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## IMPACT OF LONGER AND HEAVIER TRUCKS ON BRIDGES



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### Abstract

This paper assesses the consequences for bridges of introducing a given proportion of longer and heavier trucks, i.e. the 25.25 m and up to 60 t modular combinations so-called EMS, in a French traffic. The aggressiveness of single EMS on bridges is compared to the aggressiveness of conventional workhorses (16.5 m and 40 t). Then, some sequences of 2 EMS are compared to sequences of workhorses. Finally, the load effects induced by a real traffic flow, measured on a heavy trafficked motorway in south of France by a WIM system, are compared to the load effects induced by the same traffic flow in which some trucks are re-combined into EMS, without increasing the total freight in volume or load. It is shown that EMS induce higher load effects, but remaining in the safety margin of bridges. A more critical phenomenon may be fatigue, which has still to be verified.

**Keywords:** Truck, European Modular Systems (EMS), longer and heavier trucks, traffic load, bridge, load effect.

## 1. Introduction

Road freight transport was increasing for decades in the European Union (EC, 2011), even if since the beginning of the crisis a slowdown is observed. The proportion of freight on road is also high and slightly increasing in Europe, above 75%. Therefore, there are many discussions and debates on truck size and weight to improve the efficiency of road transport, and to reduce the CO<sub>2</sub> emission, fossil energy consumption and road congestion. In most cases except for bulk materials, the truck volume is more limiting than the mass. In some countries of northern Europe, experimentations of longer and heavier modular vehicles - European Modular Systems (EMS) – of 25.25 m and up to 60 t were carried out or are on-going: Netherland (Aarts & Feddes, 2008), Denmark, Norway and Germany (EMS of 40 t here), while some other countries and the European Commission carried out or commissioned studies (Knight et al., 2008), (De Ceuster et al., 2008), (Debauche, 2008), (Fraunhofer et al., 2011). Sweden (VTI, 2008) and Finland already authorized these EMS in their driving laws since 1996. Some other Member states are expecting or discussing to test these EMS.

The Directive 96/53/EC establishes maximum weights and dimensions for international transport in the EU, but remains fuzzy on the cross border operation of longer or heavier trucks between two Member States which authorize them for national transport. Some debates occurred about that, putting forward the principle of subsidiarity and a strict interpretation of the Directive.

Because the bridges are designed for long lifetimes (from 50 to 100 and more years), and the stock of existing and ageing bridges in Europe is rather high, it is important to assess these bridges against any new truck configuration and loads in order to prevent high maintenance or repair costs or even worst, bridge failures. The impact of EMS on bridge was already investigated by (De Ceuster et al., 2008), (Glaeser et al. 2008) and (Bereni & Jacob, 2009). This work intends to assess the potential bridge damage increase if a given proportion of EMS would be introduced in France to replace some workhorse trucks, mainly 5 axle articulated (16.5 m up to 40 t) and 5 axle tractors and trailers (2+3 or 3+2). A real traffic measured by an operational WIM system on a French heavily trafficked motorway was used (Section 2). Some workhorse trucks were recombined into less EMS (Section 3), and then the aggressiveness on bridges of both traffic patterns were compared (Section 4).

## 2. Traffic Data

### 2.1 WIM Data collected on a Motorway

The heavy traffic was measured by a WIM system implemented for overload scanning by the French ministry of transport (Marchadour & Jacob, 2008), over a 4 week period in February 2010 on the A9 motorway at Saint-Jean-de-Védas, near Montpellier in South of France. This traffic is rather international on a main route from and to Spain, with a high volume of trucks, above 13,000 per day in both directions. Therefore, it may be expected to be a future route for EMS if they become allowed.

The motorway has 4 traffic lanes, i.e. 2 in each direction, and the data were collected on the North bound direction. A total of 162,888 trucks were recorded on the 2 lanes, out of which 28,495 have a GVW above 38 t (17.5%). The average daily truck traffic is 6,033 (6,790 if accounting one day for a week-end) (Figure 1). 78% of the trucks have 5 axles and 85% are

articulated (tractors with semi-trailer), with 4 to 6 axles. There are only 3.2% of trucks with 6 axles and more, and no EMS are found while they are not allowed in France and Spain.

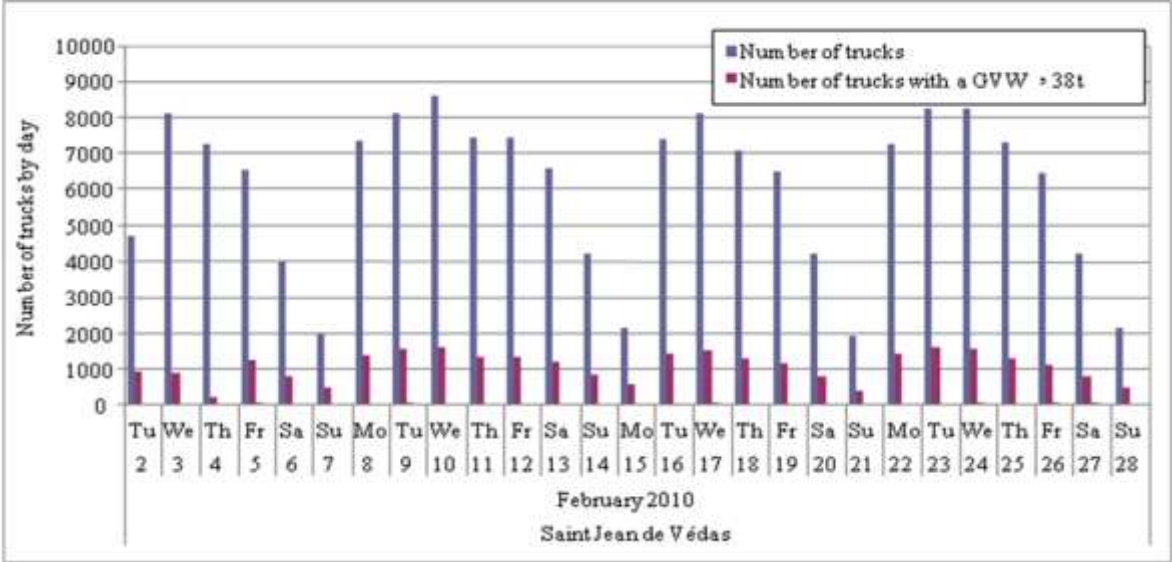


Figure 1 - Daily truck flow –  $\geq 3.5$  t and  $\geq 38$  t on A9 motorway in February 2010.

2.2 Assumptions for Truck Recombination into EMS

At this stage, we can only make assumptions on the proportion of EMS in a traffic flow if allowed, and which workhorse trucks would be replaced by EMS. The first assumption made is that the introduction of EMS would not induce additional freight on road, i.e. the total volume or masse of transported goods would not increase. That is a reasonable assumption to compare load effects on bridges with or without EMS.





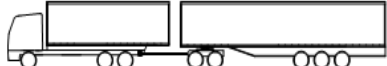
Table 1 – Current workhorse trucks.

Name	Silhouette (max GW = 40 t)
T2S3 (EU reference truck GW = 40 t)	
C3R2	
C3R3	
T3S3	

The second assumption is that only the heaviest or largest trucks would be recombined or replaced by EMS. At this early stage and without precise information about the operator policy, it is assumed that only trucks above 38 t would be recombined into EMS. According to the French (and EU) regulation, these trucks have 5 or more axles, and are the longest trucks in operation, up to 16.5 m if articulated, or 18.75 m if drawbar vehicles. The most common silhouettes of these vehicles are given in Table 1. The T2S3 is taken as the EU reference truck if loaded at 40 t because it is the most frequent silhouette; the load effects induced by other vehicles are compared to those induced by this reference truck. The possible EMS derived by recombination are given in Table 2. One leading idea is that carriers would not change too quickly their trailers or tractors. In addition, and without detailed information

of the load redistribution after the recombination, a crude and conservative assumption was made, stating that all resulting EMS were loaded at 60 t.

**Table 2 – Resulting EMS configurations.**

Name	Silhouette (GW = 60 t)
EMS 1 (T2S3 + R2)	
EMS 2 (T2S3 + R3)	
EMS 3 (T3S3 + R2)	
EMS 4 (T3S3 + R3)	
EMS 5 (C3 + dolly + S3)	

### 3. Methodology and Algorithm

#### 3.1 Algorithm of Combination of Workhorses into EMS

The algorithm developed to create EMS by combining modules of current workhorse vehicles is described in Figure 2. The workhorse trucks eligible to recombination into EMS are:

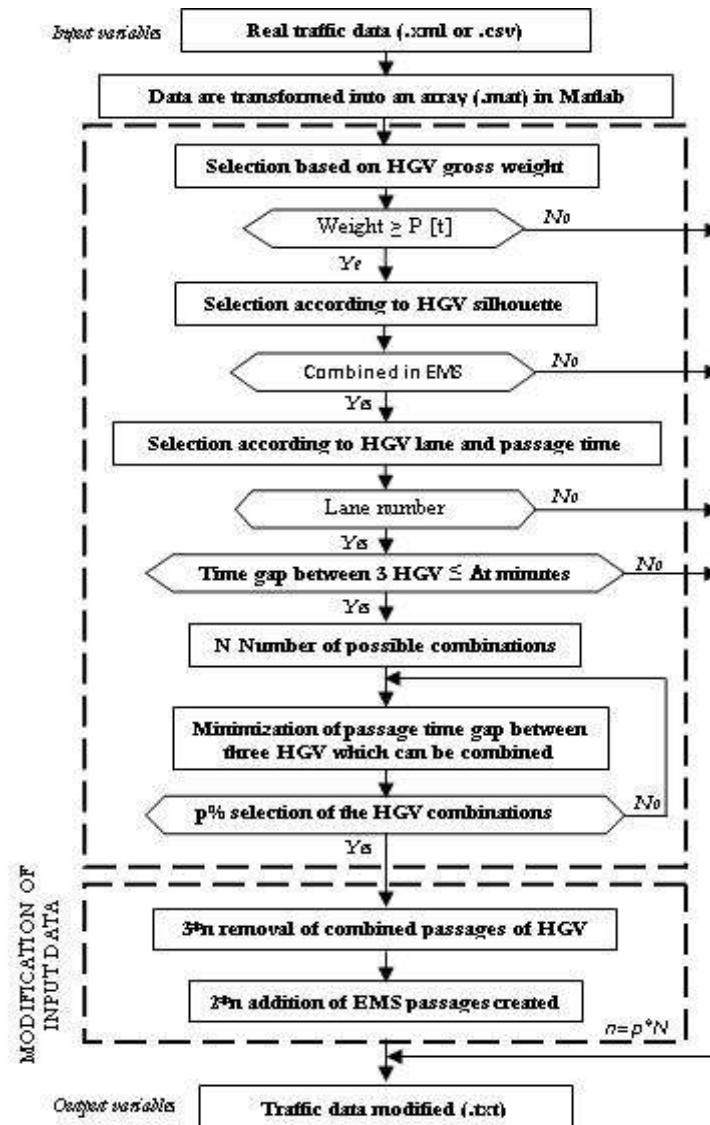
- $GVW \geq 38$  t, i.e. “Selection based on HGV gross weight” in Figure 2,
- silhouettes included in Table 1, i.e. “Selection according to HGV silhouette” in Figure 2,
- belonging to a set of 2 trucks traveling in the same lane, i.e. “Selection according to HGV lane and passage time”, and within a defined time interval, i.e. “Time gap between 3 HGV  $\leq \Delta t$  minutes”. This condition reflects the fact that trucks to be recombined into EMS shall be close each to the other, to avoid long delay.

Beside these eligibility conditions, another assumption is the percentage of EMS introduced. This percentage was chosen from 0% (no EMS) up to 60% (very high proportion), with a rather large range in order to study the impact on bridges. The algorithm described in Figure 2 was applied to the traffic file recorded with these percentages, which generated several virtual traffic flows with various proportions of EMS. All these traffic flows were applied on bridge models by simulation to assess and compare the induced maximum load effects.

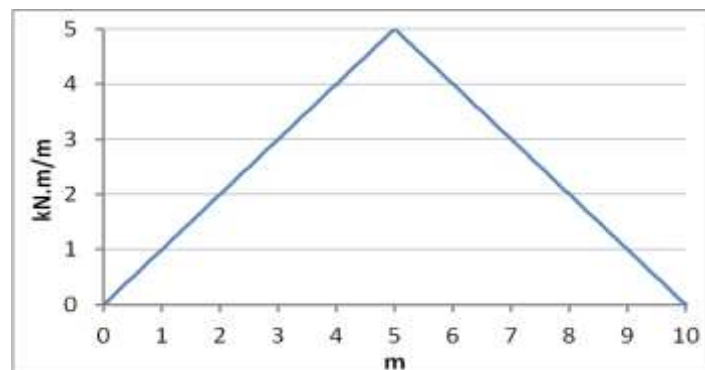
#### 3.2 Load Effects and Influence Lines

To assess the load effects of any traffic flow on bridges, influence lines are used. An influence line is a transfer function, which gives the load effect (e.g. a bending moment, a shear force, etc.) at any particular section of the bridge and in a defined part of it,  $y=f(x)$ , while a unit concentrated load is applied at the abscissa  $x$ . Influence lines are used as 1-D bridge model, i.e. if the loads are applied by traffic lane, but influence surfaces  $z=f(x,y)$  may also be used for 2-D models, if the transverse effects are important.

Influence lines or surfaces are based on the assumption of a linear and elastic behavior of the structure, which means that the effect of any set of trucks on the bridge at a time  $t$  is equal to the sum of the effects of all axles present on the bridge at this time. The effect of an axle (or a wheel for an influence surface) is equal to the product of the axle load by the influence line ordinate  $y$ .



**Figure 2 – Recombination of workhorses into EMS**



**Figure 3 – Mid-span bending moment influence line (10 m span).**

While the complete study carried out considered several load effects and influence lines, this paper only presents the results for the bending moment at mid-span of a simply supported span (Fig. 3). Simply supported bridges are very common structures and the bending moment at mid-span is the most critical load effect induced by traffic loads in bridges (OCDE, 2010).

### 3.3 Load Effect Assessment

Load effect calculations are made by the software POLLUX, developed by the LCPC, and derived from the former CASTOR-LCPC tool (Eymard & Jacob, 1989). This software simulate the traffic load flow on the bridge and calculate at each time step  $t$  the load effect(s) induced by all the axles present on the bridge length. It produces histograms of theses load effects, mini-max (local extrema), level crossing and rain-flow for fatigue assessment.

POLLUX also performs extrapolations of the extreme load effects over long structure lifetimes, and fatigue lifetime calculations using the Miner's law (Schmidt and Jacob, 2010).

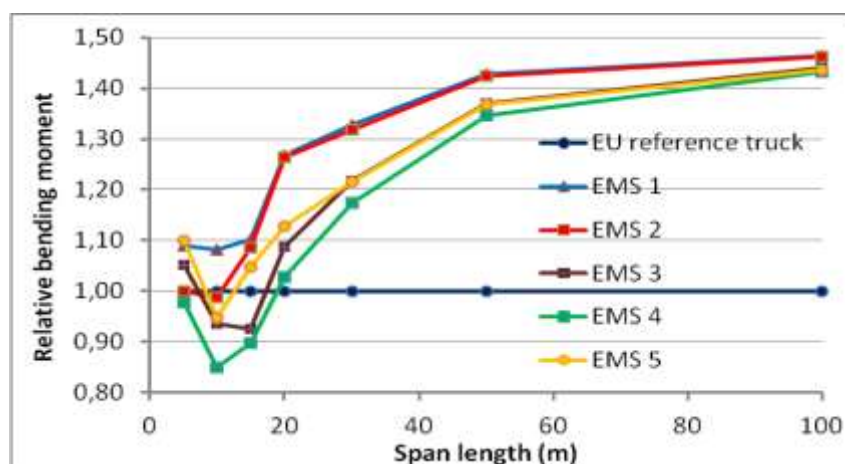
## 4. Results and Analysis

Results are presented for three cases: compared aggressiveness of five EMS shapes (of Table 2) in subsection 4.1, of sequences of two EMS resulting from a recombination of 3 workhorse trucks in subsection 4.2, and of the recorded traffic flow vs. the modified traffic flow with EMS in subsection 4.3.

### 4.1 Single EMS Aggressiveness

Maximum bending moments at mid-span of bridges from 5 to 100 m are compared for the 5 considered single EMS to the case of the EU reference truck aggressiveness (Figure 4).

For span lengths above 60 meters, the load effects do not depend on the EMS shape. It results of the similar equivalent uniform distributed load (EUDL) of all EMS on the same length, much less in that case than the span length, app. 1/3 to 1/4. The bending moment ratios compared to the EU reference truck are close to 1.5 for 100 m span length, which is the gross weight ratio of the EMS to the T2S3 (60 to 40 t). For span lengths below 60 meters, EMS 4 has the smallest effect, because it has the maximum number of axles (9), and a balanced load distribution on 3 sub-sets of 3 axles (Table 2). For the shortest span lengths, below 20 m, less than the EMS wheelbase, the EMS3, 4 and 5 induce lower bending moments than the standard T2S3, because they do not have the single driving axle of the tractor, the heaviest and the most aggressive axle, up to 13 t in France.



**Figure 4 – Ratio of the maximum mid-span bending moments of single EMS vs. T2S3**

Comparing the aggressiveness of single EMS shapes is important but not sufficient. Two EMS replacing three workhorses would circulate in a traffic flow with other workhorses. Thus in the next subsection, sets of two trucks (EMS or workhorses) are used.



## 4.2 Sets of EMS and Workhorses

The load effects of workhorse sets and EMS sets which replace them are compared. The workhorse sets are recombined into EMS as follows:

Case 1: WH 1 (workhorses: 2 \* T2S3 + 1 \* C3R2) → EMS 1+5

Case 2: WH 2 (workhorses: 2 \* T2S3 + 1 \* C3R3) → EMS 2+5

Case 3: WH 3 (workhorses: 2 \* T3S3 + 1 \* C3R2) → EMS 3+5

Case 4: WH 4 (workhorses: 2 \* T3S3 + 1 \* C3R3) → EMS 4+5

Vehicle spacing was set at 5 m in the first case (Figure 5), which corresponds to congestion, and at 50 m, the minimum allowed spacing in a free traffic case (Figure 6). In both figures, the ratios of the maximum bending moment at mid span of a simple supported bridge for the set of 2 EMS, divided by the same load effect for the 3 workhorses which were recombined are shown.

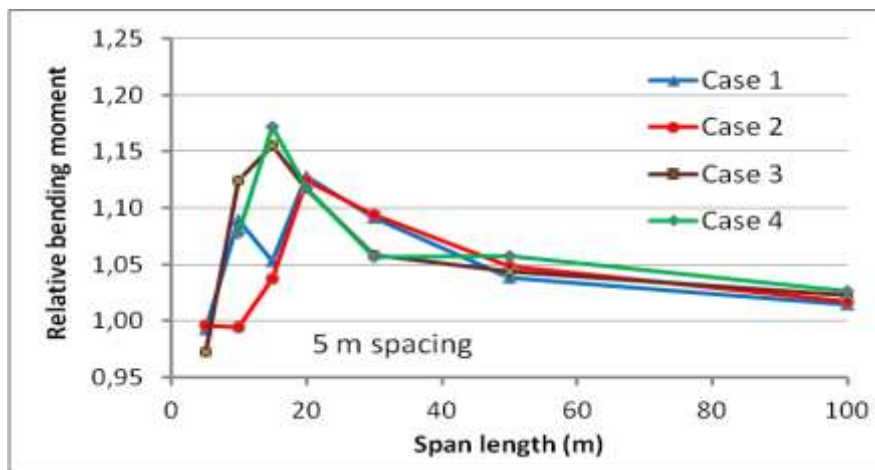


Figure 5 – Maximum mid-span bending moment ratios: set of 2 EMS by recombination / sets of 3 workhorses (vehicle spacing is 5 m, congestion).

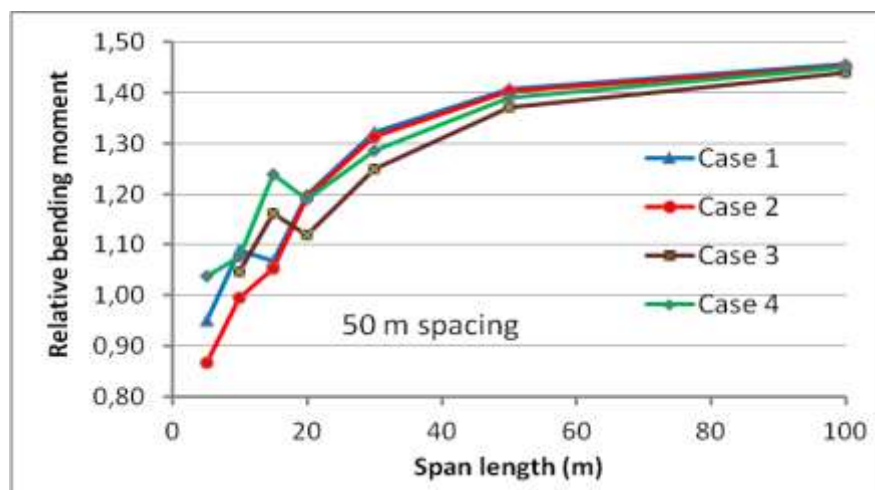


Figure 6 – Maximum mid-span bending moment ratios: set of 2 EMS by recombination / sets of 3 workhorses (vehicle spacing is 50 m, free traffic).



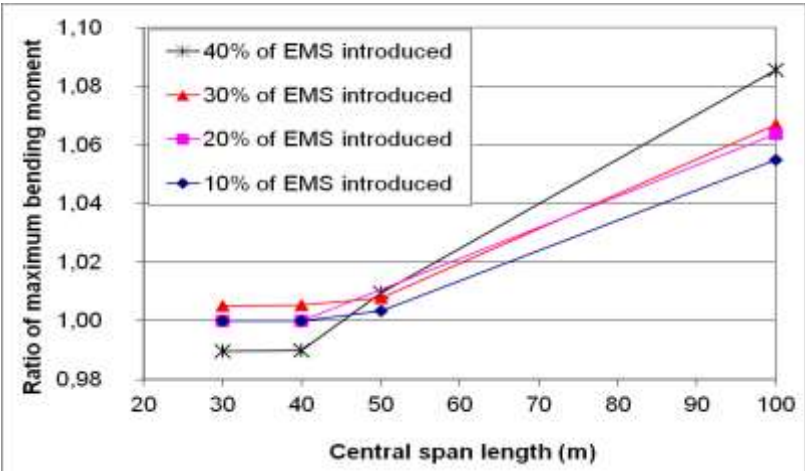
For span lengths up to 20 m the congested and free flow cases give similar results. The ratios of the bending moment induced by the recombined EMS vs. the bending moment of the corresponding workhorses slightly increase up to 15 or 20 m span, likely because some load configurations involving the rear half of the EMS are more aggressive than the workhorses alone. For span lengths above 25 m the congested and free traffic cases give opposite results. In a congested traffic, the ratios decrease while the span length increases and seems to converge to 1 (Figure 5). It is explained by the fact that with 5 m spacing between successive trucks, there are no significant differences between series of workhorses and of EMS. The whole span is loaded with axles and group of axles with homogeneous spacing.

In a free traffic (Figure 6), the EMS are more aggressive while a higher load is applied at once on the central part of the span, and the ratios are very close to those found with one EMS compared to the EU reference truck because up to 100 m, the maximum bending moment is obtained with a single vehicle at the middle of the span (the adjacent vehicles, 50 m away, are close to the bridge abutments and do not contribute significantly to the mid span bending moment. The ratio tends again to 1.5, as for single trucks, i.e. the load ratio 60 t/40 t.

The ratios obtained in congested traffic for span lengths above 30-40 m do not exceed 1.05. Because it was shown in the studies of the Eurocode EN1991-2 (Flint & Jacob, 1996) that congested traffic is governing the maximum load effects for these span lengths, the preliminary study tends to prove that the introduction of EMS would not significantly increase these maxima. For short spans or semi-local load effects, an increase of 10 to 20% may be expected, which would likely not affect too much the bridges if the overloads are strictly enforced for the EMS, and thus this increase would not be much more than the current overloads of workhorses. However, such an increase for maxima encountered many times per days could significantly increase the fatigue damages and reduce the lifetime for some types of bridges.

### 4.3 Traffic Flow with EMS

The maximum bending moment obtained with the 4 week traffic flow recorded in Saint-Jean-de-Vedas is compared to the same maximum effect if a given proportion of eligible workhorses are recombined into EMS as described above.



**Figure 7 – Ratios of the maximum mid-span bending moments of a » span bridge for increasing percentages of EMS with respect to the real traffic.**

For a 3 span continuous bridge, the bending moment at mid-central span (30 to 100 m in length) is considered. This choice intended to get a longer loaded length than the simple supported spans. The ratios of the maximum bending moments are given in Figure 7 for proportions of recombined workhorses from 10 to 50%. The spacing of the EMS was chosen at the minimum legal distance in free traffic, 50 m.

Up to 40 m span length, there is almost no difference whatever the proportion of EMS with the real traffic, and the ratios remain very close to 1. For longer spans, the ratios seem to increase proportionally to the span length, and the higher the proportion of EMS, the higher the ratio for 100 m length. However the differences are very small, from 1.05 to 1.09 with respect to the real traffic. These values are much smaller than those computed in free traffic for 3 workhorses recombined in 2 EMS (up to 1.45), because here the maximum bending moments for the whole traffic are compared over 4 weeks, and may occur for different days/hours and load configurations.

Combined with the congested results of section 4.2 (Figure 5), it proves that even with a high proportion of EMS (up to 40% of eligible trucks recombined), the studied load effects would not be increased by more than 10% whatever the span length. It indicates that bridges would not be too much affected (but in fatigue, which was not investigated yet).

## 5. Conclusion and Future Work

These preliminary results on the potential increase of simple supported maximum bending moments if EMS are introduced, and replace some workhorse vehicles, suggest that:

- single EMS are more aggressive than workhorse vehicles, above all for span lengths above 20 m, but not if compared to the 40 t 5-axle articulated vehicle on short spans, because EMS axle loads are lower with a better load distribution on more axles;
- if 2 EMS replace 3 workhorses, the maximum bending moment increases in free traffic, but in congested traffic with only trucks (no car), longer the span and closer the ratio to 1;
- under a whole traffic flow, and even if a rather high proportion of trucks above 38 t are recombined into EMS, the maximum load effect would not increase by more than 10%.

Further studies remains to be done with more realistic assumptions on workhorse recombination and considering also fatigue damage in steel and composite bridges.

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