Calibration of a Congestion Load Model for Highway Bridges Using Traffic Microsimulation

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ABSTRACT

For short- to medium-length bridges, the governing traffic loading scenario may be congested traffic. This paper presents the calibration of a congested traffic load model using traffic microsimulation. A range of bridge lengths, forms of construction, and load effects is considered. Different driving parameters and traffic composition are also considered. The influence of these parameters on the resulting load effect is determined. For each of these scenarios, a calibrated gap between trucks is determined to replicate the traffic microsimulation results. This calibrated gap can then be used as part of a simpler congestion model, suitable for bridge assessment. Such simpler models can be used to simulate much longer periods than are possible using traffic microsimulation. It is found that the calibrated gaps are either similar to, or are larger than, previous work in the area. Consequently, this approach helps to remove some conservatism from congested traffic load effect estimation, and this may find valuable application in the assessment of existing bridge structures.

KEYWORDS

Bridge, loads, traffic, congestion, microsimulation

1 INTRODUCTION

1.1 BACKGROUND

For the assessment of existing bridges traffic live load is one of the most variable parameters. A detailed traffic load model that faithfully replicates the traffic conditions at the site is therefore invaluable. Weigh-In-Motion (WIM) technology offers unbiased estimates of site-specific traffic, but the data is usually only collected for short periods. As a result, it is common practice to use computer-based Monte Carlo simulations to estimate annual or even lifetime traffic loading. However, to achieve these long-run simulations, some simplifications to the traffic model are required.

This paper presents an approach to calibrate a simple congestion model more suitable for long run simulations. It is calibrated using traffic microsimulation which replicates driving behaviour. Due to intensive computational demands, traffic microsimulation can only be used for short-run simulations. By calibrating a simpler model to the traffic microsimulation results, faithful and yet long-run results are made available, thereby improving the estimate of annual or lifetime traffic loading. This approach may find valuable application in the assessment of existing bridges.

1.2 NEED FOR SIMPLE CONGESTION MODEL

For shorter bridges, the governing live load traffic regime is accepted to be free-flowing traffic, including dynamic interactions. Recent research into the level of dynamic interaction at the lifetime level has shown that the dynamic amplification factor to be applied to free flowing traffic is generally far less than considered hitherto (see OBrien et al 2010, Caprani et al 2010, OBrien et al 2009, and González et al 2008). This has the effect of reducing the free-flowing traffic load effect for a range of bridge lengths (about 30-50 m). Consequently, the congested traffic regime may be the critical loading case. Thus there is a need for simple congestion models that can allow simulate many years of congested traffic.

Free-flowing traffic models (Bailey 1996, OBrien & Caprani 2005) can replicate measured driving behaviour using fairly simple models, such as Poission arrival process, normalized headway model (Crespo-Minguillón & Casas 1997), and the Headway Distribution Statistics model (OBrien & Caprani 2005). In contrast, congested traffic is significantly influenced by driving behaviour and so simple vehicle-to-vehicle gap assumptions may not suffice to represent the phenomenon. However, a simple gap model is very attractive as it is computationally efficient, and could be used for assessment by practitioners.

1.3 CONGESTION MODELS IN THE LITERATURE

Figure 1 provides a definition of the terms used in this work. The gap between the rear axle of the lead vehicle and the front axle of the following vehicle is termed the axle-gap. This is the gap of direct interest in calculating the load effect imparted to the bridge. The physical gap between the vehicles, which is of most importance in considering driver behaviour, is termed the bumper-gap. The front and rear overhangs are thus essential in determining the relationship between the gap reacted to by the driver (bumper-gap) and the gap ‘felt’ by the bridge (axle-gap).

Nowak and Hong (1991) modelled static configurations of traffic with assumed axle-gaps of 15 ft (4.57 m) and 30 ft (9.14 m). Vrouwenvelder and Waarts (1993) use two models: for establishing distributed lane loads an axle-gap of 5.5 m is used, whilst for full modelling a random axle-gap of 4 to 10 m, depending on speed, is used. In the background studies to the Eurocode (EC1.2 2003), Bruls et al (1996) and Flint & Jacob (1996) use a constant 5 m axle-gap (Prat 2001). Notably, Bailey (1996) uses beta distributions to model the distance between vehicles for different speeds. For a speed of 18 km/h corresponding approximately to congestion, the mode of the distribution gives a bumper-gap of approximately 6.4 m, with a minimum bumper-gap of 1.2 m. A survey of vehicles using inductive loops was used to determine distributions of overhangs. Caprani & OBrien (2008) consider normally-distributed 5, 10, and 15 m axle-gaps, all with a coefficient of variation of 5%. In fact this work, and Bailey (1996), appear to be the only work using statistical gaps between congested vehicles. For long span bridge live load modelling, Lutomirska (2009) uses a 25 ft (7.62 m) axle-gap, corresponding to a bumper-gap of 15 ft (4.57 m) for an Interstate semitrailer WB-20 vehicle (AASHTO 2001).

There is good agreement between the models described. However, the origins of the gaps chosen appear to be empirical in nature and do not seem to have been calibrated using either field data or driving simulation modelling - an exception to this is the work of Bailey (1996) who bases the gap distribution on data reported in Bez (1989). Further, the majority of models use axle-gaps and so thus include the front and rear vehicle body overhangs. This is explicitly stated to be the case for the Eurocode background studies in Prat (2001).

Driver behaviour in congested flow is surely concerned with the distance between the front of the driver's vehicle and the rear of the lead vehicle and not with the distance between axles (i.e. the bumper-gap and not the axle-gap). Therefore the minimum gap between the axles is controlled by the driver's acceptable minimum physical gap between the vehicle bodies, and the length of the two vehicles' relevant overhangs (Figure 1). The existing congestion models generally neglect these very important features. This work investigates these factors and enables comparison with the models in the literature through calibration of the bumper-gaps in congested truck traffic.

2 BRIDGE AND TRAFFIC PARAMETERS

2.1 BRIDGE GEOMETRIES AND LOAD EFFECTS

Two-lane bi-directional bridges are considered in this study. The bridge lengths and load effects considered are as follows:

- Lengths: 20, 30, 40, 50, 60 m;
- Load Effects:
  - LE1: Mid-span bending moment in a simply-supported beam;
  - LE2: Central support hogging moment in a two-span beam;
  - LE3: left hand shear in a simply-supported beam.

To account for lateral distribution of load effect the following general forms of bridge construction are considered for the different bridge lengths:

- Bridge lengths: 20, 30, 40 m: beam and slab construction, typically: steel I-beams, precast concrete beams, steel open box girder, concrete precast open box girders, multi-cell steel or concrete box girders.
- Bridge lengths: 50, 60 m: single-cell steel or concrete box girders.

Corresponding to these forms of bridge construction, representative lateral distribution factors are taken from the literature and are given in Table 1 (Hambly 1991, NCHRP 2007, Huo et al 2004, Eom and Nowak 2001).

The lane factor represents the proportion of the load on that lane contributing to the load effect in the beam under consideration. The considered beam of this study is notional and represents the typical worst loaded beam in the bridge cross section. It is to be noted that the lane factors considered in this work are a very general representative sample, and will differ for particular bridge lengths, load effects, and forms of construction. However, the overall methodology and resulting congestion model proposed in this work remains applicable to specific bridges.

2.2 TRAFFIC DATA

This work is based on data taken from the A6 motorway near Auxerre, France in 1986. This data set is important as the Eurocode traffic load model (LM1) was calibrated against it (EC1.2 2003, Bruls et al 1996, Flint & Jacob 1996). The site has 4 lanes of traffic (2 in each direction) but only the traffic recorded in the slow lanes was used. In total 17 756 and 18 617 trucks were measured in the north and south slow lanes respectively, giving an average daily truck flow of 6744 trucks. This represents one week of traffic data which, it is acknowledged, is short in duration.

The traffic characteristics of the Auxerre site are modelled as described in Caprani (2005) and Monte Carlo simulation is used to generate new traffic, closely matching the statistical distributions of the measured traffic. It should be noted that only trucks of up to 5-axles are included in this study. Far heavier special-permit trucks are possible, and as a result this study only reflects normal highway traffic loads.

3 MICROSIMULATION MODELLING OF TRAFFIC

3.1 INTRODUCTION

The use of microscopic simulation for bridge traffic load effect is very new. OBrien et al (2010) use commercial microsimulation software to estimate the number of truck platoons that can be expected on a particular bridge. Chen and Wu (2011) describe the use of a cellular automaton model (the well-known Nagel-Schreckenberg model (Nagel & Schreckenberg 1992)). This approach suffers from a significant drawback however, in that the road is discretized into cells, thereby imposing cell-sized gaps between vehicles. For bridge traffic load effect these gaps are critical.

3.2 THE INTELLIGENT DRIVER MODEL

The Intelligent Driver Model (IDM), developed mainly by Treiber (Treiber et al 2000a, Treiber et al 2000b) is a continuous-space discrete-time microscopic driving model. Its equations describe the motion of an individual vehicle in response to its surroundings, given some mechanical and driver performance parameters:

$$\frac{dv}{dt} = a\left[1-\left(\frac{v}{v_0}\right)^{\delta}-\left(\frac{s^*}{s}\right)^2\right] \tag{1}$$

This expression combines the vehicle's acceleration towards the desired velocity, v_0, where a is the maximum acceleration and δ is the velocity exponent (usually taken as 4), with the vehicle's decelerations due to interaction with the vehicle in front, based upon the ratio of the current gap, s, to the desired minimum gap, s^*, described by:

$$s^* = s_0 + s_1\sqrt{\frac{v}{v_0}} + vT + \frac{v(\Delta v)}{2\sqrt{ab}} \tag{2}$$

in which s_0 and s_1 are the minimum and elastic jam distances respectively, T is the desired time headway, Δv is the approach velocity to the leading vehicle, and b is the comfortable deceleration.

3.3 DRIVER AND ROAD PARAMETERS

The IDM driver parameters used as a basis in this study are based upon those of Treiber (2000a) and are given in Table 2.

The road used for this work is two-lane bi-directional, and thus overtaking events are not permitted to occur. Vehicles are injected at the start of a 3 km section of road and their driving behaviour along this section of road is simulated using equation (1). At the far end (at 2.5 km) over a 500 m section of road, the safe-time headway (T) of each vehicle is increased by 1.3 seconds. This is a common strategy for inducing flow-conserving bottlenecks into the traffic stream (Treiber et al 2000a). The strongest congestion is induced here – that of homogenous or oscillatory congested traffic (HCT/OCT) and can be seen in Figure 2.

For each direction, 100 m before the inhomogeneity begins there is a 'virtual' loop detector on the road. Each time a vehicle crosses this detector, its time of arrival at the detector and its physical and traffic characteristics are output to file for later load effect calculation.

4 SIMULATIONS AND STATISTICAL ANALYSIS

4.1 OVERALL METHODOLOGY

The proposed simple congestion model is shown in Figure 3 and consists entirely of a stream of trucks, separated by a nominal axle-gap. The nominal axle-gap is that which is to be calibrated, so that the simple congestion model returns similar load effects to those realised from the more computationally-demanding and realistic traffic microsimulation model, which may or may not include cars in the traffic stream. Load effects from the proposed simple congestion model are determined for nominal gaps of 1, 5, 10, 15, 20, and 25 m. Gaps are taken to be normally distributed with coefficient of variation of 5%. It must be noted that the results of this study may differ with a different chosen coefficient of variation. However, the sensitivity of the results to this decision is not thought to be significant in comparison with the other simulation parameters considered.

The truck characteristics for the proposed simple congestion model should be taken from the site under study, using weigh-in-motion technology, for example. If enough data is collected, it may be possible to use the measured data directly. However, for shorter measurement periods, Monte Carlo simulation of the trucks can be undertaken, as was done here (see Section 2.2), with generated characteristics that closely match those of the measurement site.

4.2 SIMULATION PARAMETERS

Traffic is a highly variable phenomenon and this work examines the influence of some important variables, whilst making conservative or neutral assumptions about others:

1. *Traffic composition:*
   In this work, 0%, 50% and 80% cars are considered in the traffic stream; trucks comprise the remaining percentages. The unlikely case of 0% cars is included to represent a conservative load model approach, and this is similar to some previous authors (Bruls et al 1996, Flint & Jacob 1996, Lutomirska 2009). Within the truck population, the measured percentage of each vehicle class (2-axle, 3-axle, etc) at the Auxerre A6 site is kept.
2. *Traffic Volume:*
   In order that load effects from each traffic composition case are comparable, the overall traffic volume is varied so that the truck flow volume is that measured in the slow lane of the Auxerre A6 site. The use of motorway slow lane truck flow on a bi-directional two-lane bridge means that there remains a level of conservatism in the developed congestion model, when applied to two-lane bridges.
3. *Bottleneck Strength:*
   The bottleneck strength imposed here is of the strongest form, resulting in the heaviest possible congestion, giving the most closely spaced vehicles.
4. *Driving Behaviour:*
   Two forms of driving behaviour are included here to assess its influence on load effects, and the resulting calibration of the SCM:
   - Deterministic driving parameters, those of Table 2.
   - Stochastic driving parameters in which each vehicle has the following parameters of the IDM randomly generated and individually assigned:
     - Desired velocity: taken as normally distributed – for cars, N(110 km/h, 10 km/h) is assumed (giving 85% compliance with a 120 km/h speed limit); for trucks N(80 km/h, 4 km/h) is taken (high adherence to heavy vehicle speed limit).
     - Safe time headway: taken as normally distributed – for cars N(1.2 s, 0.12 s) is assumed (a range of 'aggressiveness'); for trucks N(1.7 s, 0.085 s) is used (better training of heavy vehicle drivers).

5. *Vehicle Overhangs:*
   To include the effect of vehicle overhangs into the microsimulation models, the minimum jam distance of the IDM (s_0) is taken as normally distributed for cars and trucks: for cars N(1.5 m, 0.3 m) is taken (estimated from the VC-COMPAT (2006)); for trucks N(4.0 m, 0.75 m) is used (estimated from a survey of manufacturers' data).

Table 3 summarizes the implemented traffic models of this study.

4.3 STATISTICAL ANALYSIS

For each traffic model, 1-year equivalent congestion is simulated. Breakdown to congestion and clearing of congestion phases are excluded from the data set. It is assumed that there are 250 working days per year with 2 hours of congestion per day. The maximum load effect recorded in each 2-hour block of congestion is retained. From this population, the expected annual maximum load effect is predicted and used as the basis of comparison between models. Lifetime maximum (100-years) or a 1000-year return period (commonly used – see Caprani et al (2008)) are not used as the basis for comparison because as the extrapolation 'distance' increases, the statistical model choice influence increases. As a result, the calibration should be reasonably independent of the statistical extrapolation model adopted.

The parent population of bridge load effect is not identically distributed. For example, the distribution of load effects caused by 2-trucks is not identical to that caused by 3-trucks. Caprani et al (2008) use a Composite Distribution Statistics (CDS) approach, given by:

$$G_C\left(x\right)=\prod_{j=1}^{n_t}G_j\left(x\right) \tag{2}$$

In which n_t is the number of event types, G_j(.) is the distribution of the j-truck loading event and G_C(.) represents the CDS distribution. The Generalized Extreme Value (GEV) distribution is used to estimate the distribution of each event type:

$$G(x)=\exp\left\{-\left[1-\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{1/\xi}\right\} \tag{3}$$

where μ,σ,ξ are the location, scale, and shape parameters respectively. In recognition of the fact that an infinite load effect is impossible, the fitting algorithm is restrained to $\xi\geq 1\times 10^{-6}$, thus excluding Fréchet (or unbounded) tails (Coles 2001).

5 RESULTS & OBSERVATIONS

5.1 BASIS OF RESULTS

To illustrate the results obtained, the commonly-assumed (see above) SCM-5 traffic model with 0% cars is considered. An example 2-hourly maximum loading event is shown in Figure 4 and the histogram of 2-hourly load effects is given in Figure 5. The loading event fits, CDS distribution, and extrapolation is shown in Figure 6 on Gumbel probability paper (Ang and

Tang, 1984). Also shown is the predicted annual maximum expected load effect of 1982 kNm.

Figure 7 shows the expected annual maximum load effects for Load Effect 1 for each of the simple congestion models considered, for 0% cars whilst Figure 8 shows the results from the statistical analysis of Load Effect 1 results from the IDM-1 traffic model for each car percentage. Figure 9 shows the ratio of the simple congestion model load effects to those determined from the IDM-1 traffic microsimulation model for 0% cars and LE1. The simple congestion model with 5 m gap replicates the results (i.e. ratio of 1.0) generally well. For the length of 50 m, the ratio of SCM-5 lies above unity (1.038) whilst for SCM-10 it lies below (0.818). As a basis for comparison of results, the nominal simple congestion model gap that would replicate the IDM results (i.e. a ratio 1.0), is determined by linear interpolation between the surrounding SCM results. Thus, from Figure 9, the corresponding 'target' SCM nominal gap is determined as 5.62 m.

5.2 TARGET SIMPLE CONGESTION MODEL NOMINAL GAPS

The complete set of target SCM nominal gaps is given in Table 4. Also given are global means for comparison of the results. Some general observations can be made:

- The percentage cars in the vehicle stream that the SCM is to replicate (in terms of load effects) has a significant effect on the target nominal gaps, regardless of the traffic model adopted.
- Allowing for stochastic driving behaviour leads to similar or smaller target gaps. This is surely due to the occurrence of successive 'aggressive' drivers.
- Incorporating an allowance for vehicle overhangs has an important effect for low car percentages, and reduced effect for the 80% cars vehicle stream.
- The target gaps are not particularly sensitive to the lateral-distribution lane factors used in the study (change in factors from 20-40 m bridge lengths to those of the 50-60 m).
- For the 50% and 80% cars, for each driving model, there is an (unsurprising) increase in the target gap with bridge length.

In comparison to previous work on congestion modelling, some observations can be made:

- The target nominal gaps for the proposed simple congestion model are quite similar to those of previous authors (Prat 2001, Bailey 1996, Nowak & Hong 1991, Lutomirska 2009).
- The 5 m gap assumption of the background studies to the Eurocode (EC1.2 2003, Prat 2001) corresponds to load effects observed in the very conservative case of a 0% cars traffic stream. This is not surprising given that the same data used in this study was used to calibrate the Eurocode itself.
- Given that the percentage cars has significant influence, and given that the target gap thus increases with bridge length, it seems that many of the gap proposals in the literature may be very conservative if applied to longer bridge lengths.

6 SUMMARY & CONCLUSIONS

6.1 SUMMARY

Recent research has shown the importance of congested traffic modelling for load effects on short-to-medium length bridges. As a result, a simple congestion model is proposed here, consisting of a stream of random trucks (only) separated by nominal gaps, with vehicle class percentages and other characteristics (such as GVW, axle-to-axle gaps etc.) modelled on the site under study. The main focus of this work is the calibration of suitable nominal gaps between the trucks of this simple congestion model. To accomplish this, load effects are determined from this postulated model for a wide range of nominal gaps.

A continuous-space traffic microsimulation model is introduced here. This allows high fidelity modelling of driving behaviour in response to various traffic incidences. In this work, congestion is introduced through a simulated bottleneck and vehicle positions are used to calculate resulting load effects. This is done for three different driver behaviour sets.

Through comparison of the load effects from the simple model and the microsimulation model, a target nominal gap for the simple congestion model is found. This gap is found for a range of load effects and bridge lengths with suitable allowance for different bridge construction types, for each of the forms of driving behaviour model.

6.2 CONCLUSIONS

Microsimulation is found to be an ideal tool in determining load effects resulting from congested traffic situations. However, given the computational demands associated with it, a simple congestion model is still required for simulating longer time periods of congested traffic. Calibration of this simple congestion model to the microsimulation model shows good similarities to previous authors in the area. However, its use has also shown that for medium-length bridges, and for higher percentages of cars in the vehicle stream, the assumptions of previous authors may be overly conservative, especially for the assessment of existing bridges. Further, an allowance for vehicle overhangs is found to have a large influence on congested traffic load effect. As a result, for critical bridge assessment cases, vehicle overhang information should be obtained from site measurements, or from a detailed vehicle manufacturer survey. Finally, microsimulation appears to be an ideal tool to remove much uncertainty (and associated justifiable conservatism) from the estimation of congested traffic load effects for medium-to-long span bridges.

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TABLES

Table 1: Lateral distribution lane factors for each load effect and bridge length.

Bridge Lengths	Load Effect*	Lane 1 Factor	Lane 2 Factor
20, 30, 40 m	LE1	0.6	0.25
	LE2	0.6	0.25
	LE3	0.9	0.05
50, 60 m	LE1	1.0	1.0
	LE2	0.6	0.25
	LE3	1.0	1.0

*LE1: Mid-span bending moment in a simply-supported beam;
LE2: Central support hogging moment in a two-span beam;
LE3: left hand shear in a simply-supported beam.

Table 2: Base values of the IDM model parameters for this study

Vehicle Type	v_0 (km/h)	T (s)	a (m/s^2)	b (m/s^2)	s_0 (m)	s_1 (m)
Cars	120	1.2	0.8	1.25	1	10
Trucks	80	1.7	0.4	0.8	1	10

Table 3: Summary of implemented traffic models.

Model Type	Name	Parameter Set
Simple Congestion Models	SCM-1	1 m nominal gap, 5% coefficient of variation
	SCM-5	5 m nominal gap, 5% coefficient of variation
	SCM-10	10 m nominal gap, 5% coefficient of variation
	SCM-15	15 m nominal gap, 5% coefficient of variation
	SCM-20	20 m nominal gap, 5% coefficient of variation
	SCM-25	25 m nominal gap, 5% coefficient of variation
Microsimulation Models	IDM-1	Deterministic driving parameters (Table 2)
	IDM-2	Stochastic driving parameters (see text)
	IDM-3	IDM-2, including vehicle overhangs (see text)

Note: All models implemented for 0%, 50% and 80% cars (see text).

Table 4: Target Simple Congestion Model nominal gaps.

Traffic Model	Bridge Length	0% Cars			50% Cars			80% Cars		
		LE1	LE2	LE3	LE1	LE2	LE3	LE1	LE2	LE3
IDM-1	20	5.03	5.17	7.51	4.90	6.08	5.44	10.63	8.88	10.50
	30	5.31	5.45	5.61	6.08	6.59	5.80	9.13	8.80	8.42
	40	5.01	5.28	5.20	6.27	5.70	5.93	8.70	8.93	8.78
	50	5.62	5.53	5.67	7.12	6.77	6.34	8.73	8.64	9.34
	60	5.42	5.50	5.36	7.62	6.69	7.44	9.14	8.24	9.18
	Mean		5.51			6.32			9.07	
IDM-2	20	4.90	5.22	4.88	7.39	7.09	7.38	10.68	8.80	11.66
	30	4.91	5.38	5.17	7.07	6.98	6.32	8.96	8.96	8.35
	40	4.61	4.93	4.92	6.85	7.20	6.99	8.76	8.60	8.56
	50	5.16	5.19	5.16	6.80	6.71	6.75	8.19	8.67	8.71
	60	5.40	5.15	4.98	6.75	6.70	6.70	9.24	9.16	9.17
	Mean		5.06			6.91			9.10	
IDM-3	20	8.66	7.62	7.73	7.44	7.89	9.66	9.83	8.83	11.17
	30	7.56	7.40	6.32	8.26	8.87	7.85	10.09	10.55	8.82
	40	7.41	6.52	7.00	8.58	7.50	8.07	10.81	9.18	9.66
	50	7.86	7.24	7.21	9.17	8.45	8.87	9.86	9.49	10.23
	60	7.71	7.37	7.40	9.14	8.82	8.68	10.26	10.32	10.01
	Mean		7.40			8.48			9.94	

FIGURES

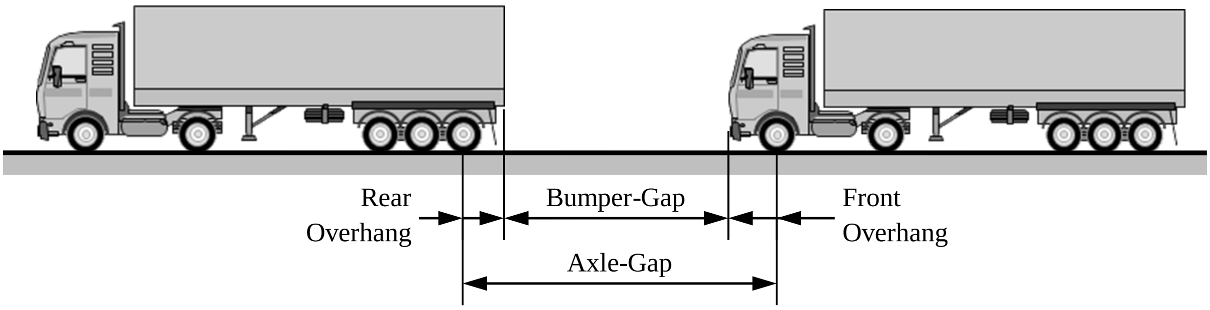

Figure 1: Definition of gap and overhang terms.

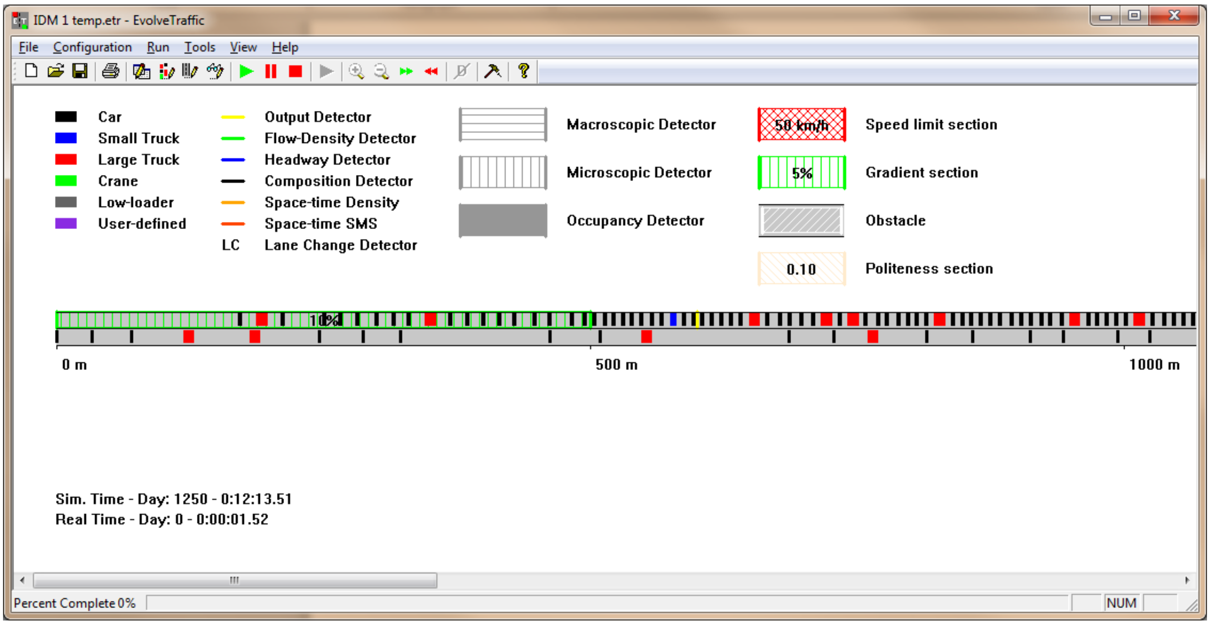

Figure 2: Screenshot of microsimulation illustrating formation of vehicle queue behind the inhomegineity in the negatoive (top) direction (note the width of the vehicles is not to scale).

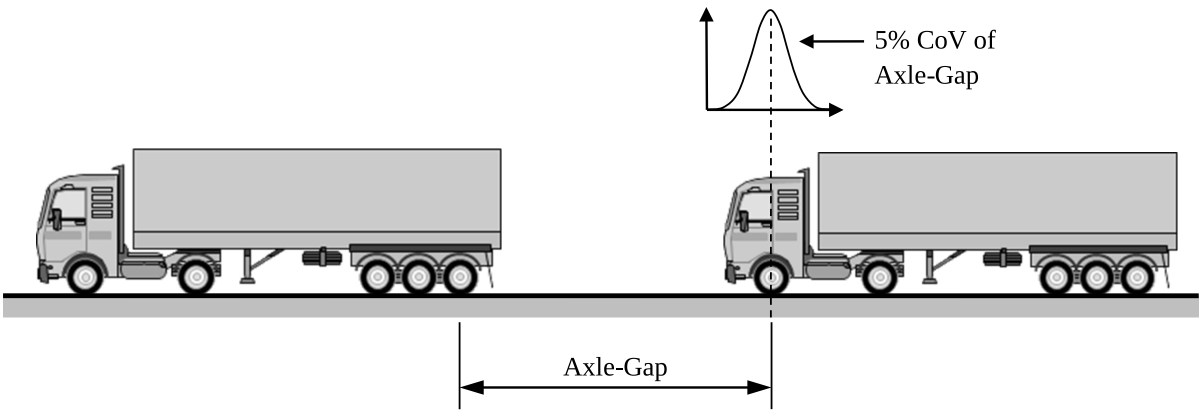

Figure 3: Simple gap model description showing nominal gap and variation.

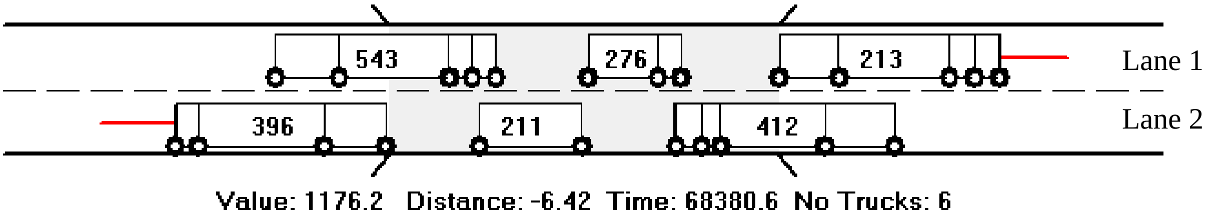

Figure 4: Sample maximum 2-hour congestion load event for the SCM-5 traffic model on 20 m bridge length, LE1 (mid-span bending moment on simply supported span) (the numbers on the trucks are the GVW in deci-tonnes).

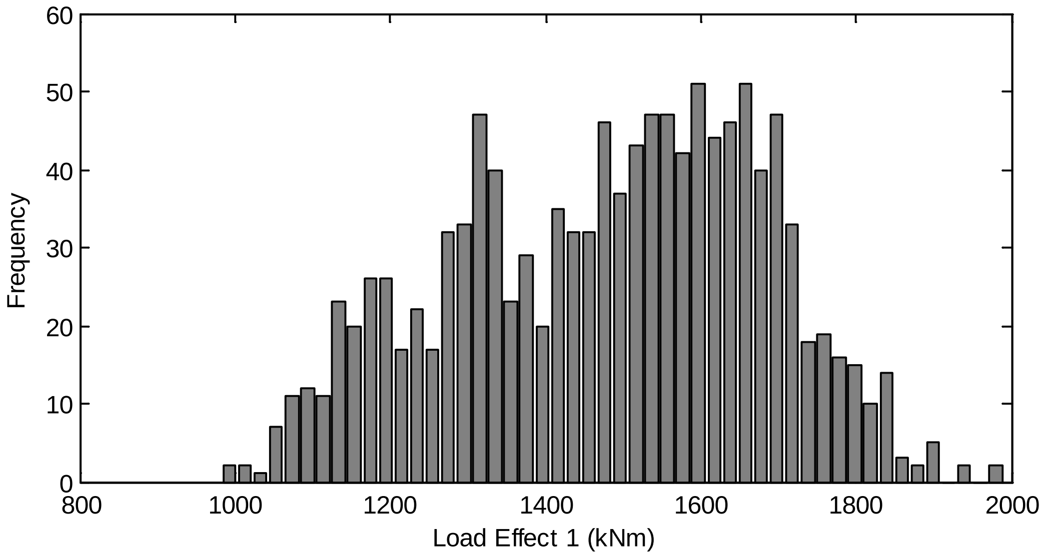

Figure 5: Histogram of 2-hourly maximum load effects, LE1, bridge length 20 m, SCM-5 traffic model.

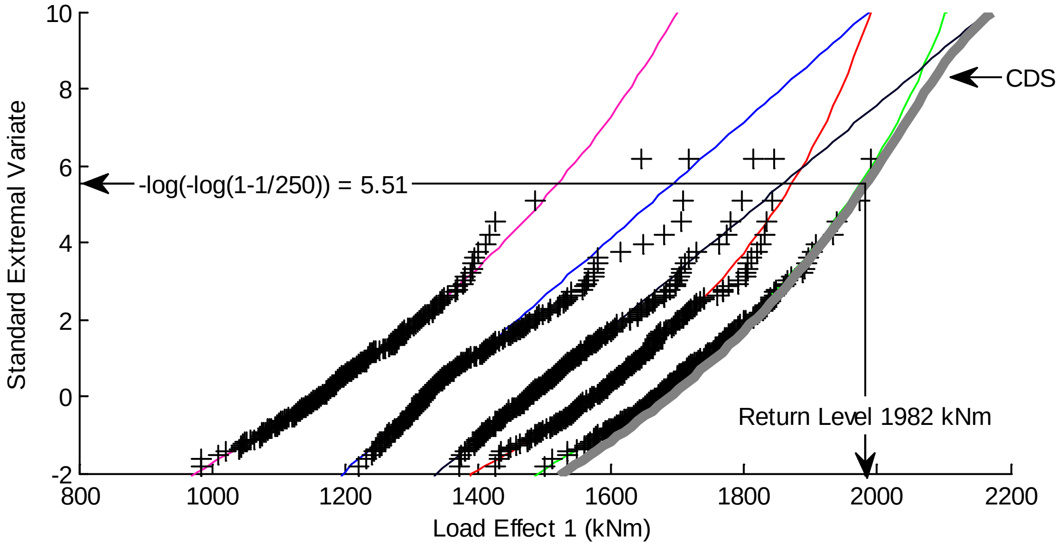

Figure 6: Example fit and extrapolation on Gumbel probability paper to expected annual maximum load effect showing different loading event distributions and the resulting composite distribution (CDS) for LE1, bridge length 20 m, SCM-5.

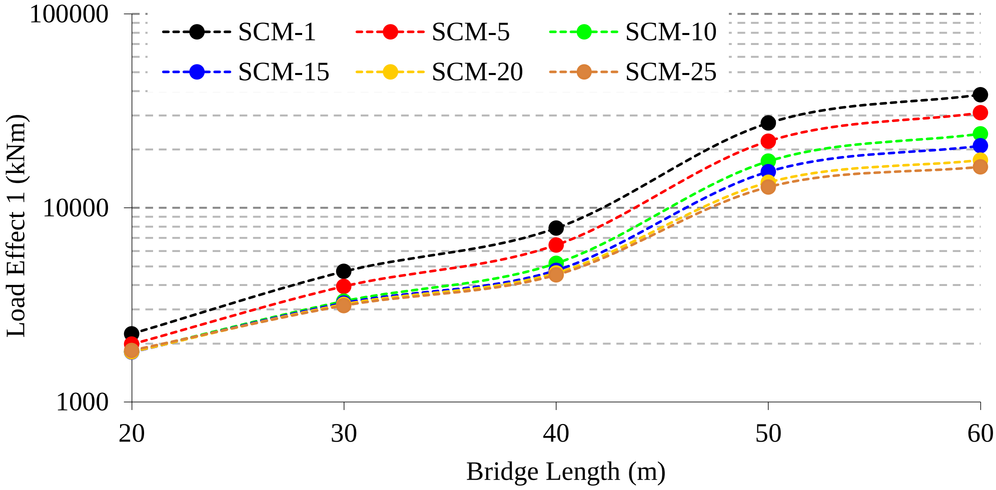

Figure 7: Load Effect 1 results for all SCMs and 0% cars.

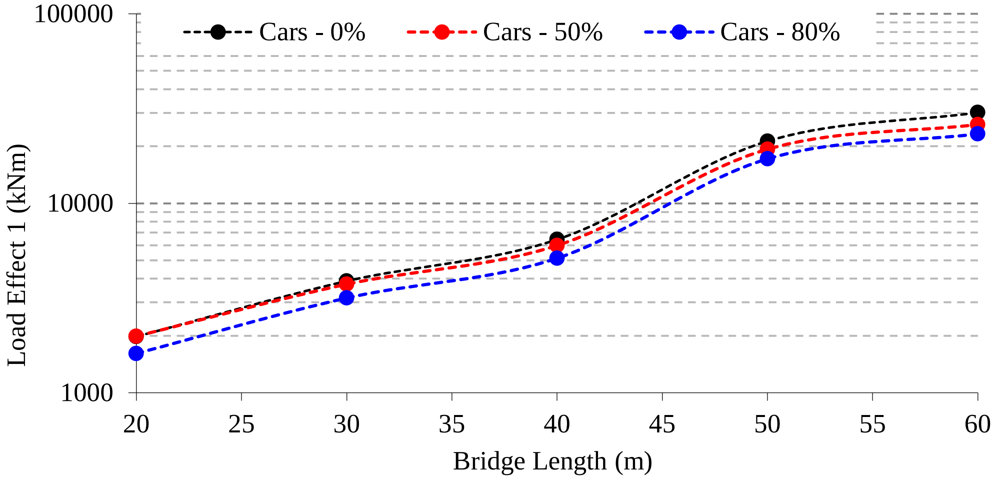

Figure 8: IDM-1, Load Effect 1 results for each car percentage considered.

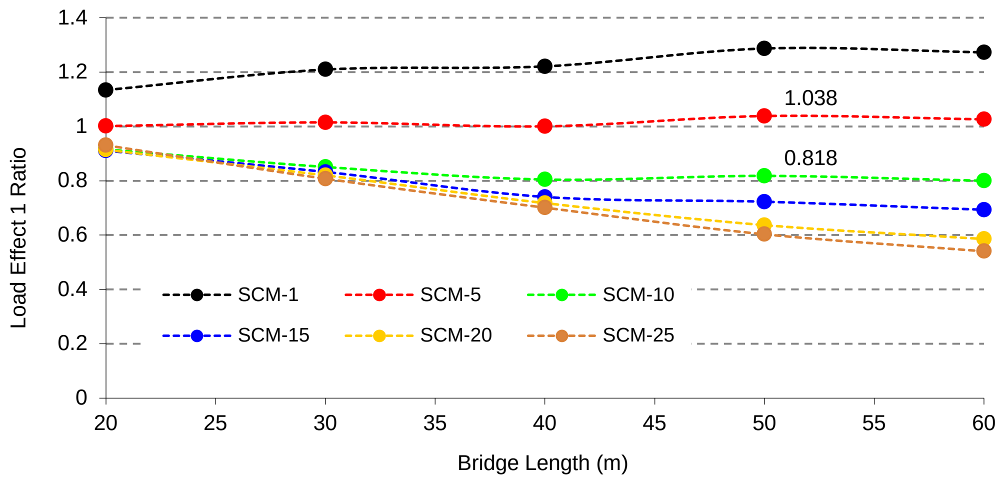

Figure 9: Ratio of SCM load effects to IDM-1 load effects for LE1, 0% cars.