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Multi-lane factor for bridge traffic load from extreme events of coincident lane load effects

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ABSTRACT

A novel framework for multi-lane factors (MLFs) for bridge traffic loading is proposed in this work. A general equation of MLF, consisting of a combination coefficient, a lane correction coefficient, and a share factor is established. The calculation methodology for lifetime MLF uses bivariate extreme-value theory based on coincident extreme lane loading events. Example application of the framework to a site using Weigh-In-Motion (WIM) data is demonstrated, in which traffic simulations and bivariate extreme value bootstrapping are implemented to calibrate the MLF model. For the site studied, statistical results of WIM data indicate the traffic loads in adjacent lanes are different but correlated. Calibration of the MLF model illustrates that the dependence between extreme coincident lane load effects is influenced by the correlation of traffic loads in adjacent lanes. Two key parameters, share factor and weight restriction, are found to have distinct influences on the calibrated values of MLFs, and so need to be considered in a site-specific assessment of multi-lane bridge traffic loading. The proposed general MLF framework provides a deep understanding of multi-lane traffic loading, and can be calibrated for any bridge or traffic stream.

1. Introduction

Multi-lane roads are very common and are constructed to cater to the increasing demands of freight transportation and traffic growth. Due to road rules and/or driving behavior, traffic volume or load is not the same across all the lanes of a road [1]. Indeed, in traffic engineering, an adjustment factor is used to determine multi-lane traffic volume capacities when unified to the maximum lane traffic volume [2]. Similarly, for the design and assessment of bridges with multiple lanes, a multi-lane factor (MLF) or multiple presence factor is commonly used to adjust the total load response based on the reference lane traffic load model. Clearly, this is a critical aspect of bridge loading specifications.

There is quite a variation of MLFs specified in design codes, as presented in Table 1. The underpinning approaches that result in these MLF models can be classified into three categories.

- Method 1 considers reduction factors based on the independently and identically distributed lane load assumption, which was mainly proposed by Jaeger and Bakht [3,4] and adopted by several national design codes [5,6]. In this method, the vehicle weights in each lane are assumed to be identical normal distributions, and the total weights in all lanes are determined by the probability of the simultaneous presence of trucks which is calculated using the Poisson distribution for a given traffic volume. Then, multi-presence reduction factors are calibrated using the ratios of the total loads in multiple lanes to the loads in a single lane.
- Method 2 is based on a statistical theory of the load effect (LE) induced by the presence of multiple trucks. The framework for this was mainly proposed by Nowak [7,8] in the analysis of simple span moments, shears, and continuous span negative moments. This research formed the basis of the MLF model in the US code [9], and was further extended with many more LEs and loading patterns of multiple trucks involved [10–12]. In this method, e.g., [7,8], the maximum single lane LE is regarded to be caused either by a single truck or multiple trucks following behind each other, and the reference lane load model is determined by extrapolating these loading effects. The multiple presence factors are determined from the incremental load effects induced by the simultaneous presence of trucks in adjacent lanes. In doing so, the correlation between truck weights in a single lane and in adjacent lanes is considered. The presence of multiple trucks is well-known to govern the most adverse loading responses for short- and medium-span bridges

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Nomenclature

MLF	multi-lane factor
LLE	lane load effect
GEV	generalized extreme value
ELLE	extreme lane load effect
CLLE	characteristic lane load effect
LE	load effect
TLE	total load effect
GVW	gross vehicle weight
CTLE	characteristic total load effect
BEVD	bivariate extreme value distribution

Table 1
Categorized MLFs in bridge design specifications.

Method	Specification		Lane number							
			1	2	3	4	5	6	7	8
1	CSA-2006		1.00	0.90	0.80	0.70	0.60	0.55	0.55	0.55
	JTG D60-2015		1.00	1.00	0.78	0.67	0.60	0.55	0.52	0.50
2	ASSHTO LRFD-2004		1.20	1.00	0.85	0.65	0.65	0.65	0.65	0.65
3[a]	ASCE-1981		1.00	0.85	0.70	0.63	0.58	0.55	0.53	0.51
	BS5400-1978[b]		1.00	1.00	0.78	0.67	0.60	0.56	0.52	0.50
	EC-2003	TS[c]	1.00	0.83	0.67	0.50	0.40	0.33	0.29	0.25
		UDL	1.00	0.64	0.52	0.46	0.42	0.40	0.38	0.37

Note:
[a] Not specified but transferred based on the reference (maximum) land load model.
[b] HA load is considered here for overall loading.
[c] Tandem System in live load model of Eurocode.

[7,8,10,13]. Interestingly, in the US code, the multiple presence factor for a two-lane road is used as the basis for load effects, and so the factor for single lanes becomes 1.2.

- Method 3 is represented by ASCE guideline for long-span bridges [14], BS5400 [15], and the Eurocode [16]. In this approach of ASCE guideline, the full lane load model is applied in the traffic lane that contributes the greatest loading response. The lane that contributes the second greatest response uses a factor of 0.7, and the other lanes all take 0.4 of the full lane load, respectively. Thus, in this method, values of the load models in adjacent lanes are different from each other, which are well aligned with the phenomenon of the traffic volume distribution across lanes. This reflects that this method was developed from simulations of traffic on multiple lanes, albeit with many incorporated assumptions [14,21].

Many statistical results based on realistic data reveal that the vehicle composition, traffic volume, and vehicle load in adjacent lanes are quite different, especially when the number of lanes is large [17,18]. Therefore, it is not appropriate to assume that the extreme LEs in adjacent lanes are identically distributed as Method 1 assumes. Furthermore, the maximum total load effect (TLE) across all lanes is not the simple addition of maximum single lane load effects (LLEs), but should be a reduced value [12,19]. Based on an independent Poisson arrival model for each lane, Method 1 determines this reduction. Method 2 addresses the reduction through the statistical frequency of occurrence of the presence of multiple trucks based on various correlations of truck weights, determined through site observations [7,8], or measured weigh-in-motion data [10–12]. Methods 1 and 2 are reliable for the calculation of MLFs of short and medium span bridges, since only few trucks can be arranged on their loading lengths. However, when the critical traffic loading scenario is traffic congestion [20], for example on long-span bridges, the governing situation becomes the presence of many trucks. In this case, issues such as how many trucks should be involved, whether and how these trucks are separated by cars and located over multiple lanes, and what are the gaps between different types of vehicles, are difficult to quantify. Therefore, the reduction probability of Model 1 or occurrence frequency of Model 2 which are appropriate for short to medium span bridges do not readily apply to long span bridges. Method 3, on the other hand, aimed to address this issue for long-span bridges, but with some basic assumptions of traffic behavior (e.g., 25–75% split of heavy vehicles to cars for the Eurocode [21]). In summary, a multi-lane traffic load model along with its underpinning methodology that is applicable to both short- and long-span bridges is needed.

Current MLF models and the relevant research [8,10,12] provide knowledge on multi-lane traffic loading. Generally, only a single coefficient is presented, incorporating all parameters of the problem. In this paper, the issue is addressed from a different perspective—that of extreme events of coincident LLEs—which improves understanding of the basic mechanisms of multi-lane traffic loading. A generalized framework of a structure-related MLF model for bridge traffic load is first proposed, which considers extreme events of coincident LLEs. Methodology of bivariate extreme value is then used to calculate MLF. The proposed framework and methodology are shown to be applicable to bridges with any span length. Example application to a specific site based on WIM data is demonstrated, and some key parameters influencing the calibrated coefficients of the MLF model are studied. Finally, the calibrated MLF model from the specific site is compared with models in design codes. The extension of the model to a wider range of sites, considering various WIM data, lane numbers, influence line types and span lengths etc. is discussed. As such, the proposed MLF model can be adopted for implementation in future engineering practice.

2. The proposed MLF framework

2.1. Coincident lane load effects

For a given bridge with N lanes, suppose there are M components supporting the bridge deck and traffic loads. The components