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REVIEW

The Impact of Freight Vehicle Load on the Condition of Roads in Bosnia and Herzegovina

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Abstract: The number of registered commercial freight vehicles in Bosnia and Herzegovina has been increasing over the years, which affects the traffic load and the condition of roads, especially in Bosnia and Herzegovina. Vehicle overloading is considered to be one of the biggest causes of damage to part of the road surface, especially with regard to the load-bearing road substructure. The focus of the research is the vehicle overloading on the roads of Bosnia and Herzegovina, with special emphasis on determining the type and degree of overloaded vehicles and determining the equivalence factor (EF). In the research phase, data from weighing control stations were used, taking into account the total weight of vehicles, the distribution of total weight on vehicle axles and the equivalent standard axle load for a particular vehicle type over a period of two years. A high degree of overloading was found, especially 5-axle vehicles (58.7%). The level of overloading in the range of 10-20% in relation to the maximum allowed weight is especially apparent. The calculated EF is 3.64 and is higher than the standard EF.

Key words: vehicle overloading, design road pavement, axle weight.

INTRODUCTION

Vehicle overloading is an axle weight that exceeds the legally permitted values for vehicles, which dramatically contributes to the accumulated damage to the road [1]. It has been found that an increase in the occurrence of vehicle overloading causes a noticeable increase in road damage [2],[3],[4],[15]. As the share of road transport of goods has increased compared to other modes of transport, it is expected that freight vehicles will remain a common sight on our roads in the foreseeable future. Therefore, special attention should be paid to optimizing the use of vehicles and damage to road infrastructure caused by them.

Freight vehicles moving from the starting point to the destination use the public road network. If the control of axle weight and total weight of freight vehicles is not carried out, high loads can cause significant damage to the road infrastructure. Consequently, certain legal load limits have been imposed. Three types of load weight data are of particular importance: total vehicle weight, distribution of total weight on vehicle axles and equivalent standard axle weight for a particular vehicle type. Dimensions, total weight and axle weight of vehicles on the roads are determined by the adopted bylaws (Official Gazette of BiH, No. 23/07 and 101/12). Repetition to the loading and overloading of heavy goods vehicles adversely affects the road, the design life of the road becomes shorter, although the same quality standard is used in design and construction [5],[6],[7],[8]. The research study stated that, allowing the axle weight to increase from 10 to 13 tons, the road will last only half of its projected life in relation to axle weight of 10 tons [11].

Research in the USA and South Africa has shown that damage to road pavement caused by overload has increased disproportionately, (axle weight twice the legal limit can cause 4 to 60 times more damage than the permissible axle weight, depending on the structure and type of road). High vehicle wheel loads, tire pressure, frequency and duration along with environmental factors are important for road performance. However, the most important parameter is the axle weight. The main factors responsible for damage to the road caused by the vehicle, such as dynamic axle weight, number and type of axles (e.g. single, tandem), tire properties (e.g. larger widths, double) and road properties (e.g. road type, thickness, temperature and roughness) are given in research studies [1],[9],[10],[12],[13],[18],[19].

The road network in Bosnia and Herzegovina covers about 22,733 km and is divided into four main categories (toll highways - 198 km, - 4,039 km, regional roads - 4,496 km, and local roads). Their lifespan is between 10 and 15 years, however, damage to the road structure is still present and occurs earlier than expected. One of the new issues related to road transport is the overload behavior that is usually caused by freight vehicles when they are out of control, and at the same time these roads cannot provide load-bearing capacity with a certain design lifespan.

It is worrying that the determined degree of overload is extremely high, where 5-axle freight vehicles particularly stand out with the share of 58.7%. The research [20] has shown that the most significant level of overload is in the range of 10-20% in relation to the maximum allowed mass.

Overloaded vehicles endanger the lives of road users. Overloaded vehicles are difficult to drive, they are less stable, and require a longer stopping distance; which makes them very dangerous, especially on sharp curves and steep slopes.

In addition, overloading can also cause several detrimental effects on the integrity of the road pavement structure, shorten the life of the pavement itself, and can cause serious damage that could lead to traffic accidents [14],[16],[17].

Due to these problems, overload is recognized as a problem that must be taken into account. Therefore, the main objectives of this study were to determine the types of overloaded vehicles, the percentage of overloaded vehicles and the average equivalence (EF) for all vehicles.

RESEARCH METHODS

The main goal of this research is to understand the significance of the problem, ie the extent to which there is a problem with the overload on our roads.

Measuring total mass and axle weight of vehicles on the roads in Bosnia and Herzegovina began with the introduction of static scales that perform measurements while the vehicle is at rest, or out of traffic, so that reliable measurement results are obtained. These measurements are used to determine the axle weight exceedance and the total mass of the vehicle. Data collection was performed at a total of 45 selected locations over a period of two years, throughout Bosnia and Herzegovina.

The overloaded vehicles considered in this study include freight vehicles (rigid and articulated vehicles with 2 axles, 3 axles, 4 axles, 5 axles, 6 axles and possibly 7 axles). The percentage of vehicle overload and the average equivalence factor (EF) for each vehicle type were analyzed as secondary data. The percentage of vehicle overloading was analyzed in terms of vehicle types of overloaded vehicles and overload percentage per vehicle. Of the statistical techniques for data processing, nonparametric techniques such as the Kruskal-Wallis test, the Man-Whitney U-test, c2 test, and the Fisher test were used.

RESEARCH RESULTS AND DISCUSSION

Number of overloaded vehicles

In the observed time period, a sample of 504 controlled fright vehicles was observed, by measuring axle weight and total mass, using static scales, at 45 selected locations. In 122 controlled cases, vehicle overload was determined, which represents the total percentage of 24.2% of violations, compared to the number of controlled ones (Table 1).

The application of the Mann-Whitney U-test (Figure 1) gave significant differences (U = 5653,000, z = -12,602, p = 0,000) in the total weight (tons) of freight vehicles overloading (N = 122, Md = 41.34) of the total weight or axle weight in relation to vehicles without overloading (N = 382, Md = 34.70).

The intensity and quality of these controls does not meet the real needs, so the number of violations in terms of overloading freight vehicles is much higher.

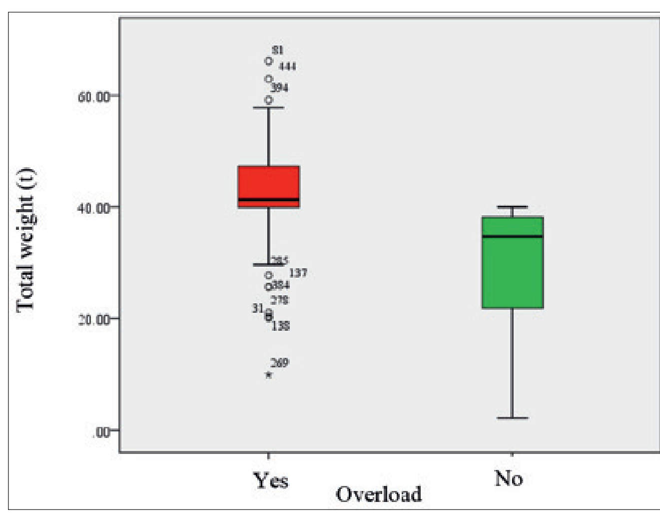

Figure 1: Ratio between overloading and total vehicle weight

***Table 1**: Total weight (t)*

Overloading	N	Minimum	Maximum	Range	Median	Mean	Std. Dev.
Yes	122	9.96	66.16	56.20	41.3400	42.5475	8.77453
No	382	2.20	40.00	37.80	34.7000	29.4702	10.53944
Total	504	2.20	66.16	63.96	36.6500	32.6357	11.58003

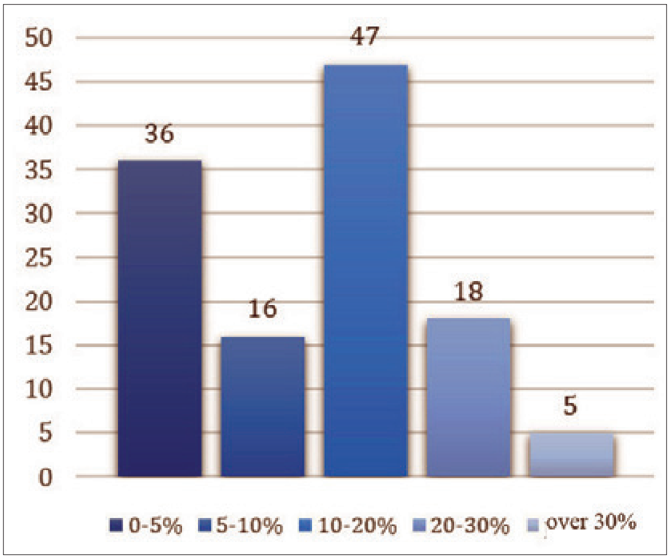

Figure 2: Overloading in percentage groups

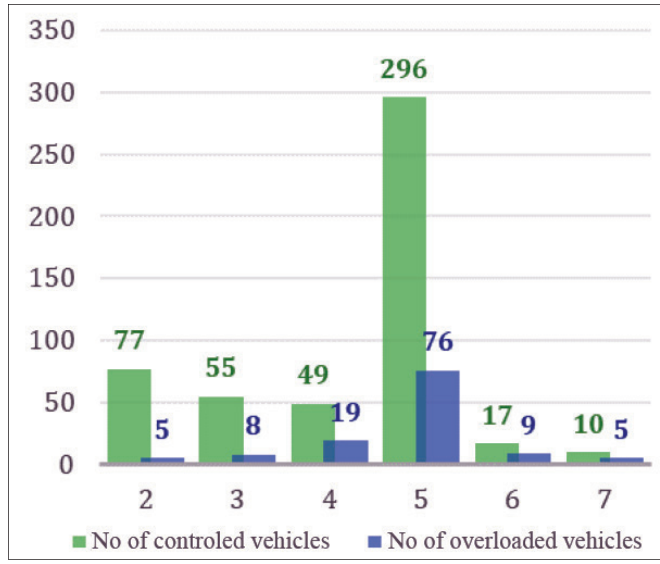

Figure 3: Overloading in relation to the number of axles

Although exceeding the total permissible vehicle weight can be considered quite high, even more worrying are the range of overloading values and the degree of overloading above the permissible limit for each category of commercial vehicles. The share of overloading in relation to overloading percentage groups was analyzed (Figure 2), as well as the share of overloaded vehicles in relation to axle groups of vehicles (Figure 3).

Table 2: Overruns

Number of axles	2	3	4	5	6	7	Total
YES	5 (6.5%)	8 (14.5%)	19 (38.8%)	76 (25.7%)	9 (52.9%)	5 (50.0%)	122 (24.2%)
NO	72 (93.5%)	47 (85.5%)	30 (61.2%)	220 (74.3%)	8 (47.1%)	5 (50.0%)	382 (75.8%)
Total	77 (15.3%)	55 (10.9%)	49 (9.7%)	296 (58.7%)	17 (3.4%)	10 (2.0%)	504 (100.0%)

The data on the performed axle weight measurements, according to the types and groups of axles, and in accordance with the legal regulations (Table 3, 4) were also analyzed, which is also presented graphically (Figure 4,5).

Table 3: Axle overloading

Axle	N	Minimum	Maximum	Range	Median	Mean	Std. Dev.
2	5	.36	6.40	6.04	1.3400	2.1720	2.40494
3	8	1.35	7.21	5.86	4.7150	4.2138	1.94870
4	18	.90	14.00	13.10	5.4050	5.6833	3.23061
5	56	.12	18.79	18.67	3.3400	3.9084	3.33334
6	9	2.10	15.72	13.62	5.6000	6.3678	4.69638
7	3	5.15	12.60	7.45	7.3400	8.3633	3.82897
Total	99	.12	18.79	18.67	3.8700	4.5267	3.48859

Table 4: Total axle overloading

Number of axles	N	Minimum	Maximum	Range	Median	Mean	Std. Dev.
2	5	.36	6.40	6.04	1.3400	2.1720	2.40494
3	8	1.35	7.21	5.86	4.7150	4.2138	1.94870
4	19	.90	14.00	13.10	4.9000	5.4100	2.91191
5	76	.02	17.86	17.84	3.4900	4.5241	4.57343
6	9	5.10	22.96	17.86	15.7200	14.3611	5.09210
7	5	.26	26.16	25.90	10.3600	11.2400	11.48072
Total	122	.02	26.16	26.14	4.8300	5.5462	5.39209

Overloading by vehicle types

In the structure of overloaded commercial vehicles by groups, the highest percentage of overruns was recorded in five-axle freight vehicles (58.7%). They are followed by two-axle freight vehicles (15.3%), three-axle freight vehicles (10.9%), and then four-axle freight vehicles (9.7%) in the observed sample (Table 2). The application of the χ^2 test gave a statistically significant difference ($\chi^2 = 33,260$, $p = 0,000$) for the presence of overruns in relation to the number of axles of the vehicle.

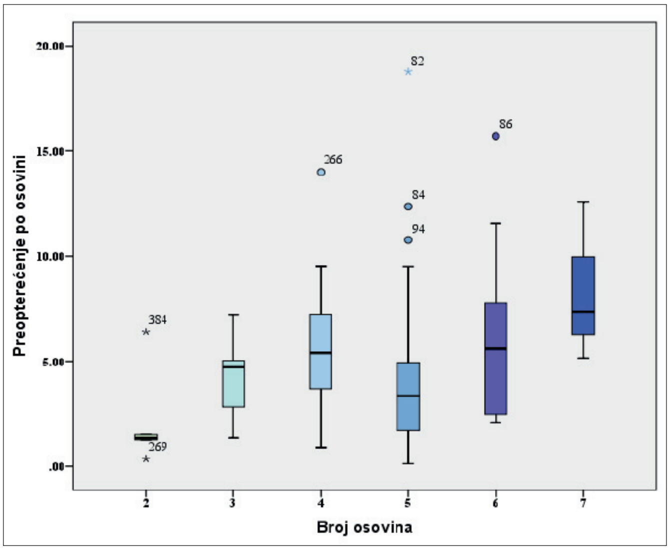

Figure 4: Axle overloading

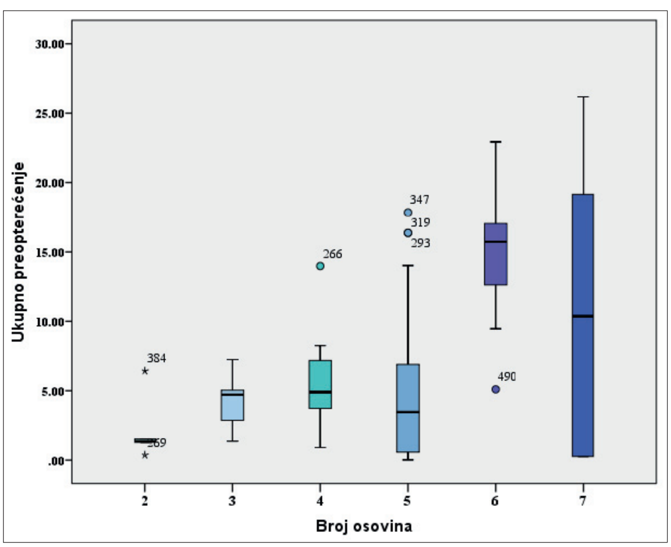

Figure 5: Total axle overloading

Axle overload testing (six groups: 2 to 7 axles) in the application of the Kruskal Wallis test, returned a statistically significant difference (c2=21.283, p=0.001) of the total overloading by axles. Additional analysis was then performed with the Mann-Whitney U-test (Table 5).

Additional tests using the Mann-Whitney U-test, give a statistically significant difference in total overload by axles (U=1,000, z=-2,867, p=0.004) of the tested vehicles with two axles (N=5, Md= 1.34) and six axles N=9, Md=5.60); three axles (N=8, Md=4,715) and six axles (U=1,000, z= -3,370, p=0.001); four axles (N=19, Md=5,405) and six axles (U= 2,000, z=-3,617, p=0,000); and five axles (N=76, Md=3.34) and six axles (U=59,000, z=-4,042, p=0,000). The statistically significant difference between the two and four axes is (U=17,000, z=-2,169, p= 0.030). In other cases, no statistically significant difference was detected.

Determination of equivalence factor (EF)

The impact of vehicle flow on the road is expressed by the number of equivalent traffic load for dimensioning asphalt pavement structures, according to the standard JUS U.C4.010 from 1981, which increases by the degree of four with increasing axle weight of vehicles (Figure 6), which means that overloads of 10% above the permissible weight, contribute to the damage of the road structure by 40%.

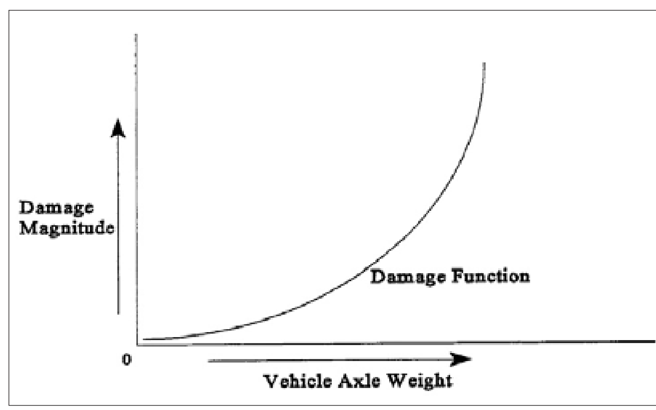

Figure 6: Ratio between vehicle overloading and road damage

Data from the place of control and weighing were analyzed by sorting data on vehicles according to the number of axles and the total weight of the vehicle. Dam-

Table 5: Significance of total overloading by axels

Number of axles	2 (5)	3 (8)	4 (19)	5 (76)	6 (9)	7 (5)
2 (5)		0.091	0.030*	0.468	0.004**	0.600
3 (8)	0.091		0.457	0.573	0.001**	0.557
4 (19)	0.030*	0.457		0.094	0.000**	0.545
5 (76)	0.468	0.573	0.094		0.000**	0.346
6 (9)	0.004**	0.001**	0.000**	0.000**		0.640
7 (5)	0.600	0.557	0.545	0.346	0.640	

Table 6: Equivalent factor (EF) for all vehicles

Freight vehicle type	Number of vehicles	Average equivalent factor (EF) per axle							Total average EF	Total EF	EF for all vehicles
		1	2	3	4	5	6	7			
2-axle	77	0.08	0.70						0,78	60.06	3.64
3-axle	55	0,59	0.94	0.96					2.49	136.95	
4-axle	49	0.75	0.72	1.80	1.81				5.08	248.92	
5-axle	296	0.36	2.06	0.68	0.65	0.62			4.37	1293.52	
6-axle	17	0.36	0.34	0.40	1.17	1.19	1.09		4.55	77.35	
7-axle	10	0.34	0.30	0.28	0.26	0.27	0.24	0.23	1.92	19.20	
TOTAL	504									1836.00	

age or equivalence factor (EF) for each weighted axis was calculated using equation (1). Table 6 shows the calculated EF for all vehicles. The result shows that the EF based on the current traffic volume is 3.64. Comparing the EF acquired in this research with the EF used in the design of road pavement structures for a standard load of 80kN per axle, which is 3.0, we see that the calculated EF has a higher value than the standard.

$$\text{Equivalent Factor (EF)} = (N/8.16)^{4.5} \quad (1)$$

where:
EF – is equivalent damage effect factor
N – is axle weight (tons)
4.5 – is exponent of load equivalence
8.16 – is Standard axle weight (tons)

The damage caused by the cumulative overloading on the pavement structure affects its lifespan, by shortening the time of the road operation in relation to the normative lifespan. The unplanned traffic load leads to endangering safe operation of traffic, or in the best case scenario it will lead to premature need to invest in renewal of the pavement in order to maintain the required level of quality and safety of traffic, causing increased costs for road infrastructure maintenance.

Overloading as a phenomenon in transport is often an indicator of economic growth, especially in developing countries such as ours. On the other hand, we cannot ignore the negative impact on road infrastructure (roads and bridges) and traffic safety when assessing the potential risks of overloaded vehicles.

CONCLUSION

Based on the results of the research, the following can be concluded:

- The results of the research showed the significance of the problem of overloaded commercial vehicles on the roads in Bosnia and Herzegovina. What is worrying is the degree of overloading, which is extremely high, especially for 5-axle vehicles (58.7%), followed by 2-axle and 3-axle vehicles. The most apparent degree of overloading ranges from 10-20% of the allowed total weight.
- Freight road traffic causes high costs in terms of maintenance and rehabilitation of the road pavement of the damaged road network, which occurs as a result of vehicle overloading. Also, the relative damage depends on the type and number of axles on each vehicle, as well as the type of pavement on which the vehicle is moving. Every vehicle moving on the road network currently causes significant deformation on the pavement construction of the road.

The total flow of vehicles has a cumulative effect that gradually leads to deformation of the pavement, followed by erosion. The effect of overloading is not felt in one day, but it is visible over a certain period of exploitation.

- The calculated EF for the current traffic volume was higher and was 3.64, compared to the standard EF which is 3.0. It can be concluded that the road network is not sufficiently well dimensioned because the current traffic load is significantly higher, and this is a result of overloaded freight vehicles moving on the road network of Bosnia and Herzegovina.

In order to prevent damage to the pavement due to the increased number of overloaded vehicles, the road network in Bosnia and Herzegovina must be controlled in terms of bearing capacity, establishing a good-quality control of total weight and axle weight of freight vehicles in order to withstand the current and the future traffic loads.

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