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Implications of Future Heavier Trucks for Europe's Bridges

Colin C. Caprani
Technological University Dublin, colin.caprani@tudublin.ie

Bernard Enright
Technological University Dublin, bernard.enright@tudublin.ie

Eugene O'Brien
University College Dublin

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Colin C. Caprani
Dublin Institute of Technology, colin.caprani@dit.ie

Bernard Enright
Dublin Institute of Technology

Eugene O'Brien
University College Dublin

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Eugene OBrien
Professor
University College Dublin
Dublin, Ireland
eugene.obrien@ucd.ie

Bernard Enright
Lecturer
Dublin Institute of
Technology, Dublin, Ireland
bernard.enright@dit.ie

Colin Caprani
Lecturer
Dublin Institute of
Technology, Dublin, Ireland
colin.caprani@dit.ie

Abstract

European Road freight transport has increased by 38% between 1995 and 2005 and this strong growth trajectory seems likely to continue into the future. To address this growth without compromising the competitiveness of European transport, some countries are contemplating the introduction of longer and heavier trucks, with up to 8 axles and gross weights of up to 60 t. This has the advantage of reducing the number of vehicles for a given volume or mass of freight, reducing labour, fuel and other costs. However, many roads authorities are concerned about the implications for Europe's bridge infrastructure. For bridge loading, it is the combination of gross weight and truck length that determine load effects such as bending moment and shear force in the deck. A probabilistic analysis is required to assess whether these proposed trucks will lead to greater maximum lifetime (characteristic) load effects. If this was found to be the case, it would necessitate the strengthening of a great number of vulnerable bridges throughout the continent or it could even prevent the introduction of heavier trucks.

This paper reviews the factors governing traffic loading on short/medium span bridges. There is considerable conservatism in the Eurocode traffic loading model. Hence, bridges designed to this or similar modern codes of practice can be shown to be safe in the presence of significant numbers of longer and heavier trucks. Even more significantly, using data from one of Europe's most heavily trafficked highways, it is shown that the critical loading events are often special permit trucks such as cranes or low-loaders with up to 12 axles. Hence, characteristic load effects (bending moments etc.) are unlikely to be strongly influenced by the most common truck type – 5-axle articulated trucks – and are therefore unlikely to be affected by the introduction of longer and heavier versions of them.

1. Introduction

Road freight transport in Europe, measured in tonne-km, has grown at a rate slightly above the Gross Domestic Product from 1995 to 2005 (Ref. 1). At the same time rail transport is almost unchanged. If this trend continues into the future, as is likely, there is an urgent need to take steps to cater for this growth, to prevent excessive congestion and loss of competitiveness in the marketplace.

What is needed is an integrated road freight transport solution, to address Europe's medium and long-term needs. It must increase transport effectiveness, reduce fossil fuel consumption and environmental impact while at the same time reducing freight transport costs. It is an essential ingredient in a vibrant European economy and a strong internal market as required by the Lisbon agenda.

A key issue from a medium-term perspective, where existing infrastructure will be present, is to investigate the possibilities for new vehicle concepts and combinations. Bigger and possibly heavier vehicles may increase the stresses on road infrastructure, particularly bridges. However, there is considerable reserve strength in most highway structures. The authors are currently working to quantify the extent of such reserves. The implication is that it may be possible to carry new vehicle combinations without the need for significant infrastructure upgrading.

2. Measuring Truck Data

For this study, Weigh-in-Motion (WIM) measurements were taken over a 20-week period at a site in the Netherlands. This large sample size allows for accurate estimation of the underlying statistical distributions and gives an insight into what the future may hold for other less densely trafficked locations. The data is supported by photographic evidence which both helps to identify errors and gives greater confidence in the records of great vehicle weights, unusual axle configurations and very small inter-vehicle gaps. The most notable feature of the measured traffic is the regular occurrence of very heavy trucks, with about ten vehicles per day being over 70 t and a maximum recorded gross vehicle weight (GVW) of 165.6 t.

WIM data was provided by the Rijkswaterstaat Centre for Transport and Navigation (DVS), an advisory institute of the Dutch Ministry of Transport, Public Works and Water Management in the Netherlands. The sensors are on the three westbound lanes of the A12 highway near Woerden, 30 km east of the port of Rotterdam. Data is for truck traffic in the two inner lanes of the 3-lane highway for the 20 week period from 7 February to 25 June, 2005. Data was analysed for a total of 664 343 trucks weighing 3.5 t or more, with time stamps recorded to a precision of 0.01 seconds.

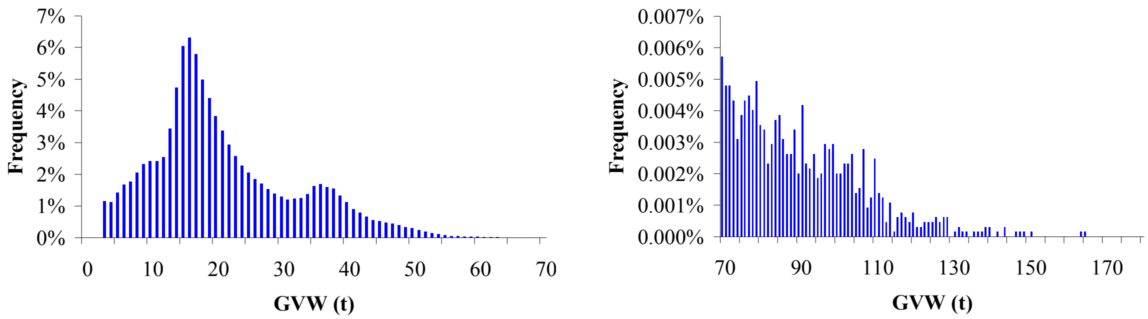
Cameras were used at the WIM locations to photograph selected trucks. A total of 965 photographs of trucks of particular interest were examined to verify the great Gross Vehicle Weights (GVWs) observed and to investigate data quality issues.

92.3% of trucks were in the inner (slow) lane, and 7.7% are in the middle (faster) lane. These were recorded on a total of 128 days in the 20-week period, including weekends and days on which, for operational reasons, the WIM equipment was not functioning continuously throughout the 24 hours. There are 77 weekdays for which a full record is available. The average daily flows are 6 540 trucks per day in the slow lane and 557 trucks per day in the faster lane.

The GVW histogram is illustrated in Fig. 1. The frequencies of weights up to 70 t (Fig. 1(a)) are typical of heavily trafficked European highways (OBrien et al. 2006, Grave 2001, Bailey 1996). Because of the location and the quantity of data analysed, significant numbers of very heavy vehicles were also recorded, as can be seen in Fig. 1(b). This includes 236 vehicles with GVW in excess of 100 t, up to the heaviest observed GVW of 165.6 t.

Details of the ten heaviest vehicles in the database are presented in Table 1. These extremely heavy vehicles would be expected to have special permits and escort vehicles, but were recorded travelling close to the speed limit of 80 km/h, and are typically part of the general traffic on this highway.

Many of these heavy trucks, such as that illustrated in Fig. 2 are “low loaders” which are characterised by a set of front axles close together, followed by a large axle spacing (11.2 m in this case), followed by a set of closely spaced rear axles. Other extremely heavy vehicles have a



(a) Histogram for vehicles up to 70 t *(b) Histogram for vehicles with GVW >70 t*

Figure 1. GVW (both lanes) for nearly 600 000 vehicles on A12 in the Netherlands

Table 1. Ten vehicles with highest GVW

GVW (t)	No. Axles	Wheelbase (m)	Speed (km/h)	Maximum Axle Spacing (m)
166	12	28.7	78	11.0
165	12	27.3	85	10.6
152	13	28.4	80	10.5
150	12	28.8	79	11.1
148	13	19.5	76	2.8
147	12	28.8	81	11.1
145	11	24.8	82	11.2
145	13	29.4	80	10.5
143	12	28.8	77	11.1
140	13	28.3	84	10.4

Figure 2. Vehicle with GVW of 145 t

maximum axle spacing of 3 m or less. These vehicles are typically cranes, or trucks carrying crane ballast (which often travel in convoy with cranes).

3. Calculation of Characteristic Bridge Load Effects

In the assessment of existing highway bridges, measurements of site-specific traffic can be used to estimate the characteristic traffic load effects (bending moments, shear forces etc.). Eurocode 1 for the design of new bridges is based on the load effects with a 1000 year return period, i.e., 10% probability of exceedance in a 100 year design life or 5% in a 50 year design life (EC1 1994, Bruls et al 1996, Flint & Jacob 1996). An approach used to derive the Eurocode (O'Connor et al 1998) and adopted by many authors (Nowak 1993, Caprani et al 2008, O'Connor 2001, Bruls et al 1996) is to measure traffic data for some weeks, to derive statistical distributions for vehicle weights, inter-vehicle gaps and other parameters from the measured traffic, and to use these distributions as the basis for Monte Carlo simulations. Simulated load effect statistics such as daily, monthly or yearly maxima are plotted on probability paper as illustrated in Fig. 3. This is a plot of cumulative frequency versus load effect (a cumulative frequency distribution) but the frequencies are rescaled to a standard extremal variate which better illustrates the parts of the graph where probabilities are small.

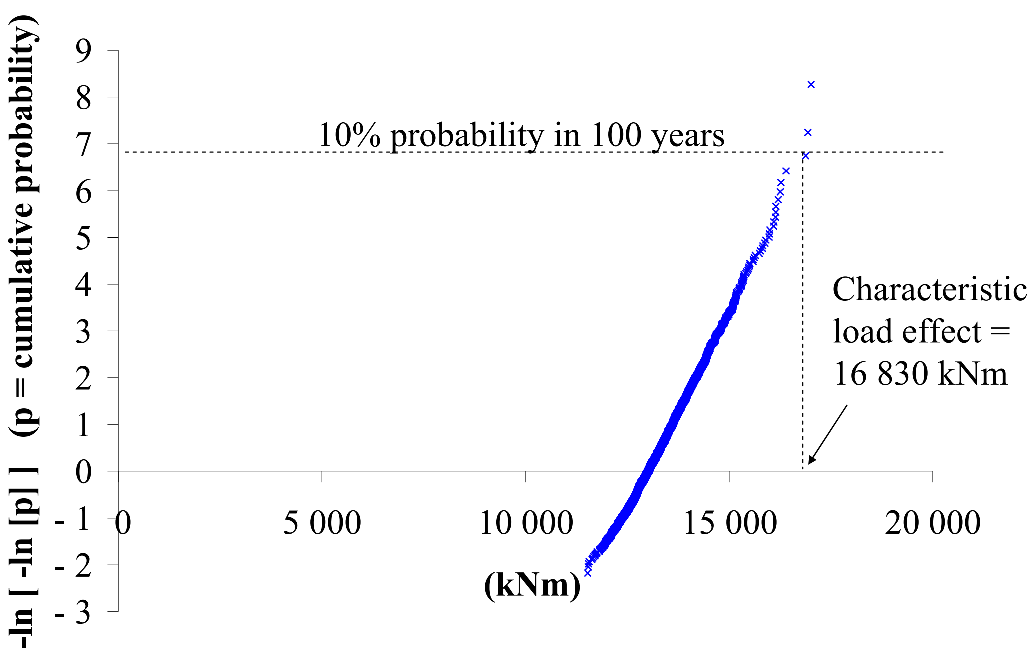


Figure 3. Yearly maximum mid-span bending moment for 45 m simply supported bridge – simulated over 2300 years.

It can be seen that for the example of Fig. 3, the bending moment with a 10% probability of being exceeded in the 100 year life, is 16 830 kNm. Variations in this approach have been reported in the literature. However, results to date have been quite variable and the method is quite sensitive to some of the assumptions made regarding the nature of extreme vehicles (Caprani 2006).

4. Separating Loading Events by Type

Plotting load effect data such as maximum bending moment per year on probability paper is based on the assumption that individual loading events are independent and identically distributed (iid). However, Caprani et al (2008) have pointed out that load effects can be the result of any of a number of quite different loading events, involving different numbers of trucks. In general, a load effect due to the passage of a single vehicle has a different statistical distribution to the same load effect due to an event involving multiple vehicles. To mix load effects from such different loading events violates the iid assumption used in extreme value analysis. Caprani et al (2008) show that accuracy can be considerably improved by considering the load effects due to different events separately and subsequently combining the probabilities of bridge capacity being exceeded. This is illustrated in the probability paper plot of Fig. 4. While all three event types contribute to the probability of moment exceeding a given threshold, the dominant event type is the right-most one, i.e., the 2-truck meeting event.

Mixing load effects from different events has been shown to result in significant errors in calculated characteristic value – considerably more accurate results can be achieved by separating the load effects according to their source as illustrated in the figure.

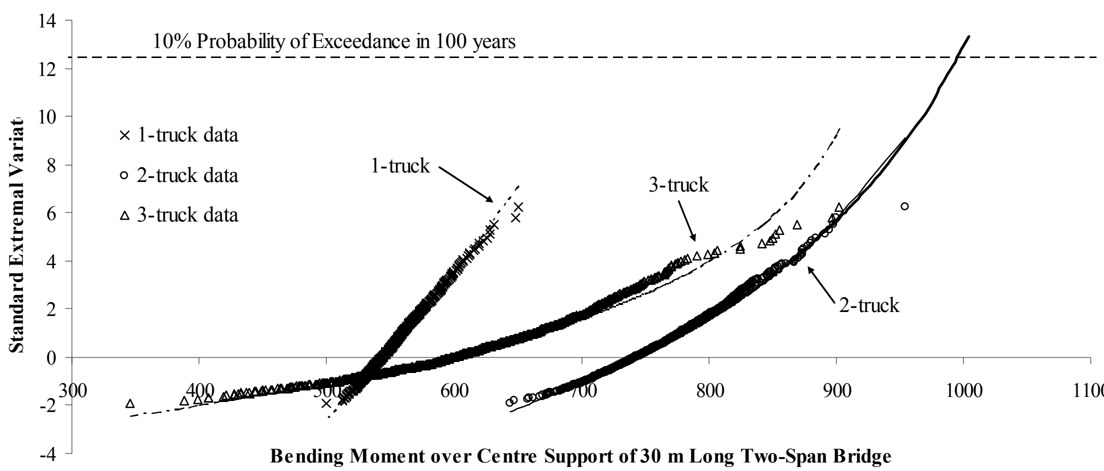
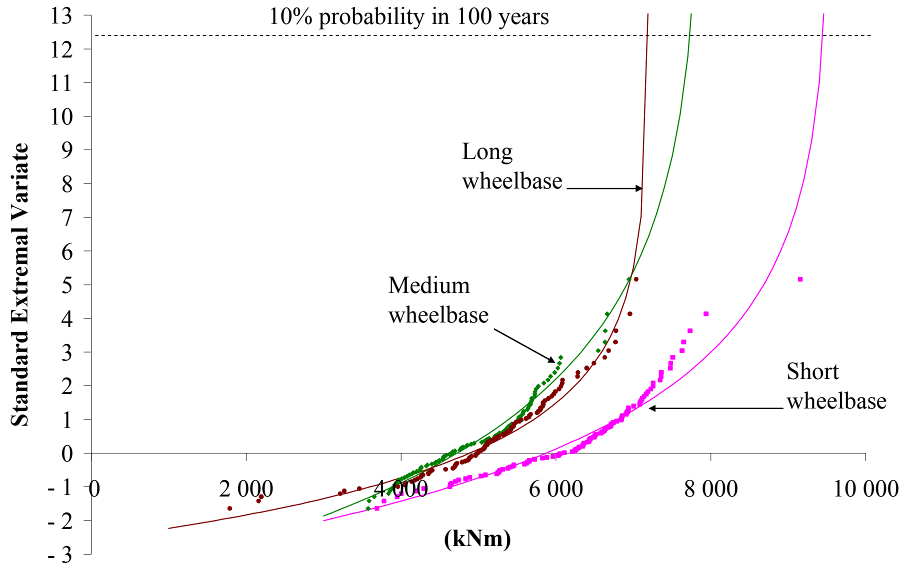


Figure 4. Mixed loading events with the return level and extrapolation shown.

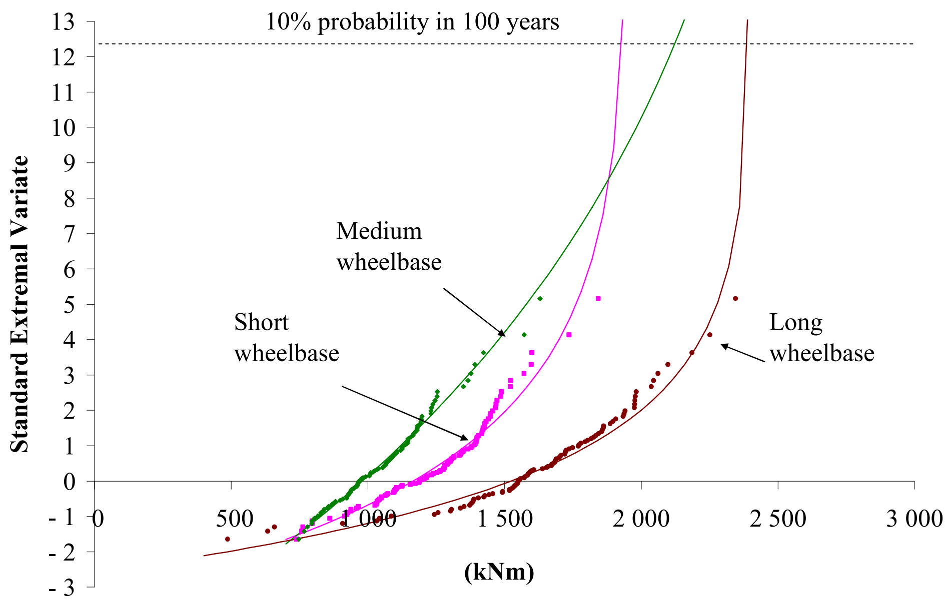
5. Results of Simulated Extreme Bridge Loading

The approach of separating load effects according to the type of event is extended here to truck type. For single truck crossing events, trucks are separated into 3 types: low loader (long wheelbase), crane (short wheelbase), and other trucks (medium wheelbase). The measured data on the A12 in the Netherlands is used here to calculate two load effects, LE1 – mid-span bending moment in a simply supported span and LE2 – hogging moment over the central support of a 2-span continuous bridge. In each case, load effects due to the 3 different types of truck are considered separately.

It can be seen that LE1 appears to be governed by cranes: the contribution of other truck types to the probability of exceedance is minimal. For LE2, on the other hand, the characteristic value is governed by low loaders. In both cases, truck types other than cranes and low loaders made no significant contribution to the characteristic load effect.



(a) Load Effect LE1: Mid-span bending moment on a 35 m simply-supported bridge



(b) Load Effect LE2: Hogging moment over the central support of a two-span 35 m bridge

Figure 5. Extreme 1-truck events from the A12 in the Netherlands.

6. Discussion and Conclusions

For most bridges, two or more lanes of traffic need to be considered. In such cases, the governing load case is often assumed to consist of an extreme truck in one lane (over the beam or section of slab of interest) and a frequent truck in the other (Grave 2001, Nowak 1993, Caprani 2006). For the A12 data, Figure 5 would suggest that the extreme truck will be a low-loader or a crane. The frequent truck in the other lane may be a medium wheelbase truck such as the very common 5-axle truck of today.

If in the future, the allowable size and weight of non-permit trucks is increased, then it will not influence the characteristic weights of cranes or low-loaders. However, it may increase the weight and the number of axles in the most common truck forms. For example, the 2nd truck in an extreme 2-truck loading event may change from a 5-axle to an 8-axle. This may lead to an increase in the characteristic load effects in bridges. However, it is reasonable to assume that the effect would be quite small for a number of reasons:

- the fact that the medium-wheelbase trucks will be longer with approximately the same weight per axle, reduces some load effects such as bending moment;
- the weight of the frequent vehicle is small relative to the weight of an extreme low loader or crane – perhaps of the order of 70% less heavy;
- the load effect under the extreme truck will be less affected by a truck in another lane – depending on the form of construction, this lane factor may be of the order of 15%;
- the loading event described above (extreme truck in one lane, frequent truck in the other) is only one possible type of critical event – it represents only one contribution to the total probability of exceeding the capacity.

This paper has demonstrated the importance of cranes and low-loaders as the dominant feature in extreme traffic loading on bridges at a very heavily trafficked site in the Netherlands. Medium-wheelbase non-permit trucks do not appear to make a great contribution. Many European countries are discussing the possibility of increasing the allowable weight and length of such non-permit trucks. It is proposed to further study this issue in the coming years in order to quantify the implications for Europe's bridges. It is the opinion of the authors that a significant increase in the allowable number of axles in non-permit trucks will not significantly change the characteristic traffic loading on short to medium span bridges.

Acknowledgement

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