Bridge Weigh-in-Motion as a tool for Road Damage Remediation

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Road pavements are structures with finite lives. They are designed to withstand a specific number of equivalent single axle loads (ESALs). Consequently, the truck traffic consumption of ESAL design life, and increased road infrastructure costs associated with it, can increase rapidly where significant volumes of truck traffic is involved.

During the construction of major infrastructure or other objects it is usually necessary to shift large amounts of material from one location to another. The individual works causes higher traffic on the main and regional roads with construction site vehicles, usually within a specified, short period of time, causing more damage and more rapid deterioration of these roads, which are not dimensioned to facilitate that kind of traffic load. Maintenance and restoration of these roads are therefore very high and usually not provided for in planning documents.

The solution to the problem concerns the sharing of costs for reinforcement or repairs of roads between all parties; owner of the road, investor of the construction and/or operators of these works. For this purpose a methodology was developed to determine the necessary corrective measures in the main and regional roads, where increased volume of truck traffic due to construction of certain infrastructures is calculated against the normal volume of the trucks on a measured road section. Then, construction cost per lane per kilometre and design life of the road is used together with the real traffic data measured before and during the construction works with Bridge Weigh-in-Motion system.

Keywords: remediation, weigh in motion, ESAL, construction cost, methodology.

Introduction

Data on traffic loads are an essential element of the design, construction and maintenance of pavements. Traffic load is the sum of the loads of all individual vehicles and cause fatigue of the carriageway structure of the materials, thus the onset and progression of damage to the road surfaces.

The impact of the vehicle on the fatigue of carriageway construction materials built can be evaluated with its equivalency factor ESAL. Traffic load is the sum of ESALs of all trucks, which in a certain period of time (day, year of the project period) traversing the cross-section of the carriageway.

ESAL of the vehicle can only be determined by weighing each of its axles. It would be ideal, to statically weigh each axle of each truck, which is not possible in practice, since it is not possible to stop every truck. Therefore, systems have been developed for weighing commercial vehicles in motion (WIM - Weigh-In-Motion), first in slow motion (SS WIM - Slow Speed WIM), and later in a free-flow (HS WIM - High Speed WIM). WIM measurements in free-flow can be further divided according to the mode of installation on the road (Pavement WIM) and bridge (Bridge WIM).

In the following chapters, impact of the commercial vehicles to the carriageway structure will be present, together with methodology to define sharing the costs of road repairs.

Impact of the (over) loaded commercial vehicles on the carriageway structure

In Slovenia, Slovenian Infrastructure Agency and DARS, Motorway Company in the Republic of Slovenia monitor the actual traffic loads with SiWIM® Bridge Weigh in motion system, which measures real traffic loads while weighing vehicles in free-flow traffic. Only with this system it is also possible to determine the overloading of commercial vehicles and to evaluate additional traffic due to the construction of major infrastructure facilities or in quarries and gravel pits, as well as the timber transport.

Based on WIM measurements assess impacts and consequences of overloaded commercial vehicles and increased traffic are:

- higher investment costs,
- increase of the cost for maintenance and renewal,
- shorten the life of the pavement,

- faster onset and progression of damage to the road surfaces.

Equivalency factors of commercial vehicles and traffic loads

The impact of the vehicle on the pavement fatigue evaluate its equivalency factor ESAL, which can only be determined by weighing the individual axles.

When we weighed all the axles of the vehicle, in accordance with the technical specifications of the TSC 06.511: 2009 [1] we calculate its equivalency factor ESAL expressed by the number of passages of nominal axle which has two dual tires and axle load of 100 kN (ESAL 100 kN - Equivalent Single Axle load). Truck ESAL is calculated from the sum of the individual contributions of the axle loads of the vehicle to the actual arrangement of the axles and wheels $ESAL_{a,w}$, according to the equation 1:

$$ESAL = \sum ESAL_{a,w} = 10^{-4} \cdot \sum_{i=1}^{N} f_{a,i} \cdot \left(f_{w,i} \cdot A_i \right)^4 \qquad (1)$$

Where:

$f_{a,I}$ - axle type factor (1.0 for single, 0.0953 for double and 0.0301 for triple)

$f_{w,I}$ - wheel type (1.0 for double, 1.2 for super single, 1.3 for single)

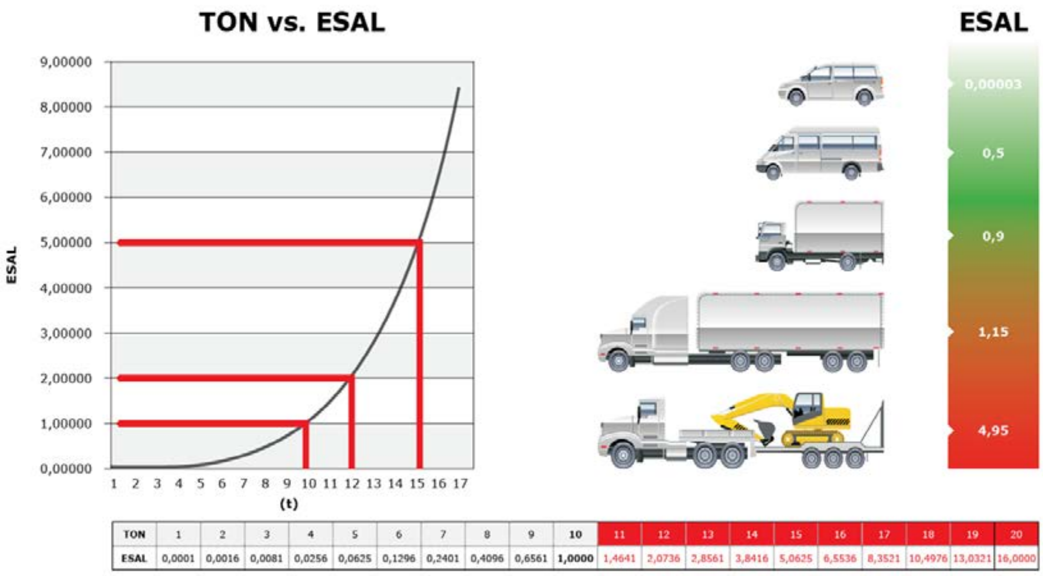
A_i - load in tons

N - number of axles

ESAL increases with the fourth power compared to the load on the axle [2], so for example, 20% exceeded axle load (12 tonnes instead of 10 tonnes) more than doubled its equivalency factor and thus traffic load (Figure 1).

Traffic load is calculated based on available traffic data:

- theoretical traffic load is calculated from the number of vehicles by category, and their average ESAL (procedure defined in the TSC 06.511: 2009 [1]),
- actual traffic load is determined by weighing commercial vehicles in free-flow, which weigh each axle and determine the actual ESAL for individual vehicles.



TON	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ESAL	0,0001	0,0016	0,0081	0,0256	0,0625	0,1296	0,2401	0,4096	0,6561	1,0000	1,4641	2,0736	2,8561	3,8416	5,0625	6,5536	8,3521	10,4976	13,0321	16,0000

Figure 1: Relation between ESAL and axle load

Theoretical traffic load according to the TSC 06.511:2009

For the determination of traffic volumes every vehicle should be weighed calculated its ESAL, then sum all the individual ESAL values. But in the real world this cannot be done, therefore, according to the hundred thousands of ESAL calculations and years of measurements average $ESAL_v$ for different representative vehicle was calculated. The results are related to the types of vehicles and are summarized in table 1.

Table 1: Average $ESAL_v$ values for representative vehicles in relation to the road type

Representative vehicle	Road type		
	Highway	Main roads	Local roads
Car	0,00003	0,00003	0,00003
Bus	1,4	1,15	0,85
Van up to 3,5 t	0,005	0,005	0,005
Truck from 3,5 to 7 t	0,6	0,5	0,4
Heavy truck above 7 t	0,7	0,9	1,0
Truck with trailer or semi-trailer	1,6	1,4	1,25

Mean $ESAL_v$ values for representative vehicles [1] have been defined on the basis of real traffic, which means that some vehicles were empty and some partially full, some full, some also overloaded.

All these calculations with the average traffic load fit in the normal flow of traffic when traffic in both directions is alike. Problem and a big error in the calculations of traffic loads can occur in cases where the traffic in one direction runs mostly with fully loaded (and even overloaded) commercial vehicles, but in the other direction most of the vehicles are empty, like construction of major infrastructure or other objects or traffic to the quarries.

Actual traffic load – WIM system

In comparison to the theoretical ESAL values, determined for different vehicle types, actual weighing with WIM system provides actual traffic load and realistic ESAL values. Weigh in motion is also only solution for actual information about the empty, loaded and overloaded vehicles. Discrepancy between theoretical ESAL value and actual, measured one, can be as high as 500%.

Asymmetrical heavy vehicles traffic

So called "one-way" or asymmetrical freight traffic is related to very uneven traffic load per lane/direction. This is happening in the construction of infrastructure facilities in the surrounding quarries, gravel pits and mines, as well as in wood harvesting. In this case, the calculation of traffic load equivalency factors with average theoretical $ESAL_v$ fails completely as traffic counters only record the number of vehicles by vehicle category and do not distinguish between empty and full, or even overloaded vehicles. Usage of the Bridge WIM system is a must in such cases. If we assume that on a certain stretch of the road to the quarry daily leads *X* empty commercial vehicles and full from the quarry, their theoretical and actual traffic loads will differ for up to 5 times, compared to theoretical values and even more if actual values for most overloaded vehicle compared to empty one is calculated.

Traffic loads therefore have values ranging from very mild to severe. For the dimensioning of pavement structures and renovations, the traffic load is essential information, because a direct influence on the choice of materials and thicknesses of the layers in the carriageway structure of the materials, thereby naturally also on the cost of the construction, maintenance and renewal, but also on the life of the pavement.

Impact of the overloading on the carriageway structure

Overloaded truck and asymmetrical freight as well as an increase in traffic due to the construction of major infrastructure facilities created:

- higher investment costs,
- increase in the cost of maintenance and renewal,
- shorten the life of the pavement,
- faster onset and progression of damage to the road surfaces.

Lifetime of a road structure is determined by the traffic load (expressed by the number of passages of ESAL 100 kN in the project life), for which it was designed. If the actual traffic load is greater than that at which it was designed, the remaining service life (RSL) is reduced, otherwise extended, as presented in the equation 2.

$$RSL = (ESAL_D * DL) / ESAL_M \qquad (2)$$

Where:

RSL - Remaining service life

DL - Design life

$ESAL_D$ - ESAL value used for design

$ESAL_M$ - measured ESAL value

Sharing the cost of repairs

Methodology

The chapter presents the methodology for the determination of the necessary measures and cost sharing for the increased volume of construction site duty vehicles or quarry trucks or similar on state roads

Roads, after undergoing additional construction site freight are often dimensioned to facilitate traffic loads and a large number of heavy goods vehicles causing them to overload. The cost of maintenance and reconstruction of these roads are therefore very high and usually not provided for in planning documents. The solution of the problem of sharing the costs of reinforcement or repair affected roads, namely the operator of these roads and the investor of the facility, which will be built and / or the contractors which will perform these works.

The methodology is broken up into several levels. Each stage can be performed independently, the greatest impact and best results will be when we will carry out all stages of all procedures in this sequence. The methodology includes activities to be carried out on one side as owner of additionally burdened main and / or regional roads, as well as investor and contractors. Activities are interlocked, which asks for the cooperation of all parties involved.

The first stage of the methodology includes preparation and preliminary estimate of the necessary measures and costs. Several alternatives can be proposed, where owner together with and the investor / operators choose the most optimal.

Following the adoption of solutions and signing a contract to implement the necessary measures, operators will begin with the construction of facility. In the second stage owner (Roads Agency in most cases) monitors the state of the roads and carry out counting and weighing of construction site vehicles.

The third stage occurs after the completion of construction with the review of the road with a final damage assessment and in the event that estimated damage is too low, or the actual damage is greater than expected re-calculation of the costs of remediation.

Monitoring the traffic during construction period

The most important period is the period of construction of the facility. Investor / contractors puts the main burden on the road during this period with the construction site vehicles. Owner should during this period perform periodic checks to the state of roads and take appropriate action if any major damage to the road happened. At the same time bridge weigh in motion system is implemented to measure traffic counts and traffic loads, separately for construction site and other vehicles. It is of most importance, that measurement with bridge weigh in motion is performed during this period to correctly calculate impact of the construction site traffic.

Settlement at the end of works and proposal for renovation

The third step involves the activity at the end of construction of the facility. During this period owner organizes once again review of previously excessive used roads and assessment of the damage caused during construction. In the case that the road is not been properly repaired before the construction of the facility, it is necessary now. Therefore, it is necessary to review earlier study made by the damage assessment and proposed measures and costs, and supplemented by a final assessment on the costs and cost-sharing. If the final costs vary for a given percentage of the previously calculated cost (to be defined in the contract), additional settlement should be carried out.

Determination of the required rehabilitation measures

Based on all the available information, necessary measures for the rehabilitation of damages are determined. The measures are dimensioned for a period of at least 10 years. In determining the measures it is necessary to take into account the time of implementation of the action before the construction, during construction or after completion of construction and expected traffic load. Normal traffic load (without the construction site freight vehicles) shall be determined as AADT and forecasted traffic after the construction of the facility. For the increase in traffic (traffic with additional construction site vehicles) the actual data during the construction period and other available data is taken into account.

On badly damaged road surface, especially if they are on geological and hydrological unfavourable basis, it is necessary to implement the measures earlier. It is therefore essential that the contract is signed and the measures carried out before the start of the drive of construction site vehicles. If the damage is not great, good load capacity, geological and hydrological basis are favourable, the measures can also wait until the end of construction of the facility. However, even in this case the contract is signed at the beginning of the construction, rehabilitation is carried out at the end. Typical measures for improving the pavement on the existing carriageways are:

- Resurfacing,
- Reinforcement,
- Recycling

- Recovery and
- Reconstruction.

Calculation of cost recovery measures

Based on the projected remedial measures calculated costs of measures are performed using a valid price lists. The aim of the agreement between the owners of national roads and investors / operators is to determine remedial actions as well as the ratio of cost sharing these measures among the signatories of the contract.

Road condition immediately after its surrender in use begins to deteriorate. Therefore, in the case when only expected traffic load was on the road, the cost of the remedial measures bear the operator of these roads. Where large additional load due to the local construction additionally deteriorate road the operator cannot provide unplanned and also the relatively large financial resources for rehabilitation. In this case, the investor / contractors, which led to an increase in construction site vehicles, undertake to settle part of the costs for the rehabilitation of roads. The main starting point for determining measures are the capacity of the pavement and traffic loads. Therefore usage of a Bridge WIM system is highly recommended for proper measurements.

Cost division ratio is then calculated by the following equation:

$$CRM_{I/O} = CRM * (1 - RSL/ERL) \quad (3)$$

Where:

$CRM_{I/O}$ - Cost of remedial measures of the investor/operator
CRM - Total cost of remedial measures
RSL - Remaining service life
ERL - Expected remaining life

Conclusions

Dimensioning of roadway construction is based on the assumption that all impacts in this section are similar and will not change. If so, when additional traffic loads are present, the above-mentioned assumptions no longer hold, and the state of the road begins to deteriorate rapidly, affects the damage and deformation, and sometimes there may be even to the destruction of the pavement. Roads, after undergoing additional construction site freight are often dimensioned to facilitate traffic loads and a large number of heavy goods vehicles causing them to overload.

The cost of maintenance and reconstruction of these roads are therefore very high and usually not provided for in the planning documents. The solution of the problem is in sharing the costs of reinforcement or repair of affected roads, namely between the operator or owner of these roads and the investor of the facility, which will be built and / or operators of these works.

The presented methodology includes activities to be carried out on one side by the owner of the main and / or regional roads and the investor or contractors. For all measurements, Bridge WIM should be used, because the only way to obtain real data, especially in situations, where so-called "asymmetrical traffic" occurs.

References

[1] TSC 06:511:2009, Technical Specifications for the roads, Traffic Loads, Slovenian Infrastructure Agency, 2009
[2] AASHO Interim Guide for the Design of Rigid and Flexible Pavements, American Association of State Highway and Transportation Officials, 1993