Weight-in-Motion Data Analysis of Vehicle Loads of A6 Motorway in Latvia

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***Abstract*: This paper presents the data analysis obtained using piezoelectric Weight-In-Motion measurement system. Data were collected for a six-month period. Statistical analysis showed that the vehicle loads of a particular Latvian highway have a considerable number of heavy weight vehicles and also presence of extremely heavy vehicles with a total weight more than 120t. Processed data of the vehicle gross and axle weight distribution as well as traffic intensities are remarkably different from the prototype data in current design codes. Vehicle's time and space distribution also shows the distinction from the existing Latvian and European design experience. To develop the practically viable methodology for assessment procedures for new and existing bridges it is necessary to study bridge design loads, their character and trends. WIM systems have proven themselves to be the most effective tool for this type of study.**

***Keywords*: WIM (Weight-In-Motion), traffic load, traffic data, load analysis, bridge.**

1. Introduction

Many structural engineers apply the load models given in Eurocodes for evaluation of load carrying capacity of existing bridges. These load models are provided for design of new bridges and are conservative in order to be valid for a wide range of bridge types and loading conditions. They often cover real and future traffic loading and in many cases provide significant load carrying reserves. Evaluation of existing structures could be based on actual data of structural condition and actual traffic load data [8].

The development of traffic loading rules for bridge design or assessment purposes requires up to date information on axle and vehicle's loads and also on the distribution of vehicle types within the traffic lines and between them of a multilane bridge.

Traffic action usually is the quantity with a great uncertainty due to the lack of statistical data. With the introduction of Weight-In-Motion systems, it is possible to collect vehicle information without interruption of the traffic. This includes the data on the number of axles, wheelbase, speed and axle loads, which altogether shapes the picture of actual loading degree on roads and bridges [7]. Many European countries are already using WIM equipment to support bridge design procedures and load evaluation [1], also in China [12], Brazil [4] and Venezuela [2] WIM equipment has been used. Some data of the traffic loads on Latvian and Lithuanian roads could be found in [5].

This paper analyses the traffic data which Latvian Road Administration collected from 2002 till 2008 and which could be used for evaluation of actual traffic loads on Latvian bridges and that could be taken into account studying target safety level of the existing bridges.

2. Traffic data collected by Weight-in-Motion system

The traffic data directly obtained by the WIM system are mainly axle load and wheelbase. However, data used in this study contain data on date, time, channel, direction, gap, vehicle speed and length. Collected field data was exported into Microsoft Excel files for further analysis.

Location for data collection was chosen at the crossroads of A4 and A6 roads. Two piezoelectric WIM sensors were placed into both traffic lanes as well as four inductive loops two in each lane, see Fig.1.

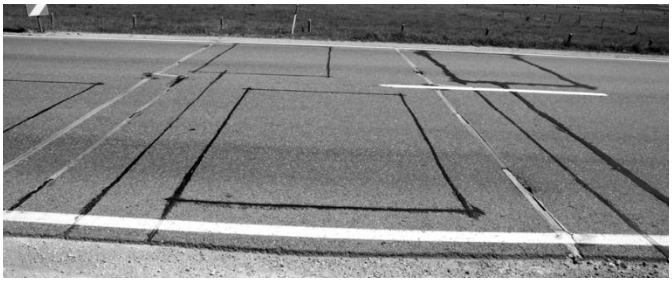

Fig.1. Installed piezoelectric WIM sensors and inductive loops.

Data collecting station was established in 2002 and remained functional for 6 years until 2008. However, data quality decreased significantly in 2005 due to deterioration of asphalt and sensors, caused by traffic loads. In 2011, sensors were found to be almost completely destroyed Fig.2.

Fig.2. WIM sensors in 2011.

It is also established that WIM sensor failures are assumed to be 5% in year one, 15% in year two and 25 % in year three [10]. Therefore, data from 2005, 2006, 2007 and 2008 were disregarded and year 2004 was chosen for in-depth statistical analysis due to its relative record stability. 2002 and 2003 were dismissed due to the limited period of data collecting.

3. Traffic Load Analysis

3.1. Vehicle distribution according to their weight and type

The WIM system recorded data of 1.172.842 vehicles on two lane two direction highways in total. 449.218 of them were vehicles with gross weight less than 3.5t and 663.101 vehicles with gross weight larger than 3.5t. Unreliable and false data of 60.523 vehicles were filtered and removed. The statistical result of different vehicle types according to the number of axles is shown in Table1.

TABLE 1

Percentage of different vehicles according to their axle number

Number of Axles	Number of Vehicles	Percentage
2	861165	79.82%
3	23064	2.14%
4	33962	3.15%
5	134656	12.48%
6	10320	0.96%
>6	15733	1.46%
Total:	1078900	100.00%

The statistical analysis shows that there are 861.165 two-axle vehicles, which is the largest proportion of traffic, i.e., 79.82% of the total. Second largest traffic group (12.48%) is formed by five-axle vehicles. Three-axle, four-axle and six-axle vehicles have a striking influence on load standard value, which constitutes 6.25% in total.

The frequency of two-axle vehicles is shown in Fig3, with 0.2t as the minimum vehicle weight, 56t as the maximum and 3.4t as the average; the majority of two-axle vehicle weight is less than 6t, with 765.041 such as vehicles constituting 88.86% of this group. Gross weight of 95% probability is 11t Fig.4. The frequency of three-axle vehicles is shown in Fig5, with 0.42t as the minimum, 105t as the maximum and 22t as the average; the majority of three-axle vehicle weight is less than 54 t, with 20.737 such vehicles constituting 90.02% of the particular group. Gross weight of 95% probability is 61t Fig.6. Three statistical populations can be identified here, that is at 4-5t, 21-22t and 37-38t. The frequency of four-axle vehicles is shown in Fig.7, with 0.8t as the minimum, 105t as the maximum and 22t as the average. The statistical population weights of four-axle trucks are mainly concentrated between 9t and 38t with bimodal distribution. There are 32.271 vehicles weighting less than 78t, which constitutes 95% of the total vehicle number, average gross weight is 39t Fig.8. The frequency of five-axle vehicle weight is shown in Fig.9, with 0.9t as the minimum, 155t as the maximum and 73t as the average, the distribution of which is also bimodal, with the two peaks in the range of 38-39t and 89-90t respectively. Similar bimodal distribution of five axle vehicles was obtained by [12]. Gross weight of 95% probability is 78t Fig.10. The frequency of six-axle vehicle weight is shown in Fig11, with 1t as the minimum, 213t as the maximum and 75t as the average.

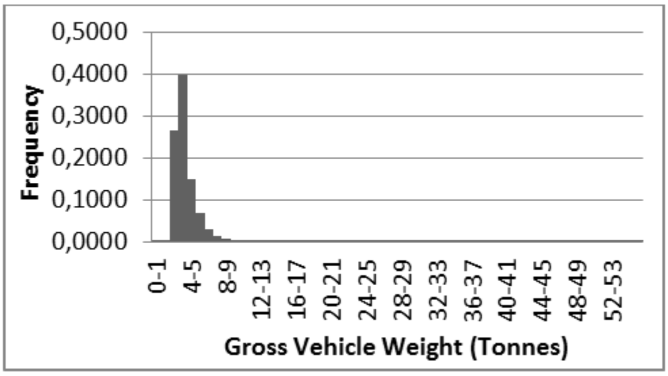

Fig.3. Weight distribution of two-axle vehicle.

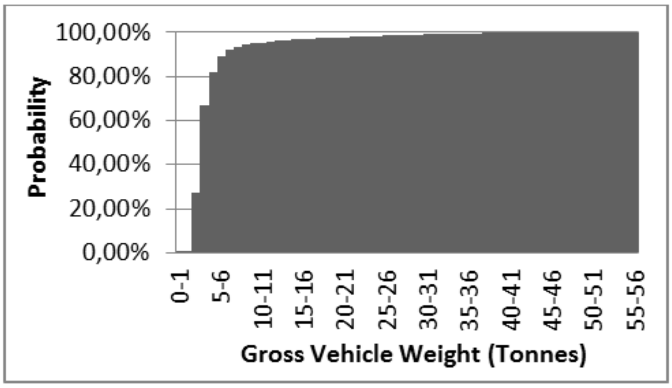

Fig.4. Cumulative weight distribution of two-axle vehicle.

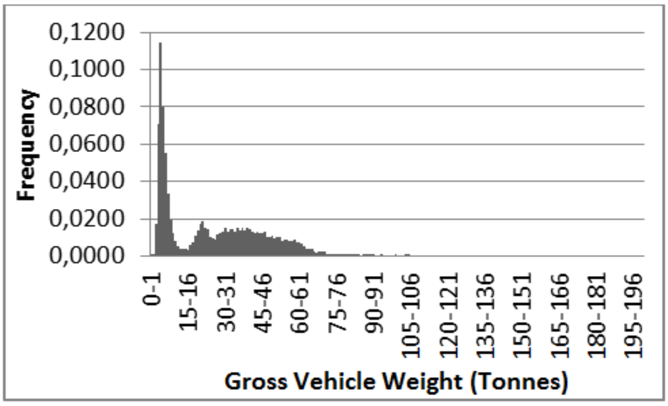

Fig.5. Weight distribution of three-axle vehicle.

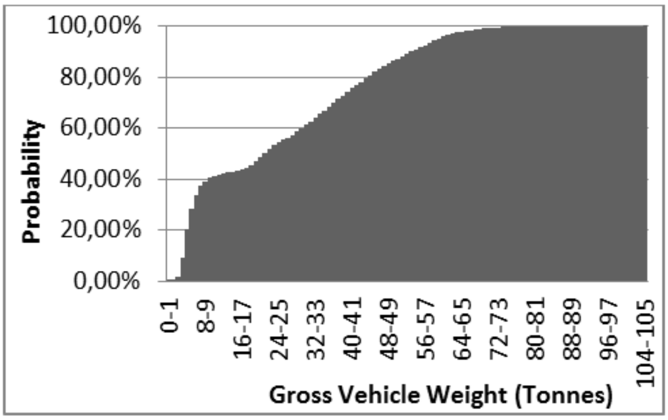

Fig.6. Cumulative weight distribution of three-axle vehicle.

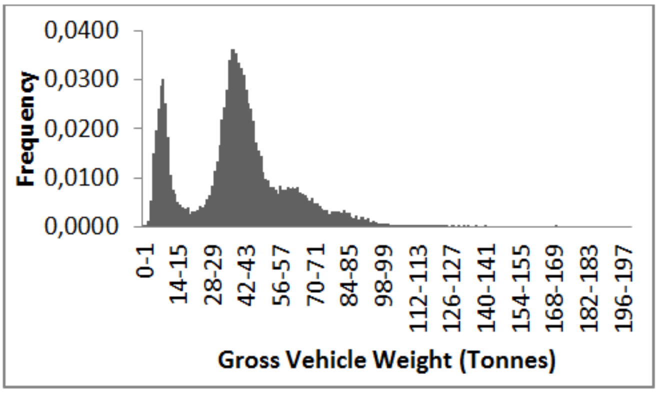

Fig.7. Weight distribution of four-axle vehicle.

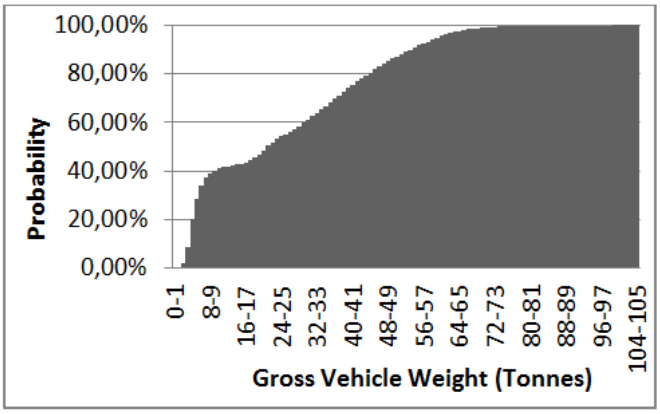

Fig.8. Cumulative weight distribution of four-axle vehicle.

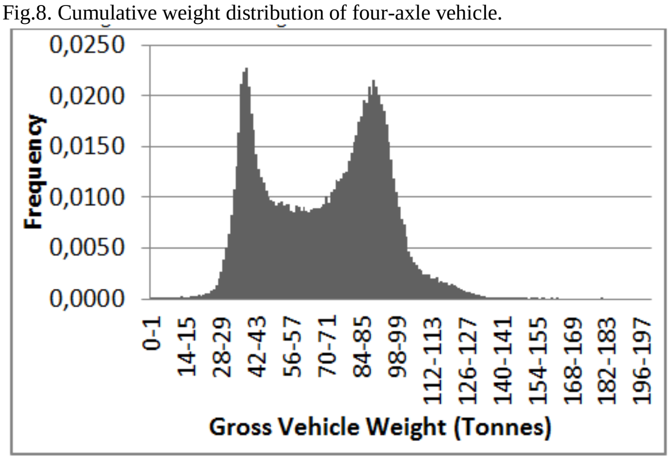

Fig.9. Weight distribution of five-axle vehicle.

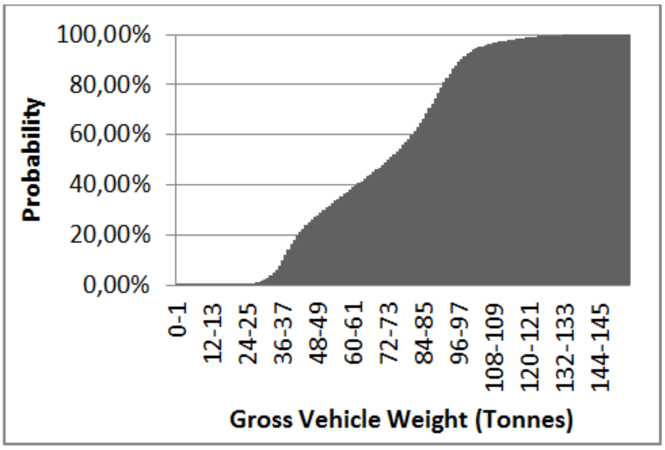

Fig.10. Cumulative weight distribution of five-axle vehicle.

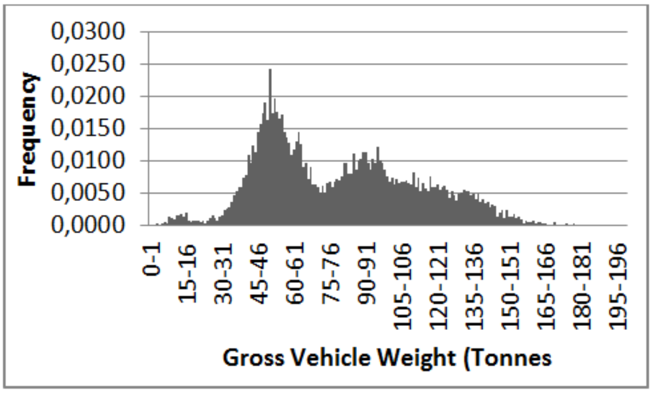

Fig.11. Weight distribution of six-axle vehicle.

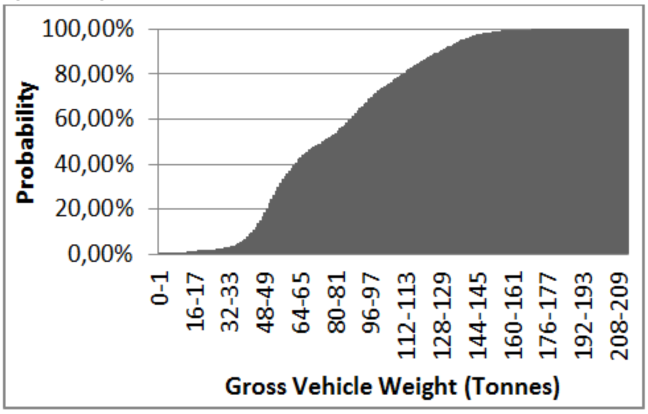

Fig.12. Cumulative weight distribution of six-axle vehicle.

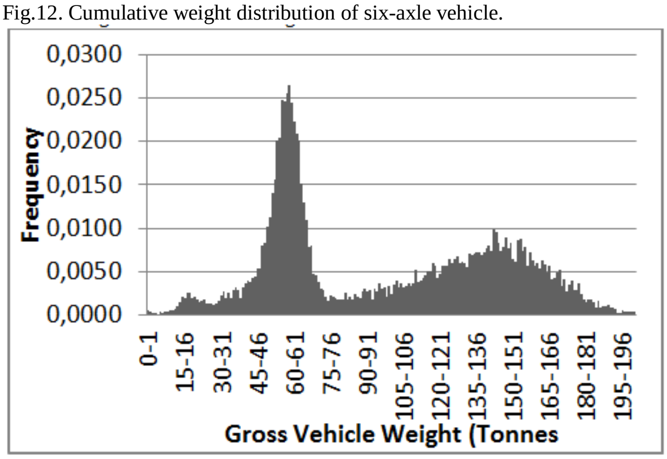

Fig.13. Weight distribution of vehicle with more than six axles.

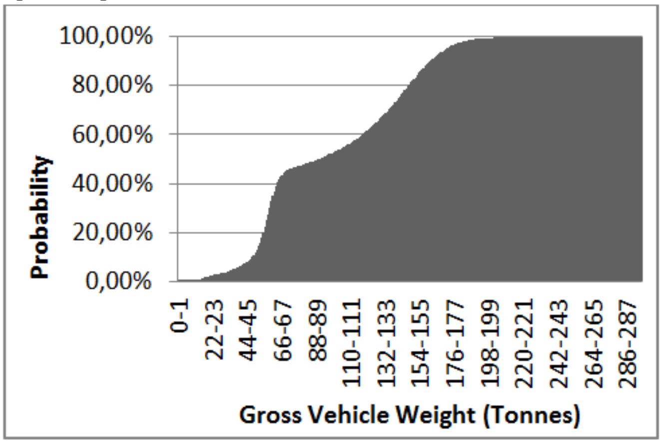

Fig.14. Cumulative weight distribution of vehicle with more than six axles.

The figure of weight frequency clearly indicates statistical populations at least of two peaks at 51t and 96 t respectively. Gross weight of 95% probability is 138t Fig.12.The weight frequency of vehicles with more than six axles is shown in Fig13, with 1.2t as the minimum, 296t as the maximum and 91t as the average. Gross weight of 95% probability is 138t Fig.13.

3.2. Vehicle distribution according to gross and axle weight

In 1.078.403 vehicle weight samples obtained by WIM in 33 weeks, the minimum weight is 0.2t, the maximum 302t, the average 4t. Gross weight of 95% probability is 87t Fig.16. The numbers and proportions of vehicles in different ranges of weight are given in Table 2 and displayed in Fig 15.

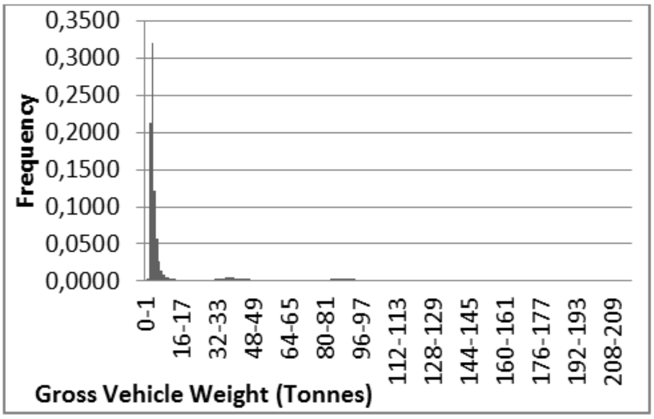

Fig.15. Total gross weight distribution.

The statistics indicates that the majority of vehicle weights are concentrated in the range of 3-8t, which is approximately 75.7% of the total traffic. It can be concluded from the diagram of weight variability that the distribution of vehicle weight is quite large and for more refined data analysis it may be worth looking at different vehicle subgroups, and the data is rather discrete.

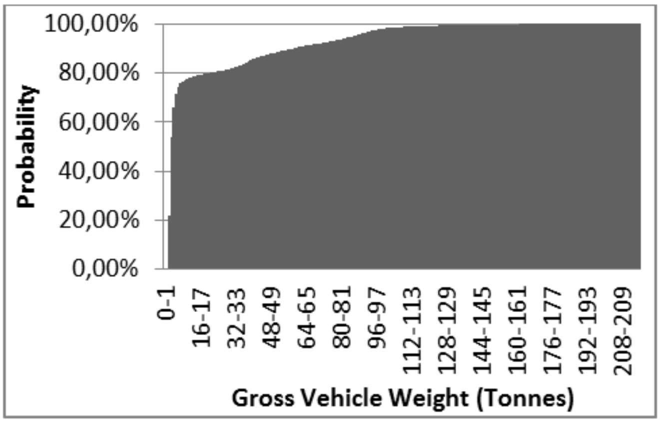

Fig.16. Total cumulative gross weight distribution.

Statistical results of 2.776.078 axle load samples are presented in Table3, Maximum, minimum and average axle loads are 42, 0.2 and 2.4t respectively. It is shown that three statistical populations can be highlighted at 1.4-1.6t, 5.2-5.4t and 14.8-15t. Major axle loads are concentrated within the upper limit of 3.8t, which constitutes 60.66% of the total axle number.

TABLE 2

VEHICLE DISTRIBUTION IN DIFFERENT GROSS WEIGHT RANGES

Weight Range (t)	Number of Vehicles	Proportion
0-20	859720	79,7208%
20-40	58836	5,4558%
40-60	53359	4,9479%
60-80	36115	3,3489%
80-100	49729	4,6113%
100-120	11443	1,0611%
120-140	4626	0,4290%
140-160	2819	0,2614%
160-180	1371	0,1271%
180-200	288	0,0267%
200-220	45	0,0042%
220-240	28	0,0026%
240-260	13	0,0012%
260-280	6	0,0006%
280-300	5	0,0005%
>300	10	0,0009%
Total:	1078413	100,000%

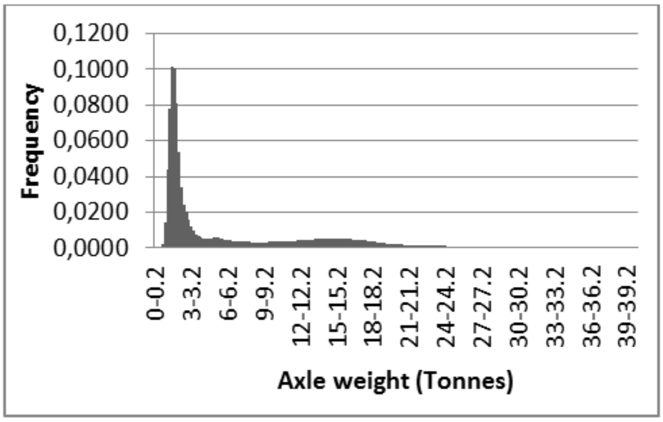

Fig.17. Total axle weight distribution.

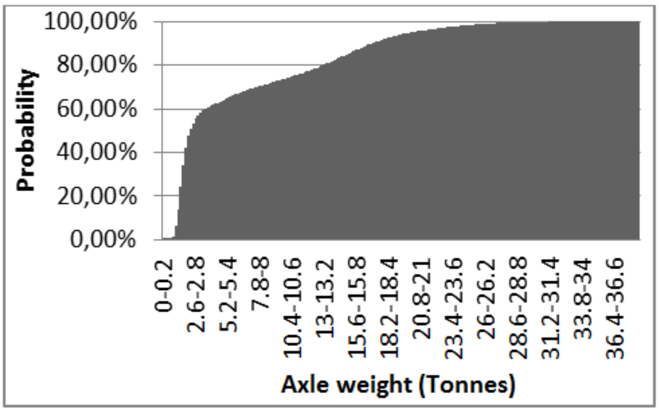

Fig.18. Total cumulative axle weight distribution.

During this research, it became clear that there were many limitations of sample handling tasks using Microsoft Excel platform. It was impossible to assemble all samples in one file, because of unmanageable size; it was impossible to generate a weight distribution graph without manually entering the weight range.

TABLE 3
VEHICLE DISTRIBUTION IN DIFFERENT AXLE WEIGHT RANGES

Weight Range (t)	Number of Vehicles	Proportion
0-5	1773822	63,893%
5-10	274113	9,874%
10-15	307659	11,082%
15-20	276110	9,946%
20-25	101194	3,645%
25-30	35114	1,265%
30-35	6978	0,251%
35-40	1088	0,039%
>40	140	0,005%
Total:	2776218	100,000%

3.3. Data quality analysis

Filtering and processing vehicle data have been one of the biggest challenges in this research. Although year 2004 has 33 weeks of traffic data, there are some gaps concerning information in September, October and November. Nevertheless, data collected until July is quite extensive and certain correlations can be found.

First of all, some research [12] has pointed out that traffic flow on highways and their load characteristics are found to be related to workdays and holidays. To analyse this phenomena graph of two weeks Fig.19, one-month Fig.20, three-month Fig.21 and six-month traffic data Fig.22 were created. Graphs indicated some fluctuation in daily recorded vehicle numbers as well as indicated a relapse of traffic flow maximum and minimum values. Return period of maximal traffic value encores in seven days, peaking on Friday. Second peak can be identified on Tuesday, although it is not absolutely certain.

This kind of information may be useful when planning and scheduling infrastructure related events such as maintenance work, transportation of dangerous goods, etc. In the particular analysis it was determined that traffic flow on Saturdays, for instance, was approximately 23% less and on Saturdays 31% less compared to Fridays.

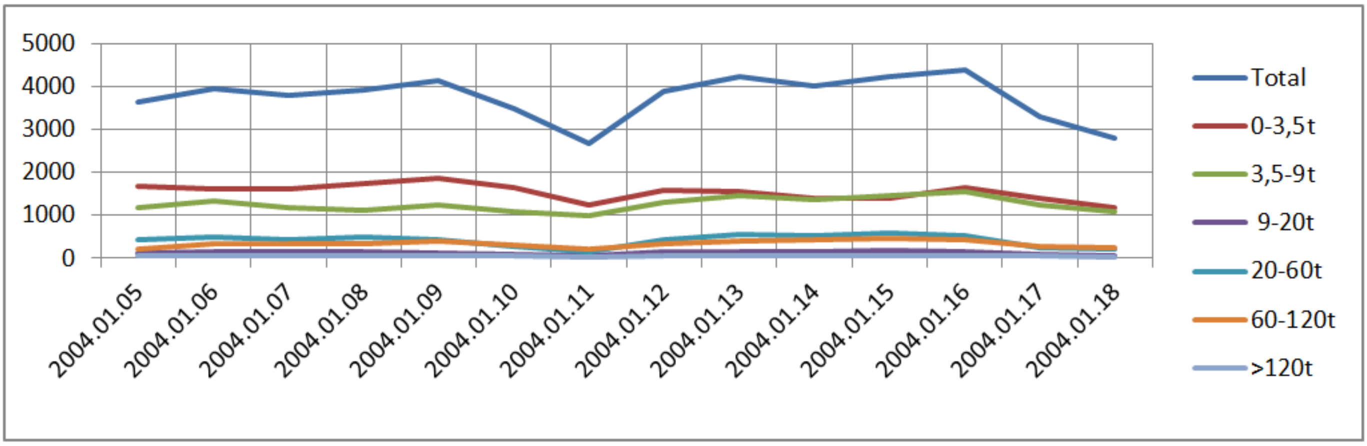

Fig.19. Two weeks of traffic data.

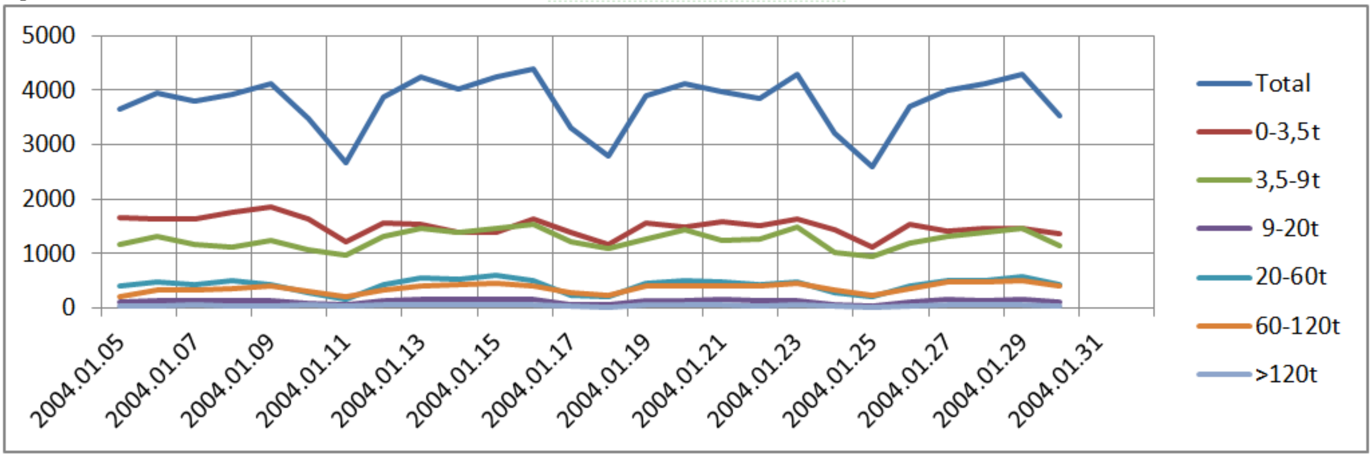

Fig.20. One month of traffic data.

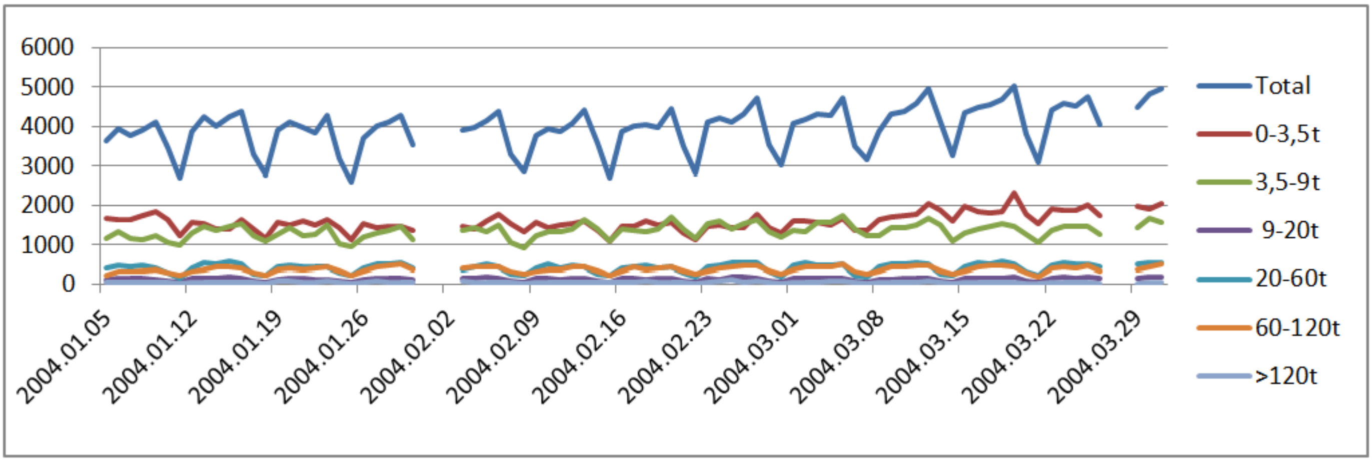

Fig.21. Three month of traffic data.

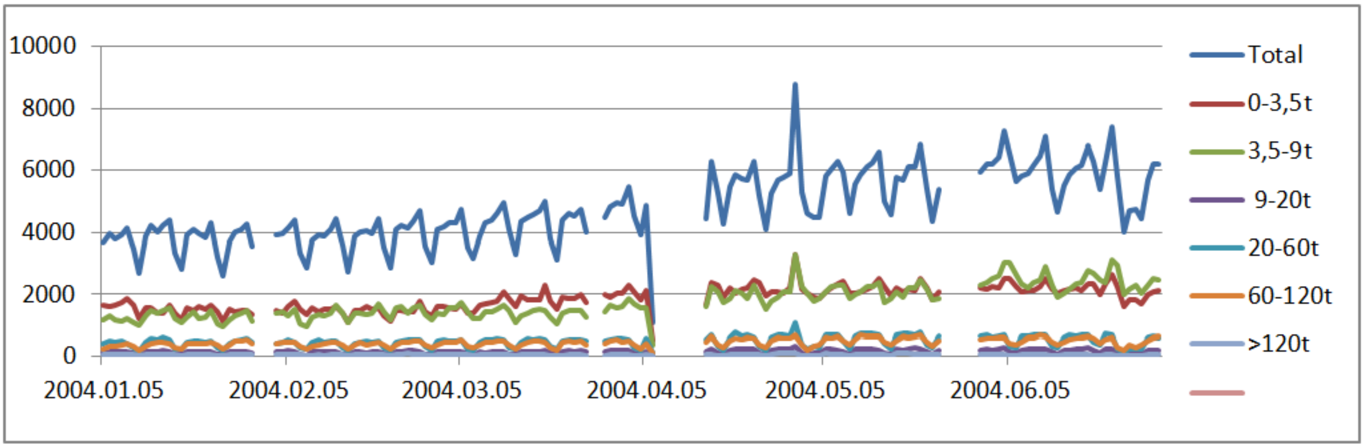

Fig.22. Six month of traffic data.

Secondly, not all traffic measurements are aimed at determination of loading. In the simplest case, it is just traffic intensity that has been measured. However, once correlation patterns are established between different traffic variables it becomes relatively easy to quantitatively interpret them against each other. In this study correlation between total and heavy (Fig.23, Fig.24, Fig.25 and Fig.26) as well as total and light (Fig.27, Fig.28, Fig.29 and Fig.30) traffic has been searched. At first, it presented data for two-week period, then one month, three-month and finally six-month period.

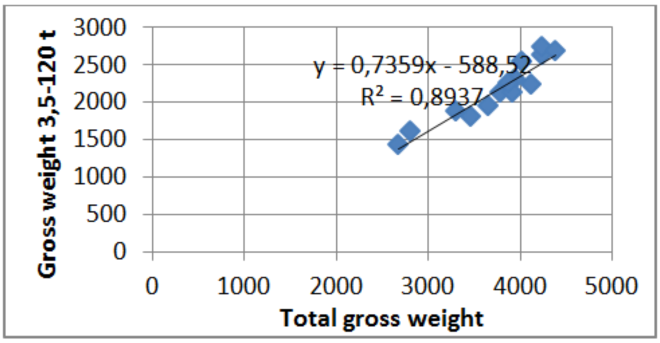

Fig.23. Correlation applying Two weeks of traffic data.

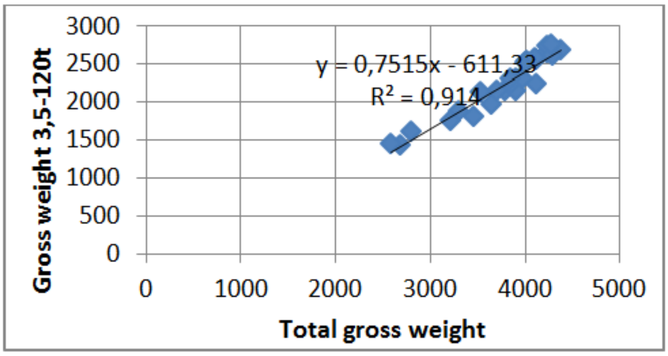

Fig.24. Correlation applying One month of traffic data.

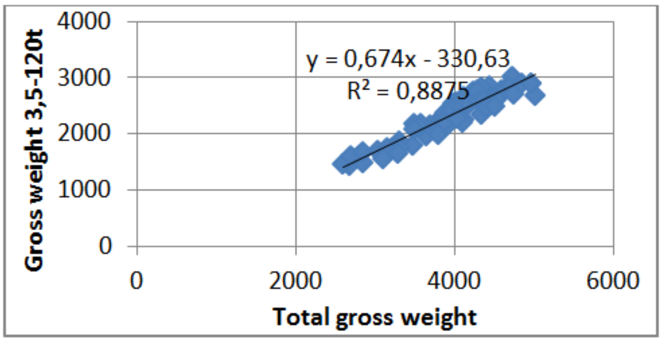

Fig.25. Correlation applying Three month of traffic data.

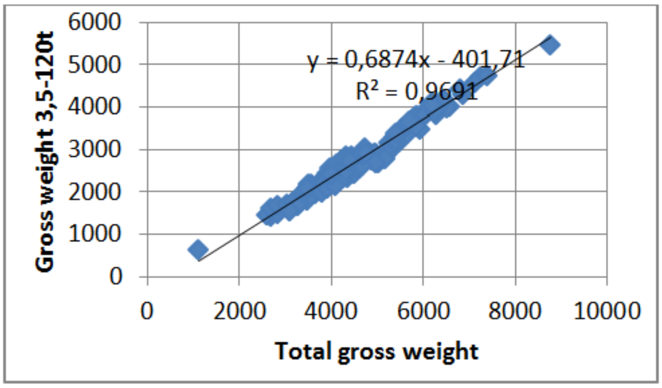

Fig.26. Correlation applying Six month of traffic data.

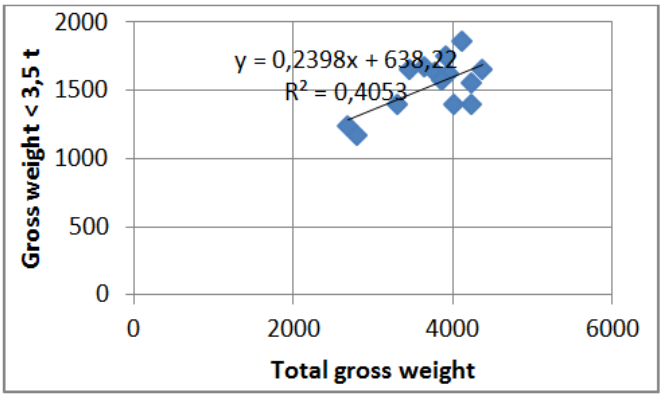

Fig.27. Correlation applying Two weeks of traffic data.

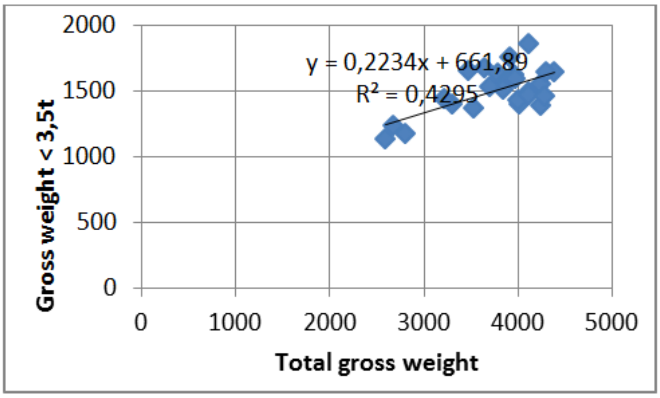

Fig.28. Correlation applying One month of traffic data.

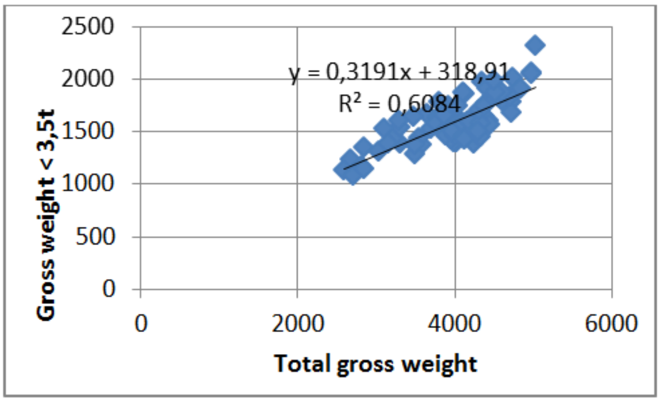

Fig.29. Correlation applying Three month of traffic data.

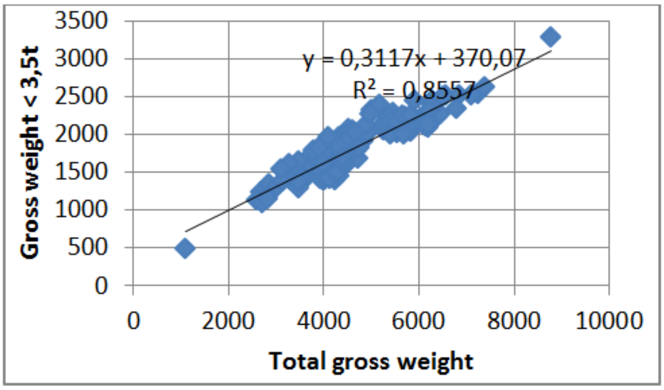

Fig.30. Correlation applying Six month of traffic data.

Analyzing the findings it can be stated that by adding more data tendencies of a regression coefficient, the model of these samples can be described as a function:

$$y = 0{,}6874x - 401{,}71$$

For regression of gross weight, heavy traffic coefficient of regression R=0.9691 is achieved using the following linear model.

4. Conclusions

Applying Weight-In-Motion system it is possible to collect vehicle information without interruption of traffic. The collected data must be filtered due to feasible unrealistic sample values caused by deterioration of sensors. For acquisition of reliable data, it must be collected during first three years of service if piezoelectric sensors are used.

The statistical analysis shows that the traffic load on A6 road mainly consists of the two-axle vehicles (79.82%). The second group comprises the five-axle vehicles (12.48%), and in the third group there are three-axle, four-axle and six axle vehicles (7.71%). The statistics indicates that the majority of vehicle weights are concentrated in the range of 3-8t.

During the study the vehicle weight and axle load accumulative distribution was obtained.

The traffic flows on the motorway were analyzed in relation to their distribution on workdays and holidays. It was determined that traffic flow on Saturdays was approximately 23% less and on Saturdays 31% less than on Fridays. If traffic measurements are oriented towards detecting peaks, then in particular regions Fridays are found as an appropriate day of the week.

Fairly good correlation patterns were found between heavy vehicle gross weight and total vehicle gross weight as well as between light vehicle gross weight and total vehicle gross weight.

The obtained results could be used for evaluation of actual traffic loads on Latvian bridges and could be taken into account studying target safety level of the existing bridges.

5. References

[1] Dolcemascolo V.; Sjogren L. 2008. Bridge weight in motion: French tests and Swedish experience, in *Proc. of the 5th International Conference on Heavy Vehicles*, Paris, France, May 19-22, P 214-219.

[2] Fargier L.B. 2010. A proposed live load model for bridge design in Venezuela, *in Proc. of 34th IABSE Symposium*, Venice, Italy, September 22-24, 2010. P.1-8

[3] Getachew A.; Obrien E.J. 2005. Simplified site-specific traffic load models for bridge assessment, *Structure and infrastructure Engineering*, Vol.3, No.4: 303-311.

[4] Goltsman H., Paiva M., Valente A., Pantoja F. 2008. Test of WIM sensors under Brazilian conditions, in Proc. of the 5th International Conference on Heavy Vehicles, Paris, France, May 19-22, P 86-92.

[5] Lazda Z., Smirnovs J. 2009. Evaluation of road traffic safety level in the State main road network of Latvia, *The Baltic Journal of Roads and Bridge Engineering*, Vol. 4, No 4, p.156-161.

[6] Marchadour Y.; Jacob B. 2008. Development and implementation of a WIM network for enforcement in France, in *Proc. of the 5th International Conference on Heavy Vehicles*, Paris, France, May 19-22, P 266-274.

[7] OConnor A.; Obrien E.J. 2005. Traffic load modeling and factors influencing the accuracy of predicted extremes. *Canadian Journal of Civil Engineers*, Vol.32; 270-278.

[8] O'Brien E.J., Znidaric A., Brady K., Gonzalez A. 2005. Procedures for assessment of highway structures, *Proc. of the Institution of Civil Engineers*. Transport 158, Issue TRI, P. 17-25.

[9] Paeglitis A., Paeglitis A. 2010. Simple classification method for the bridge capacity rating, *Construction science, Scientific Journal of Riga Technical University*, Ser. 2, Vol. 11. P. 44-50.

[10] Pratt A.J. 1998. Weigh in Motion technology – Economics and Performance, in *Proc. of NATMEC'98*, Charlotte, North Carolina, USA, May 11-15, P. 1-6.

[11] Sivilevičius H.; Šukevičius Š. 2007. Dynamic of vehicle loads on asphalt pavement of European roads which cross Lithuania, *The Baltic Journal of Roads and Bridge Engineering*, 2007, Vol. II, No 4, p.147-155.

[12] Xin R., Xuefei S. 2010. Analysis of highway vehicle load in China based on WIM data, in *Proc. of 34th IABSE Symposium*, Venice, Italy, P.1-8.

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Andris Paeglītis, Ainārs Paeglītis, Raitis Lācis. Latvijas autoceļu slodžu analīze pēc „Weight-in-motion" mērījumu sistēmas datiem
Latvijā esošo tiltu un ceļu nestspēja galvenokārt ir atkarīga no satiksmes slodžu lieluma. Pieaugot satiksmes intensitātei, īpaši smagā transporta kustībai, svarīgi ir noteikt, kādas slodzes un cik bieži ir sastopamas uz Latvijas Valsts ceļiem un tiltiem. Agrāk transportlīdzekļu ass un kopīgo svaru nebija iespējams fiksēt, un šis lielums tika uzskatīts kā nenoteiktība, kas jāizvērtē, izmantojot drošības koeficientus un vienkāršotus modeļus. Pielietojot transportlīdzekļu monitoringa sistēmu "Weight in motion", tika vākti dati laika posmā no 2002. līdz 2008. gadam. Iegūtā informācija aptvēra gan laiku, kad transportlīdzeklis pārvietojies, gan tā ātrumu, pārvietošanās virzienu, attālumu starp asīm, kā arī katras ass svaru. Iegūtie dati tika analizēti, izvērtējot satiksmes sastāvu, konstruējot slodžu sadalījuma histogrammas atsevišķi 2,3,4,5,6 un >6 asu transportlīdzekļiem. Tika izvērtēts iespējamais intensitātes maksimums un minimums, kā arī aplūkota korelācija starp kopīgo intensitāti un smagsvara transportlīdzekļu skaitu. Iegūto rezultātu statistikas analīze liecina, ka satiksmes slodze uz A6 ceļa galvenokārt sastāv no divasu transportlīdzekļiem (79.82%). Otrajā grupā ietilpst piecu asu transportlīdzekļi (12.48%) un trešajā grupā – trīsasu, četrasu un sešu asu transportlīdzekļi (7.71%). Statistika liecina, ka lielākajai daļai transportlīdzekļu svars sastāda 3-8t. Pētījuma rezultātā iegūts transportlīdzekļu masas un ass slodzes kumulatīvais sadalījums. Pētījumā analizēts satiksmes plūsmas sadalījums darbdienās un brīvdienās. Konstatēts, ka satiksmes plūsma sestdienās bija aptuveni par 23 % mazāka un svētdienās par 31 % mazāka nekā piektdienās. Pētot satiksmes intensitāti, tika konstatēts, ka visintensīvākā satiksme ir piektdienās. Iegūtos rezultātus var izmantot, lai novērtētu faktiskās transporta slodzes uz Latvijas tiltiem un to drošuma līmeņa novērtējumam.

Андрис Паэглитис, Айнарс Паэглитис, Райтис Лацис. Анализ транспортной нагрузки на автомобильных дорогах Латвии по данным системы „Weight-in-motion"
Несущая способность существующих мостов и дорог Латвии, в основном, зависит от величины нагрузки от транспортного средства. Увеличение интенсивности транспорта, в частности, тяжелого транспорта, важно определить, какие существуют нагрузки и как часто они встречаются на латвийских дорогах и мостах. Раньше не было возможности определить вес осей и общий вес автомобилей во время его движения. Вес автомобиля считался как неопределенность, которая принималась во внимание с коэффицентом безопасности и упрощеннимы моделями. При использовании системы мониторинга за транспортом "Weight in motion", были получены данные в период с 2002 - 2008 год. Полученная информация охватывает как дату движения транспортного средства, так в его скорость, направление движения, расстояние между осями и вес каждой оси. По полученным данным был проанализирован состав транспортного потока, используя гистограммы распределения нагрузки отдельно для автомобилей с 2,3,4,5,6 и> 6 осей. Был оценен возможный максимум и минимум интенсивности движения, а также рассматривалась взаимосвязь между общей интенсивностю движения и количеством тяжелых транспортных средств. Анализ статистики полученных результатов показывает, что транспортная нагрузка на дороге А6 главным образом состоит из двухосевого транспортного средства (79.82%). Во вторую группу входят пятиосные транспортные средства [12.48 (%),] и в третьей группе – трехосные, четырёхосные и шестиосные транспортные средства (7.71%). Статистика показывает, что большинстве случаев вес транспортных средств составляет 3-8 t. В результате исследования полученно кумулятивное распределение массы транспортных средств. В исследовании изучено распределение транспортного потока в рабочие и выходные дни. Установлено, что транспортный поток в субботу был приблизительно на 23 % меньше, а в воскресенье на 31 % меньше, чем в пятницу. Изучив интенсивность сообщения, было установлено, что самое интенсивное сообщение наблюдается в пятницу. Полученные результаты могут быть использованы для оценки фактических нагрузок транспорта на мосты Латвии и оценки уровня безопасности.