CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering
Prof. emer. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. emer. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
Assist. Prof. Maja Ahac
Assist. Prof. Saša Ahac
Assist. Prof. Ivo Haladin
Assist. Prof. Josipa Domitrović
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. Rudolf Eger
Prof. Kenneth Gavin
Prof. Janusz Madejski
Prof. Nencho Nenov
Prof. Andrei Petriaev
Prof. Otto Plašek
Assist. Prof. Andreas Schoebel
Prof. Adam Szeląg
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

INFLUENCE OF THE OVERLOADED VEHICLES ELIMINATION ON THE ROAD PAVEMENT DURABILITY

Piotr Zieliński[1], Malwina Spławińska[1], Piotr Burnos[2], Janusz Gajda[2]
[1] *Cracow University of Technology, Poland*
[2] *AGH University of Science and Technology, Poland*

Abstract

Overloaded heavy vehicles is currently big issue in Europe. It is proved that overloading contributes to shortening the fatigue life of the pavement structure. To counteract this unfavourable phenomenon, effective tools for the elimination of overloaded vehicles should be developed, one of them being the use of Weigh-in-Motion (WIM) systems. In our work, we show how the accuracy of weighing in WIM systems affects the efficiency of vehicle elimination from road traffic and how this is translated to the road pavement durability. We took into account the weighing results from real WIM site equipped with 16 axle load sensors. The sensitivity of the pavement structure durability to the elimination of overloaded vehicles was analyzed. The obtained results allowed to state that with the increase of system accuracy (which allows to increase the percentage of overloaded vehicles eliminated from traffic), the global load factor for the entire vehicle decreases and thus the fatigue life of the road pavement increases. Completed calculations show that in the case of rigid pavements (cement concrete), the elimination of overloaded vehicles will result in an even greater increase in durability than in case of flexible structures (asphalt pavement). A sensible solution seems to be the use of WIM system with accuracy of 6 % which translate to use 5 to 7 axle load sensors. Further increase of number of sensors does not give such large effects in terms of extending the fatigue life of the road pavement.

Keywords: Weigh-in-motion systems, WIM, accuracy, road pavement durability, overloaded vehicles, axle load equivalency coefficient

1 Introduction

The first stage in the design of the road pavement is the calculation of the forecasted total traffic of heavy vehicles (converted into equivalent standard axles of 100 kN) throughout the design period [1]. Other categories of vehicles due to low gross vehicle weight GVW (below 35 kN) are ignored. In Poland, the design period for flexible road pavements is 20 years or, in the case of highways and expressways, 30 years. In the case of existing roads, it is possible to monitor the GVW by measuring the axle loads of vehicles in motion using Weigh-in-Motion (WIM) systems [2]. Such measurements, according to the study [3], were used, among others to determine the aggressiveness coefficients related to the load of individual profiles of heavy vehicles. It was found that the type of vehicle which has the greatest impact on the degradation of the pavement is a road tractor with a semi-trailer (two single axle tractor and one triple axle semitrailer). According to the above study, the relative aggressiveness of this class of vehicles in the total fatigue damage of the pavement ranges (depending on the measuring station) from 56 % to 80 % (on average 72 %). Therefore, in this publication, the analysis is limited only to this class of vehicles.

DOI: https://doi.org/10.5592/CO/CETRA.2018.792

In many countries for vehicle control purposes, static scales, weighbridge platforms or Low-Speed WIM scales are commonly in use. Such scales are subject to legal metrological control and are allowed to use for enforcement purposes. In Poland the body authorized to carry out such controls is the Inspectorate of Road Transport (IRT) which has 300 static weighing stations. Static vehicle control requires each inspected vehicle to be stopped and directed to a weighing station.
Common accuracy of static axle scales is 2 %. The occurrence of a weighing error causes that the allowable values of GVW and axle loads must be increased by the amount of this weighing error. This action results from caution and prevents the normative vehicle from being considered as overloaded. Thus, the higher the weighing error is, the less overloaded vehicles will be eliminated from traffic.
This effect is illustrated in Figure 1, which shows an example of distribution of GVW for 2C+3N vehicles. If we assume that permissible GVW is 40 tons, all vehicles with GVW above this value are considered to be overloaded and should be eliminated from the traffic. But due to the occurrence of weighing error allowable values of GVW must be increased. As consequence some overloaded vehicles are not eliminated from the traffic (red shaded area in the Figure 1). Just vehicles with GVW in green area are considered to be overloaded.

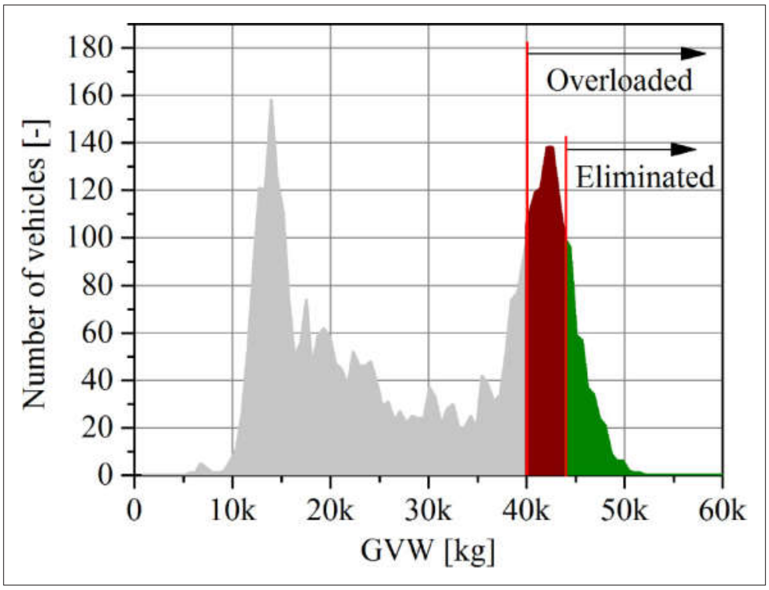

Figure 1 Distribution of the GVW and the influence of the WIM system accuracy on the effectiveness on the elimination of overloaded vehicles.

This leads to the conclusion that the more accurate the measurements, the more overloaded vehicles are eliminated from the traffic. In case of WIM's, accuracy of the vehicle weight measurement depends on the number of axle load sensors used in the system [4]. For one sensor accuracy is circa 15 %, for two sensors (most common configuration) is about 10 %, and so on [5].
The purpose of this publication is to answer the question: how the accuracy of weighing in WIM systems translates into the effectiveness of elimination of overloaded vehicles from traffic and, consequently, on the road pavement fatigue durability?

2 Test methods

In order to answer the question posed within the aim of the paper, an analysis of the vehicle weighing results of the 16-sensor WIM system (located within the National Road no. 81 in Gardawice) was carried out. The vehicles were weighed continuously in a period of 3 months. The weighing results of two axle tractor and one triple axle semitrailer vehicles collected in this way were analyzed in 9 variants. The first variant referred to all registered traffic, while the next variants to traffic reduced by overloaded vehicles weighed in the WIM system equipped sequentially with the following number of axle load sensors: 2, 4, 6, 8, 10, 12, 14 and 16. It was assumed that the weighing relative error in the WIM system equipped with one load sensor is 15 %. This is the maximum value of error. Whereas, for systems equipped with a larger number of sensors, this error changes according to the dependence, Eq. (1):

$$\varepsilon = \frac{u}{\sqrt{n}} \tag{1}$$

Where:
u – measurement error in the WIM system with one load sensor (the adopted value was 15 %);
n – number of sensors.

In analysis we eliminated vehicles that, due to their GVW, exceeded the maximum value specified in the applicable legal regulations, increased by the value of measurement error, in accordance with Eq. (2):

$$GVW^{*} = GVW(1+\varepsilon) \tag{2}$$

Where:
GVW* – permissible GVW including measurement error;
GVW – permissible GVW (for Poland it amounts to 40 tons).

Next, the data were divided according to the type of axle (two single, one triple) and the load histogram for each axle was determined (interval length of 2 kip according to the 1993 AASHTO method , 1 kip = 4,45 kN) [6]. The shares of individual axle load intervals for a given number of sensors were determined as the quotient of the number of vehicles with axle load in the range of a given interval and the total number of vehicles, Eq. (3):

$$u_i = \frac{l_i}{L} \tag{3}$$

Where:
u_i – share of the i-th axle load interval for a given number of sensors;
l_i – number of vehicles with axle load in the i-th interval range for a given number of sensors;
L – total number of vehicles for a given number of sensors.

3 Results of analysis

The The exemplary results for the second single axle that most affects the pavement are summarized in Table 1.

Table 1 Ratio of vehicles with a given axle load [%] – second single axle

Axle weight [kip*]	Total traffic	WIM system accuracy							
		10 %	7.5 %	6.1 %	5.3 %	4.7 %	4.3 %	4.0 %	3.7 %
		Number of load sensors							
		2	4	6	8	10	12	14	16
0 – 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 – 4	0.13	0.14	0.15	0.16	0.16	0.17	0.17	0.17	0.17
4 – 6	5.98	6.48	6.92	7.18	7.35	7.47	7.57	7.64	7.70
6 – 8	14.14	15.34	16.38	16.98	17.39	17.68	17.91	18.07	18.23
8 – 10	7.53	8.16	8.72	9.04	9.25	9.41	9.53	9.61	9.70
10 – 12	6.38	6.92	7.39	7.66	7.84	7.97	8.08	8.15	8.22
12 – 14	5.58	6.05	6.46	6.70	6.86	6.97	7.06	7.13	7.19
14 – 16	5.95	6.45	6.89	7.15	7.32	7.44	7.54	7.60	7.67
16 – 18	5.84	6.28	6.68	6.89	7.02	7.11	7.13	7.19	7.22
18 – 20	6.89	7.41	7.82	7.98	8.07	8.11	8.11	8.11	8.08
20 – 22	11.56	11.81	11.68	11.34	11.06	10.94	10.75	10.57	10.52
22 – 24	13.96	13.00	11.78	11.09	10.40	9.98	9.60	9.38	9.01
24 – 26	10.17	8.31	6.40	5.41	5.18	4.80	4.60	4.43	4.40
26 – 28	3.92	2.49	1.98	1.83	1.54	1.40	1.42	1.40	1.34
28 – 30	1.25	0.81	0.49	0.38	0.36	0.33	0.34	0.34	0.34
30 – 32	0.61	0.29	0.22	0.22	0.20	0.20	0.20	0.20	0.21
32 – 34	0.08	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
34 – 36	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

** 1 kip = 4,45 kN*

Analyzing the load histograms for the second axle of the vehicles presented in Table 1, it can be concluded that with the increasing accuracy of weighing in WIM systems (conditioned by the increase in the number of sensors) their share in traffic is reduced, while the share of vehicles with less than the standard load increases. The next step was to calculate normalized load equivalency coefficients for individual load intervals and axle types, taking into account the share of load in each analyzed interval and the type of axle. The method of so-called 4th power, being a generalization of the 1993 AASHTO method, was applied here [6] Eq. (4):

$$F=\left(\frac{Q}{Q_0}\right)^m \tag{4}$$

Where:

F – axle load equivalency coefficient;

Q – axle load for a single axle, for the triple axle the sum of loads of three component axles (in the calculations the average value for each load interval was adopted);

Q_0 – equivalent axle load was adopted according to paper [2] as follows: for single axle Q_0 = 100 kN, for triple axle Q_0 = 263 kN;

m – power exponent (for flexible pavements m = 4, for rigid pavements m = 8 according to [7]).

Next, the sum of normalized load equivalency coefficients for all load intervals recorded for each studied axle was determined, obtaining the global load equivalency coefficient for individual vehicle axles in two construction variants: for flexible and rigid pavements, Eq. (5):

$$F_j = \sum_{i=1}^{k} F_i * u_i \tag{5}$$

Where:
F_j – global j-axle load equivalency coefficient;
k – number of load intervals for the j-th vehicle axle;
F_i – axle load equivalency coefficient for the i-th load interval;
u_i – as in Eq. (3).

After adding these coefficients, the global load equivalency coefficient was calculated for the analyzed vehicle type (two single axle tractor and one triple axle trailer) for all vehicle axles according to Eq. (6):

$$F_v = \sum_{i=1}^{n} F_j \tag{6}$$

F_v – vehicle load equivalency coefficient;
F_j – global j-axle load equivalency coefficient according to Eq. (5).

The results of calculations of the global load equivalency coefficients of axle and vehicle for individual load spectrum and types of pavement structure are presented in Tables 2 and 3. Analyzing the results presented in Tables 2 and 3, it can be concluded that with the increasing accuracy of the WIM system (which allows for increasing the effectiveness of elimination of overloaded vehicles from the traffic), the global load coefficient for individual axles of the analyzed vehicle decreases (to the largest extent in the case of the second-drive axle and triple axle), but it also does for the whole vehicle. The largest differences were observed for the rigid pavement.

Table 2 Global load equivalence factors for 2C + 3N vehicle for individual load spectra (flexible pavement)

Number and type of axle	Total traffic	WIM system accuracy							
		10 %	7.5 %	6.1 %	5.3 %	4.7 %	4.3 %	4.0 %	3.7 %
		Number of load sensors							
		2	4	6	8	10	12	14	16
1 (single)	0.236	0.224	0.216	0.212	0.209	0.206	0.205	0.204	0.203
2 (single)	0.723	0.621	0.550	0.514	0.492	0.476	0.467	0.460	0.453
3+4+5 (triple)	0.353	0.280	0.237	0.215	0.201	0.191	0.183	0.178	0.173
Total vehicle	1.31	1.13	1.00	0.94	0.90	0.87	0.86	0.84	0.83

Table 3 Global load equivalence factors for 2C + 3N vehicle for individual load spectra (rigid pavement)

Number and type of axle	Total traffic	WIM system accuracy							
		10 %	7.5 %	6.1 %	5.3 %	4.7 %	4.3 %	4.0 %	3.7 %
		Number of load sensors							
		2	4	6	8	10	12	14	16
1 (single)	0.071	0.064	0.059	0.057	0.055	0.054	0.053	0.053	0.052
2 (single)	1.189	0.911	0.748	0.675	0.631	0.601	0.589	0.578	0.568
3+4+5 (triple)	0.308	0.200	0.156	0.134	0.121	0.112	0.105	0.101	0.096
Total vehicle	1.57	1.18	0.96	0.87	0.81	0.77	0.75	0.73	0.72

In the last stage of the analysis, the obtained values of global vehicle load equivalency coefficients were reversed, obtaining fatigue durability of the pavement, and normalized according to F_V determined for the variant with the total number of vehicles, without elimination of overloaded ones. Figures 2 and 3 present the obtained results of fatigue durability of the pavement along with the adjusted power functions.

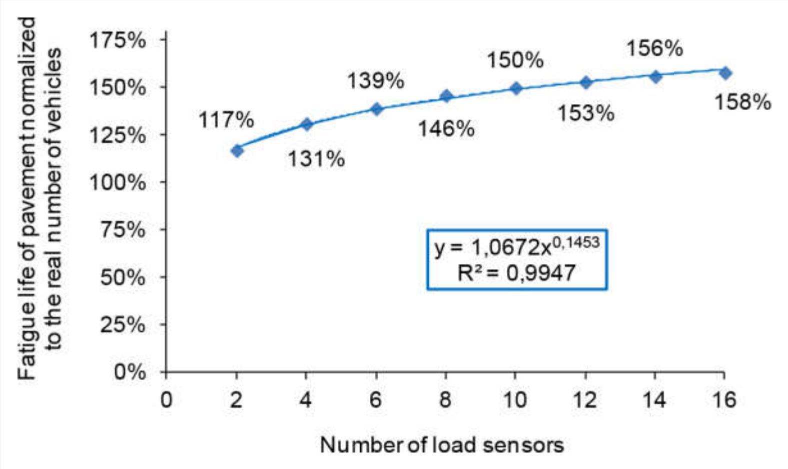

Figure 2 The result of the sensitivity analysis of durability of the flexible pavement structure to the elimination of overloaded vehicles, depending on the number of load sensors

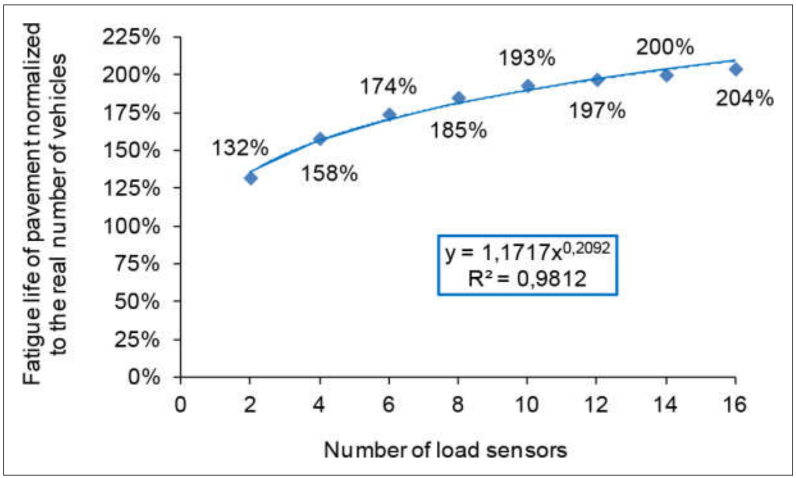

Figure 3 The result of the sensitivity analysis of durability of the rigid pavement structure to the elimination of overloaded vehicles, depending on the number of load sensors

4 Conclusions

Presented in this paper analyses allowed to draw the following conclusions:

- The obtained results show that with the increasing accuracy of weighing in WIM systems (by increasing the number of axle load sensors), the effectiveness of elimination of overloaded vehicles from the traffic increases. This contributes to the increase of fatigue durability of the pavement. Overloaded vehicles cause accelerated reduction in fatigue durability of the pavement, which was described by the so-called fourth power law, Eq. (4). The value of the power exponent depends on the type of pavement construction; for flexible asphalt pavements, it usually takes the value between 4 and 5 (in the analyzed example the adopted value was 4), while in the case of rigid concrete pavements, it ranges from 8 to 12 (in the analyzed example the adopted value was 8). Completed calculations show that in the case

of rigid pavements, the elimination of part of overloaded vehicles will result in an even greater increase in durability of the pavement.
- With the elimination of overloaded vehicles on the basis of 16 WIM sensors (high accuracy 3.7 %), the calculated increase in fatigue durability of the flexible pavement is approximately 50 %, while for rigid pavement, durability increases more than twice, in relation to the pavement conditions without elimination of overloaded vehicles.
- The elimination of overloaded vehicles based on the WIM system equipped with 2 load sensors (low accuracy 10 %) gives an increase in fatigue durability of flexible pavement by 17 %, while for rigid pavement, this increase is 33 % compared to the actual load spectrum (without elimination of overloaded vehicles).
- The obtained results indicate a greater sensitivity of fatigue durability of pavement at changes in the number of sensors in the range from 2 to 6 (accuracy 10 % to 6 %). This sensitivity decreases for a larger number of sensors.
- It seems wise to use WIM systems equipped with at least 6 load sensors. A further increase in the number of sensors (weighing accuracy) does not significantly increase the fatigue durability of the road pavement.

References

[1] Katalog typowych konstrukcji nawierzchni podatnych i półsztywnych, GDDKiA, Warszawa 2014.

[2] Burnous, P., et al.: “Road traffic parameters measuring system with variable structure,” Metrol. Meas. Syst., vol. 18, no. 4, pp. 659–666, 2011.

[3] Judycki, J., Jaskuła, P., Pszczoła, M., Ryś, D., Jaczewski, M., Alenowicz, J., Dołżycki, B., Stienss, M.: Analizy i projektowanie konstrukcji nawierzchni podatnych i półsztywnych. WKiŁ, Warszawa 2014

[4] Burnos, P., Gajda, J., Piwowar, P., Sroka, R., Stencel, M., Zeglen, T.: “Accurate weighing of moving vehicles,” Metrol. Meas. Syst., vol. 14, no. 4, pp. 507–516, 2007.

[5] Gajda, J., Burnos, P., Sroka, R.: “Accuracy Assessment of Weigh-in-Motion Systems for Vehicle’s Direct Enforcement,” IEEE Intell. Transp. Syst. Mag., vol. Spring, pp. 88–94, 2018.

[6] AASHTO Guide for Design of Pavement Structures, AASHTO, USA 1993.

[7] Szydło, A.: Nawierzchnie drogowe z betonu cementowego, Polski Cement, Kraków, 2004.