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Using systematic indices to relate traffic load spectra to pavement performance

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Abstract

The application of truck axle load spectra in the Mechanistic Empirical Pavement Design Guide (MEPDG) has brought great advancement in pavement design through quantifying pavement accumulated damage due to individual axle loads. However, how to relate the truck axle load volume and spectra directly to pavement performance remains a practical challenge for pavement engineers. This paper presents a systematic index approach to this issue that characterizes three aspects of traffic loading to pavement performance: volume, load, and damage. Four summary indices were investigated in this study: cumulative truck volume (CTV), cumulative truck load (CTL), equivalent single axle load (ESAL), and relative pavement performance impact (RPPI). The involved concepts and calculation procedures were first introduced, followed by a numerical evaluation analysis of 30 axle load spectra, 18 vehicle class distributions, 2 truck configurations, and 2 pavement types. To demonstrate how these summary indices could be used, a case study was presented. Overall results suggested that the systematic indices introduced in this study had a clear relationship with pavement performance, so it could be used to assist engineers in many ways such as comparing different load spectra, communicating between engineers, and understanding the relationship between traffic and pavement performance for a specific design at any point in time.

Keywords: MEPDG; Load spectra; Load equivalency factor; Equivalent single axle load; Pavement performance

1. Introduction

The Mechanistic Empirical Pavement Design Guide (MEPDG) and its accompanying software use load spectra to characterize traffic loading. Load spectra contain the distribution of loading for different vehicle classes (class 4 to class 13) and different axle types (single, tandem, tridem and quad). With these detailed loading data, the design process can quantify the cumulated damage from any specific type of loading that an aggregated traffic index (e.g. equivalent single axle load, ESAL) was not capable of [1]. However, using load spectra raises some practical challenges for pavement engineers. First, how to compare different load spectra? For example, while many states are preparing detailed load spectra data for the implementation of MEPDG, most of the time engineers have to use ESAL to assess the difference between the local load spectra and the national default load spectra (e.g. a load spectra is lighter than the national default because it only produces 50% ESAL of the national load spectra). Practically, a summary index or indices are necessary to provide a snapshot for engineers to understand the load spectra and communicate with other engineers. Second, how to relate cumulative traffic loading to pavement performance in a concise manner? For instance, for a pavement structure

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in use, how to relate its performance to the cumulated traffic loading expressed by load spectra at year 5, 10, or 15? For the AASHTO 1993 Design Guide, this can be accomplished by correlating the performance with traffic loading expressed in ESALs that the pavement has carried, but there is no such a convenient way to do so using load spectra.

Currently the ME Design software provides two summary indices for traffic: cumulative heavy trucks and the estimated ESAL. Cumulative heavy trucks is the total volume of all truck classes that a pavement would carry in its design life. The accumulated volume does not consider truck loading (e.g. empty or fully loaded), nor monthly and hourly distribution. ESAL is the cumulative number of applications of the chosen standard single-axle load that will have an equivalent effect on pavement serviceability as all applications of various axle loads and types in a mixed-traffic stream. ESAL is determined by summing the calculated load equivalency factors (LEF) for each individual axle according to axle load and type on all vehicles in the traffic stream for a defined pavement structure [2]. The current MEPDG software calculates ESAL using two sets of LEF, one for flexible pavements and one for rigid pavements. Since LEF was developed using data from the AASHO Road Test in 1960s, ESAL only provides an approximate evaluation of the amount of traffic loading.

Haider and Harichandran [3] correlated the characteristics of a mixture bimodal axle load distribution with rigid pavement performance. The study found that cracking was related to the 85th percentile load, faulting was strongly related to the overall mean, and roughness (IRI) was strongly associated with the root of the 4th moment of the axle load spectra. Although these characteristics can directly indicate the relative pavement damage caused by axle distributions, they are not cumulative indices (in comparison to the well-known cumulative concept of design ESALs). The complexity to build mathematic models and calculate these indices may also hinder its implementation.

Therefore, there is a need to develop an approach that is convenient (easy to use), meaningful (represents the overall traffic load), and innovative (overcomes the deficiencies of ESAL) to relate cumulative traffic loading to pavement performance.

Some efforts were made to improve ESAL by updating LEF. Ioannides et al. [4] developed a mechanistic-empirical approach to derive LEF applicable to wheel assemblies and pavement cross-sections not included in the AASHTO guide tables. Divinksky et al. [5] developed new LEFs based on the extended California Bearing Ratio method because the AASHTO LEFs in the Israeli design method led to an under design of approximately 10 percent in pavement thickness and a reduction of 70 percent in design life. Recently, Selezneva and Hallenbeck [6] determined a set of *W*-factors through MEPDG analysis during developing the new MEPDG axle loading defaults from the Long Term Pavement Performance (LTPP) traffic data. Although improvements were made through these studies, they all relied on the fundamental concept of load equivalency and linear damage accumulation. This paper presents a research work that studied this issue from a different perspective and explored four potential traffic indices that can be used as a system to correlate cumulative traffic loading with pavement performance.

2. Objectives

The objective of this study was to explore approaches that can (1) provide a meaningful and concise snapshot of the load spectra, and (2) relate cumulative traffic loading to pavement performance, in order to (1) assist design engineers in comprehending a load spectrum, and (2) support maintenance engineers in understanding why a pavement performs as it does from the perspective of traffic loading. Such an approach could be using a single index, several indices, or any other innovative methods. For this purpose, four summary indices representing the three aspects of traffic (volume, load, and damage) were investigated: cumulative truck volume (CTV), cumulative truck load (CTL), ESAL, and relative pavement performance impact (RPPI). Definition and calculation algorithms of the four indices are first explained, followed by research methodology and data source. Results analysis and findings are discussed in detail. Finally, a case study is included to demonstrate the application of the proposed approach.

3. Traffic summary indices

Traffic can be characterized from three perspectives, namely, volume, load, and damage to infrastructure. Traffic volume is the primary focus for traffic engineers who need to know how many vehicles and what type of vehicles travel on a road at what time. Traffic load is of interest for trucking industry and government load enforcement. Logistics engineers are always striving for the best arrangement to deliver the most tonnage with the lowest cost. Besides of traffic volume and load, civil engineers care more about the damage to infrastructure (bridges and pavements), because it is the accumulated damage that deteriorates a bridge or a pavement.

In this study, four summary indices were chosen as candidates to represent a traffic stream. The definition and algorithm for each index are described in the following sections.

3.1. Cumulative truck volume (CTV)

The volume of traffic is no doubt the first and the foremost widely used index to capture the condition of a traffic stream. For example, annual average daily traffic (AADT) indicates how busy a road is. Interstates and primary routes usually carry more AADT than secondary and local roads. City roads often have a larger AADT than rural roads. If AADT is multiplied by the percentage of trucks,