Comparison of Real Axle Loads and Wheel Pressure of Truck Units for Wood Transportation with Legal Restrictions

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Abstract:
In Croatian Forestry wood transportation is usually carried out by trucks with trailers (forest truck unit) and trucks with two-axle semitrailers (forest semitrailer unit). As they travel on public roads, they are subject to severe legal restrictions defined by the "Regulation on Technical Conditions of Vehicles in Road Traffic" - (Official Gazette "Narodne novine", No. 51/10). Based on the analysis of the said regulation, it can be concluded that all restrictions are set on allowable loads of axles and total mass of the vehicle. At the same time axles of trucks and trailers are equipped with dual tires to decrease wheel pressure on road surface.
The aim of this research is to determine axle loads of the truck with trailer and truck with semitrailer during transportation of different types of loads (type of wood assortments, species of wood, wood moisture and way of piling wood assortments in the truck load space) as well as to determine contact pressure of truck and trailer/semitrailer wheels.
The research was performed on the Scania truck with trailer, Iveco Trakker 440 with trailer and MAN truck with semitrailer. The axle loads were measured by a portable measuring platform and scales. Different mathematical models based on tire characteristics (dimensions, inflation pressure) were used for the calculation of wheel contact area. Wheel pressure was determined based on measured wheel load and calculated contact area.
By comparing the results with the legal restrictions of the Regulation, analysis could be made of the right way of setting restrictions of timber transportation by trucks with trailers or semitrailers, which would reduce wheel pressure on road surface and, in a longer period, reduce maintenance costs of forest roads as well as increase the life cycle of technical equipment.

Key words: axle load, wheel pressure, truck with trailer, truck with semitrailer, regulations

1 Introduction

In Croatia, wood transportation is usually carried out by two variants of truck units: truck with trailer and truck with two-axle semitrailer (truck with semitrailer). Since wood transportation by trucks is the most expensive form of wood transport (Krpan et al. 2002.), special attention should be focused on seeking new technical–technological and organizational solutions. Malnar (2000) concludes that the success of truck transport depends on a series of factors, some of which are affected by forestry profession - technical construction of truck units, organization of forest road landings, while the legal regulations on dimensions and carrying capacity of truck units, speed restrictions, road condition and traffic frequency are beyond our control.

Forest roads are characterized by low traffic (Koczwański and Nowakowska-Moryl 1992, Fertal 1994) and high contact pressure generated by traffic of loaded truck units, whose loads exceed 80 kN per axle (Trzciński and Kaczmarzyk 2006), contributes to the damage of forest roads. Wheel load and contact pressure cause temporary deformations both of the forest road surface and substructure (Bayoglu 1997). Due to the effect of the contact pressure, forest roads are damaged (Figure 1), which can result, after some time, in complete forest road inaccessibility due to the damage occurred because of wheel overload and lack of adequate maintenance (Öztürk and Sentürk 2009).

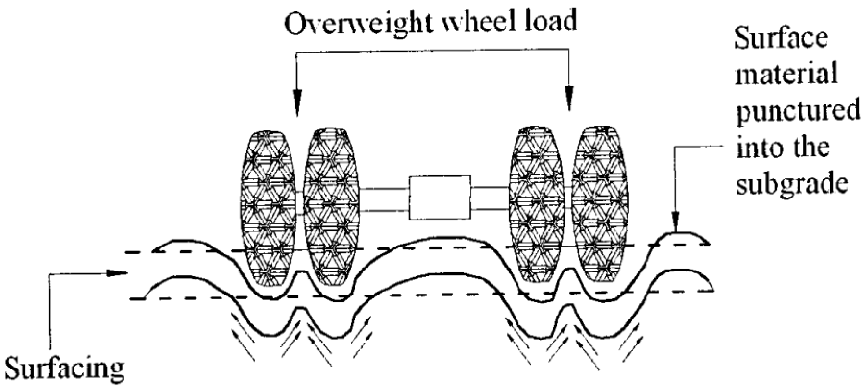

Figure 1: Road damage due to wheel overload (Izvor Keller and Sherar 2003)

The basic law in Croatia that regulates technical characteristics of truck units is the ″Regulation on Technical Conditions of Vehicles in Road Traffic” - (Official Gazette “Narodne novine”, No. 51/10), which uses the mass measuring unit for restrictions of technical conditions of truck transport. At the same time, while the mass measuring units are used for the axle load and total load, the truck and trailer axles are equipped with dual tires in order to lower the contact pressure of truck units on road surface. Axle loads allowed by the above Regulation are shown in Fig. 2.

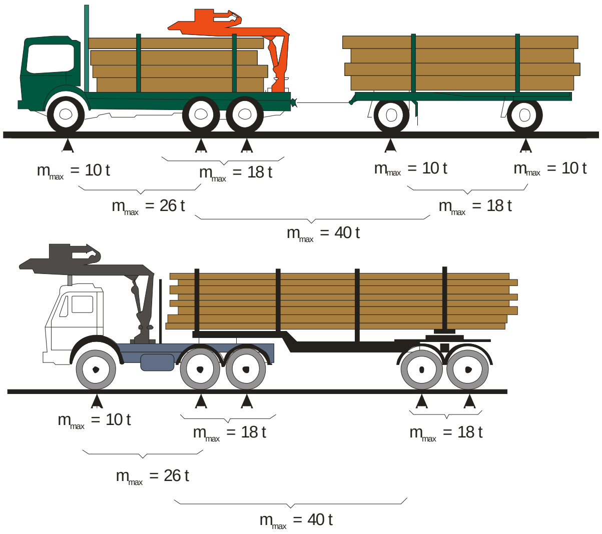

Figure 2: Allowed axle and total load of truck and trailer/semitrailer units

The aim of research was to measure the axle loads of truck and semitrailer units with different types of load, so as to provide the possibility to calculate the wheel/road contact pressure based on selected equations for the calculation of the wheel contact area.

2 Materials and methods

The research was carried out on two trucks with trailer (Iveco Trakker 440 and Scania), and on MAN truck with semitrailer. Four different loads were used during the research and namely common fir (*Abies alba* Mill.), common beech (*Fagus sylvatica* L.), pedunculate oak (*Quercus robur* L.), which were measured on the truck with trailer Scania, and mixed load of oak (*Quercus robur* L.), narrow-leaved ash (*Fraxinus angustifolia* Vahl) and European hornbeam (*Carpinus betulus* L.), which were measured on the truck with trailer Iveco and truck with semitrailer MAN.

2.1 Measuring systems

In measuring axle loads, two measuring systems were used. The first measuring system is made of four independent scales of the Swedish manufacturer TELUB. Each scale is equipped with four independent dynamometers intended for the measurement of pressure strains. The limit load of each scale is 90 kN. Since the load does not need necessarily to be symmetrically distributed on all four dynamometers, in extreme situations each of these pressure dynamometers can be individually loaded with the limit carrying capacity of the whole scale. Pressure dynamometers on each scale are installed on all four angles of the scale base, and they are fastened by screws both on the scale base and its cover. All dynamometers on a scale are connected into an integrated system, which is much more sensitive than each of them individually. For illustration, it should be noted that the force of 1 daN can be reliably measured, although it represents only 0.011% of the nominal carrying capacity of each dynamometer. Before measurement, all scales have been calibrated in the polygon for testing agricultural machinery of the Faculty of Agriculture, University of Zagreb. All scales, connected with the measuring amplifier manufactured by Hottinger Baldwin Messtechnik GMBH and connected with the portable personal computer, make an integrated system for data collecting (Figure 3) (Horvat and Šušnjar 2002).

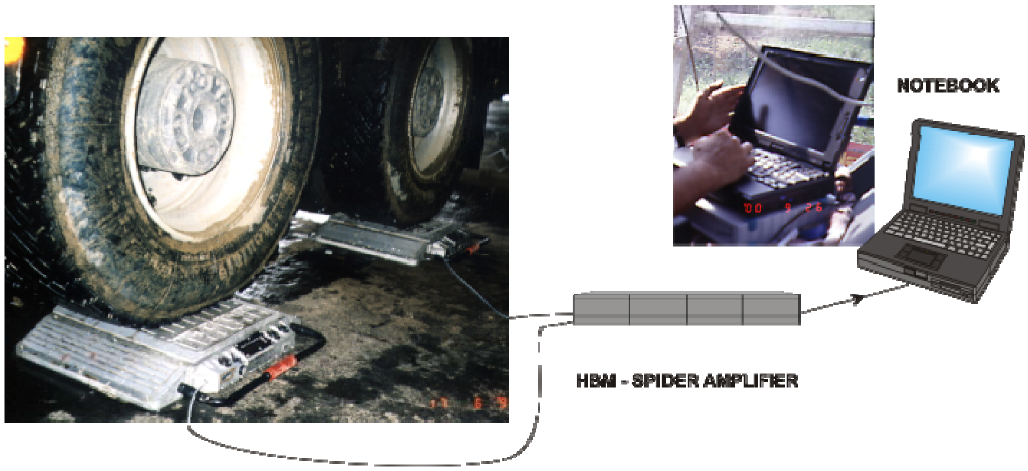

Figure 3: Scheme of the system for data collecting

The other measuring system is a portable measuring platform developed for the purpose of measuring axle loads during dispatch of forest biomass (Figure 4a). The platform dimensions are 3000×2700 mm, which enables putting dual axles of truck and trailer/semitrailer, thus simplifying the measurement. The system consists of two steel boards inside which 4 sensors are installed - ASC model (Figure 4b) manufactured by Vishay. The sensors of this model are made of stainless steel, and the welded construction enables the work in unfavourable conditions common in forests. During the measurement, sensors of the maximum individual load of 30 tons were used. All measuring cells are connected parallel into a measuring box (Figure 4c) of the same manufacturer. The collecting box is connected with a portable computer (Figure 4d). Maximum horizontal shift of the sensors is 18.5 mm at the maximum angle of 7 . The construction of the measuring platform with the use of sensors and the possibility of deflection is required because of the arrival of the loaded wheels of the truck unit that causes the strain of the upper board of the platform in horizontal direction.

For the purpose of field measurement, the platform was calibrated. Certified weights of 500 kg each were used for the calibration. By increasing the load gradually up to 10 tons, slight differences were observed of values measured by the measuring platform, ranging between -2 kg and 4 kg. The measurement precision was also tested at the angles of the measuring platform with the load of 8 tons. Higher values were measured (from 8 kg to 22 kg) and they showed the measurement error ranging from 0.1 % to 0.275 %. A lag of the measured value of 20 kg was also observed, primarily after the platform load exceeded 19 tons. Hoffman (1989) calls the said phenomenon *"elastic after-effect"* and explains that, depending on the material on which the measurement is made, the measuring cell makes record of a certain strain (force action) in a short time after the load. This measuring platform proved to be good for measuring axle loads because the measurement precision is satisfactory, it is simple for handling, and it can be easily transferred from one place to another, thus reducing the disruption of production cycles (Šušnjar et al. 2011).

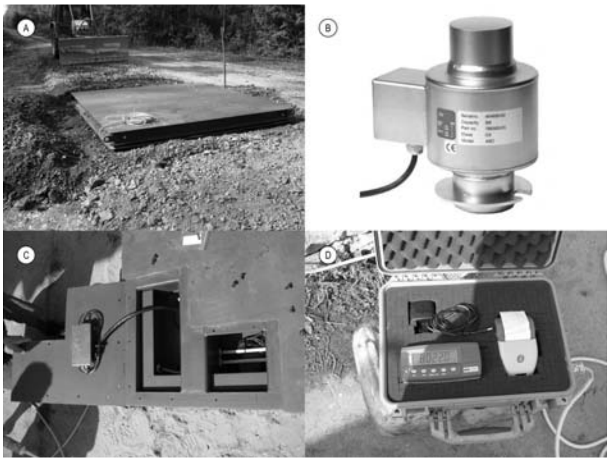

Figure 4: Portable measuring platform and its components

2.2 Models for calculating contact area and pressure

The form and size of the wheel/soil contact area, with the distribution of pressure in it, affects the distribution of pressure on the forest road. It is very difficult to measure the wheel/soil contact area because it depends on many factors and primarily on tire characteristics, tire dimensions, tire pressure, tire load as well as on the characteristics of the forest road, defined by Trzciński and Kaczmarzyk (2006) as deformation modulus and elastic deflection of the road. Ronai and Klinar (1977) stated that the form and size of the contact area highly depend on the tire inflation pressure. With lower inflation pressure, the form of the contact area is more elliptic and larger. Under constant tire inflation pressure and constant wheel load, the contact area depends on the factor that affects the road carrying capacity – current moisture, width of the upper layer and content of the lower layer, i.e. condition and content of the soil where the forest road has been constructed. If the tire pressure is above a certain critical pressure, the wheel tire starts to behave as a solid wheel. Tire deflection is a significant characteristic that defines the size of the contact area, and it depends on the tire pressure, number of fibers and structure (cross play or radial). At lower tire inflation pressure, the deflection affects the increase of the contact area size. Saarilahti (2002a) determines tire deflection as the difference between the diameter of the loaded and unloaded wheel. In the research, the deflection was not measured on-site, and its value was calculated by the theoretical expression given by Saarilahti (2002b).

$$\Delta = 0{,}008 + 0{,}001 * \left(0{,}365 + \frac{170}{pi}\right) * Gk \qquad (1)$$

Where:

Δ – tire deflection of vehicle wheel, m
p_i – tire inflation pressure, kPa
G_k – vehicle wheel load, kN

Additional pressure of the vehicle on the soil is the ratio between mass and contact area. The pressure between wheel and soil can be measured directly by gauges fastened on the tire surface (Horvat 1993). The indirect method for determining the contact pressure (calculation) is based on knowing the load of individual wheels of the vehicle, i.e. of the wheel/soil contact area.

Many scientists have developed different theoretical models for the calculation of the contact area and contact pressure between wheel and soil – forest road. Saarilahti (2002a) gives a survey of all models, while in this research only three models have been used as shown in Table 1.

Table 1: Survey of expressions for determining wheel/soil contact area and contact pressure

Author	Contact area	Nominal pressure of the vehicle wheel
Mellgren (1980)	$A = r \cdot b$	$NGP = \frac{G_k}{r \cdot b}$
		Contact pressure of the vehicle wheel
Komandi (1990)	$A = \frac{c \cdot G_k^{0,7} \cdot \sqrt{\frac{b}{d}}}{p_i^{0,45}}$	$p = \frac{G_k^{0,3} \cdot p_i}{c \cdot \sqrt{\frac{b}{d}}}$
Maclaurin (1997)	$A = b^{0,8} \cdot d^{0,8} \cdot \Delta^{0,4}$	$p = \frac{G}{b^{0,8} \cdot d^{0,8} \cdot \Delta^{0,4}}$
Legend key: p – contact pressure, kPa NGP – nominal pressure, kPa G – vehicle mass, kN G_k– vehicle wheel load, kN A – contact area, m^2 d – diameter of unloaded wheel tire, m	r – radius of unloaded wheel tire, m Δ – tire deflection of vehicle wheel, m b – width of unloaded wheel tire, m p_i – tire inflation pressure, kPa c - coefficient of soil type:(3 - 3.2 for hard soil)	

In most cases, models for calculation of the contact area and contact pressure between wheel and soil are developed for the estimation of tractive performance of military vehicles on different types of soils and farming tractors on agricultural types of soils.

The models of calculation of contact area and pressure between the wheel and soil used in this research have been selected on the basis of different parameters used in equations as well as on the basis of types of soils on which models are developed. Mellgren's expression was chosen because it provides simple and quick calculation, although it is known that as the tire deflection of the loaded travelling wheel is neglected as well as the inflation pressure, the effect of wide tires is overestimated. The other expression, Komandi (1990), has been selected because inflation pressure is used in the equation, which has a direct impact on the size of the contact area. Komandi developed model for farming tractors on different types of soils i.e. different bearing capacities of soils. He introduced coefficients of soil type and the hardest soil type could be chosen as an equivalent to the forest road surface. Maclaurin (1997) developed model for military vehicles with different types of tires on grassy lands which have higher bearing capacity than forest soil or bearing capacity similar to the forest road surface. Maclaurin's equation has been selected because it uses the tire deflection, which has a direct impact on the size of the contact area, and hence also on the value of the contact pressure.

2.3 Forest truck units

Truck units used in this research are Scania, which consists of the truck and trailer, is equipped with forestry devices and crane Jonsered 1090 (Figure 4). Truck unit Iveco Trakker 440, which consisted of the truck and trailer. It is equipped with forestry devices and crane Epsilon Palfinger E110Z (Figure 5). Semitrailer unit consists of the truck MAN equipped with the crane Cranab 2190 and semitrailer equipped with forestry devices (Figure 6). Table 2 presents the models of tires used by the researched truck and semitrailer units. The tire pressure of all researched truck and semitrailer units was 8 bar (800 kPa).

Figure 4: Scania truck and trailer

Figure 5: Iveco truck and trailer

Figure 6: MAN truck and semitrailer

Table 2: Data on tires used by truck and semitrailer units

Axles	Truck SCANIA with trailer	Truck IVECO with trailer	Truck MAN with semitrailer
1. truck	Continental 315/80 R22,5 HS45	Michelin 385/65R22.5	Sava 13R22.5
2. truck	Continental 315/80 R22,5 HS75)	Michelin 315/80R22.5	Sava 13R22.5
3. truck	Continental 315/80 R22,5 HS75	Michelin 315/80R22.5	Sava 13R22.5
1. trailer	Continental 315/80 R22,5 HS75	Michelin 295/80R22.5	Sava 12R22.5
2. trailer	Continental 315/80 R22,5 HS75	Michelin 295/80R22.5	Sava 12R22.5

3 Results

The results of research show the measurement of axle loads and total mass of unloaded and loaded truck units and semitrailer unit, as well as the calculated values of contact pressure by selected equation and by individual researched unit. Axle loads of truck units and semitrailer unit were determined by the above said methods. In measuring the axle loads of the loaded units, four different loads of approximately the same volume were used. The load volume ranged between 22.34 m^3, fir (*Abies alba* Mill.*)*, 22.42 m^3 - pedunculate oak (*Quercus robur* L.), 22.61 m^3 - mixed load of pedunculate oak (*Quercus robur* L.), narrow-leaved ash (*Fraxinus angustifolia* Vahl) and European hornbeam (*Carpinus betulus* L.), and 22.87 m^3 - common beech (*Fagus sylvatica* L.).

The obtained results show the starting differences in mass and contact pressure (Table 3) of unloaded trucks units and unloaded semitrailer unit. The semitrailer unit had the largest starting mass of 20652 kg, followed by IVECO truck unit of 19960 kg, while the truck unit SCANIA had the lowest starting mass of 18723 kg. The highest contact pressure, according to all equations used for the calculation, is generated under the wheels of the front axle of the semitrailer unit.

Table 3: Measured axle loads of unloaded truck units and calculated contact pressure

Truck with trailer		SCANIA				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Measured loads (kg)		5010	4845	4283	2396	2189
Contact pressure (kPa)	Mellgren (1980)	145.05	70.13	62.22	34.71	31.70
	Komandi (1990)	1287.48	1035.29	998.78	838.36	815.85
	Maclaurin (1997)	219.98	133.08	118.07	64.15	58.58
Truck with trailer		IVECO				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Measured loads (kg)		4690	5010	5010	2430	2820
Contact pressure (kPa)	Mellgren (1980)	135.78	72.55	72.55	35.18	40.85
	Komandi (1990)	1262.23	1045.89	1045.89	841.77	880.34
	Maclaurin (1997)	205.92	137.67	137.67	65.02	75.49
Truck with semitrailer		MAN				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Measured loads (kg)		8336	4051	4051	2104	2104
Contact pressure (kPa)	Mellgren (1980)	241.33	58.68	58.68	30.46	30.46
	Komandi (1990)	1499.93	981.37	981.37	806.15	806.15
	Maclaurin (1997)	366.00	111.34	111.34	56.29	56.29

Total masses of the loaded trucks and semitrailer unit are shown in Fig. 7. The results presented in Fig. 7 clearly show that the trucks units SCANIA, with the load of oak and beech are overloaded, as well as the IVECO and semitrailer unit MAN with the mixed loads. Only the truck unit SCANIA with the load of fir is not overloaded. With the truck unit SCANIA, with the load of oak, the second axle of the truck is overloaded, and with the load of beech, the rear axle of the trailer is overloaded.

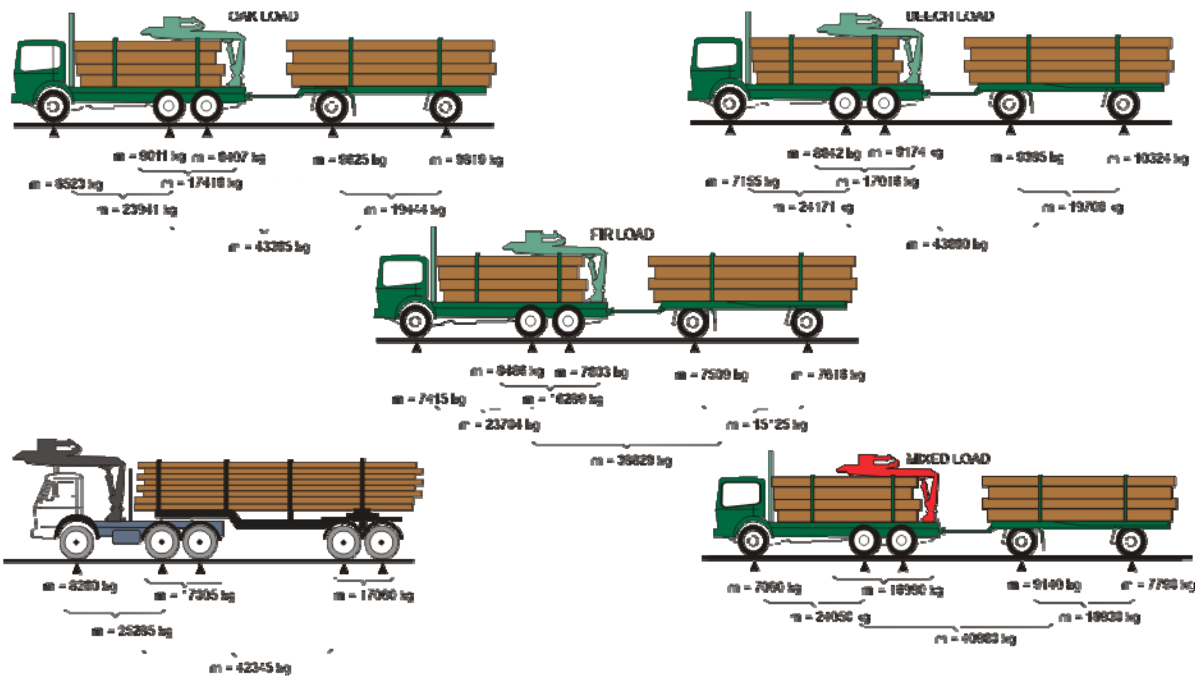

Figure 7: Axle loads and total masses of loaded truck units and semitrailer unit

Table 4: Measured loads of the loaded truck units and calculated pressure

Truck with trailer		SCANIA				
Load		OAK				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Axle loads (kg)		6523	9011	8407	9625	9819
Contact pressure (kPa)	Mellgren (1980)	188.88	130.46	121.72	139.35	142.16
	Komandi (1990)	1393.62	1247.19	1221.50	1272.10	1279.74
	Maclaurin (1997)	292.51	217.23	205.13	229.28	233.04
Truck with trailer		SCANIA				
Load		BEECH				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Axle loads (kg)		7155	8842	8174	9385	10324
Contact pressure (kPa)	Mellgren (1980)	207.18	128.02	118.35	135.88	149.47
	Komandi (1990)	1432.83	1240.13	1211.24	1262.50	1299.14
	Maclaurin (1997)	347.37	243.96	229.83	255.16	273.97
Truck with trailer		SCANIA				
Load		FIR				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Axle loads (kg)		7415	8486	7803	7509	7616
Contact pressure (kPa)	Mellgren (1980)	214.71	122.86	112.97	108.72	110.27
	Komandi (1990)	1448.25	1224.93	1194.48	1180.80	1185.82
	Maclaurin (1997)	356.31	236.48	221.80	215.34	217.70
Truck with trailer		IVECO				
Load		MIXED LOAD				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Axle loads (kg)		7060	8495	8495	9140	7790
Contact pressure (kPa)	Mellgren (1980)	167.89	122.99	122.99	145.64	124.13
	Komandi (1990)	1288.45	1225.32	1225.32	1274.88	1215.20
	Maclaurin (1997)	293.92	236.67	236.67	270.07	239.16
Truck with semitrailer		MAN				
Load		MIXED LOAD				
Axles		1. truck	2. truck	3. truck	1. trailer	2. trailer
Axle loads (kg)		8280	8502.5	8502.5	8530	8530
Contact pressure (kPa)	Mellgren (1980)	225.83	115.95	115.95	128.30	128.30
	Komandi (1990)	1518.37	1243.15	1243.15	1263.83	1263.83
	Maclaurin (1997)	367.17	225.76	225.76	244.77	244.77

The measured loads and the calculation of the contact pressure of loaded truck units and loads of loaded semitrailer unit are shown in Table 4. By comparison of unloaded and loaded truck units and semitrailer unit, the increase of the load can be seen on all axles. The highest increase of the load was recorded on dual axles of the semitrailer. The load on the fornt axles of trucks ranges between 15 % and 20% of the total load, depending on the type of truck and type of load. It can be clearly seen from the table that maximum values of contact pressure are generated under wheels of the front axle. The highest contact pressure was calculated for the front axle of the semitrailer unit.

4 Conclusion

The results of research show the measured values of axle loads and total masses of unloaded and loaded forest trucks with trailer and truck with semi-trailer, and the wheel/road contact pressure on each axle.

It can be seen that the starting mass of the truck with semi-trailer is on average higher by approximately 700 kg than mass of truck IVECO with trailer or approximately 2000 kg than mass of truck SCANIA with trailer. Based on this data it could be concluded that it would be better to use trucks with trailers for long-distance wood transportation, but it should be noted that the truck with semi-trailer was purchased before and that the semitrailer was made of heavier materials than the trailer of the truck unit. Such data indicate the possible development trend of the semitrailer. The use of more modern materials for the construction of semitrailers and installation of a more modern and lighter crane of the same capabilities would decrease the starting total mass of the track with semitrailer, which would ultimately enable the transportation of a larger useful load.

Research results show that with approximately the same load volume, trucks with trailers or track with semitrailer are overloaded – total mass higher than 40 tones. Only truck SCANIA with semitrailer with load of fir logs are not overloaded due to smaller wood density of fir. However, only one axle was overloaded which could be explained by irregular piled wood assortments in the load space.

The law regulations uses the mass measuring unit for restrictions of technical conditions of truck transport but wheel load and contact pressure of truck wheels cause deformations of the road surface. Oveloading the axles will affect on durability and utilization of trucks and the real impact of truck on road surface responds through contact pressure of wheels.

The highest contact pressures were always noticed under the wheels of the front axle of the truck regardless on type of truck unit.

It could be concluded that in the law regulations need to introduce contact pressure of truck wheels although there is no reasons for equipping rear axles of truck with dual tires. On the other hand, with equipping the front axle of trucks with wider tires or with dual tires will have a great impact of decreasing contact pressure in the aim to avoid the greater disturbance of road surface and to reduce maintenance costs of forest roads in a longer period.

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