum permissible dimensions of vehicles and combinations of vehicles, the maximum permissible masses of vehicles and combinations of vehicles, other technical requirements for vehicles and combinations of vehicles in relation to weights and dimensions and the marking of vehicles and combinations of vehicles. We also use this regulation to determine the maximum permissible axle loads. The maximum permissible axle load is for motor and trailer depending on whether it is an individual axle, drive axle, twin axle or three-axle motor and trailer. Given the many options that may arise from a legislative or technical point of view and to avoid duplicate values, the table lists the values with a load of 7t to 10t for single-use and from 10t to 13t for dual-use. On average, the total contact area of real tires were 34% lower than the tire on design axle. The smaller the contact area is, the greater is the pressure. Most tires in the permitted load exceed the pressure values of design axle, there are also those that not only do not exceed this pressure but also have some margin. This implies that they should not have a significant negative effect on the road. This applies in particular to dual-use tires, which we can claim to be more environmentally friendly. Similar conclusions were reached (Decký et al), but based on different analyses. Based on the calculated data, I have come to the conclusion that the design axle over which the design traffic load is calculated is on average undersized in 73% of single-assembly and 36% of dual-fit cases. Table. 3 also mentioned a recalculation of what is the maximum weight per axle that would not exceed the design axle pressure. I have retained the parameters of the tires I had at my disposal. The calculated masses correspond to the design axle pressure, and if the freight growth coefficients are correctly predicted, these loads should not have a significant impact on road damage.

Tab. 3 - Conversion of weights per axle to design axle, at selected tire sizes

Single-assembly	Average contact area cm2 (single-assembly)	Weight per axle	Average contact area cm2 (dual-fit)	Weight per axle
Tires N3				
315/70R22.5	545	6,7	1090	13,3
315/60R22.5	525	6,4	1050	12,8
315/80R22.5	598	7,3	1196	14,6
295/80R22.5	579	7,1	1158	14,2
265/70R19.5	388	4,7	776	9,5
385/55R22.5	631	7,7		
385/65R22.5	641	7,8		
Tires N3G				
315/80R22.5	603	7,4	1206	14,8
11.00R20	510	6,2	1020	12,5
14.00R20	874	10,7	1746	21,4
385/65R22.5	740	9,1		
395/85R20	749	9,2		
445/60R22.5	900	11,0		
Tires O4				
265/70R19.5	388	4,7	776	9,5
285/70R19.5	445	5,4	890	10,9
365/80R20	670	8,2	1340	16,4
275/70R22.5	441	5,4	882	10,8
315/80R22.5	570	7,0	1140	13,9

Source: Authors

METHODOLOGY

The article is dedicated to the contact areas of tires. Based on paret's analysis we have determined the most used tire sizes. After that we comparative analysis of contact area of each tire and compare it with the tire of design axle. In practical part of this article we made several simple calculations which shown the problem of under-sizing design axle. Also we made a table with the calculation of the axle loads that would not damage the road. Subsequently, we applied the method of deduction and synthesis on the basis of which we came to the individual conclusions.

CONCLUSION

It has been found that a larger proportion of tires, even under legally permitted axle loads, exert a pressure on the road that is greater than design axle. There are several alternatives to address this issue:

a) reducing the permissible axle loads, which would be contrary to Directive 95/53 / EC, which prescribes the total axle weights and loads for vehicles in international traffic to be applicable as normal vehicles in each Member State;
b) modification of design axle parameters
c) assessment of axle load capacity by tire type.

Perhaps the most sensible solution would be variant c). In the case of (a) this could also limit vehicles that meet their criteria with their tires and do not cause damage to the road in terms of higher pressure than design axle. In case b), the problem with the routes already built would not be resolved, but the road design procedures of TP033 need to be reassessed in the future. Given that we have a toll system where trucks and buses over 3.5 tonnes are tracked on most roads in Slovakia, we have an accurate overview of the number of vehicles and axles of vehicles up to 5 axles that have passed through individual toll sections. I therefore think that these statistics should be more easily accessible and more accounted for than the traffic census data. The most important parameters in assessing the pressure on the road are surface and silo. We can deduce the vertical force acting on the road if we know the weight per axle. This can either be measured by means of scales or can be determined as the maximum legislative load per axle. The main problem with pressure detection is the tire contact area. Determining the average tire contact area would be inefficient because of the number of tire types. Recalculating pressure using the design axle area would not be true because, as we have said, the tire design area of the design axle is considerably oversized, thus considering lower pressure on the road. One solution to this problem could be a tire manufacturers agreement to provide this information to their customers. However, tire parameters are a delicate issue for manufacturers, and it is difficult to estimate what their willingness to do in this regard would be. This problem would be solved by regulations that, like today, prescribe for each tire load data, would also put pressure on the tire at maximum tire load.

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