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Estimating the marginal costs of bridge damage due to overweight vehicles using a modified equivalent-vehicle methodology and in-service data on life-cycle costs and usage

Bismark R.D.K. Agbelie [a,*], Samuel Labi [b], Kumares C. Sinha [b]

[a] The Catholic University of America, Department of Civil Engineering, 620 Michigan Ave NE, Washington, DC 20064, United States
[b] Purdue University, Lyles School of Civil Engineering, 550 W Stadium Ave, West Lafayette, IN 47907, United States

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ABSTRACT

Civil infrastructure managers have a profound interest in knowing the costs of infrastructure degradation caused by user operations that exceed statutory limits; that way, they are better informed to establish or revise policies related to permit fee structures for such extra-legal operations. In the specific context of vehicle weight permitting for highway bridges, past determinations have typically relied largely on bridge damage simulation using theoretical relationships between the loading and failure modes. Unlike the theory-based simulations, empirical data analysis uses observed field data and therefore are expected to yield more intuitive insights about the actual relationship between in-service loading patterns and their damage (and the cost of repair thereof). A few past studies have used such empirical approaches with some success but have generally been stymied by practical considerations including the lack of adequate translational relationships between the vehicles operating on the road and the vehicle classes typically considered in load analysis. Also, the overweight (OW) cost differences across different bridges attributes (material type, design type, functional class, and age) remain to be investigated. In a bid to overcome these limitations, this paper uses observed in-service data for vehicle loads and the life-cycle costs associated with bridge deterioration repair. The proposed methodology includes a technique that correlates AASHTO design vehicles to FHWA vehicle classes, estimates the total life-cycle cost of bridge upkeep, and allocates this cost to each user group (vehicle class) based on the axle configuration and usage frequency (vehicle-miles travelled) of that class. For each vehicle class, the marginal cost of bridge damage is determined on the basis of the incremental cost responsibility (as a result of adding that vehicle class to the traffic stream) and the typical traffic volume of that vehicle class, and were found to range from $0.01 to as much as $36.35 per ft. length per pass of bridge, depending on OW class, and bridge functional class, material type, and age. The paper quantifies the extent to which bridge damage cost due to an overweight truck is influenced by the attributes of the truck and the bridge. The results can be of help to agencies seeking to formulate, update, or evaluate current or future OW permitting policies from the perspective of highway bridge damage among other impacts. This effort is considered timely in the current era when several highway agencies are considering relaxation of their OW permitting policies as a part of efforts to project a business-friendly image in a bid to spur economic development in their states.

* Corresponding author.
E-mail address: agbelie@cua.edu (B.R.D.K. Agbelie).

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1. Introduction

1.1. Background and problem statement

Tasked with the stewardship of taxpayer-owned civil infrastructure worth billions of dollars, infrastructure agencies have a profound interest in estimating the costs of infrastructure degradation caused by user operations that exceed statutory limits. Such degradation may relate to operational performance (safety and congestion) or physical performance (condition). From the perspective of the latter, agencies typically seek to adopt policies that prevent undue deterioration of these assets through excessive loading. To that end, they seek knowledge of the extent of the bridge damage caused by OW vehicles and the associated repair costs. With such information, the agencies can (i) identify and implement appropriate permit fee policies that reflect the true costs of OW vehicle operations (Meyburg et al., 1998) and (ii) quantify the consequences of possible future increases in highway vehicle weight limits (Fu and Fu, 2006).

Jaffer and Hansson (2009) showed that concrete bridge damage is exacerbated when they experience sustained OW truck operations because such vehicle loads accelerate the incidence and severity of fatigue cracking, leading to exposure of reinforcements to moisture and subsequent corrosion and cover concrete spalling. Also, Altay et al. (2003) used data from Minnesota to demonstrate the increase in steel and pre-stressed bridge maintenance costs due to OW truck operations. An AASHTO study found that OW trucks operations can significantly impair bridge condition (AASHTO, 2002). In this paper, OW vehicles are those whose gross vehicle weight (GVW) exceeds the 80,000-lbs legal limit (USDOT, 2013; TRB, 1990). For smaller trucks, this maximum limit is lower than 80,000 lbs but these vehicle classes were not considered in this paper.

For a given bridge, the damage costs can be expected to differ across different vehicle classes; also, for a given load, the damage costs can be different across different bridges. Thus, equity is an important issue that often arises in infrastructure damage cost estimation, cost allocation, and permit fee analysis (Hendrickson and Kane, 1983; Humphrey, 1988; Castano-Pardo and Garcia-Diaz, 1995; Forkenbrock, 1999; Andrijcic et al., 2013). OW vehicles are often placed in classes, depending on the extent of their excess weight. The current policy at most highway agencies is that for any bridge used by an OW vehicle in a given OW class, irrespective of bridge functional class, age, or material type, the permit price is the same for vehicles of that OW class. OW trucks that seek permits typically have their routes already mapped out, and there is knowledge of which specific bridges they cross. Clearly it is not equitable to charge the same amount for an OW truck for a route that has bridges of different distributions of age, material type compared to another route. For example, the damage occasioned by a given OW truck may be different for a new precast concrete bridge compared to an old steel bridge, *ceteris paribus*. In other words, it is reasonable to argue that OW vehicles inflict different levels of damage to infrastructures of different attributes (material type, functional class, and size). As such, for a more equitable fee policy, different vehicles (even those of different weights within the same vehicle class) should pay different amounts depending on the attributes of the bridge crossed; this is the problem statement that drives the motivation for this paper.

Unfortunately, most literature on the subject addressed the load damage of heavy vehicles (the upper range of legal weights, often, 60,000–80,000 lbs) rather than overweight vehicles. Secondly, most past studies have analyzed the bridge damage predominantly using bridge damage simulations based on theoretical relationships between the loading and failure modes (Cha et al., 2014). Recognizing that the actual load-damage relationships observed for in-service bridges may be different than suggested by a theory-based approach, greater insights could be earned by analyzing observed data from in-service bridges. In addition, most existing literature on this subject used relatively short-term analysis periods of loading applications rather than long-term (life-cycle) impacts. Further, until recent studies on the subject, past literature had examined the damage effects (rather than costs of repairing such damage).

In sum, past studies have thrown light on the effect of loading on bridge damage, and particularly, have quantified the OW damage cost variations across the different classes of OW vehicles, such as the recent Indiana and South Carolina studies (Ahmed et al., 2013; Chowdhury et al., 2013; Everett et al., 2015; Dey et al., 2015). While such recent research is valuable, an unanswered question is how to update OW fee policies to reflect differences in the attributes of bridges on the permit routes (these attributes include the bridge functional class, material type, length, and age). Such a lacuna exists in the literature because estimation of such costs across different levels of these attributes remains lacking. The issue of OW impacts on bridge damage remains pertinent and efforts to investigate the related issues of damage costs by vehicle class and bridge age and type, are timely. ASCE (2013) estimated that over a third of highway bridges in the United States have exceeded their design lives, a situation that is exacerbated by inadequate funding.

1.2. Objectives, scope, and organization of this paper

Pursuant to the above problem statement, this paper proposes a new methodology to estimate the bridge damage cost caused by OW vehicles using empirical data on the costs of bridge usage (loadings) by vehicle classes and the costs of damage repair over their life cycles. The proposed methodology intends to provide the underlying analytical structure for the development of permit fee policy that is equitable in the sense that different vehicles pay different amounts that depend on the attributes of the vehicle in question and the characteristics of the bridge crossed.