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AXLE LOAD OF ROUND WOOD TRANSPORT VEHICLES IN RELATION TO WOOD ASSORTMENT

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Introduction

High variability of transported assortments, species variability, and varied moisture content of wood do not allow to unequivocally determine the weight of transported raw material [Koirala et al. 2017; Hamsley et al. 2007; Tymendorf and Trzciński 2020]. This very often affects the excess gross vehicle weight of the transport over the legal limit [Brown 2008; Ghaffariyan et al. 2013; Owusu-Ababio and Schmitt 2015; Trzciński et al. 2017 and 2018].

Currently, in many countries the permissible gross vehicle weights (GVW) of transport units have been raised to 60t or 76t, or even to 92t, in order to improve the efficiency of round wood transport. [Lukason et al. 2011; Sosa et al. 2015; Palander et al. 220; Pålsson et al. 2017; Väätäinen et al. 2020; Liimatainen et al. 2020].

Wheel load and contact pressure cause temporary deformation of both the forest road surface and substructure [Martin et al. 1999; Varin and Saarenketo 2014]. Under contact pressure, forest roads are damaged, which may, after some time, make them completely impracticable due to damage from wheel overloading [Öztürk and Sentürk 2009; Martin et al. 1999].

Introduction

One of the main factors influencing the gross vehicle weight (GVW) and axle load of wood transport units is the legislation [Trzciński and Tymendorf 2017; Liimatainen and Nykänen 2017; Palander et al. 2017; McKinnon 2005]. An important element in this respect are the legal limits associated with the permissible gross vehicle weight (GVW).

The European Union Member States adopted Directive 96/53/EC in 1996, setting vehicle weights of 40 Mg and 44 Mg, single axle loads of 100 kN and double axle loads of 160 kN [Directive EU 2015]. In EU countries, public transport and highway authorities have the power to limit GVW with the possibility of limiting allowable axle loads or increasing them from those specified in EU legislation.

Introduction

Table 1. Weight per axle and permissible maximum weights of lorries in European countries

Country	Weight per axle [tonnes]		Permissible maximum weights of lorries [tonnes][1]			
			Road train 5 axles	Articulated vehicle 5 axles	Articulated vehicle	
	nondrive	drive			6	7
Austria	10.0	11.5	40	44		
Croatia	10.0	11.5	40	44		
Denmark[2]	10.0	11.5	44	44	50	56
Finland[3]	10.0	11.5	44	44	56	60
Germany	10.0	11.5	40	40		
Ireland	10.0	11.5	42	44	46	
Italy	12.0	12.0	44	44		
Netheralnds	10.0	11.5	50	50		
Norway[2]	10.0	11.5	46-47	40	50 60[5]	
Portugal[2]	10.0	12.0	44	44 (60)[6]		
Sweden[3]	10.0	11.5	40	44	56	60

[1][ITF 2019] https://www.itf-oecd.org/sites/default/files/docs/weights-2019.pdf
[2] Under specific conditions EMS (European Modular System) combinations may have a maximum length of 25.25 m and maximum weight of 60 t.
[3] Finland and Sweden are piloting even longer and heavier vehicles, with maximum weight of up to 104 t and maximum length of up to 34.5 m [Liimatainen et al. 2020]
[4] Palander et al. 220
[5] timber transport between 19.5 m and 24 m with an overall wheelbase of at least 19 m
[6] 60 t is allowed under specific conditions: transportation of woody material, paper, wood paper and ceramic products.
[7] Asmoarp et al. 2018

Introduction

In Poland, there are also regulations limiting the permissible total gross vehicle weight (GVW) of vehicle transport unit on the road, which depends on the number of axles and their drive. The GVW consists of the weight of empty vehicle units and the weight of the load [Act… 2016; Act… 2012]. In Poland, the GVW for five-axle or six-axle sets is 40 tonnes, and the axle load depends on several factors: whether it is a drive axle, whether it is a double/triple axle, and the distance between the component axles (Table 2) [Regulation...2002].

Table 2. Permissible axle load for transport sets in Poland

Axle set	Permissible load for axle or axle unit [t]		
single axle not drive	10		
single drive axle	11.5		
Distances (d) between the component axles [m]	d<1.0	1.0≤d <1.3	1.3≤ d < 1.8
double axle trailers and semi-trailers	11	16	18
double drive axle	11.5	16	18 (19)
two axles of engine vehicles, where one component axle is a driving axle	11.5	16	
Distances (d) between the component axles [m]	d<1.3	1.3 < d ≤ 1.4	1.4 ≤ d < 1.8
triple axle trailers and semi-trailers	21	24	27
three axles of engine vehicles, where one component axle is a driving axle	21	24	27

Purpose and scope

The variety of wood loads and its parameters (humidity, density, assortment) are often the cause of the increased total weight of the vehicle (GVW). With significant GVW exceeding, forest roads are exposed to high tonnage vehicles, which results in vehicle axle loads above the accepted design parameters for the pavement.

The aim of the study was to investigate the real axle loads of roundwood transport vehicles resulting from the gross vehicle weight (GVW) of the transport unit in different seasons of the year and depending on the type of transport unit and the type of wood assortments.

The scope was to analyses of transports depending on the:

- period of their realization,
- gross vehicle weight (GVW,
- axle loads,
- type of transport unit,
- type of wood assortments.

Material and Methods

Measurements of axle loads for round wood trucks were carried out on the sites of three large wood industry companies from the north of Poland, which process different types and assortments of wood.

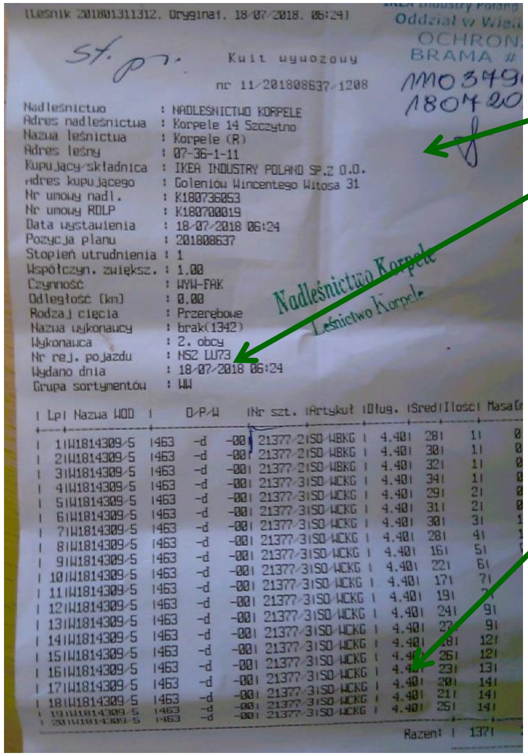
In total, measurements were made for 904 round wood deliveries, made by different transport sets: truck and trailer unit with 473 deliveries, including 344 deliveries by six-axle sets, truck and semi-trailer, 334 deliveries, where 193 was made by six-axle sets.

Transporting truck units were divided by truck and trailer arrangement and trailer type into: truck and trailer (TT), truck and semi-trailer (TS), truck and dolly (TD), truck and lightweight semi-trailer (TP) [Trzciński et al. 2013 and 2018], and number of axles in the set (five-axle and six-axle).

Large-size wood was assimilated to the round wood with a thin end minimum diameter of 14 cm (excluding bark), calculated in single pieces. The large-size general-purpose wood is comparable to the assortment defined as sawmill wood. Medium-size round wood (industrial wood) is the wood with a minimum diameter of at least 5 cm (excluding bark), with a thick end diameter of up to 24 cm, calculated in single pieces, in pieces as groups and in piles [PN-93/D-02002; Regulation No 51].

Material and Methods

The transport was performed by external companies acting on behalf of the processing plant. Characteristics of transported wood load (assortment): large-size (Ls), sawlogs (Sw) and its length (Sw 3.7; Sw4.0; Sw4.4; Sw5.0; Sw8.4; Sw8.8), medium-size (Ms) were determined on the basis of a delivery note issued by the State Forest District to the carrier, which is shown to the buyer and verified by him.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Kwit wywozowy

nr 11/201808637/1208

Nadleśnictwo : NADLEŚNICTWO KORPELE
Adres nadleśnictwa : Korpele 14 Szczytno
Nazwa leśnictwa : Korpele (R)
Adres leśny : 07-36-1-11
Kupujący/składnica : IKEA INDUSTRY POLAND SP.Z O.O.
Adres kupującego : Goleniów Wincentego Witosa 31
Nr umowy nadl. : K180736053
Nr umowy RDLP : K180700019
Data wystawienia : 18/07/2018 06:24
Pozycja planu : 201808637
Stopień utrudnienia : 1
Współczyn. zwiększ. : 1.00
Czynność : WYW-FAK
Odległość [km] : 0.00
Rodzaj cięcia : Przerębowe
Nazwa wykonawcy : brak(1342)
Wykonawca : 2. obcy
Nr rej. pojazdu : NS2 LU73
Wydano dnia : 18/07/2018 06:24
Grupa sortymentów : WW

Lp	Nazwa WOD		O/P/W		Nr szt.	Artykuł	Dług.	Śred	Ilość	Masa
1	W1814309/5	1463	-d	-00	21377/2	SO/WBKG	4.40	28	1	[illegible]
2	W1814309/5	1463	-d	-00	21377/2	SO/WBKG	4.40	30	1	[illegible]
3	W1814309/5	1463	-d	-00	21377/2	SO/WBKG	4.40	32	1	[illegible]
4	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	34	1	[illegible]
5	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	29	2	[illegible]
6	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	31	2	[illegible]
7	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	30	3	[illegible]
8	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	28	4	[illegible]
9	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	16	5	[illegible]
10	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	22	6	[illegible]
11	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	17	7	[illegible]
12	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	19	[illegible]	[illegible]
13	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	24	9	[illegible]
14	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	27	9	[illegible]
15	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	18	12	[illegible]
16	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	26	12	[illegible]
17	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	23	13	[illegible]
18	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	20	14	[illegible]
19	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	21	14	[illegible]
20	W1814309/5	1463	-d	-00	21377/3	SO/WCKG	4.40	25	14	[illegible]
								Razem	137	

Nadleśnictwo Korpele
Leśnictwo Korpele

The delivery date resulted from the recipient's documents (sawmill) and the delivery note issued by the State Forest, which allowed for the analysis for individual months.

Dane dotyczące sortymentu drewna: długość, objętość, gatunek.

Material and Methods

The gross weight of the truck unit (GVW) expressed in Mg is understood as the actual weight of the vehicle and trailer or truck unit and semi-trailer with all the equipment, the driver and round wood load. GVW was determined based on weighing the entire truck unit on a stationary scale at the factory at the moment the wood raw material was delivered.

Figure 1. Weighing station for whole transport sets on a stationary scale (roundwood carried by truck and trailer).

Material and Methods

The load on the individual axles of high tonnage truck units was measured using Model DINI ARGEO WWSD portable truck scales with a 3590M309 weighing terminal with 0.01t graduation. The weigh station was selected in such a way it maintained a level road scale, so that the measured axles were kept leveled. The analysis was based on the results of measurements, taking into account a 5% allowable measurement error in accordance with the recommendations of the Polish Road Transport Inspectorate.

Figure 2. Measured the load on the individual axles of high tonnage truck units.
Weighing the wheel axles of a truck unit hauling timber.

Material and Methods

The obtained results were analysed statistically with the use of the STATISTICA 12 package. Therefore, the significance of differences was mainly determined using the Mann–Whitney test for two independent variables, as well as the Kruskal–Wallis test, and Dunn's multi-sample rank mean comparison test (significance level was 0.05). To evaluate the relationship between the axle loads of a transport unit and its GVW (determined from a stationary scale), the Spearman correlation coefficient (Spearman's rank correlation test) was used. For the statistical tests Kruskal-Wallis, Dunn and Manna-Whitney were not taken for some of the observations groups (e.g. type of vehicle, or delivery date) due to the low number of results in a specific group (less than 15).

Results - Characteristics of the gross vehicle weight of the transport sets

The transport units analyzed had average GVW ranging from 45.99t with a standard deviation (SD) of 2.22 (five-axle TP set) to 51.08t (with SD = 3.22) for truck and trailer (six-axle) (Table 4). The spread of registered GVW results from the stationary scale is significant from a minimum of 33.58t to 64.20t for TT - five-axle sets (Table 3). In all observed deliveries (904), almost 50% of the GVW results fall in the range from Q1 (first quartile) to Q3 (third quartile), that is, from 44.50-49.25t to 46.50-53.05t.

Table 3. Characteristics of the gross vehicle weight of the transport sets

Truck unit	Number of axles	GVW (t)					
		Mean	SD	Min	Max	Q_1	Median
TS	five-axle	49.13	3.98	34.42	59.94	46.80	49.62
	six-axle	50.40	2.62	42.28	57.05	48.95	50.45
TT	five-axle	49.05	4.22	33.58	64.20	46.85	49.25
	six-axle	51.08	3.22	39.58	60.00	49.25	51.15
TD	five-axle	49.99	3.85	40.06	59.64	46.78	50.18
TP	five-axle	45.99	2.22	43.60	51.65	44.50	45.85

Results - Characteristics of axle loads

Preliminary comparative analysis by Kruskal-Wallis test of all axle load results depending on the vehicle types, number of axles showed statistically significant differences. This led to the decision to present the results separately for 5- and 6-axle sets and vehicle type (Table 4). The lowest axle load for all transport sets occurs on the first axle in the range of mean values 7.07-7.86t with a spread of results from 4.49 to 10.20t. The highest average axle loads of 9.15-12.43t were found on axle two for all the test sets where the maximum value of 14.52t was also found.

Results

- Characteristics of axle loads

Table 4.
Basic statistical characteristics of axle loads

Truck unit	Number of axles	Axle	Mean	SD	Min	Max	Q_1
Truck and semi-trailer	five-axle[1]	1	7.73	0.59	5.77	8.91	7.35
		2	10.79	0.98	7.39	13.19	10.45
		3	9.90	1.43	3.75	12.54	9.07
		4	9.70	1.63	5.76	13.90	8.50
		5	9.66	1.52	5.80	13.69	8.44
	six-axle[1]	1	7.81	0.62	5.15	10.20	7.48
		2	9.15	1.25	4.46	13.87	8.38
		3	8.74	1.11	6.37	13.78	8.16
		4	8.67	1.44	5.10	13.04	7.76
		5	8.15	1.07	5.06	12.03	7.51
		6	8.11	1.17	4.91	13.48	7.45
Truck and trailer	five-axle[1]	1	7.36	1.01	4.49	9.46	6.68
		2	10.63	1.46	7.33	14.52	9.57
		3	9.93	1.43	6.95	13.40	8.81
		4	10.02	1.67	5.99	14.11	8.94
		5	9.98	1.87	3.99	14.38	8.90
	six-axle[1]	1	7.21	0.71	4.96	9.47	6.75
		2	9.89	1.17	6.97	12.92	9.04
		3	9.42	1.22	5.29	12.59	8.71
		4	8.27	0.96	4.07	11.50	7.62
		5	7.42	1.35	4.16	13.22	6.61
		6	7.21	1.01	3.29	10.81	6.61
Truck and dolly	five-axle[1]	1	7.86	0.58	6.54	8.98	7.55
		2	11.02	1.05	8.19	13.05	10.47
		3	10.58	1.17	6.19	12.73	10.00
		4	10.19	1.62	7.06	14.31	8.89
		5	10.20	1.25	8.03	13.01	9.21
Truck and lightweight semi-trailer	five-axle[2]	1	7.07	0.69	5.42	8.02	6.94
		2	12.43	0.86	10.82	14.02	11.94
		3	8.30	0.85	7.13	10.61	7.65
		4	8.17	0.84	7.08	10.27	7.51
		5	7.97	0.87	7.05	10.36	7.32

(Axle load values (t): Mean, SD, Min, Max, Q_1)

Notes: SD - standard deviation, Q1 - first quartile, Q3 - third quartile 1axle 1-3 truck, 2 axle 1-2 truck

Results

- Analysis of the axle loads depending on the investigated parameter: transport set

The six-axle sets were TT and TS and the comparative analysis (Kruskal Wallis test) of individual axle loads between those units showed statistically significant differences (Fig. 3a).

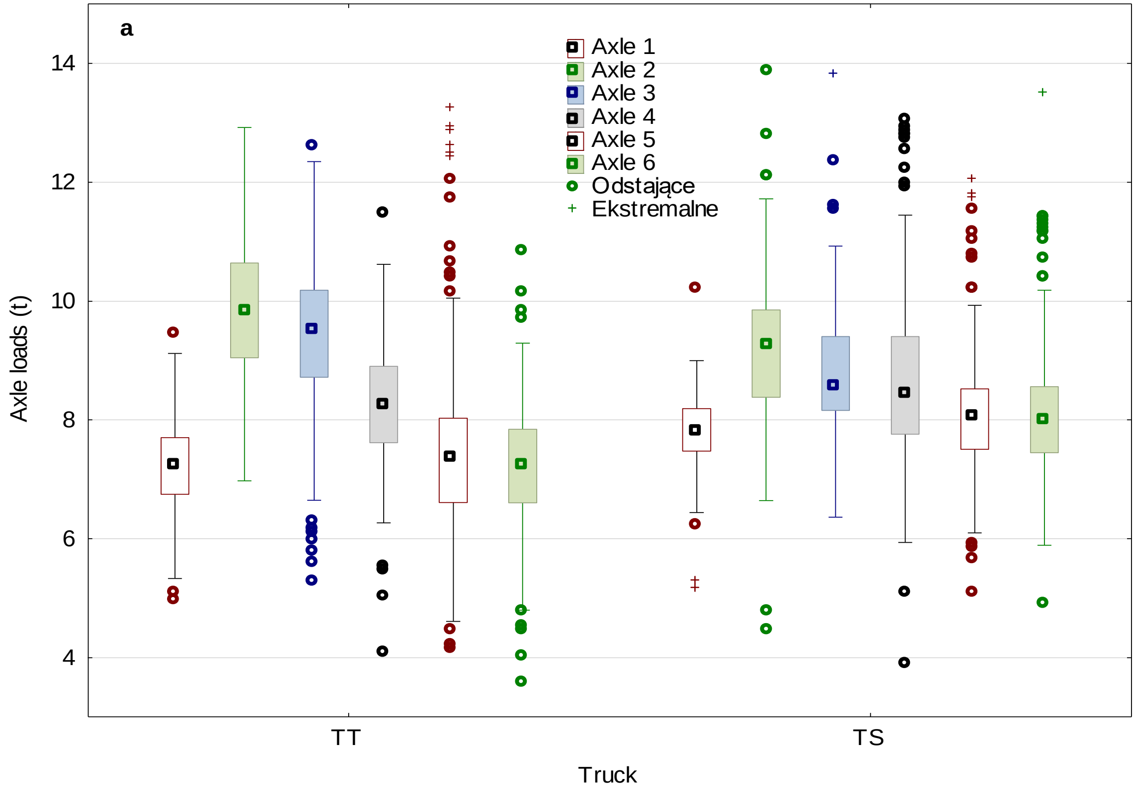

Figure 3a. Distribution of axle loads in six-axle transport sets according to: a) transport set.

Results

- Analysis of the axle loads depending on the investigated parameter: transport set

After analyzing the axle loads in relation to the transported wood assortment, it can be concluded that there are also statistically significant differences (Fig. 3b).

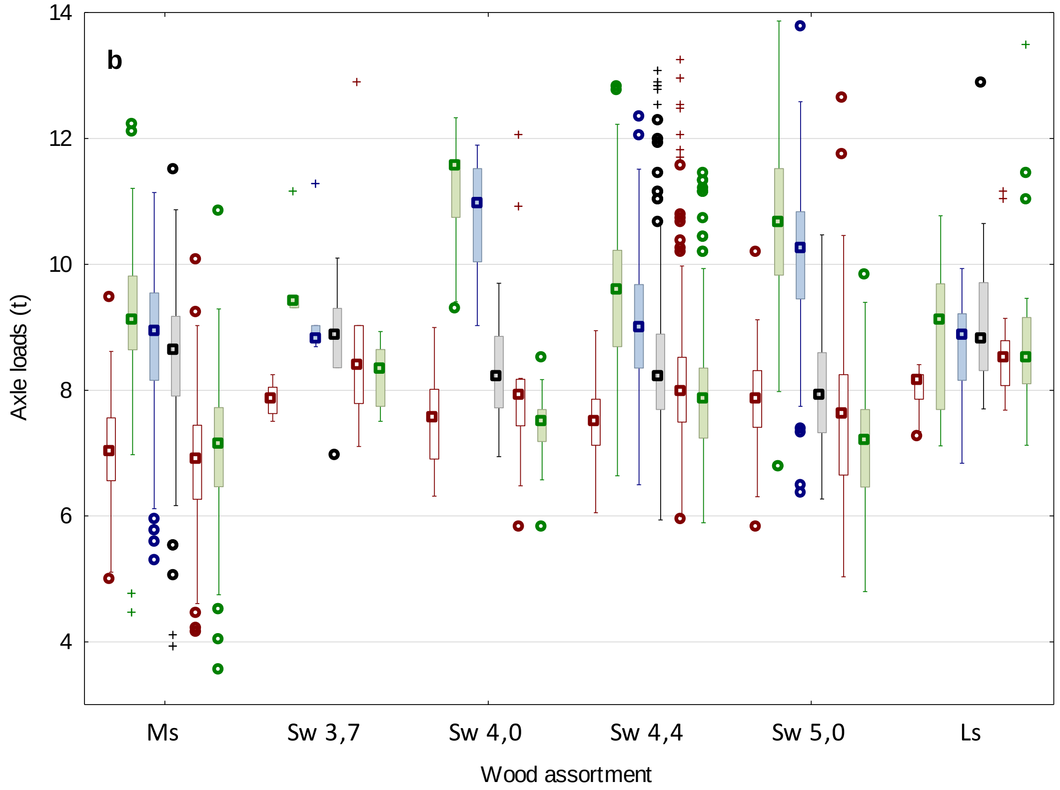

Figure 3b. Distribution of axle loads in six-axle transport sets according to : b) wood assortment.

Results

- Analysis of the axle loads depending on the investigated parameter: transport set

Statistical analysis showed that there were no significant differences in axle loads for axle 1 ($p=0.7549$) and axle 4 ($p=0.1436$) depending on the delivery date, while for the other axles the differences were significant (Fig. 3c).

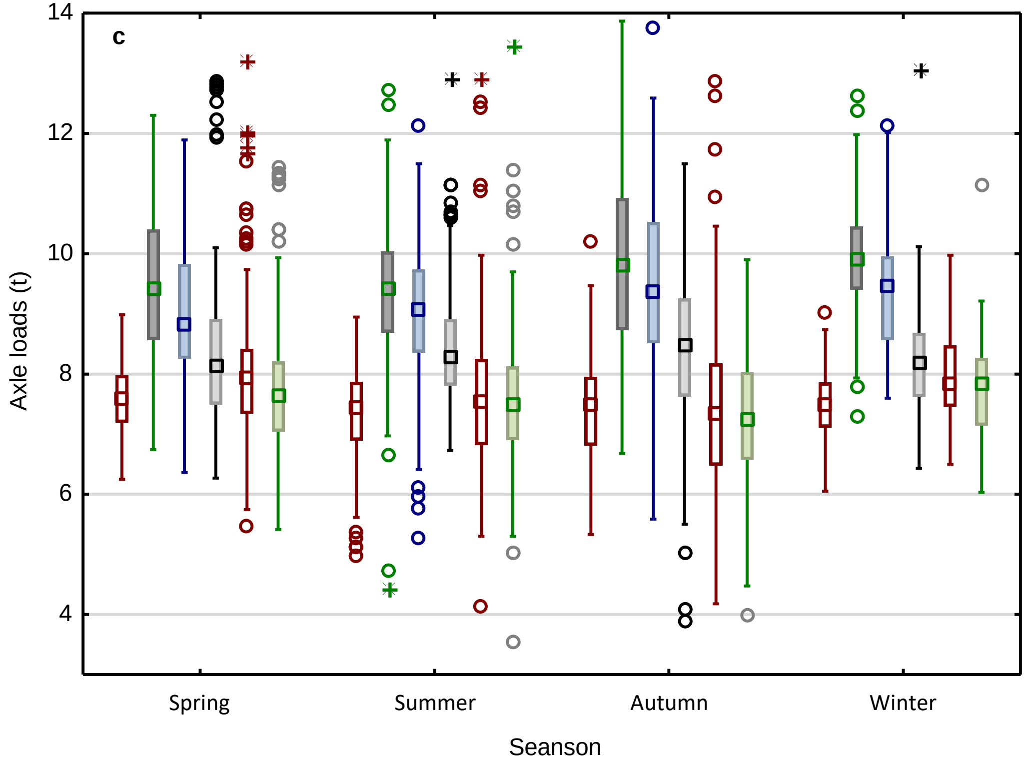

Figure 3c. Distribution of axle loads in six-axle transport sets according to: c) delivery date

Results - Analysis of the axle loads depending on the investigated parameter

As in the case of the six-axle sets, not every wood assortment was transported with all types of sets in the five-axle sets. In these sets, this is more evident for TD and TP, therefore an analysis of axle loads for individual units depending on the wood assortments in the load is also presented (Fig. 4). In the group of five-axle truck and trailer sets, as opposed to six-axle sets, there is also a unit with an extendable trailer, which makes it possible to transport longer loads (Ls and Sw 8.8 m) (Fig. 4a). When transporting large-size timber (Ls) for TT, TS and TD sets, the first axle has the lowest average loads of 8t, while the other axles (3-5) average between 10.5-12.0 t.

Results - Analysis of the axle loads depending on the investigated parameter

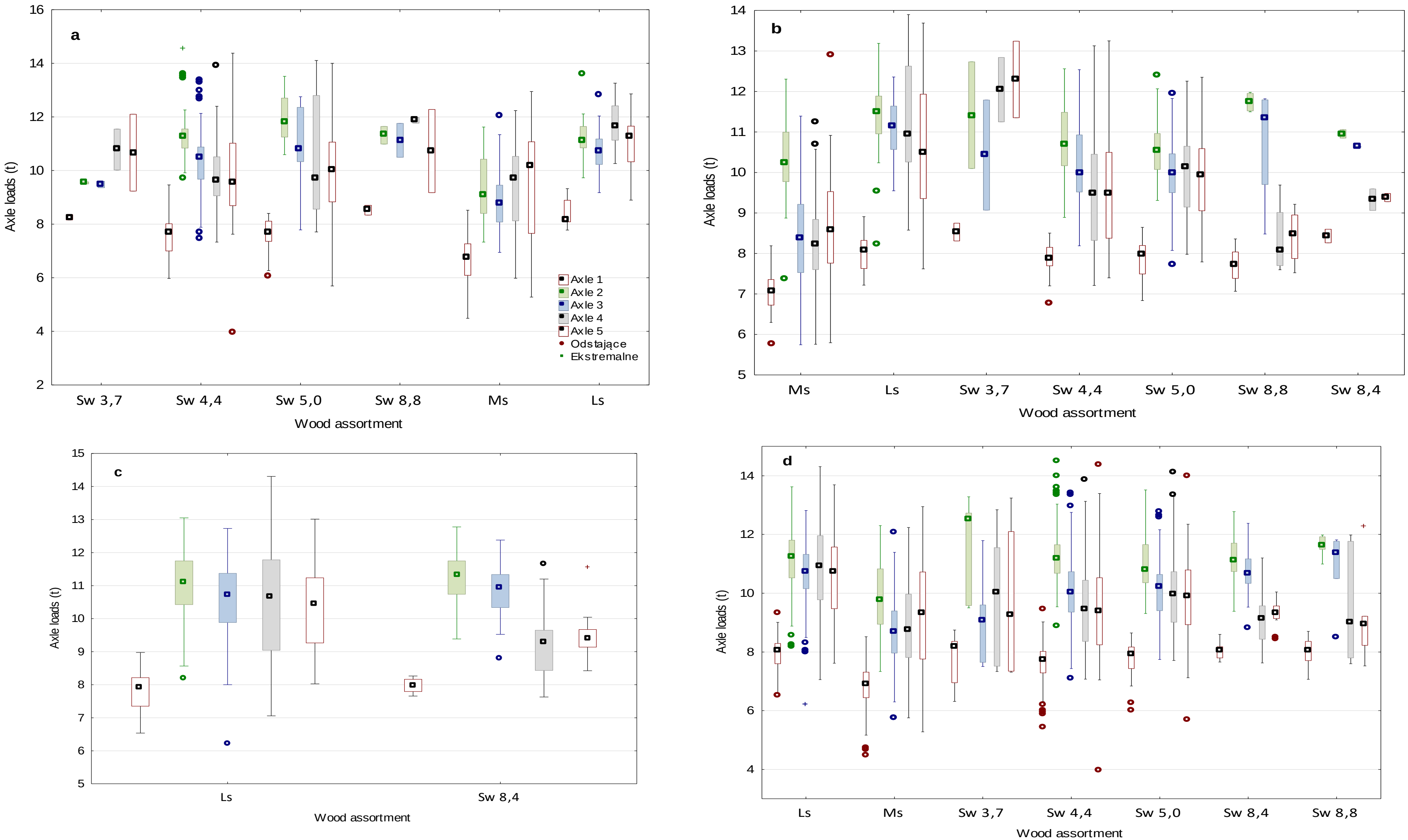

Fig. 4. Axle loads on five-axle sets depending on the wood assortment: a) truck and trailer, b) truck and semi-trailer, c) truck and dolly, d) truck and lightweight semi-trailer.

Results - Distribution of gross vehicle weight among the axles

In six-axle combinations, on average almost 0.30 of the GVW falls on the second axle with a range of results of 0.13-0.40 (Fig.5). The smallest share on average of 0.14-0.15 in GVW goes to the first axle with a range of results of 0.09-0.19. The mass per truck is on average 0.60 GVW (observed range 0.40-0.80) and per trailer/semi-trailer 0.46 with a range of results 0.33-0.72. The comparative analysis performed confirmed that there are statistically significant differences between the six-axle TT and TS sets in the distribution of GVW per truck and trailer/semi-trailer and individual axles.

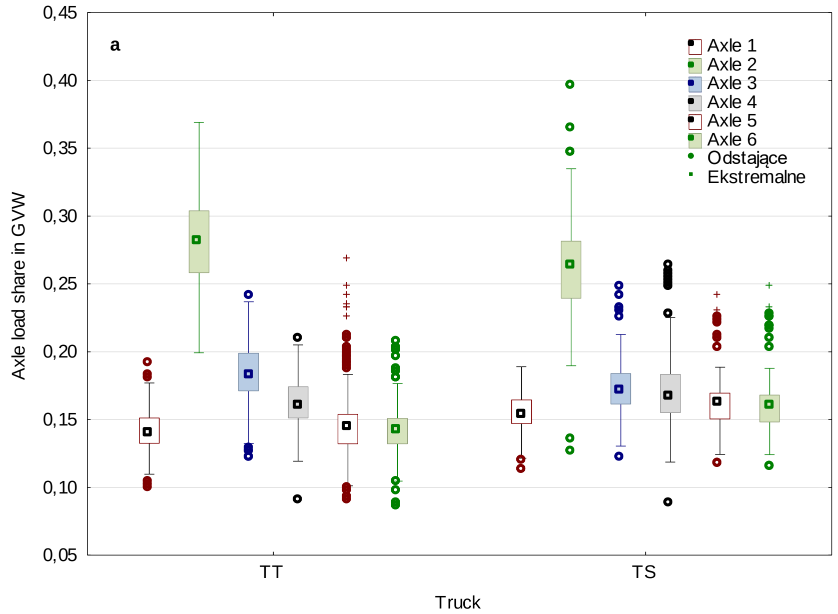

Fig.5. Distribution of the gross vehicle weight between the six-axle sets.

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Results - Distribution of gross vehicle weight among the axles

In the TP five-axle set, the distribution of GVW per axle differs significantly from the others, with a large average contribution of 0.28 to the GVW of the second axle (Fig.6). In the other units TT, TS, and TD, the first axle averages about 0.16 GVW and the other axles each average 0.19-0.22 GVW. In the TT, TS and TD (3+2 axles) sets, there is an average of 0.58 GVW per truck (observed range 0.44-0.85) and an average of 0.40 GVW per trailer/semi-trailer or dolly (with a range of 0.27-0.54). The TP averages are: 0.42 GVW per truck (observed 0.38-0.46) and 0.53 GVW (with a range of 0.48-0.62) per lightweight semi-trailer. The distributions of GVW per truck and trailer and per axle for the five-axle combinations are statistically significantly different.

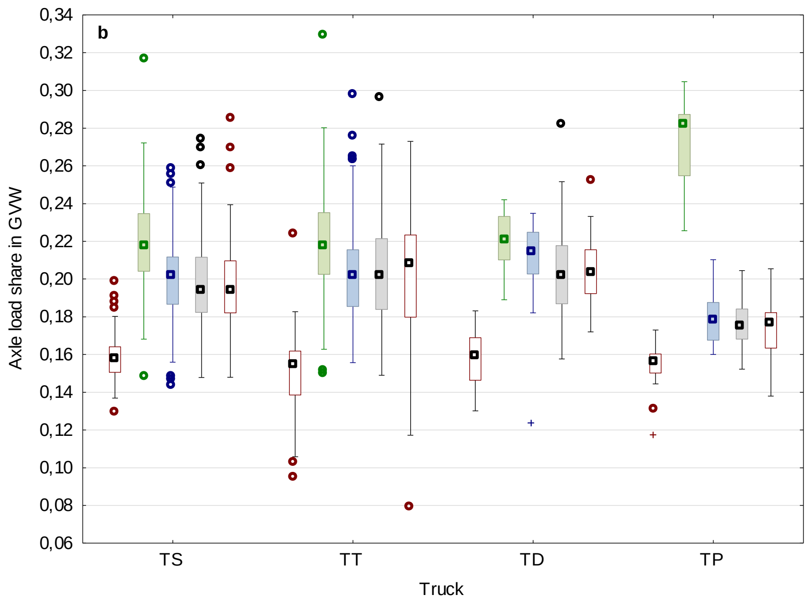

Fig.6. Distribution of the gross vehicle weight between the five-axle sets.

Results

- Spearman correlation coefficients between axle loads and gross vehicle weight

The distribution of GVW mass varies between axles as well as between types of transport units. Therefore, a correlation analysis was performed between axle loads and GVW of the unit. In the six-axle sets, statistically significant correlations were obtained for all axles, where the largest coefficient of 0.5435 is for the sixth axle in the TT set, and the other axles of this set have larger values than in the TS (Table 5). In the five-axle sets, the correlation coefficients are much higher at 0.4152 (axle 3 in the TT set) to 0.8031 (axle 4 in the TD set).

Table 5. Spearman correlation coefficients between axle loads and GVW

Axle	Six-axle sets		Five-axle sets			
	TS	TT	TS	TT	TD	TP
Axle 1	0.1864	0.2608	0.5316	0.5330	-	0.6123
Axle 2	0.3275	0.3835	0.2995	0.4152	0.6734	-
Axle 3	0.3826	0.4532	0.6817	0.5725	0.6857	-
Axle 4	0.3698	0.3956	0.7763	0.6316	0.8031	0.6413
Axle 5	0.4457	0.4309	0.7420	0.5886	0.7718	-
Axle 6	0.3841	0.5435				

- no statistically significant correlation

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Discussion

Studies conducted over several years have collected a large empirical material (904 deliveries) for different combinations of transport units (6 combinations) with different wood assortments and GVW. At the same time this is one of the reasons for the large range of results in the individual axle loads of the transport set (Table 4).

We observed a change in the types of sets, where six-axle sets predominate and there are no transports by truck and dolly and truck and lightweight semi-trailer sets, which is a result of the change in the assortments of transported wood and the legislation and its modifications [Regulation...2002; Regulation...2018; Trzciński and Tymendorf 2017]. Changes in transport units are also due to legal changes defining GVW and transport companies adapting to customer demands and improving transport efficiency [McKinnon 2005; Pålsson et al. 2017; Väätäinen et al. 2020; Liimatainen et al. 2020; Brown 2021].

Turning to the discussion of the results of loads on particular axles and the factors that determine them, it is clear that in Poland it is the regulations that introduce the determination of wood mass on the basis of wood density conversion factors [Act...2012; Regulation 2012]. In our study we obtain average weights of transport sets at the level of 46-51t, which means exceeding the GVW=40t (Table 3). The problem of overloading of transport units is not a new issue and has been widely described in the literature.

Discussion

With such a high real GVW, overloading of any of the axles beyond the permissible values can also be expected, and this is what we found in our study. However, axle overloading is not only necessarily due to GVW, as confirmed by the study of Baugras [1976], where GVW overloading was found for only 1.46% of transports and truck tandem axle overloading in 58.1%, a similar situation is presented by Owusu-Ababio and Schmitt [2015].

Similar results of axle loads ranging from 8.3 to 13.3t for a seven-axle Volvo combination with a four-axle trailer were presented by Mackenzie [2008]. In other studies (after converting from pounds Ibs to tons) with GVW values of 35-45t, axle loads were obtained with very different values from 3.5t to 11.5t, which is also confirmed by our study (Table 5). This is largely influenced by the arrangement of the load, as exemplified by Fig. 7-8, and the length (assortment) of the transported wood, as confirmed by statistical analyses (Fig. 3b, and 4).

Discussion

Fig. 7. Transport set truck and semi-trailer with different wood assortments: a) five-axle (3+2) with Ls; b) six-axle with Sw4.4; c) five-axle with Sw8.8; d) six-axle with Sw4.0

Discussion

The weight distribution of the GVW unit on the truck and trailer/semi-trailer and dolly (TT, TS, TD) on average are close to 58-60% and about 40%, respectively, which is due to the drivers' actions in arranging the load to ensure the stability and traction of the truck (drive axle). The obtained values of GVW distribution on truck and trailer/semi-trailer are consistent with other works [Šušnjar et al. 2011b; Owusu-Ababio and Schmitt 2015; Šušnjar et al. 2016]. The percentage share of individual axles in GVW also depends on the wood assortment and its arrangement (Figs. 7-8), where statistically significant similarities can already be found between some transport sets (TT and TS , TD and TP and TS and TD), which may be the result of transporting similar wood assortments (Figs. 4).

Discussion

Fig. 8. Transport set truck and trailer with different wood assortments: a) six-axle with Ms; b) six-axle with Sw5,0; c) five-axle with Sw4,0; d) six-axle with Sw3.7

Conclusions

The lowest axle load for all sets occurs on axle one in the range of average values of 7.07-7.86t with a spread of results from 4.49 to 10.20t. The highest average axle loads of 9.15-12.43t were found on axle two for all observed transport sets, where a maximum value of 14.52t was also found. There were statistically significant differences in the values of loads on individual axles depending on the type of truck set, type of wood assortment.

The distribution of the total gross vehicle weight of the set is on average 58-60% to the truck (three axles) and 40-42% to the trailer/semi-trailer (two axles) in five-axle sets, and in six-axle sets the truck and trailer/semi-trailer (three axles).

The loads of transported wood (assortments) also influence the resulting axle loads, which was confirmed by statistical analysis.

For most axles there are differences in axle loads for sets with MS (medium-size, industrial wood) deliveries and the other assortments. Additionally on axles 4-5 there are differences between Ls (large-size) deliveries and the other deliveries.

Thank you for your attention

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