MIRSAD KULOVIĆ, Ph.D.[1]
(Corresponding author)
E-mail: m.kulovic@hotmail.com
ZORAN INJAC, M.Sc.[2]
E-mail: zinjac@putevirs.com
SLAVKO DAVIDOVIĆ, M.Sc.[3]
E-mail: davidovic.slavko@hotmail.com
IVO POSAVAC, M.Sc.[4]
E-mail: ivoposavac8@gmail.com
[1] Paneuropean University Apeiron,
College of Traffic & Transportation Engineering
Pere Krece 13, 78000 Banja Luka, Bosnia & Herzegovina
[2] Public Company "Republic of Srpska Roads" Ltd
Trg Republike Srpske 8, 78000 Banja Luka,
Bosnia & Herzegovina
[3] City of Banja Luka, Department of Transportation
Trg srpskih vladara 1, 78000 Banja Luka,
Bosnia & Herzegovina
[4] Public Company Road of the Federation of B&H
Terezija 54, 71000 Sarajevo, Bosnia & Herzegovina

Science in Traffic and Transport
Preliminary Communication
Submitted: 20 Jan. 2017
Accepted: 24 Nov. 2017

MODELLING TRUCK WEIGH STATIONS' LOCATIONS BASED ON TRUCK TRAFFIC FLOW AND OVERWEIGHT VIOLATION: A CASE STUDY IN BOSNIA AND HERZEGOVINA

ABSTRACT

The number of registered commercial freight vehicles is constantly increasing, increasing therefore as well the traffic load on the roads in Bosnia and Herzegovina. A significant part of freight vehicles moving along the main and regional roads are overloaded and cause significant damage to road infrastructure, affect road safety and result in an increase of emissions of harmful gases for people and the environment. The overloading rate is extremely high, in particular with 5-axle trucks representing 58.7%. The research showed that the increased overload level ranges from 10-20% of the maximum permissible weight. The importance of load limits was recognized early in the history of road development. This interrelation led directly to limitations on vehicle loads, and laws were enacted in many countries to establish the maximum allowable motor vehicle sizes and weights. Strict enforcement of motor vehicle size and weight laws is a step toward reducing motor vehicle size and weight violations, heavy truck accidents, and, even more, improving road maintenance, rehabilitation expenditures and road safety. Thus, based on the applied model the objective of this paper is to evaluate and optimize the locations of truck weigh stations on the road network of Bosnia and Herzegovina.

KEY WORDS

vehicle overloading; freight vehicles; weigh station; weight-in-motion (WIM) scales;

1. INTRODUCTION

Road infrastructure is significantly influenced by road freight vehicles, which in practice represents vehicles with a mass exceeding 3.5 tons. Traffic load has an important impact on traffic safety in each country. Under the current economic conditions, many carriers are trying to make savings by reducing the number of transports, and by increased vehicle charges. In this way, the axle load and the overall weight of the freight vehicles exceed the legally permissible values, which on the network of the main and regional roads in Bosnia and Herzegovina on which these overloaded freight vehicles operate, leads to major damage to the roadway, shortening the lifetime of use and endangering road safety. It is therefore, important that the company that manages the road infrastructure carries out regular monitoring and prevention of the occurrence of overloading of freight vehicles by the carrier on the roads in Bosnia and Herzegovina.

Enforcement is a critical element of any plan for controlling vehicle weights. Effective enforcement must assure those who operate in violation of the established limits that it is likely that they will be apprehended and will be given penalties and sanctions of sufficient magnitude to function as a deterrent [1].

Several studies were conducted to assess and evaluate truck weight regulatory policies and enforcement efforts [2, 3, 11, 12].

The purpose of a truck weighing program is to enforce legal load limits and thus prevent trucks from damaging roadways and bridges. Essential to truck weight enforcement is the effective combination and deployment of various types of scales (permanent, portable, and semi-portable). Through the use of data collected in truck traffic studies, permanent scales can be located where there are many overloaded trucks, and these scales can be supported by roving portable-scale crews [4].

The location of sites for permanent weigh stations, semi-portable stations, and supporting portable weigh units is basic for good truck weight enforcement. Many US states have conducted studies to determine the factors that should be considered in truck weigh stations' site selection. Two studies conducted in Georgia, USA, identified the following items to be relevant: road systems and functional classifications, geographic location, traffic volume, season of the year, direction of route, service provided, product being transported, economic status of the transportation zone, and truck traffic patterns [4].

The US state agencies interviewed in the preparation of NCHRP SYN 82 [4] identified criteria to be used in selecting and evaluating a site after the route and general location have been established by a truck traffic flow study. All the US state agencies recommend that the site be on a segment of highway that trucks cannot bypass.

California is one of the few US states that has prepared criteria for site selection. There, the primary consideration of selecting locations for permanent weigh stations is commercial vehicle traffic volume. The minimum average daily commercial vehicle count, exclusive of two-axle trucks, is set at 600 vehicles per day (both directions) for a permanent platform scale to be installed. Other criteria include considerations such as [4] the following:
- Location of other facilities (existing or planned) on other highway routes should be accounted for;
- Origin and destination counts should avoid double interception of a sufficient percentage of the commercial vehicle traffic;
- Dual inspection facilities on each side of the highway should not be constructed if 80% or more of the trucks would be intercepted at one side of the highway;
- Locations that can be bypassed easily must be avoided;
- Sufficient land must be available, and
- Other local conditions, e.g. utilities availability, climate, should be accounted for.

A Federal Highway Administration (FHWA) report [5] suggests numerous possible considerations for station site selection. These include:
- Average daily traffic volume;
- Percentage of trucks;
- Percentage of trucks of each type;
- Variations in the percentages of trucks carrying different types of commodities;
- Whether there is a seasonable variation in the number of trucks in the ADT, and whether within the season there is a variation in the type of commodities carried;
- Relative amount of interstate trips and intrastate trips;
- Land use characteristics, adjacent to the station site and at origin and destination of truck traffic;
- Ease-difficulty of trucks bypassing the station to avoid being weighed; and
- Nearby alternative routes.

Another study [6] suggested some guidelines for identifying general locations or corridors within which stations can be located:
- Establish stations on routes with high truck volumes;
- Locate stations on major intercity or interregional routes;
- For stations on lower order roads, special care should be taken to avoid locations with atypical traffic conditions; and
- Within the above criteria, stations should be located at or near vehicle classification sites or Automatic Traffic Recorder sites wherever possible.

A study [7, 22] found that US state weight law enforcement programs were not adequate deterrents to overweight trucking. In response to this, the US Federal Highway Administration (FHWA) developed a three-point plan: (a) evaluate Weigh-in-Motion (WIM) equipment and promote its use by states, (b) evaluate scale avoidance by trucks that either bypass an open scale or stop and wait until the scale is closed, and (c) develop and test a statistically valid prototype state weighing plan. WIM scales are also used quite effectively to screen trucks on busy highways so that only those trucks that appear to be operating above the legal or statutory weight limits are removed from traffic to be weighted on static or portable scales. The drivers of overweight trucks frequently are warned about weigh stations over citizen band (CB) radios and avoid scales by pulling over to the roadside until the scales are not in operation or by choosing an alternate route [7].

Truck weight data are routinely collected for estimating the frequencies of each type of truck and year-to-year changes in axle and gross weights. Many studies and practice manuals are directed towards the selection of truck weigh sites based on a statistically-based sampling scheme designed to insure statistical representation. For example, the US Traffic

Monitoring Guide states that the truck weight sample should consist of at least 90 measurements taken over a 3-year cycle with 1/3 of the sample concentrated on the Interstate highway system [1, 13, 19].

It is obvious from the above review of international criteria for selecting the locations of truck weigh stations that they are generally local in nature and do not provide a macroscopic view of strategic and/or optimum locations [21].

The truck weigh stations should be located at a limited number of control points on the road network so as to achieve the optimum utilization of available resources and to accomplish the system's objectives [15, 16]. This statement is in some way a general motivation for this paper.

2. PROBLEM BACKGROUND

Bosnia and Herzegovina (B&H) covers an area of 51.2 thousand square kilometres, with a population density of 75.6 persons/km2. The total population is 3.9 million (2013 Census) with 78% living in urban areas. These cities and towns are connected by a highway network of about 45,000 km in length. The number of freight road vehicles in B&H has doubled in the last decade with more than 86,000 trucks using the highway network for goods movement between and within urban areas. It is expected that the daily volume of transport by trucks will increase more than 80% compared to the year 2010 (*Table 1*). Truck trips in Bosnia and Herzegovina are split roughly into two thirds – one third between rigid trucks (up to three axles) and articulated trucks (trucks with more than three axles).

The pattern of trips is very different between rigid and articulated trucks. In the former type, 70 percent of trips that begin in the Federation of B&H, and 58 percent of trips that begin in the Republic of Srpska, end in the Federation of B&H and the Republic of Srpska, respectively. Conversely, 21 percent of trips that begin in the Federation of B&H, and 32 percent of trips that begin in the Republic of Srpska, end in the Republic of Srpska and the Federation of B&H, respectively.

However, in case of articulated trucks, only 52 percent of trips that begin in the Federation of B&H, and 37 percent of trips that begin in the Republic of Srpska, end in the Federation of B&H and the Republic of Srpska, respectively. Further 23 percent of trips that begin in the Federation of B&H, and 25 percent of trips that begin in the Republic of Srpska, end in the Republic of Srpska and the Federation of B&H, respectively. [20].

Collecting data on the weight of freight vehicles is very important in many aspects including the need for correct dimensioning of the carriageway, road maintenance, bridge design, and the successful implementation of legislation and so on. The three types of data on the weight of freight vehicles are of particular importance: Gross Vehicle Weight, the distribution of the total weight of the axles of vehicles and the equivalent standard axle load for a specific type of vehicle. The dimensions, total mass and axle load of vehicles are determined by the state regulations (Official Gazette of B&H, No. 23/07 of 02.04.2007). An example of the permitted axle load is shown in *Figure 1*.

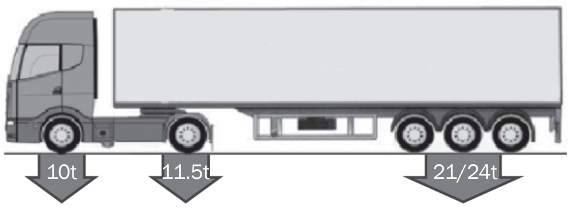

Figure 1 – The permitted axle load in Bosnia and Herzegovina

The truck fleet owners, in an attempt to reduce their unit transportation cost (KM/tonnes-km), have often loaded their trucks to the maximum and to over the capacity. These heavily loaded trucks can cause high costs in terms of maintenance and rehabilitation of the damaged road network as a result of overloading the vehicle. Also, the relative damage depends on the type and number of shafts on each vehicle, as well as the type of carriageway on which the vehicle is moving. Every vehicle that moves along the road network causes current, very little, but still significant deformation on the roadway construction. The total flow of vehicles has a cumulative effect which gradually leads to the deformation of the carriageway and breaks down to a crack. Therefore, the effect of overloading is not felt in one day, but it is quite visible over a certain period of years, and it also affects the road safety [17].

Table 1 – Expected daily cargo transport by trucks in 2010 and 2020

	Truck type and year					
	Rigid		Articulated		Combined	
	2010	2020	2010	2020	2010	2020
Ton-kilometers (000)	6,438	11,143	10,122	17,224	16,560	28,367
Total tons	65,996	115,213	92,992	172,543	158,980	287,756

Source: The Study on the Transportation Master Plan in Bosnia and Herzegovina, JICA, 2001

Lately, every effort has been made to achieve a positive trend of improving road safety in Bosnia and Herzegovina, so that the threat to road safety can be attributed to some extent to the movement of overloaded trucks with excessive axle load and exceeding the permitted gross vehicle weight.

The measurements of the total weight and axle load of freight vehicles on the roads in Bosnia and Herzegovina started with the introduction of static scales to perform the measurement while the vehicle is stationary, or out of traffic, so as to obtain reliable measurement results. These measurements are used in order to determine exceeding the axle load and gross vehicle weight. Data collection was carried out on a total of 45 selected locations for a period of two years, on the whole territory of Bosnia and Herzegovina.

In the reporting period a total of 504 control trucks measuring axle load and total weight were performed, using a static balance, to a total of 45 selected locations. During the control, in 122 cases it was found that the vehicles were overloaded, which represents a total percentage of 24.2% of offenders of the controlled vehicles (*Table 2*).

By using the Mann-Whitney-U-stop releasing test (*Figure 2*) highly statistically significant difference (U=5653.000, z=-12.602, p=0.000) in the total weight of trucks that had an overload (N=122, Md=41.34) of the total weight or axle load in relation to the trucks which had no overload (N=382, Md=34.70) was obtained.

The intensity and quality of this control do not satisfy the actual needs so that the number of offenses in respect to exceeding the weight increases.

Observing the structure of overloaded commercial vehicles in groups of vehicles, the largest percentage of exceedance was recorded in five-axle trucks. By applying the χ^2 test a highly statistically significant difference (χ^2=33.260, p=0.000) for the presence of exceeding relative to truck axles is obtained.

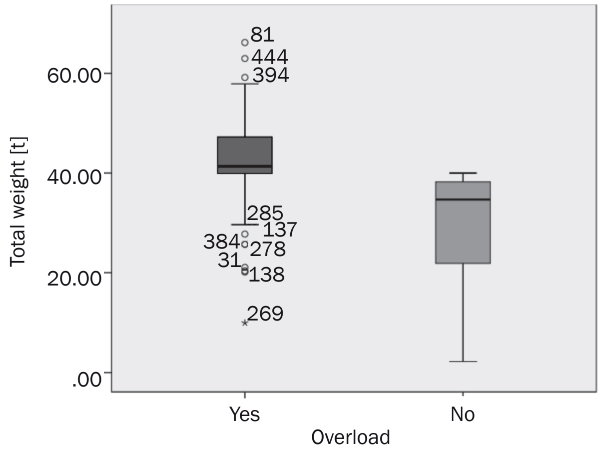

Figure 2 – Relation to overload and gross vehicle weight

Simultaneously with the data on the measurement of the total mass of freight vehicles, the data on the measuring the axle load has been analyzed according to the types and groups of axles, in accordance with the legislation (*Table 3*), which is represented graphically in *Figure 3*.

By testing the total overload of the axle (six groups: two to seven axles) and using the Kruskal Wallis test a highly statistically significant difference (χ^2=21.283, p=0.001) of the total overload of the axles was obtained.

Although it was established that the overload compared to the permissible weight of the vehicle can be considered quite high, even more worrying is the reloading value and the degree of overload over the permitted limits for the percentages of group transferred (*Figure 4*).

Table 2 – Total weight [t]

Overload	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

Table 3 – Overload per axle

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	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

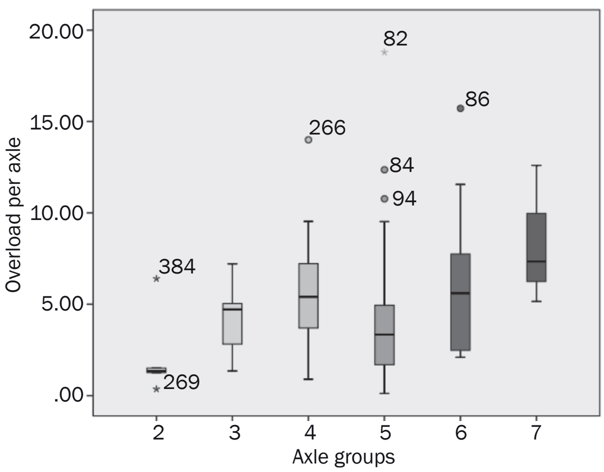

Figure 3 – Overload per axle groups

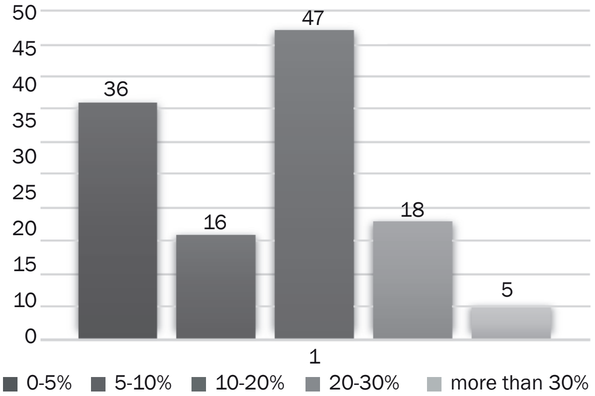

Figure 4 – Overload in percentages

It may be noted that there are cases where the actual gross vehicle weight is much higher than legally permitted for a certain commercial vehicle category. Extremely high gross vehicle weight above the permitted level may be the cause of grave concern, especially in terms of ability to handle extra heavy commercial vehicles in extraordinary circumstances. As such, additional weight creates risk for trucks and may endanger the safety of other road users. Overload as a phenomenon in the goods transport is seen in almost all countries of the world and is usually an indicator of economic growth, especially in developing countries, such as Bosnia and Herzegovina. On the other hand, we cannot ignore the negative impact on road infrastructure (roads and bridges) and traffic safety when evaluating the potential impacts of overloaded commercial vehicles.

The impact of the flow of vehicles on the road is usually expressed in the number of equivalent traffic load for dimensioning asphalt pavements, according to JUS U.C4.010 of 1981, which increases with increasing axle load vehicles with fourth degree (*Figure 5*). This means that the case overload of 10% above the permitted weight, makes damage to the pavement by 40%. Based on the information provided to the mean value of the measured overload on the road network in Bosnia and Herzegovina was 12%, while the most common, in 47 cases, was any overload in the range of 10-20%.

Figure 5 – Relationship of the vehicle overload and the damage to the carriageway

3. MODEL DESCRIPTION

This section describes the model adopted in this paper. In traditional network location theory, the demand for service originates from the nodes of the highway network [10]. However, in our case the demand for service originates from the flow (truckers) travelling on various paths of the highway network. Therefore, the objective is to locate the facilities (e.g. trucks weigh stations) so as to maximize the total flow of trucks that are intercepted during their travel and, at the same time, to maximize the number of trucks to be checked that violate the permitted weight. The term "violation of permitted weight" will be considered in two ways: weight violation frequency and weight violation volume. In our case we applied the simplified deterministic flow-interception model combined with information on the weigh violation characteristics. The problem of locating the truck weigh stations is to define the optimal number of stations on the network with maximum truck traffic flow and covering spots with the highest weight violation (e.g. frequency and volume). Here, the focus is on the deterministic version of the problem where truck traffic flow rates are known. Additional general assumptions of the model discussed here [8, 9, 10, 14, 18] are:

- The customers (truckers) make no deviation from their pre-planned tours to visit the facilities.
- The weighting program is mandatory and the waiting time of customers (truckers) at facility is not in consideration.
- The total number of customers (truckers) are intercepted with at least 85% precision level

All these assumptions are reasonable and fit well in the research problem presented in this paper.

Consider a road network with (N) nodes, truck traffic flow (T_{tf}), frequency of truck weigh violation (W_{vf}), and volume of truck weigh violation (W_{vv}), which are model parameters. The main idea of the model is that the number and location of truck weigh stations depends on the number of road network nodes and the volume of truck traffic flow. The additional factors are: the frequency of truck weight violation and the volume of truck weight violation which played a corrective role in the model. Therefore, the location of truck weigh station (m) is the function of $n(N, T_{tf}, W_{vf}, W_{vv})$

One of the most important issues related to continuous truck weight monitoring is the number of stations. It is assumed that the truck traffic data population has a normal distribution. Due to the restraints, the number of truck weigh stations must usually be small (n ≤ 30). Also, the mean and variance in the data population are unknown. To determine the minimum sample size needed to obtain some selected level of accuracy, the t distribution is used. The general form of this equation is:

$$t_\alpha = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}} \quad (1)$$

where:

αt-(1–α)-th – percentile of the t distribution with (m–1) degrees of freedom;
α=-1 – percent of confidence level chosen/100;
$\bar{x}$ – sample mean;
μ – population mean;
s – standard deviation of the sample;
n – sample size (i.e. number of truck weigh stations).

The shape of the t distribution is similar to the normal (bell curve) distribution. However, the t distribution has more probability in the tails than the normal distribution. As the number of the degrees of freedom (m–1) approaches infinity, the limiting form of the t distribution is the standard normal distribution. The values of the t distribution for 80% confidence is α=0.20, for 90% confidence it is α=0.10, for 95% confidence it is α=0.05, and so on. To be "95% confident" means that there is a 95% probability that the true population mean lies within the specified confidence interval. If we use the precision level (PL) instead of an error of the mean of the chosen confidence interval ($\bar{x}$–μ) and the coefficient of variation (CV) instead of the standard deviation from the previous equation we obtain the number of stations as:

$$n = \left(\frac{t_\alpha CV}{PL} \right)^2 \quad (2)$$

In order to utilize the model and locate n number of truck weigh stations we identified the input factors influencing the choice of truck weigh locations. The chosen input factors are: truck traffic flow rate, number of network nodes, weight violation frequency and weight violation volume. Therefore, the regional number of truck weigh stations is:

$$n_i = n \frac{F_i}{\sum F} \quad (3)$$

where:

n_i – regional number of truck weigh stations;
n – total number of truck weigh stations;
$\left(\frac{F_i}{\sum F} \right)$ – relative weigh correctional factor;
F_i – single weigh factor (T_{tf}-Truck Traffic Flow, N_f-Node Factor, W_{vf}-Violation Frequency Factor);
W_{vvf} – Volume Violation Factor.

The approach employed to obtain the information on these factors uses the truck count on the major roads accessing the largest cities in B&H, the position of nodes of a network of major roads (*Table 4*), and the existing data obtained from truck weight inspection during a two-year period.

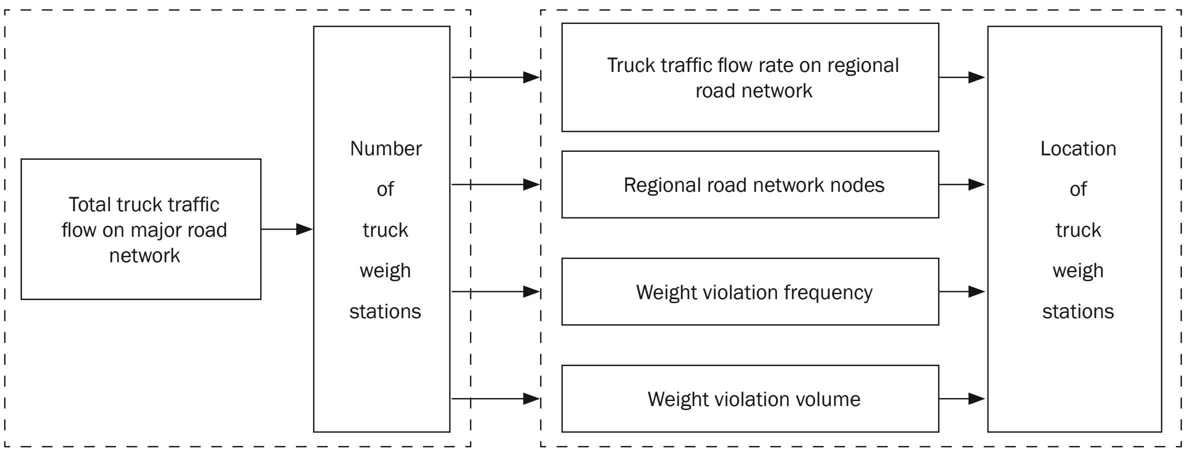

Figure 6 – Scheme of the model

Table 4 – Daily truck trip productions and attractions and network nodes for major cities/centres

City/ Regional center	Truck trips produced and attracted	%	Number of network nodes	Location of network nodes
Banja Luka	2,768	21.0	5	M16-North, M16-South, M16.1, M4, R413
Bihać	880	6.7	3	M5-West, M5-East, M14
Doboj	1,481	11.3	4	M17-North, M4-East, M4-West, R473
Mostar	1,616	12.3	3	M17, M6, M15
Sarajevo	2,276	17.3	5	M17-North, M17-South, M18-North, M18-South, M5
Tuzla	2,014	15.3	4	M18-West, M4, M1.8, R459
Zenica	1,043	7.9	3	M17, M5, M16.2
Zvornik	1,082	8.2	4	M15,M19, R456
Total	13,160	100	31	

Table 5 – Number of truck weigh stations with precision level

Number of stations (n)	n - 1	α	Coefficient of variation (CV)	$\alpha \cdot CV$	$\sqrt{n}$	Precision level ($PL\%$)
1	0	-	-	-	-	-
2	1	12.706	21.86	277.753	1.41	196.99
3	2	4.303	21.86	94.064	1.73	54.37
4	3	3.182	21.86	69.559	2.00	34.78
5	4	2.776	21.86	60.683	2.24	27.14
6	5	2.571	21.86	56.202	2.45	22.95
7	6	2.447	21.86	53.941	2.64	20.26
8	7	2.365	21.86	51.699	2.83	18.27
9	8	2.306	21.86	50.409	3.00	16.80
10	9	2.262	21.86	49.447	3.16	15.65
11	10	2.228	21.86	47.704	3.32	14.67
12	11	2.201	21.86	48.114	3.46	13.91
13	12	2.179	21.86	47.633	3.60	13.23
14	13	2.160	21.86	47.218	3.74	12.625
15	14	2.145	21.86	46.890	3.87	12.116
16	15	2.131	21.86	46.584	4.00	11.646
17	16	2.120	21.86	46.343	4.12	11.248
18	17	2.110	21.86	46.125	4.24	10.878
19	18	2.101	21.86	45.928	4.36	10.534
20	19	2.093	21.86	45.753	4.47	10.236
21	20	2.086	21.86	45.600	4.58	9.956

Table 6 – Number of optimally located truck weigh stations

City/ Regional center	Truck traffic flow factor (T_{tf})	Number of nodes factor (N_f)	Frequency violation factor (W_{vf})	Volume violation factor (W_{vvf})	Sum of factors $\sum F$	Relative weigh factors $\left(\frac{F_i}{\sum F}\right)$	Number of stations (n)
Banja Luka	0.210	0.161	0.12	0.37	0.861	0.146	2
Bihać	0.067	0.097	0.10	0.29	0.554	0.094	1
Doboj	0.113	0.129	0.17	0.40	0.812	0.138	2
Mostar	0.123	0.097	0.11	0.33	0.660	0.112	1
Sarajevo	0.173	0.161	0.12	0.38	0.834	0.142	2
Tuzla	0.153	0.129	0.12	0.40	0.802	0.136	1
Zenica	0.079	0.097	0.13	0.35	0.656	0.112	1
Zvornik	0.082	0.129	0.13	0.36	0.701	0.119	1
Total	1.00	1.00	1.00	2.88	5.88	1.00	11

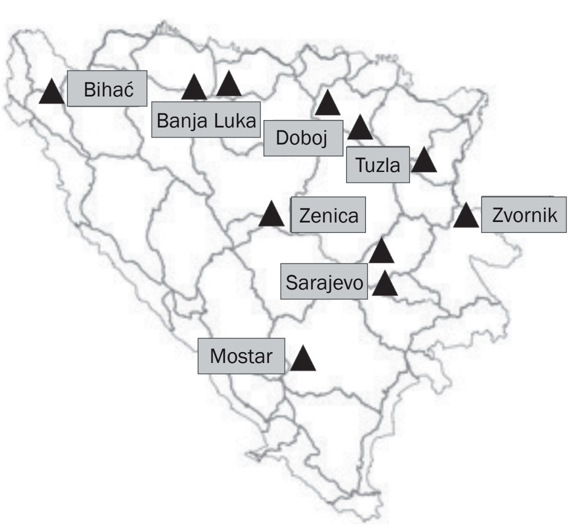

Figure 7 – Proposed optimal locations of truck weigh stations in Bosnia and Herzegovina

Table 5 summarizes the results of having a number of weigh stations ranging from one to the number that meets the required level of precision which turned out to be 21 stations with 90% precision level. However, in this work the requirement was set that the precision level must be at least 85% which can be satisfied with 11 stations. *Table 6* shows the number of optimally located truck weigh stations and *Figure 7* shows the map of Bosnia and Herzegovina with the proposedlocations of 11 permanent truck weigh stations that guarantee satisfactory coverage of the targeted truck traffic flow with the required precision level.

4. CONCLUSION

The results of this research have shown the size of the problem of overloaded commercial vehicles on the roads in Bosnia and Herzegovina. What is even more worrying is the degree of overload, which is extremely high, especially in case of 5-axle trucks (58.7%), followed by 2-axle and 3-axle trucks. The research found that the most pronounced level of overload ranges from 10-20% of the permissible total weight. In addition to the damaging impact on the road infrastructure (roadway) and pollution of the environment through the emission of harmful gases, overloading of the vehicles also leads to restrictions on the stability of freight vehicles and the prolongation of the braking distance for overload vehicles. In addition, if the truck is not in good condition and/or the road is wet/slippery, a high level of overload can lead to a fatal outcome in the event of an accident.

Since significant efforts are being made in Bosnia and Herzegovina to improve the road infrastructure through the construction of a new and reconstruction of the existing road network, thus achieving a reduction in the risk of traffic accidents, the problem of overloading should be taken very seriously, and the approach to control the measurement of the total weight and axle loads of commercial vehicles are maximally intensified to counter these phenomena, which includes:

- Increase the control measures that will reduce the number of unpunished offenders;
- Define and implement the optimal number and locations of truck weigh stations that will include mainstream cargo transportation;
- Improve the quality of work and cooperation among relevant agencies for roads and police on truck weight control;
- The cost of violations (e.g. fines and other actions) to truckers must increase and should depend on the frequency of the violation and the amount exceeding the weight limit.

In this paper, based on the analyzed data on the control of freight vehicles on roads in Bosnia and Herzegovina, a model for determining the locations for measuring the axle load and the total mass of freight vehicles was presented, which would suppress the observed phenomena and protect the road infrastructure. Real case application represents an additional benefit of this research.

In order to utilize the model and locate the optimal number of truck weigh stations we identified the input factors influencing the choice of truck weigh locations. The chosen input factors are: truck traffic flow rate, number of network nodes, weigh violation frequency and weigh violation volume. The approach employed to obtain the information on these factors uses the truck count on major roads accessing the largest cities in Bosnia and Herzegovina, the position of nodes of a network of major roads and the existing data obtained from truck weight inspection during a two-year period. In this work we set the requirement that the precision level must be at least 85% which can be satisfied with 11 truck weigh stations with the proposed locations that guarantee satisfactory coverage of targeted truck traffic flow with the required precision level.

The proposed locations for truck weigh control need not be occupied by permanent static scales because of the posibility for drivers with overloaded trucks to choose alternative routes or wait until the station is closed. Therefore, it could be more appropriate to utilize the Weigh-in-Motion (WIM) scales which will record truck weight and enhance data credibility.

Dr. **MIRSAD KULOVIĆ**
E-mail: m.kulovic@hotmail.com
dipl. ing. **ZORAN INJAC**
E-mail: zinjac@putevirs.com
dipl. ing. **SLAVKO DAVIDOVIĆ**
E-mail: davidovic.slavko@hotmail.com
dipl. ing. **IVO POSAVAC**
E-mail: ivoposavac8@gmail.com

MODEL ZA ODREĐIVANJE LOKACIJA ZA MJERENJE OSOVINSKOG OPTEREĆENJA I UKUPNE MASE TERETNIH VOZILA: STUDIJA SLUČAJA U BOSNI I HERCEGOVINI

SAŽETAK

Broj registrovanih komercijalnih teretnih vozila je u stalnom porastu, a time i saobraćajno opterećenje na putevima u Republici Srpskoj. Značajan dio teretnih vozila koji se kreće magistralnim i regionalnim putevima je preopterećen i izaziva značajna oštećenja putne infrastrukture, utiče na bezbjednost saobraćaja i povećanje emisije štetnih gasova po čovjeka i njegovu okolinu. Zabrinjavajući je utvrđeni stepen preopterećenja koji je izuzetno visok, a posebno se ističu 5-osovinska teretna vozila koja su zastupljena sa 58.7%. Istraživanje je pokazalo da se naizraženiji nivo preopterećenja kreće u granicama 10-20% u odnosu na maksimalno dozvoljenu težinu. Efekat preopterećenih vozila i njihov uticaj, prije svega, na opterećenje na putevima, održavanje i vijek trajanja, kao i ukupnu bezbjednost saobraćaja ilustruje ozbiljnost situacije za koju je potrebno striktno sprovođenje zakonske i podzakonske regulative od strane relevantnih agencija i upravljača puteva kao korak ka sprečavanju evidentiranog saobraćajnog problema. Prema tome, cilj ovog rada je da procijeni i predstavi optimalan broj lokacija za mjerenje osovinskog opterećenja i ukupne težine teretnih vozila na putnoj mreži Bosne i Hercegovine.

KLJUČNE RIJEČI

preopterećenje; teretna vozila; put; bezbjednost saobraćaja;

REFERENCES

[1] U.S. Department of Transportation. *Traffic Monitoring Guide*. 3rd ed. Federal Highway Administration, Office of Highway Information Management; 1995.

[2] Hanscom FR. *Developing Measures of Effectiveness for Truck Weight Enforcement Activities*. NCHRP Research Results Digest: 229, 1998.

[3] Hanscom FR, Goelzer MW. Truck Weight Enforcement Measures of Effectiveness: Development and Software Application. *Transportation Research Record.* 1998;1643: 152-160.

[4] Downs HG. *Criteria for Evaluation of Truck Weight Enforcement Programs*. Transportation Research Board. NCHRP Synthesis of Highway Practice: 82, 1981.

[5] Winfrey R, Howel P, Kent P. Federal Highway Administration. Truck Traffic Volume Data for 1971 and Their Evaluation; 1976.

[6] Gardner WD. *Truck Weight Study Sampling Plan in Wisconsin*. Transportation Research Board, Annual Meeting; 1983.

[7] Washington DC. Transportation Research Board. *Truck Weight Limits: Issues and Options.* National Research Council. Special Report: 225, 1990.

[8] Hodgson MJ, Rosing KE, Shmulevitz F. A Review of Location-Allocation Applications Literature. *Isolde VI Survey Papers. Studies in Locational Analysis*. 1993; 3-29.

[9] Berman O, Larson RC, Fouska N. Optimal Location of Discretionary Facilities. *Transportation Science*. 1992;26: 201-211.

[10] Berman O, Hodgson MJ, Krass D. Flow-Interception Problems, Chapter 17. In: Drezner Z (editor). *Facility Location: A Survey of Applications and Methods*. Springer Series in Operations Research; 1995.

[11] Walton CM, Yu C-P. Truck Size and Weight Enforcement: A Case Study. *Transportation Research Record.* 1983;920: 26-33.

[12] Fekpe E. Evaluating Truck Weight Regulatory Policies. *Canadian Journal of Civil Engineering.* 1995;22: 35-39.

[13] Dueker K, Rabiega WA, Rex B. *Locating Truck Data Collection Sites in Oregon Using Representation Optimal Sampling.* Oregon State Highway Division, Department of Transportation. Final Report, 1988.

[14] Gendreau M, Laporte G, Parent I. Heuristics for the Location of Inspection Stations on a Network. *Naval Research Logistics*. 2000;47: 287-304.

[15] Šelmić M, Teodorović D. Vukadinović K. Location inspection facilities in traffic networks: an artificial intelligence approach. *Transportation Planning and Technology*. 2010;33: 481-493.

[16] Jun, Y, Min Z, He B, Yang C. Bi-level programming model and hybrid genetic algorithm for flow interception problem with customer choice. *Computers & Mathematics with Applications.* 2008;57: 1985-1994.

[17] Podborochynski D, Berthelot C, Anthony A, Marjerison B, Litzenberger R, Kealy T. Quantifying Incremental Pavement Damage Caused by Overweight Trucks. Paper prepared for presentation at the Effects of Increased Loading on Pavement Session of the *2011 Annual Conference of the Transportation Association of Canada, Edmonton, Alberta;* 2011.

[18] Jacob B, La Beaumelle VF. Improving truck safety: Potential of weigh-in-motion technology. *IATSS Research*. 2010;34: 9-15.

[19] Straus SH, Semmens J. *Estimating the Cost of Overweight Vehicle Travel on Arizona Highways*. Arizona Department of Transportation. Final Report: 528, 2006.

[20] Republic of Srpska. Republican Bureau of Statistics. *Transport and comm. - Statistical Yearbook;* 2015.

[21] Karim MR, Ibrahim NI, Saifizul AA, Yamanaka H. Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass and enforcement capability. *International Association of Traffic and Safety Sience*. 2014;37(2): 124-129.

[22] NDSU. Upper Great Plains Transportation Institute. *North Dakota Truck Harmonization* Study. Final Draft Report, 2016.