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Impacts from truck traffic on road infrastructure

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Economic constraints nowadays require transporting greater volumes of freight at lower cost. Yet the physical profiles of trucks do not all generate the same effects on road infrastructure for a given tonnage hauled. The objective then lies in finding an optimal service level that reduces the damage (wear) caused to infrastructure. Results derived for the impact of trucks on pavements relate specifically to rutting as well as the potential for evaluating the aggressiveness with which axle configurations induce fatigue on asphalt pavements. The impact of truck traffic trends on road bridges will also be discussed herein.

IMPACTS ON ROAD PAVEMENTS

Pavement wear is a process involving various deterioration phenomena either acting on their own or with one another. Among the factors influencing this type of wear is the actual traffic load (i.e. the focus of this paper), which takes into close consideration the following elements: the number of axles, axle configurations (single, tandem or tridem), wheel assemblies (single or twinned), wheel loads, and tire characteristics (dimensions, pressure).

Case of rutting

Road pavement rutting as a function of the physical specifications (profile) of trucks was the topic of a European project (COST 334, 2001), during which a method was specifically proposed to calculate the level of distress (or aggressiveness) caused to pavements based on the following set of formulae:

$$LEF = \left(\frac{SAL}{10}\right)^2,$$

$$TCF = \left(\frac{TW}{470}\right)^{-1.65} \times \left(\frac{TD}{1059}\right)^{-1.12},$$

$$AWF = TCF \times LEF,$$

$$VWF = \sum AWF,$$

where:

- LEF is the axle load (SAL) equivalency factor, as measured with respect to a 10-ton axle;
- TCF is the tire equivalency factor of the considered tire, designed with width TW and diameter TD , expressed in millimeters;
- AWF is the equivalent axle wear factor;
- VWF is the equivalent vehicle wear factor, derived by summing the equivalent wear factors of all axles on the vehicle.

Table 1 lists the results for a European-type semitrailer (40 tons, 5 axles). The axles the most prone to causing rutting are the powered axles and steering axles, whose loads are quite high for relatively narrow tires.

The aggressiveness directed at the pavement per ton transported is used as a benchmark to compare various vehicle types and may be calculated using the PER ratio, i.e.:

$$PER = \frac{VWF}{PL}, \text{ where } PL \text{ is the load being transported (or payload).}$$

Figure 1 compares these ratios for 10 vehicles or vehicle combinations, of which 9 are traveling (or capable of traveling) in Europe while the tenth is on Australian roads. The level of pavement wear does not always increase with the size of the load hauled, especially when the load is well distributed over all axles, as is the case for vehicle combinations currently being experimented in various European countries, i.e. European Modular Systems (EMS).

These calculations also indicate that a vehicle carrying a 38-ton load distributed on 4 axles, which amounts to 2 tons over the 36 presently authorized, would cause 20% more pavement distress per ton transported compared to the standard 40-ton, 5-axle truck.

Case of asphalt pavement wear and the effects of adjacent axles

The French pavement design method characterizes the aggressiveness of a given truck (by virtue of the overall fatigue imposed upon the layers of a road sub-base) via a set of coefficients that allow calculating the basic damage induced in these particular layers.

As a convention, the so-called coefficient of aggressiveness on the reference axle, i.e. a twin configuration allocated a 13-ton load, is equal to 1. For axle i with a different geometry and/or load, this coefficient of aggressiveness is defined by:

$$CA = \frac{N_{ref}}{N_i},$$

where:

- N_{ref} is the allowable number of reference axle passages that yields a cumulative wear equal to 1 at the most heavily loaded point of the road structure;
- N_i is the number of passages producing this same effect for test axle i .

The values of N_i are calculated based on a multilayer elastic model of the pavement subjected to the action of this test axle (according to Burmister's model). These results then serve to calculate the loadings caused by maximum extension (i.e. strains, stresses), depending on the material fatigue laws used to correlate these quantities with the number of cycles to failure.

For multiple axle configurations, it is assumed that the level of aggressiveness can be deduced from the aggressiveness of a single axle, by summing over the total number of axles in the configuration, followed by weighting with a coefficient of equivalence that takes into account the full extent of interactions between adjacent axles. For an asphalt pavement, the coefficient of aggressiveness for a given axle configuration is expressed as:

$$CA = \frac{N_{ref}}{N_{multi}} = K_{eq} n_{essieux} \left(\frac{\epsilon_{ti}}{\epsilon_{tref}} \right)^{\frac{1}{b}}$$

where:

- N_{multi} is the number of loads at failure for the multiple axle configuration,
- ϵ_{ref} is the maximum tensile strain at the base of the asphalt layers for the reference axle,
- ϵ_{ti} is the maximum tensile strain at the base of the asphalt layers for a single axle supporting the same wheel load as the multiple axle configuration,
- $n_{essieux}$ is the total number of axles contained in the studied axle configuration,
- $\beta = -1/b$ characterizes the material fatigue law (the value of β is on the order of 5).

Table 2 provides the coefficient of equivalence values K_{eq} for tandem and tridem axles with respect to the asphalt pavement design, along with the output from a sample calculation of multi-axle aggressiveness. The current method used to calculate CA values does however present several limitations.

A study of the impact of various truck profiles raises, above all, a question over including the "multi-peak" loadings observed in the sub-base layer during the passage of multiple axles, whether tandem or tridem (Fig. 2), as well as their equivalence expressed in terms of number of standard axle passages (see Table 2).

Recent research findings have led to proposing an extension to the typical fatigue law for asphalt materials, so as to better incorporate the actual curves showing strain evolution in road pavements as multiple axle configurations travel over the test section. This extended law was established from laboratory fatigue tests that simulate real-world axle configurations. Instead of including just the maximum strain, this law introduces 4 independent parameters related to the *in situ* signal form (Fig. 2).

This law, when combined with the data in Figure 2, illustrates the aggressiveness calculation results of two EMS-type truck profiles for two pavement structures built on a platform with a load-bearing capacity of 120 MPa, one designed for moderate traffic levels (6-cm layer of semi-coarse asphalt concrete + an 18-cm GB3 layer of bitumen-coated macadam), the other for very heavy traffic (8 cm of semi-coarse asphalt concrete + 31 cm of the GB3 macadam). These results are expressed in terms of total allowable cumulative load (weight of both the vehicles and their cargo) over the entire pavement life cycle. According to this criterion, the 8-axle EMS2 is less aggressive for both pavements than the 7-axle EMS1. With the EMS1 model, the isolated powered axle is a tremendous hindrance (i.e. a coefficient of aggressiveness = 2.35), whereas the addition of a second powered axle on the EMS2 model serves to reduce aggressiveness by a wide margin, despite a higher total load.

IMPACTS ON ENGINEERING STRUCTURES

The most recent civil works on road infrastructure were designed based on Eurocodes, although the vast majority had nonetheless been calculated using prior rules, which were calibrated with lower-density traffic and lighter vehicles than what is being observed on today's roads. It is thus necessary to recalculate the effects on structures operating under current traffic conditions.

Impact of traffic trends

Typical traffic densities and truck profiles have evolved over time. Figure 4 shows the hourly truck traffic flows by time of day in both 1986 and today, in specifying the composition of traffic flows from both periods.

The calculations of extreme traffic effects from 1986 and 2010 reveal (Fig. 5a) that the Eurocode load model has always remained on the safe side relative to current traffic patterns. Figure 5b indicates that 1986 traffic effects surpass those generated by present traffic levels, hence the safety margin has been reduced due to increased traffic.

An evaluation of the long-term effects on engineering structures however is quite complex, as the diversity of extrapolation methods leads to variable results. It is essential to increase the number of traffic observations over long periods on the European road network.

Impact of various truck configurations

European studies on the potential effects of EMS systems have been undertaken, in drawing comparisons with effects induced by currently authorized configurations. We have also compared the maximum effect (bending of an isostatic bridge span) of measured traffic with the effect caused by this same traffic level, yet modified by replacing three current trucks with two EMS. Up to span lengths of 50 m, the level of aggressiveness stays similar, but as these lengths expand the effect becomes more pronounced (Fig. 6).

These various studies have demonstrated that the impact of traffic on bridges depends to a large extent on: truck configurations (both weight and dimensions), traffic density, travel conditions (specifically the spacing between trucks), and initial bridge design and type. One approach to easily verifying and comparing the aggressiveness of any truck configuration on road bridges and then confirming acceptability consists of implementing a bridge formula, like the one applied in the United States and several other countries, but not yet common practice in Europe.

CONCLUSION

The increase in total weight and flows of freight vehicles has led road facility managers to periodically verify that the infrastructure is still capable of withstanding traffic under acceptable safety and cost conditions. More refined methods are being developed in order to evaluate the effects of new truck configurations on pavements, the surface layer (rutting) and the overall structure (fatigue cracking).

As for bridges, which represent critical nodes on the road network, the forecast of increasingly intense extreme traffic effects now warrants sophisticated extrapolation methods. To implement such methods, it is necessary to produce reliable load measurements spanning the long term, along with periodic monitoring of vehicle

configuration modifications and changes in traffic conditions. The safety and sustainability of currently operational facilities, in addition to maintenance and repair costs, depend heavily on not only the freight tonnage being transported by road, but also the new truck configurations resulting from revised regulations. The future challenge thus consists of reconciling the optimization of road freight transport plus its environmental costs and impacts (promoting heavier and bigger vehicles) with an optimized road facility management strategy. Political tradeoffs, relying on accurate scientific and technical studies, must be made and a suitable fare schedule adopted in order for the benefits of some to cover the expenses of others.

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*Table 1: Impact on road pavement by a 5-axle, 40-ton semitrailer
(26-ton payload)*

Tire spec	295/80R22.5	295/80R22.5	385/65R22.5	385/65R22.5	385/65R22.5
Twin vs. Single	Single	Twin	Single	Single	Single
Axle load (tons)	6.5	11.5	7.33	7.33	7.33
TCF	3.14	1.00	2.25	2.25	2.25
AWF	1.33	1.32	1.21	1.21	1.21
VWF	6.28				
PER	26 (tons) = 0.24				

*Table 2: Tandem and tridem trailer equivalence relative to single wheel assemblies, and equivalent number of standard axles for asphalt pavement fatigue
Axles have been allocated a 10.5-ton load, with asphalt materials
(exponent 5 in fatigue, use of the French design method)*

Type of trailer	Coefficient of equivalence	Equivalent number of axles
Tandem trailer with single wheels	0.75	0.52
Tridem trailer with single wheels	1.10	1.14

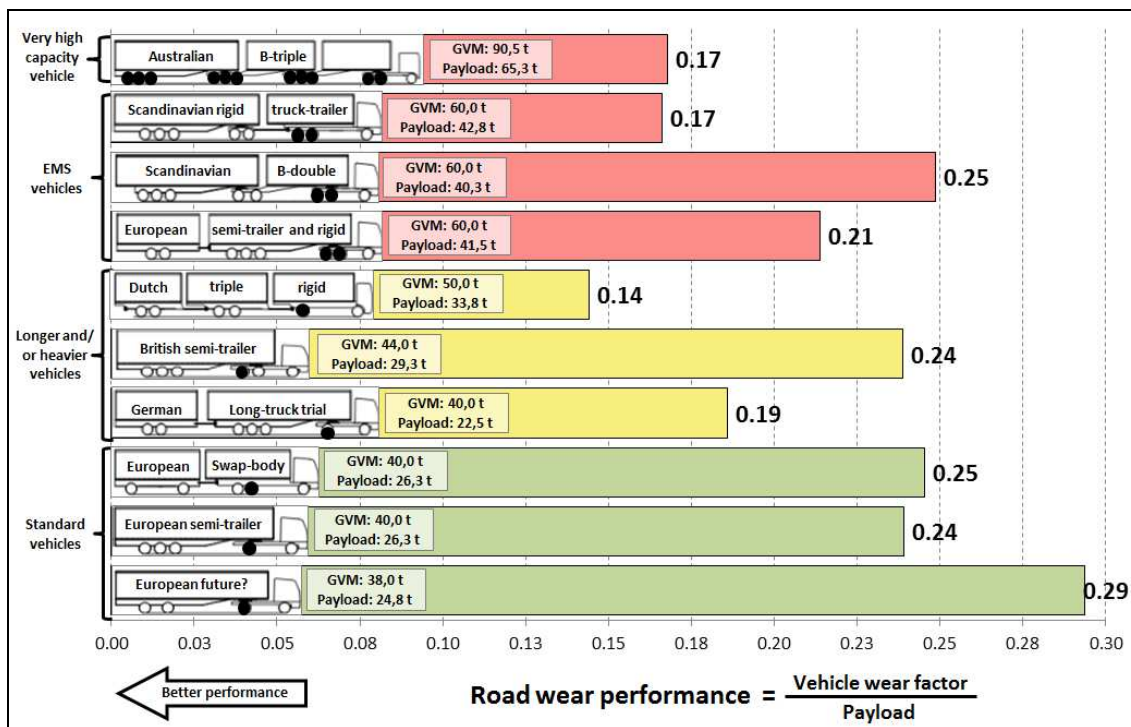


Figure 1: Ratio of pavement impact to load transported for various vehicle combinations. Single axles shown in white, twin wheel assemblies in black (Glaeser and Ritzinger, 2012)

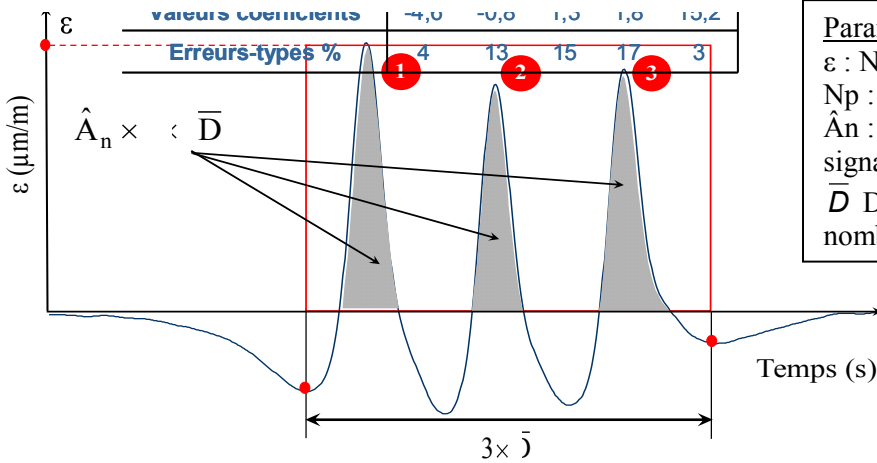
Multi-peak fatigue model: $\log(N_f) = a \log \epsilon + b \log(N_p) + c \hat{A}_n + d \bar{D} + e$

"valeurs coefficients" =
"coefficient values"
"Erreurs-types %" = "%
standard deviation values"

Parameters:

ϵ : Strain level
 N_p : Number of signal peaks
 \hat{A}_n : Signal filling rate
 \bar{D} : Signal duration divided
by the number of peaks

"Temps (s)" = "Time (s)"



Paramètres :

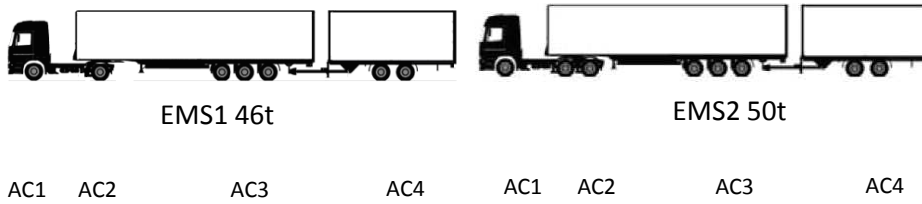
ϵ : Niveau de déformation
 N_p : Nombre de pics du signal
 \hat{A}_n : Taux de remplissage du
signal
 \bar{D} : Durée du signal divisée par le
nombre de pics

Multi-peak fatigue model: $\log(N_f) = a \log \epsilon + b \log(N_p) + c \hat{A}_n + d \bar{D} + e$

	a	b	c	d	e
Valeurs coefficients	-4,6	-0,8	1,3	1,8	15,2
Erreurs-types %	4	13	15	17	3

"valeurs coefficients" =
"coefficient values"
"Erreurs-types %" = "%
standard deviation values"

Figure 2: Longitudinal strain under a tridem axle, shape parameters and the multi-peak fatigue model established experimentally for a GB3 bitumen-coated macadam at 20°C



	AC1 (axle configuration)	AC2	AC3	AC4	Total rolling load allowable on Structure 1	Total rolling load allowable on Structure 2
EMS1	Single axle, RS - 6 tons	Single axle, RJ - 11.5 tons	Tridem, RS - 18 tons	Tandem, RS - 10.5 tons	11.3 10^6 ·tons	398· 10^6 tons
EMS2	Single axle, RS - 6 tons	Tandem, RJ - 12.5 tons	Tridem, RS - 17 tons	Tandem, RS - 14.5 tons	20.4 10^6 ·tons	969 10^6 ·tons

Parameters:
 ε : Strain level
 N_p : Number of signal peaks
 A_n : Signal filling rate
 D : Signal duration divided by the number of peaks

Paramètres :
 ε : Niveau de déformation
 N_p : Nombre de pics du signal
 \hat{A}_n : Taux de remplissage du signal
 \bar{D} : Durée du signal divisée par le nombre de pics

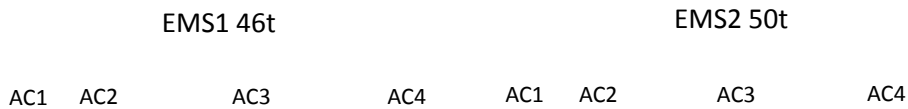


Figure 3: EMS profiles used to calculate the aggressiveness on structures 1 and 2 - Total loads allowable on each structure

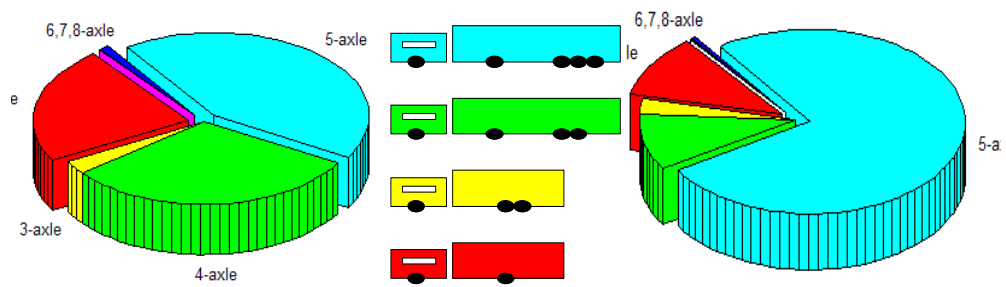
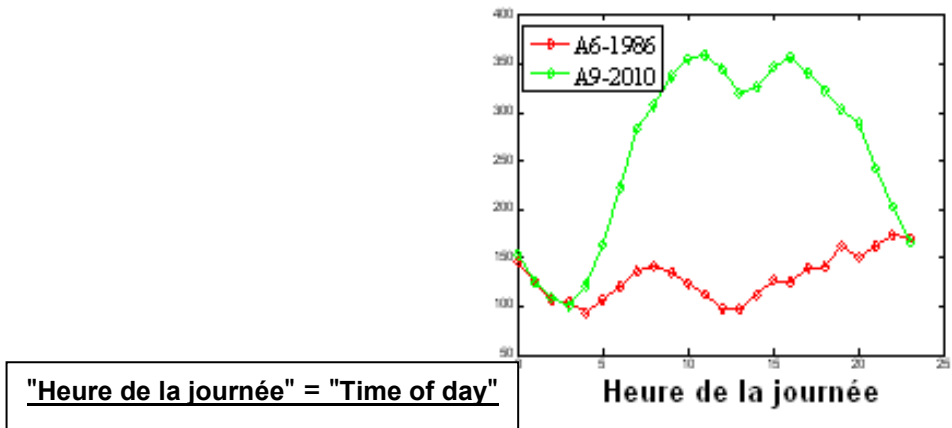
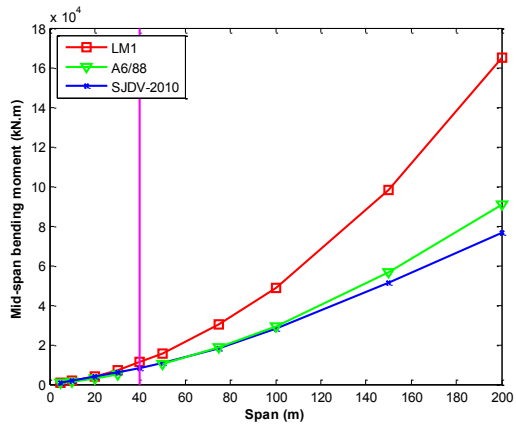
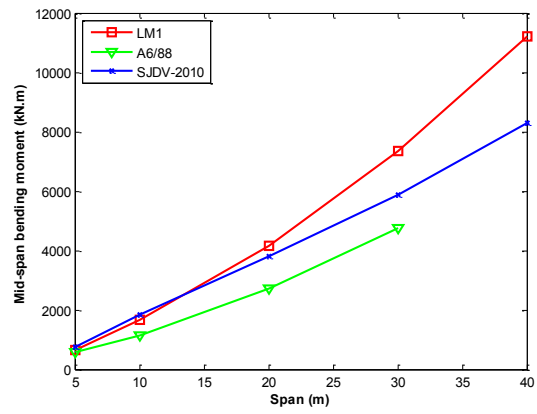


Figure 4: Evolution in hourly traffic flows and breakdown of truck traffic (Auxerre-1986 and A9 Motorway-2010)



(a)



(b)

Figure 5: Bending moment at mid-span along the span direction

LM1 = Eurocode 1 load model, A6/88 = Auxerre 1986 vehicle traffic,
 SJDV-2010 = A9 motorway traffic (Saint Jean de Védas, 2010)

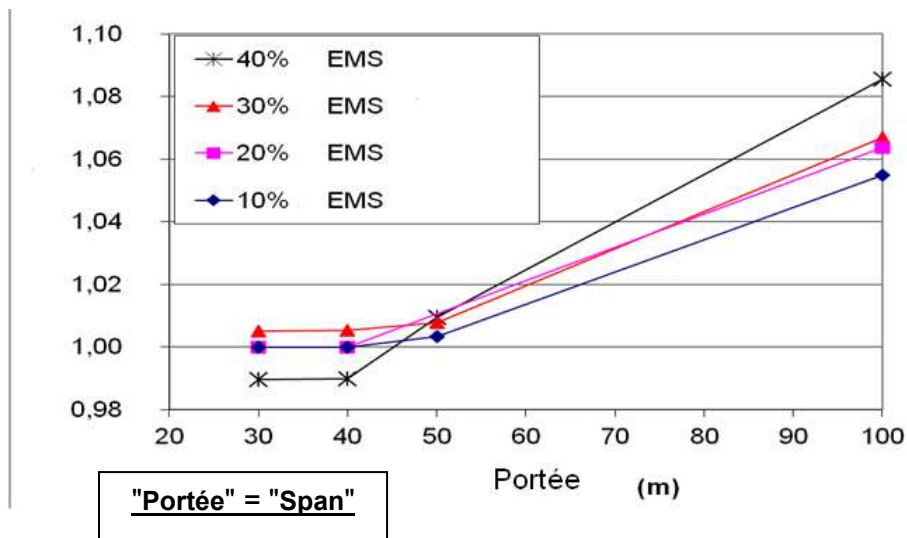


Figure 6: Increase in mid-span moment vs. span length and for various EMS proportions, in comparison with the moment resulting from current traffic (isostatic span)