PAVEMENT BUILDING COSTS ALLOCATION TO HGV COMPARISON BETWEEN THE FRENCH CASE AND THE EUROVIGNETTE DIRECTIVE RECOMMENDATIONS

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Abstract

The "Eurovignette Directive" voted in June 2006 sets a framework for future would-be Heavy Goods Vehicle (HGV) road charging system on the Trans-European Road Network (TERN). The directive claims that any new toll for HGV must be consistent with the infrastructure costs that HGV's are responsible for in order to ensure that the tolling system is fair, proportionate, transparent and non-discriminatory. These tolls must then derive from a road costs allocation study. This paper focuses on the allocation of pavement costs. It analyses how truck classes could be defined so that they gather trucks causing the same kind of damage to the pavement. It calculates allocation ratios that could be adapted to the French road network. Finally, it compares these results to the propositions of the directive annexes. This work was done using the ALIZE software developed by the Laboratoire Central des Ponts et Chaussées (LCPC) and from which derives the French pavement design method.

Keywords : Heavy goods vehicles, Pavement, Pavement design, Eurovignette, Costs allocation.

Résumé

La directive Eurovignette votée en Juin 2006 fixe des règles pour tout futur système de péage pour les poids lourds sur le réseau Routier Trans-Européen (RTE). Ainsi, pour assurer un système de péage équitable, proportionnel, transparent et non-discriminatoire, elle oblige à définir des niveaux de péage en fonction de la part de responsabilité des poids lourds dans les coûts d'infrastructures. Pour déterminer de tels péages, il faut donc définir différentes classes d'usagers de la route et leur imputer les charges d'infrastructures. Ce papier s'intéresse à l'imputation des coûts sur les chaussées. Il définit un système de classification des poids lourds en fonction de leur agressivité sur les chaussées, calcule des coefficients d'équivalence pour le réseau français et les compare aux coefficients proposés en annexe de la directive. Les résultats s'appuient sur des simulations réalisées avec le logiciel ALIZE du Laboratoire Central des Ponts et Chaussées (LCPC), logiciel utilisé pour développer la doctrine française de dimensionnement des chaussées.

Mots-clés : Poids lourds, chaussées, dimensionnement, eurovignette, imputation des coûts.

1. Introduction : HGV responsibility in pavement building costs

The French Highway Agency (Direction Générale des Routes) asked last year for a technical study on HGV responsibility in road building costs to help transposing the Eurovignette directive into French law. This paper tells about the part of this study devoted to pavement building.

In the past, several studies had already tackled this subject in order to assess the impact of HGV traffic on pavement costs. Here, it was decided to go further in details in order to assess the impact of each kind or silhouette of HGV on pavement costs using a specific criteria. This criteria was given by French pavement design methodology. In France, pavements are designed so that they can admit some "damage" due to HGV traffic (no matter the intensity of light vehicles traffic) during their lifetime. This damage can be quantified from each HGV "aggressiveness". This aggressiveness criteria can be then considered as a good criteria to characterize HGV according to the damage that they cause to pavements and to define classes gathering HGV of same aggressiveness (we decided to consider 3 classes of HGV).

Defining those 3 classes was the first step of the study. Then, 4 scenarios of HGV traffic were built. In scenario 0, it was considered that no HGV would be allowed on the pavement. In scenario 1, only HGV from the less aggressive class would be allowed. In scenario 2, HGV from both class 1 and class 2 would be allowed. In scenario 3, all HGV would be allowed. For all scenarios, appropriate pavement structures were designed and costs of these pavements were assessed in order to tell how responsible for pavement costs each class of HGV was.

The next section tells more about this methodology, explaining the theoretical background for this analysis and presenting the technical tools that were used to implement it. The third section is about results and the fourth analyses these results, regarding Eurovignette recommendations.

2. Methodology and tools

2.1 French methodology for pavement design

The French methodology for pavement design as described in the French Design Manual for Pavement Structures (Sétra-LCPC, 1994) combines a rational approach about stress evaluation (stress and strain) and an experimental approach:
- Mechanical theory is used to define a model for the pavement structure and to assess stresses due to a reference axle;
- Fatigue tests in laboratories on materials used for pavements are then used to appreciate fatigue strength;
- Experience from observations on real roads are finally used to calibrate modelled results.

2.2 Aggressiveness assessment

Stresses that have to be assessed in the first step of pavement design are due to the transit of loaded axles. These stresses damage the pavement structure. They are used to assess the axle aggressiveness (or the HGV aggressiveness in our case) that is considered. A special software is needed to assess these stresses and to value the exact impact of an HGV on pavement design. We decided to use the ALIZE software that was developed by the Laboratoire Central des Ponts et Chaussées (LCPC). It models stresses due to traffic in the different layers of the pavement structure. The model that was implemented in ALIZE is based on the theoretical

model of Burmister that models the pavement structure as a semi-infinite material made of different layers with a constant thickness with a linear elastic isotropic behaviour (Figure 1 where E is for Young's modulus of elasticity and ν is for Poisson's ratio). A full description of this software can be found on the web : www.lcpc.fr/ext/pdf/prod/alize.pdf or http://www.itech-soft.com/fr/alize/alizemeca.htm .
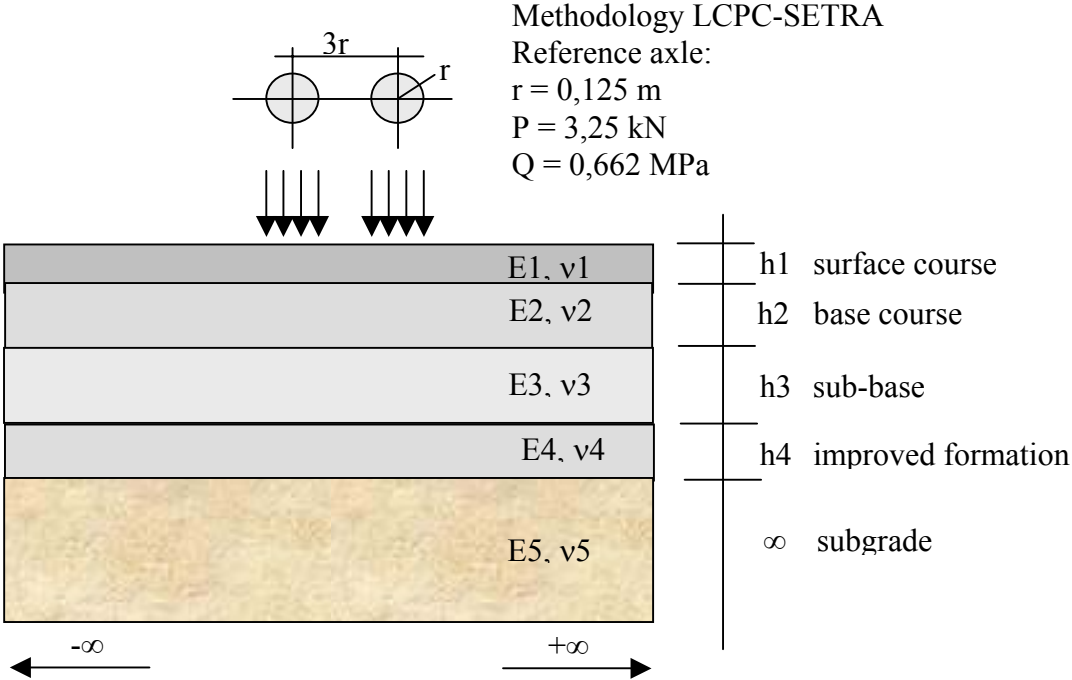

Figure 1 – ALIZE Software : example

Modelling an HGV in ALIZE requires modelling its pneumatic-tyres prints. Each print is characterized by :
- Its radius r (which is given here from the two next parameters),
- Its applied weight P (pneumatic weight),
- Its contact pressure between pavement and tyre Q (equal to 0.662 MPa for single and twinned tyres and 0.700 MPa for single tyres in a triple axle).

Then, for each HGV, the relative position of pneumatics has to be given. Finally, ALIZE requires as inputs pavement structure and HGV characteristics and returns stresses due to the considered HGV transiting on the considered pavement.

These stresses are used to assess each HGV aggressiveness from its axles aggressiveness. This is a relative value equal to the damage due to this axle divided by the damage due to a reference axle. In France, the reference axle is a single axle with twinned-tyres loaded with 130 kN (around 13 tons). The damage created in a layer from the transit of a loaded axle depends on only two parameters :
- The stress on the base of the layer;
- The layer material (bituminous or treated with hydraulic binders) that determines the stress type (respectively strain or stress) as well as the fatigue parameter to consider.

Axle aggressiveness is given by the following formula :

$$A_i = \left(\frac{\varepsilon_i}{\varepsilon_0} \right)^{\alpha} \text{ for bituminous pavements,} \tag{1}$$

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$$A_i = \left(\frac{\sigma_i}{\sigma_0}\right)^\alpha \text{ for semi-rigid pavements.} \tag{2}$$

where :
- A_i : single axle i aggressiveness;
- ε_i : tensile strain on the basis of the sub-base due to the axle i, taking into account whether the axle is included in a twinned or triple axle group;
- ε_0 : tensile strain on the basis of the sub-base due to the reference axle;
- σ_i : tensile stress on the basis of one of the bedding courses due to the axle i, taking into account whether the axle is included in a twinned or triple axle group;
- σ_0 : tensile stress on the basis of one of the bedding courses due to the reference axle;
- α : coefficient related to the fatigue slope of materials
  = 5 in France for bituminous mixtures;
  = 12 in France for hydraulically bound mixtures.

The HGV aggressiveness (A_{PL}) is given by:

$$A_{PL} = \sum_{axle\_i} A_i \tag{3}$$

When each HGV aggressiveness is given, it is possible to define a classification for HGV regarding the damage on pavements they are responsible for. The classification for French roads that was calculated with this method is presented in paragraph 3.1. It leads to put in class 1 less than 12t 2-axle HGV, in class 2 refers more than 12t 2-axle HGV or 3-axle HGV and in class 3 all other HGV.

2.3 Pavement design

Pavement design is mainly based on different hypothesis about HGV traffic that will be supported by the pavement during its lifetime. This HGV traffic is characterised by its global volume and its aggressiveness through the "Equivalent Number of Reference Axles" NE that derives from the numbers N_{PLi} of each kind (or silhouette) i of HGV:

$$NE = \sum_{PLi} A_{PLi} \times N_{PLi} \tag{4}$$

As roads are usually designed for several years, an accumulated traffic TC on the pavement lifetime is derived from this NE with the following formula (for an arithmetic traffic growth of 5% and a 30 years lifetime) :

$$TC = NE \times 365 days \times \left(30\,years + 5\% \times \frac{30\,years \times (30\,years - 1\,year)}{2}\right) \tag{5}$$

N_{PLi} are the inputs to design different kinds of pavements for the different scenarios that have to be studied. Keeping a constant global volume of HGV and changing the authorized silhouettes i of HGV on the road, it is possible to measure the impact of each HGV kind on pavement design. The following paragraphs explain how these N_{PLi} change from one scenario to another.

In scenario 0, were HGV are not allowed on roads, we consider that only 2 12t and 2-axle HGV use the road every day (for road maintenance, safety measure…). This hypothesis was borrowed from a former study made by the Union des Sociétés d'Autoroutes à Péage (USAP) in June 1992. For this scenario 0, a flexible pavement is designed.

In scenarios 1, 2 and 3 where HGV are allowed on roads, the global volume of HGV traffic is equal to 2500 HGV per day and per sense of flow. This hypothesis of a constant global volume is made in order to measure only impacts of the HGV silhouettes on pavement design and to avoid volume impacts. The N_{Pli} depends on the proportion of HGV of kind i in the population of HGV on French roads but in scenario 3, all HGV are allowed, in scenario 2, HGV from class 3 are not allowed and in scenario 1, only HGV from class 1 are allowed. The proportions N_{Pli} are given by the Stations d'Analyse du Trafic Lourd (SATL) that are "counting hardware" all over the French National Road Network (RRN). For these 3 scenarios, two different pavement structures are studied : a bituminous pavement and a semi-rigid one with a structure designed after the former Design Manual for Pavement Structure (Sétra-LCPC, 1977 and 1988). Each of these two techniques represents about 40% of the French National Road Network.

The designed structures for each scenario are built using the ALIZE software directly. The French Design Manual for Pavement Structures (Sétra-LCPC, 1998) is not used because this manual is a tool that was developed to make pavement design more simple but that is not sensitive to the parameters we want to change in the different scenarios (it does not depend on the HGV traffic structure but on the global HGV traffic, considering a single average aggressiveness for all HGV). The outputs from ALIZE are presented in paragraph 3.2.

2.4 Cost assessment

The methodology to value designed structures rests on costs and volumes of materials that the structure requires. The costs are given by an Observatory of costs of pavement techniques. We consider costs from the year 2006, they are given in current euros. The differences of costs between two scenarios have then to be allocated to the different users (light vehicles, HGV from classes 1, 2 and 3). This problem does not have a single solution (Emile Quinet, 1998). In this case, we used the following algorithm :
- Differences of costs between scenarios 3 and 2 are allocated to HGV from class 3;
- Differences of costs between scenarios 2 and 1 are allocated to HGV from class 3 and 2 proportionally to their relative part in the HGV global traffic;
- Differences of costs between scenarios 1 and 0 are allocated to HGV from all classes proportionally to their relative part in the HGV global traffic;
- Fixed costs that are measured in scenario 0 are allocated to all users proportionally to their relative part in the global traffic. An equivalence ratio of 2.5 between HGV and light vehicles is also used to take into account the fact that HGV are bigger than light vehicles and than make a more important use of the road. This coefficient is usually used in traffic modelling in France for volume-delay functions.

For HGV traffic, these hypothesis are consistent with the pavement design scenarios. For light traffic, we consider that HGV represents 12% of global traffic. This part is given by the traffic survey (Sondage de Circulation) of 2004-2005 on the National Road Network. This allocation method is derived from the Eurovignette directive recommendation that "the weighted average tolls shall be related to the construction costs and the costs of operating, maintaining and developing the infrastructure network concerned".

3. Results

In the first part of this chapter, results about HGV aggressiveness simulations are given and HGV classes are defined. In the second part, pavement structures that were designed in each scenario are reported. Finally, in the third part, the relative costs of these structures are assessed.

3.1 Modelled aggressiveness and designed pavement structures

Modelling HGV aggressiveness made us realize the different impacts of the different kinds of HGV on pavement design. One can notice the very high aggressiveness of 5 axles semi-trailers with a triple axle behind. 50% of HGV traffic is represented by these semi-trailers in France. The following table shows HGV aggressiveness and both bituminous and semi-rigid pavements and indicates for each kind of HGV its corresponding class.

Table 1 – HGV aggressiveness.

Silhouette	Weight (t)	Part in traffic	Aggressiveness (bituminous)	Aggressiveness (semi-rigid)	HGV class
	7.5	17%	0.01	1.08 e-5	1
	12	6%	0.10	0.32 e-2	1
	19	5.3%	0.74	0.36	2
	26	2.7%	0.55	0.34	2
	26	1.3%	0.49	0.05	2
	38	11.2%	0.99	0.41	3
	40	48.3%	1.80	0.66	3
	40	1.2%	0.56	0.18	2
	38	1.3%	0.93	0.17	3
	40	1%	0.62	0.10	2
	40	0.6%	0.49	0.09	2
	40	3.1%	0.20	0.02	2
Other HGV	40	1%	0.8[*]	1.3[*]	3

[*] standard value from the design manual for pavement structures

Table 2 – Scenarios

Scenario	NE	TC (x10^6)
0	0.4	4.16 10^{-3}
Bituminous pavement		
1	83.7	1.58
2	590.3	11.15
3	2731.4	51.50
Semi-rigid pavement		
1	2.1	0.04
2	218.7	4.13
3	1030.8	19.47

3.2 Structures

All hypothesis except traffic hypothesis that are required for pavement design are those that the French Design Manual for Pavement Structures recommends (risk assessment, choice for wearing course…). Abbreviations that are used in the following tables for each scenario are here summed up :

- BB : asphalt concrete (E = 5400 MPa, ν = 0.35),

- GNT2 : untreated graded aggregate (E = 400 MPa, ν = 0.35),
- PF2 : class 2 platform for the improved formation (E = 50 MPa, ν = 0.35),
- PF3 : class 3 platform for the improved formation (E = 120 MPa, ν = 0.35),
- GB3 : class 3 bituminous-bound graded aggregate (E = 9300 MPa, ν = 0.35),
- GC3 class 3 cement-bound graded aggregate (E = 23000 MPa, ν = 0.25).

Table 3 – Structure for scenario 0.

	Platform PF2		Platform PF3	
Scenario	Acceptable stress (ε_t, in µdéf)	Material thickness (cm)	Acceptable stress (ε_t, in µdéf)	Material thickness (cm)
Scenario 0	2516	4 BB 13[(*)]/15[(**)] GNT2	2516	4 BB 4[(*)]/15[(**)] GNT2

[(*)] : *simulated value*
[(**)] : *technique minimum*
µdéf *is the unit for the acceptable stress*

Table 4 - Structures for scenario 1, 2 and 3 for a bituminous pavement.

	Platform PF2		Platform PF3	
Scenario	Acceptable stress (ε_t, in µdef)	Material thickness (cm)	Acceptable stress (ε_t, in µdef)	Material thickness (cm)
Scenario 1	94.6	6 BB 20 GB3	104	6 BB 15 GB3
Scenario 2	56.2	8 BB 28 GB3	61.8	8 BB 22 GB3
Scenario 3	36.6	8 BB 37 GB3	40.2	8 BB 31 GB3

Table 5 - Structures for scenario 1, 2 and 3 for a semi-rigid pavement.

	Platform PF2		Platform PF3	
Scenario	Acceptable stress (ε_t, in µdef)	Material thickness (cm)	Acceptable stress (ε_t, in µdef)	Material thickness (cm)
Scenario 1	0.975	6 BB 25 GC3	1.072	6 BB 24 GC3
Scenario 2	0.710 0.645	6 BB 21 GC3 19 GC3	0.710 0.710	6 BB 18 GC3 15 GC3
Scenario 3	0.575 0.522	10 BB 23 GC3 18 GC3	0.575 0.575	10 BB 19 GC3 15 GC3

Tables 3 to 5 show the impact of HGV traffic and HGV silhouettes in the traffic on the thickness of the different structure layers, whatever the choice of technique is.

3.3 Pavement structures cost

We will focus on the bituminous structures for the cost analysis.

Table 6 – Pavement cost for scenario 0.

Platform	Platform PF2		Platform PF3	
	Simulated	Minimum	Simulated	Minimum
Cost (k€HT/km)	133.54	139.75	105.45	139.75

Table 7 - Pavement costs for scenarios 1,2 and 3 on bituminous pavement.

	Cost of bituminous pavement (k€HT/km)	
Platform	PF2	PF3
Scenario 1	602.34	489.61
Scenario 2	813.92	687.85
Scenario 3	1047.69	893.54

4. Analysis

4.1 Designed pavement structures

Let's compare designed structures from ALIZE with the structures that would be derived from the French Design Manual for Pavement Structures. For this exercise, we considered designed structures for scenario 3, since this is the only scenario with a HGV traffic that looks like the "real" HGV traffic on French roads for the National Road Network. We have to pick up in the manual a pavement structure designed for a HGV traffic of 2500 HGV per day and per sense of flow.

Table 8 - Comparison between a designed structure from ALIZE and a catalogue structure.

Bituminous pavement on platform PF3	
Designed structure	Manual structure
8 cm BB	8 cm BB
10 cm GB3	10 cm GB3
10 cm GB3	10 cm GB3
11 cm GB3	11 cm GB3

We could expect to find a thicker structure by using our hypothesis (because we consider full HGV in the study), but in fact we find the same structure. That's because the traffic classes in the manual are "wide" : the structure designed in the manual allows from 2000 to 5000 HGV per day and per sense of flow.

4.2 Allocation of pavement costs

To allocate pavement costs, we considered pavement costs on class PF3 platforms because in most cases, PF3 platforms lead to cheaper road (taking into account the improved formation plus the pavement costs). We also consider the technique minimum for scenario 0. Costs that are finally considered are in the following table.

Applying the costs allocation method to pavement building costs proportionally to each user traffic (light vehicles and HGV from classes 1, 2 and 3), the following equivalence ratios are found.

Table 9 – Pavement costs for a class 3 platform.

	Cost (k€HT/km)
Scenario 0	143.56
Scenario 1	489.61
Scenario 2	687.85
Scenario 3	893.54

Table 10 – Equivalence factors for pavement allocation.

Scenario 0	1
Scenario 1	25
Scenario 2	41
Scenario 3	62

5. Conclusion

As a conclusion, this study shows that it is possible to assess the responsibility on pavement building costs of each kind of HGV according to their aggressiveness.

To abide by the Eurovignette directive recommendations that any HGV charging system should be proportional to the infrastructure use, the ratios that were finally calculated should be used to allocate pavement costs. This would lead to equivalence factors for investment costs differentiated by HGV class with ratios between HGV and light vehicles bigger than 3 in all cases. To calculate these ratios, we consider that pavement costs represent 15% of investment costs on roads (other expenses refer to excavation, cleansing, bridges, fixed common costs…) and that all other expenses are allocated using the 2.5 ratio between HGV and light vehicles that was previously used for scenario 0. Equivalence factors for investment would then vary from 3.1 for class 1 HGV to 3.5 for class 2 HGV and 4.2 for class 3 HGV. These ratios have to be considered as minimums because HGV do have an impact on other expenses that has to be calculated in another study.

Finally, it would lead to different ratios for each HGV class contrary to ratios reported in the annex III directive and globally higher ratios than those presented in the preparatory documents for the directive proposition.

6. References

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