# A RATIONAL MECHANISTICALLY-BASED APPROACH FOR ALLOCATING HIGHWAY COSTS

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## ABSTRACT

The allocation of highway costs is constantly debated among legislatures, highway agencies, and highway users as it directly relates to concerns about equity in terms of cost responsibility and actual user charges. One of the major challenges in highway cost allocation stems from the need to estimate pavement damage by different vehicle classes. Normally, the calculation of damage caused by heavy vehicles to the highway infrastructure utilizes the concept of Equivalent Single Axle Load (ESAL) or E80. This concept was empirically established after the AASHO Road Test almost half a century ago. Although the E80 concept is widely used in pavement design, it has a number of shortcomings when applied for the estimation of pavement damage by different vehicle classes. Some of these limitations include: failure to account for specific infrastructure and environmental conditions, disregard of the differences in traffic configurations and composition, and the inability to capture different distress types. This leads to a fairly inaccurate and generic estimation of pavement damage by vehicle class.

This paper proposes an innovative and more rational highway cost allocation approach based on the recently completed guide for the “Mechanistic-Empirical Design Guide of New and Rehabilitated Pavement Structures” developed under the National Cooperative Highway Research Program (NCHRP) Project 1-37A. The Guide accounts for all factors that contribute to pavement deterioration, thereby addressing the shortcomings of an ESAL-based analysis listed earlier. Estimates for pavement damage attributable to each vehicle class can thus be accurately simulated. For the purposes of this study, traffic data collected at a weigh-in-motion station in Texas were used to estimate the highway cost shares of different vehicle classes, given varying pavement structural capacity.

## 1. INTRODUCTION

Almost since the designation of the U.S. highway system more than half a century ago, has highway cost allocation (HCA) been debated among interest groups, including state and federal legislators, highway agencies, and highway users. The objective of HCA studies has been to determine and assign a rational and equitable cost share (e.g., charge) to different vehicle classes. Allocating a cost share involves a series of complex factors, such as, among others, traffic characteristics, highway structural and material properties, and environmental considerations.

Because it is inherently difficult to allocate highway costs among vehicle classes, there is no unambiguous method available for conducting HCA despite the large number of studies on this topic. Many of these studies have been updated periodically at both the state and Federal levels as technologies (e.g., for collecting data) and cost allocation methods *per se* evolved. At the state level, it is essential for the state government to compare the fees paid and costs incurred by different vehicle classes to determine the magnitude of the subsidies, if any, to individual vehicle classes (*1*). For this reason, many states have embarked on their own HCA studies, including Arizona, California, Georgia, Indiana, Kentucky, Maryland, Texas, Oregon, Wyoming, and Wisconsin (*2*, *3*).

Based on the collection of HCA studies, the Federal Highway Administration (FHWA) published a document that contains a framework and methods to aid with cost estimation in 1982 (*4*). Eventually, the 1982 version of the HCA study was replaced with the1997 version. The two key reasons for updating the 1982 study were:

1. to determine the equity effects of the change in the Federal highway program and user fees, and
2. to *"coordinate this effort with the concurrent U.S. Department of Transportation Comprehensive Truck Size and Weight Study (5)"* (*1*). The document also mentioned the need for more rational HCA studies in the follow-up effort.

Highway costs involve the costs associated with pavements, bridges, and other capacity-related aspects. Pavement costs are the most significant component of total highway cost, because they represent the major part of the transportation infrastructure system. Pavement costs can be further divided into: construction costs and maintenance costs. Similar to most previous studies, this paper focuses on the construction cost component of pavement costs. Furthermore, as is suggested in the 1997 HCA study, pavement construction costs can be divided into load-related costs and non-load related (or base facility) costs. The former applies mainly to commercial trucks, while the latter applies to all vehicle classes. This paper focuses on the load-related costs as it is relatively more difficult to estimate (*6*).

The objective of this study is to allocate the construction cost share among different (truck) vehicle classes based on their individual contribution to the expected damage produced to pavements. The next section provides background information on existing HCA methods. Section 3 discusses the concept of Equivalent Single Axle Load (ESAL) as it is widely used in most existing HCA methods. Section 4 provides an overview of the recently developed mechanistic-empirical design guide, which is a key element of the new method for HCA proposed in Section 5. Section 6 presents a case study in which the proposed method was tested with actual traffic data collected in Texas before concluding (Section 6) with some major findings and summaries.

## 2. EXISTING HIGHWAY COST ALLOCATION METHODS

There are numerous approaches for undertaking HCA, which differ mainly in terms of theoretical implications and practical applicability *(7)*. The best-known approaches are incremental and proportional methods (*6*). The incremental method and more recently, the modified incremental method, are the most widely applied. In the traditional incremental method, vehicle classes are added to a base pavement - theoretically a pavement capable of sustaining the lightest vehicle class - sequentially. The incremental pavement thickness added due to the increased axle loading from the specific vehicle class can thus be determined step-by-step. The American Association of State Highway and Transportation Officials (AASHTO) pavement design equations are central in this calculation process. However, it can be shown that a difference in the order to which vehicle classes are added produce significantly different results. The weakness of this method originates from the non-linear relationship between pavement thickness and the associated allowable traffic as implied by the AASHTO equations and presented by Fwa and Sinha (*2*). To address this, several modified incremental methods were proposed. For example, the FHWA's 1982

HCA approach suggested dividing the individual vehicle classes into an equal number of sub-groups. The traffic for incremental thickness calculation is applied in a reverse order from the traditional incremental method (*4*). In other words, the saving in pavement thickness can be obtained by removing sub-groups of vehicles from the entire traffic flow step-by-step. The share of thickness saved at each step for each vehicle class is estimated through its sub-group's contribution in terms of ESALs, which is determined via the AASHTO equations. Fwa and Sinha (*2*) also proposed a thickness incremental method aiming to eliminate the need for iterated computation of ESALs required by the previous method.

The proportional method, on the other hand, is widely applied in HCA due to its ease of application. The cost is allocated among vehicle classes based on some measure or allocator, including Vehicle-Miles-Travel (VMT) and ESALs. For example, in the 1997 FHWA's HCA study, pavement construction cost consists of two parts: the non load-related portion (corresponding to base facility) and the load-related portion. ESALs are used to allocate the load-related costs among the vehicle classes.

Finally, optimization or programming techniques have been adopted to solve the HCA problem. Villarreal-Cavazos and Garcia-Diaz (*8*) devised the so-called Generalized Method based on the theory of cooperative game. Linear programming was utilized for allocating the costs among vehicle classes. Castano-Pardo and Garica-Diaz (*6*) used non-atomic game theory to estimate class-based vehicle cost by regarding each vehicle passage on the road as a player in the game. In both references, ESALs are included as decision variables.

A review of the existing literature revealed that traffic load is one of the key factors in allocating costs among vehicle classes, because a pavement is designed to sustain traffic and it deteriorates under the joint impact of traffic load and the environment. Given that all of the aforementioned approaches accounts for traffic load in terms of ESALs, the concept and implications of using ESALs are worth discussing.

## 3. DISCUSSION ON ESAL

The ESAL concept is the cornerstone in modern pavement design. ESAL is also a key component in the current AASHTO pavement design guide (*9*). It is used to convert an axle load with a different configuration and weight into its equivalent number of standard axle loads (18-kip single axle load). ESAL was originally developed based on the analysis of the AASHO Road Test results, which was motivated to facilitate cost allocation among vehicles (*10*). It should be noted that the equivalence is established in terms of the effects of the various axle loads and configurations on the loss of serviceability of the pavement structure. The number of ESALs due to the repeated running on a pavement by a particular axle load can be calculated through the following equation (*10*):

$$ESALs = n \times LEF \tag{1}$$

Where,

$n$: number of repetitions for a given axle load; and
$LEF$ : load equivalent factor.

$$LEF = \frac{W_{18}}{W_x} \tag{2}$$

Where,

$W_{18}$: number of 18-kip (80-kN) single-axle load applications to reach a serviceability $p_t$
$W_x$: number of x-kip axle load applications to reach the same serviceability.

$W_{18}/W_x$ can be obtained from the following equation (herein take flexible pavement as an example) (AASHTO 1993):

$$\log(W_x/W_{18}) = 4.79\log(18+1) - 4.79\log(L_x + L_2) + 4.33\log L_2 + G_t/\beta_x - G_t/\beta_{18} \quad (3)$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \quad (4)$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}} \quad (5)$$

Where,

$L_x$ is the load in kip for a given axle;
$L_2$ is the axle code, 1 for single axle, 2 for tandem axle, and 3 for tridem axle;
SN is the structural number, which is related to pavement thickness, material, and drainage; and
$p_t$ is a level of serviceability considered as failure.

It is shown in the above equations that LEF (and thus ESALs) is a function of a number of variables, including pavement structure and material, axle configurations, and terminal serviceability, among others. It is important to note that some of these variables have changed since the AASHO Road Test, which took place around 50 years ago. For example, pavement materials, particularly asphalt material, have evolved significantly over the last several decades. New materials, such as modified asphalt binders, have emerged, leading to asphalt mixture improvements with more desirable road-use properties. Also, the Superpave mixture design method developed in the 1990s, directed asphalt mixture design closer to field construction conditions. Axle configurations have also changed since the AASHO Road Test. During the AASHO Road Test, only single and tandem axles were tested. Since then, tridem and quadruple axles have emerged due to demands from the rapidly growing trucking industry. Besides, tire configurations have changed from bias-ply to radial-ply in order to improve the load-carrying capacity, which, in turn, would impose different damage on pavements (*12*). Tire inflation pressures have increased from an average of 80 psi to 100 psi or higher. In addition to the abovementioned physical changes that affect the determination of the measure of traffic loading and pavement impacts, three other equally important concerns deserve further discussion:

1. The first concerns the duration of the AASHO Road Test. The fact that the AASHO Road Test was an accelerated pavement test, which lasted two years, cast doubts on its capacity to fully capture a pavement’s long term performance. It should be bore in mind that flexible pavement structures are usually designed to sustain traffic and the environment for 20 to 30 years.
   a) The second concerns the generalization of the underlying design equation (AASHTO 93), which was developed based on a road test in Illinois. Whether it applies to other areas (e.g., the Southern States) with environmental conditions markedly different from Illinois has remained questionable.

b) Lastly, the abovementioned design equation suffers from model specification and estimation flaws (*13*). This resulted in a bias in estimating LEF.

## 4. MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE

To address the various concerns, the National Cooperative Highway Research Program (NCHRP) funded an ambitious research project aimed at developing a guide for the “Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures”, hereafter referred to as the M-E Design Guide (*14*). The research resulted in the most comprehensive pavement analysis tool developed to date. The M-E Design Guide is available in the form of a computer program at TRB’s web site: www.trb.org/mepdg. Figure 1 illustrates the software’s main framework, which includes input, analysis, and output blocks.

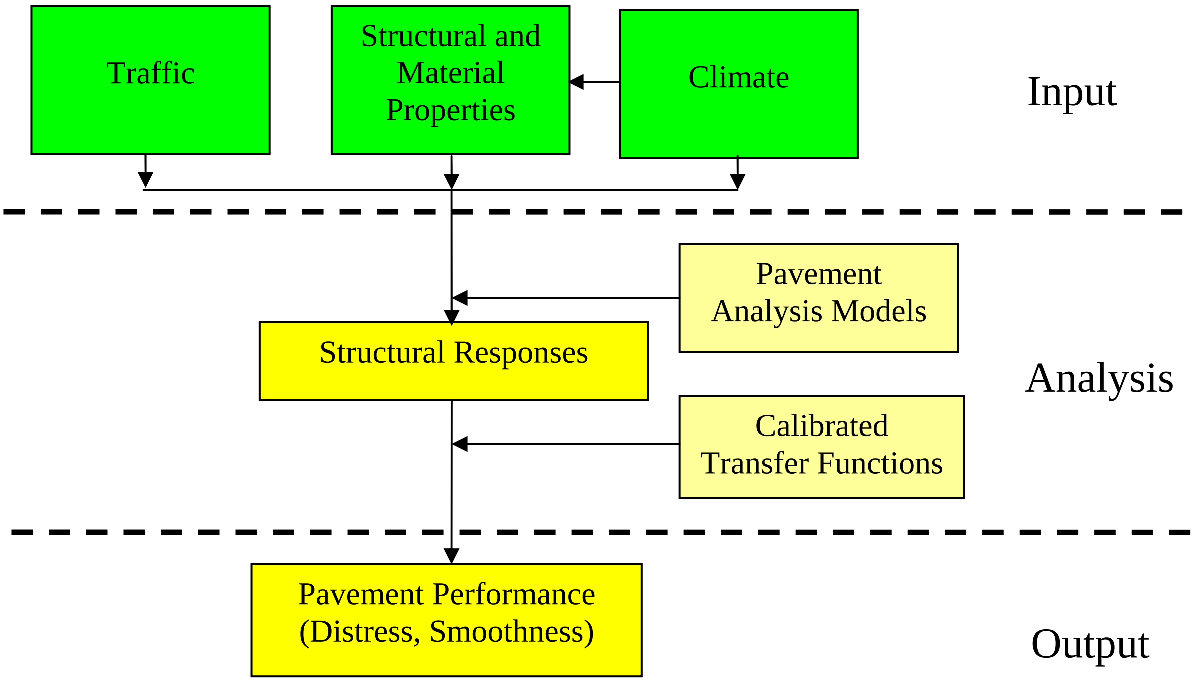

**FIGURE 1 M-E Design Guide Frame Work**

An extensive amount of information pertaining to pavement performance is required as the input parameters, including very detailed traffic volume and load data, pavement structural and material properties, and environmental conditions. The environmental information can be generated directly by selecting weather stations from a database, which covers hundreds of locations in the U.S. Traffic data are mainly composed of volume and load information. For traffic volume, both short- and long- term characteristics are required in the M-E Design Guide (*15*). For traffic load, instead of ESALs, axle load spectra are used to capture actual traffic characteristics more closely. Then, a mechanistic analysis is carried out to generate pavement responses under the joint effect of the environment and traffic. These responses are finally correlated with pavement performance indicators (e.g., cracking, rutting, and roughness) using calibrated transfer functions. The abovementioned features of the M-E Design Guide provide a more accurate methodology to determine pavement deterioration under actual pavement service conditions. More importantly, as is shown subsequently, it allows for the examination of pavement damage by different vehicle classes.

## 5. PROPOSED APPROACH TO HIGHWAY COST ALLOCATION

This paper proposes a new approach for estimating the pavement damage share by different classes of trucks. Before discussing this new approach, however, traffic classification and the main characteristics of axle load on the individual vehicle classes are worth highlighting.

According to the Traffic Monitoring Guide, vehicles can be categorized into 13 classes (*16*). Among them, trucks (including buses) constitute Class 4 to Class 13, as is shown in Figure 2. However, the proposed method in this paper can be applied to any other classification scheme. Thus, choosing this 13-class based classification by no means exclude other vehicle classification schemes.

The vast majority of trucks exhibit four types of axle configurations: single, tandem, tridem, and quads axles. The axles in the different truck classes may be loaded with different weights. However, each passing axle load can automatically be collected by weigh-in-motion (WIM) equipment to obtain a sample of axle loads for each axle type for the individual truck class. From the axle load distributions (also referred to as axle load spectra) it has been observed that the individual vehicle classes feature one mode or several modes. Figures 3 and 4 provide examples of single and tandem axle load spectra obtained at a WIM station (labeled D516) in Texas. This WIM station is located on Interstate Highway 35 (IH-35) outside San Antonio. The detailed statistical characteristics of the axle load spectra were thoroughly explored during a previous study (*17*).

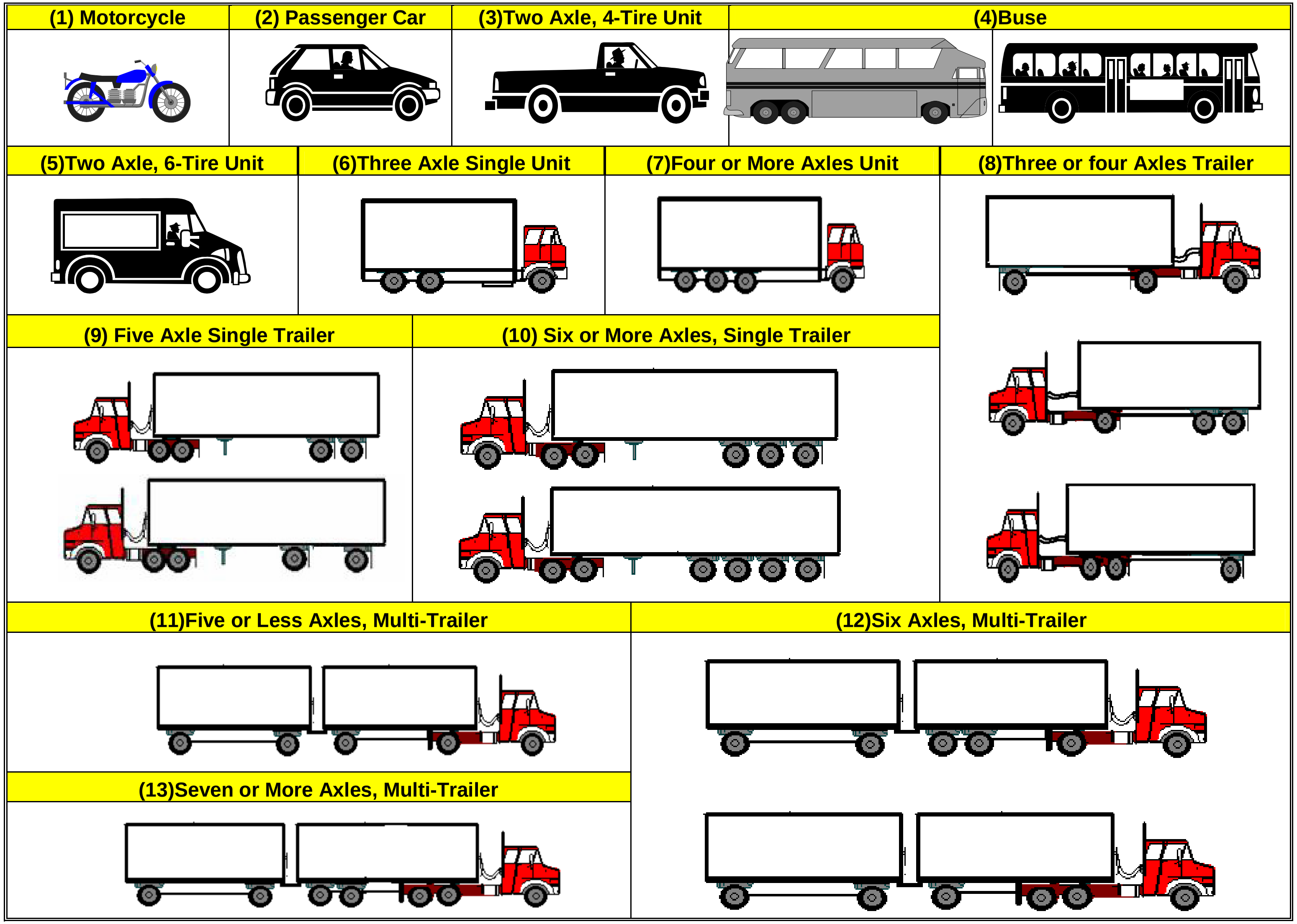

FIGURE 2 Traffic Classification Scheme by TMG2001

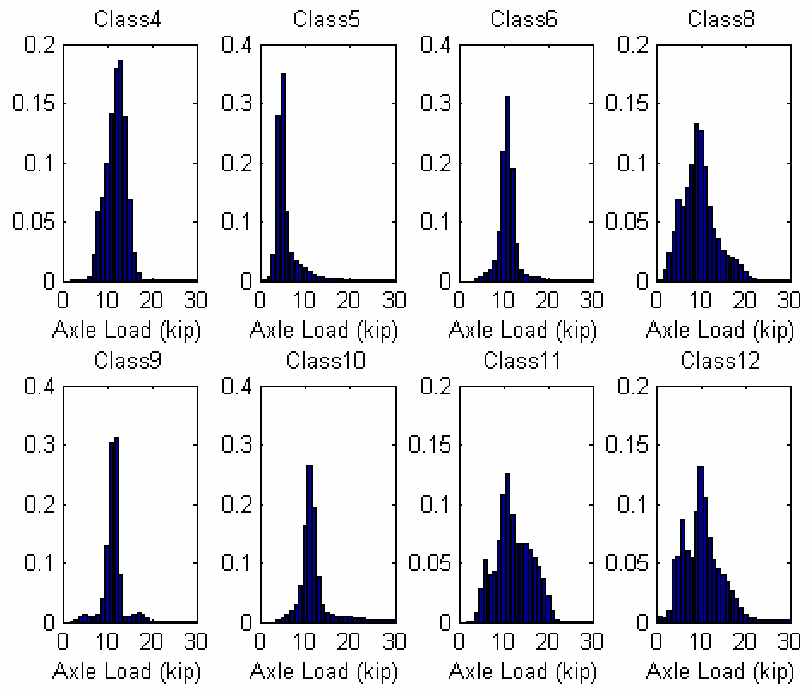

FIGURE 3 Single Axle Load Spectra

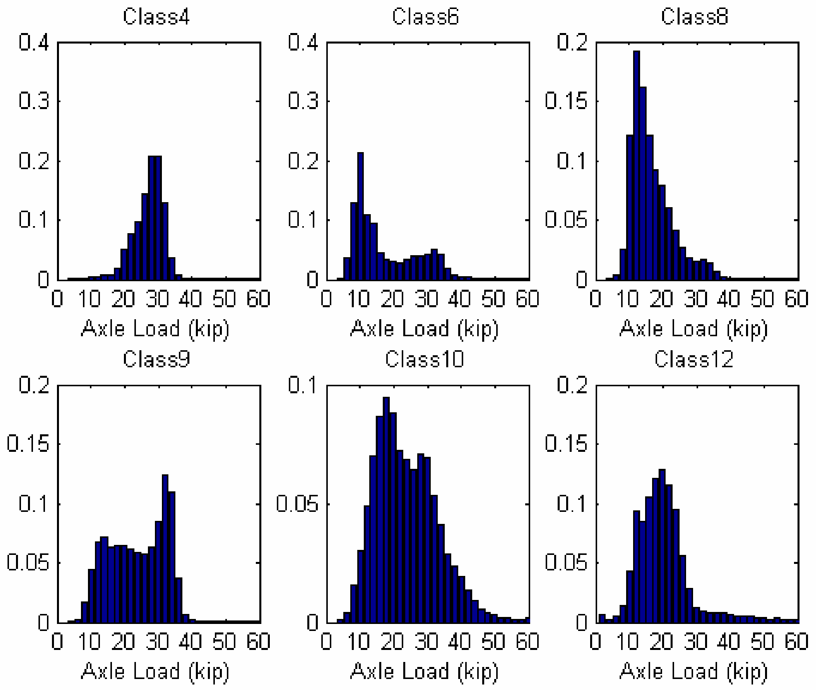

FIGURE 4 Tandem Axle Load Spectra

Since each truck class is characterized by a particular axle load distribution, the pavement damage imposed by each truck class may differ. The damage imposed by a particular truck class can be obtained as follows. First, for a given pavement and given period of time (e.g., a design life of 20 years), the maximum (allowable) number of repetitions for a particular truck class can be obtained from the mechanistic-empirical approach proposed by the M-E Guide. This number of repetitions of a particular truck class provides a measure of pavement damage from a vehicle's perspective. The higher the number, the less damage by each pass of that vehicle type is imposed on the pavement. It is important to note that all cases pertain to the same pavement, environment and duration, and pavement failure criterion. Second, a comparison of the maximum number of repetitions to failure from different vehicle types provides the relative damage among those classes. Assuming that the load-related costs associated with each truck type is proportional to its contribution to pavement wear (reflected through pavement damage), the cost share among truck classes can be calculated as being equal to the individual's relative pavement damage proportion. The detailed steps to obtain the relative damage are as follows:

1. Prepare the input information, including pavement structure, material, environment, and traffic (particularly axle load distributions for each truck class)
2. Select failure criterion and terminal condition from which the maximum allowable number of repetitions of a given vehicle type can be obtained.
3. For each truck class, calculate the maximum number of repetitions until pavement failure at the end of the design life (such as 20 years) of the pavement, denoted as $N_i$. $i = 4, \ldots 13$. Similarly, the number of repetitions until pavement failure for the mixed traffic flow is also obtained as the reference, denoted as $N_{Mix}$.
4. Define the inverse of the ratio between the allowable volumes by each truck class to the mixed traffic flow as the relative average damage by one pass of that vehicle class. Obtain the relative damage by each pass for each vehicle class as,

$$R_i = \left(N_i / N_{Mix}\right)^{-1} \tag{6}$$

5. Obtain the cost share for each truck class as,

$$C_i = (V_i R_i) / \sum_{j=4}^{13} (V_j R_j) \tag{7}$$

Where,

$V_i$ is volume percentage for Class *i* in truck traffic flow.

To facilitate the understanding of the proposed approach for allocating the cost share among truck classes, a case study with actual traffic data is provided in the next section.

## 6. CASE STUDY

### 6.1 Traffic Data Description

Actual traffic data were collected from WIM Station D516, on IH-35, near San Antonio. The traffic data from this particular WIM station covers the period from January 1998 to March 2002. The volume percentages of the individual truck classes are shown in Figure 5. From Figure 5, it is evident that approximately 63 percent of the trucks are Class 9, followed by Class 5 (around 23%). Although almost no Class 7 and 13 trucks were found in the truck flow, there is no sound reason to equate the pavement damage by these truck classes to their volume proportions since the load distributions vary significantly. Figures 3 and 4 present the detailed load distributions for single and tandem axles for all classes of trucks. The load spectra for tridem and quads were found to be negligible in the sample. The load distribution information shown in the figures was used for the mechanistic analysis using the M-E Design Guide for determining pavement damage by different truck classes.

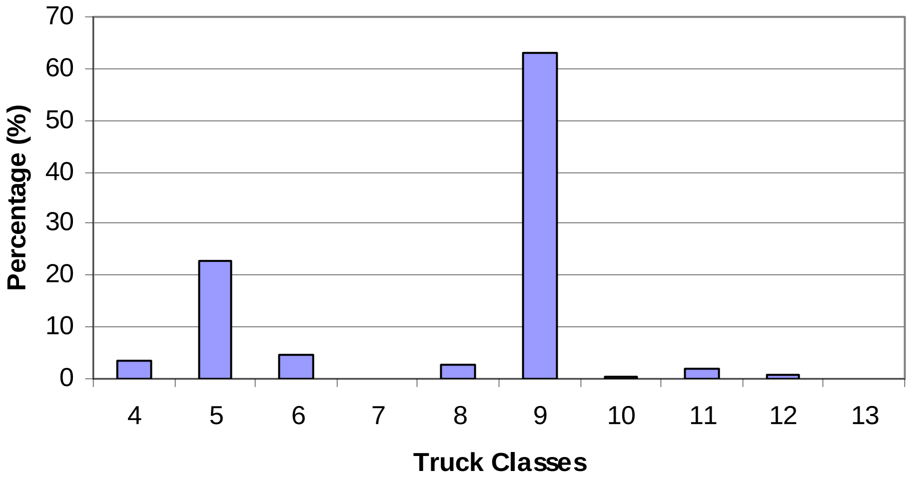

**FIGURE 5 Volume Constitute in Truck Traffic Flow**

## 6.2 Environment

The environmental information input from the weather station nearest to the traffic data collection location (i.e., San Antonio airport) was used. A file containing the necessary climatic information for all Texas weather stations can be downloaded from the M-E Design Guide's webpage (www.trb.org/mepdg).

## 6.3 Pavement structure and material

The proposed cost allocation method can be applied to both flexible and rigid pavements. In this paper, the research focus is on the flexible pavement. A typical flexible pavement structure (i.e., three-layer pavement structure) and materials (i.e., asphalt mixture serving as surface layer, granular materials as base and subbase layers, and a silty-clay material as the subgrade) used in Texas were adopted. A series of scenarios were investigated to establish the relationship between damage share among truck classes and different pavement structures. To reduce the time (approximately 45 minutes of computer running time per case) required for the analysis due to the many possible pavement structure combinations, the thickness of the base and subbase layers were fixed at 12 in. and 6 in., respectively. An analysis was undertaken to examine the sensitivity of damage share among truck classes to surface layer thickness. The surface layer thickness is designed to accommodate different traffic levels with thicker surface layers designed for heavier traffic. For this case study, the surface layer thickness ranged from 3 in. to 8 in. with 1 in. increments. Consequently, the underlying pavements' structural numbers (SN) vary from 3.66 to 5.86.

## 6.4 Pavement performance analysis

Given all the inputs, pavement performance analysis was conducted using the M-E Design Guide. For each pavement structure scenario, traffic information for the individual truck classes is entered into the analysis one at a time. The only decision variable to be determined is the number of repetitions by the individual class of truck that will result in a given failure criterion at a pre-establish design life. All the other variables remain the same. As a result, the maximum number of repetitions for the individual vehicle class (given their specific load characteristics) on the same pavement experiencing the same environment will be obtained. This provides a common basis for comparing the damage to pavement structures by different vehicle classes. As customary in Texas, pavement design life was selected to be 20 years. At the end of 20 years, the pavement thus reaches failure under a given traffic condition. For this case study, 0.5 in. (12.5 mm) of surface rutting was chosen as the failure criterion. This does not preclude selecting other failure criteria and thresholds for HCA analysis. The same approach proposed in this paper applies if a different failure criterion is specified.

To obtain the maximum number of repetitions for each vehicle class for the 20-year design life, an iterative process is adopted when running the M-E design guide program. If the pavement does not reach the failure threshold for a given traffic volume level by the end of 20 years, the volume input will be increased and vice versa. The volume can be adjusted easily considering the output from the deterioration curves.

### 6.5 Results and Discussion

Table 1 presents the results of the maximum traffic volume for each vehicle class, as well the mixed traffic flow. The results can be interpreted as follows: the larger the vehicle class volume, the smaller the damage on the pavement by "each pass" of that vehicle class given its specific load characteristics (see Figures 3 and 4). The results from Table 1 imply that Class 12 is the most damaging truck class on a per-vehicle basis. This is followed by Classes 10, 9, and 11; while Class 5 is the least damaging followed by Classes 8, 6, and 4. It is thus recommended that the truck classes could be categorized into two groups of classes with Classes 12, 10, 9, and 11 comprising the "heavy" truck group and the rest comprise the "light" truck group.

**TABLE 1 Maximum Allowable Traffic Volumes during 20-Year Period**

| Surface Layer Thickness (in.) | Class4 | Class5 | Class6 | Class8 | Class9 | Class10 | Class11 | Class12 | All Truck Classes |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 2941900 | 15198600 | 4350800 | 4489500 | 1730100 | 1452700 | 2233800 | 1189900 | 2306800 |
| 4 | 4088000 | 19461800 | 6168500 | 6248800 | 2430900 | 2284900 | 3343400 | 1861500 | 3394500 |
| 5 | 5555300 | 25236100 | 7957000 | 8526400 | 3438300 | 3387200 | 4883700 | 2642600 | 4686600 |
| 6 | 6854700 | 30798700 | 10139700 | 10621500 | 4277800 | 4409200 | 6358300 | 3569700 | 5891100 |
| 7 | 8081100 | 36959900 | 12315100 | 13059700 | 5343600 | 5803500 | 7949700 | 4416500 | 7205100 |
| 8 | 9913400 | 43756200 | 14673000 | 15366500 | 7139400 | 6445900 | 9738200 | 5657500 | 8723500 |

The underlying relationship can also be captured by calculating the relative damage by each pass of a specific truck classes. Given an individual pavement structure scenario, the relative damage on the pavement by each pass of a given truck class can be obtained by Equation (6). Figure 6 illustrates the percentage of pavement damage by each pass of different truck classes under different pavement structure scenarios. It is shown that the percentage damage among the truck classes differ when the surface layer thickness change. From Figure 6 it is evident that the share responsibility of the heavy trucks decreases as the thickness of the surface layer increases, while the light trucks' share increases. This finding supports previous research results and engineering judgment in that thinner pavement structures are more sensitive to load changes than thicker pavements.

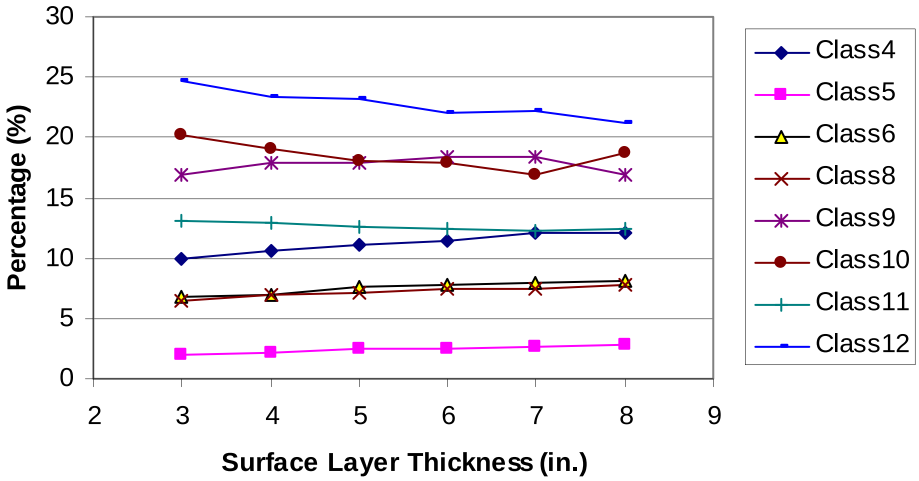

**FIGURE 6 Change in Per-vehicle Damage Share with Surface Layer Thickness**

More importantly, the results presented can facilitate decision-making on class-based charges for different truck classes as a function of their load-induced damage to pavements. For example, the results suggest that each Class 9 vehicle could be charged as much as 8.8 times more than a Class 5 vehicle for the thinner pavement analyzed (corresponding to a relatively low trafficked highway), while the ratio is 6.1 times for the thicker pavement (corresponding to a relatively heavy trafficked highway).

Another critical goal of HCA is to determine the cost responsibility among vehicle classes. This requires both the consideration of the load distribution characteristics and the traffic volume associated with each vehicle class. Integrating these two components, i.e., applying Equation (7), provides the cost shares among truck classes under different pavement structure scenarios. These percentages are presented in Table 2. It is clearly shown that Class 9 dominates the cost share among trucks, accounting for more than 80 percent of the cost share. This high percentage results from the fact that, at the location evaluated, Class 9 vehicles represents the largest volume of trucks and carries heavier loads than most other trucks. All of the other truck classes are responsible for less than 5 percent of the cost share, individually. Despite being the lightest truck class, Class 5 trucks are responsible for the second largest cost share because it accounts for the second largest volume percentage. Class 10 trucks account for the smallest cost share due mainly to low traffic volumes compared to other truck classes. It should be noted that the results presented in this section are site-specific and the methodology should be applied to several other sites to establish general trends. However, it is recommended that cost share estimation should be site-specific due to the sensitivity of pavement damage to pavement type, environmental conditions, and traffic loading characteristics.

### 6.6 An Extension to All-Vehicle Based Cost Allocation

The FHWA's HCA study (*1*) proposes that newly constructed highway costs are composed of two components. The first component is the load-related portion, which can be obtained through the above procedure. The second component is the non-load-related portion, or base facility cost. The FHWA's 1997 HCA study suggests a series of proportions attributable to base facility cost for different highway functional classes. For example, the percentages of base facility cost for rural highways (with flexible pavements) including interstate, other principal arterials, minor arterials, major collectors, minor collectors, and locals are 17.1, 22.5, 31.1, 38.8, 45.1, and 57.4, respectively. Base facility shares thus increase with a decrease in highway functional class. This implies that the cost share from the load-related portion decreases with an increase in highway functional class. Considering that higher-order highway classes are usually designed with stronger, thicker pavements, this supports the findings presented in this paper in that stronger pavements are less sensitive to traffic load.

**TABLE 2 Cost Share Responsibility among Truck Classes**

| Surface Layer Thickness (in.) | Class4 | Class5 | Class6 | Class8 | Class9 | Class10 | Class11 | Class12 |
|---|---|---|---|---|---|---|---|---|
| 3 | 2.63% | 3.53% | 2.59% | 1.36% | 85.50% | 0.81% | 2.20% | 1.38% |
| 4 | 2.66% | 3.88% | 2.56% | 1.37% | 85.50% | 0.72% | 2.07% | 1.24% |
| 5 | 2.75% | 4.20% | 2.79% | 1.41% | 84.95% | 0.68% | 1.99% | 1.23% |
| 6 | 2.78% | 4.29% | 2.73% | 1.41% | 85.10% | 0.65% | 1.91% | 1.13% |
| 7 | 2.93% | 4.45% | 2.80% | 1.43% | 84.75% | 0.62% | 1.90% | 1.14% |
| 8 | 3.14% | 4.93% | 3.08% | 1.60% | 83.32% | 0.73% | 2.03% | 1.17% |

The cost allocation pertaining to base facility among all vehicle classes can be obtained through passenger car equivalent (PCT) weighted VMT (*1*). Combining the latter with the cost shares pertaining to the load-related portion by truck class, will produce the final cost share for different vehicle classes.

## 7. CONCLUSIONS

This paper proposes a mechanistically-based approach for determining highway pavement construction cost allocation. Specifically, the load-related cost share among truck classes is evaluated and quantified. The recently developed M-E Pavement Design Guide was used to calculate pavement damage more accurately than the current empirical design guide. Unlike existing HCA studies, the new guide allows the quantification of all relevant variables affecting pavement deterioration. In particular, the use of axle load spectra to represent load characteristics makes pavement performance estimation more realistic. The M-E Design Guide provides a more rational approach for allocating the pavement damage share among different vehicle classes. A case study was conducted with actual traffic data obtained from a WIM station in Texas. A series of scenarios were evaluated to establish the relationship between cost share among truck classes and different pavement structures. In addition, a discussion on cost allocation among all vehicle classes was presented. The major findings presented in this paper can be summarized as follows:

1. The pavement damage by each pass of a truck varies significantly for different vehicle classes. This result suggests the need for a scientifically-based quantitative measure to determine the cost incurred by each pass of each truck type given their individual damage proportion. Based on the damage potential, Classes 12, 10, 9, and 11 are grouped into the “heavy” truck group, which has a higher damage contribution than Classes 4, 6, 8, and 5, which are grouped into the “light truck group.
2. The damage percentage by each pass of truck varied among the truck classes for different pavement structures. Given an increase in the thickness of the pavement asphalt layer, the “heavy” truck group’s damage share decreases, while the “light” truck group’s share increases.
3. Class 9 trucks, the “18-wheelers” contribute more than 80 percent of the damage cost attributable to truck traffic. All the remaining truck classes’ cost share is less than 5 percent each.

In conclusion, the approach described in this paper provides a scientific, more realistic, accurate, and easy-to-implement method for conducting cost allocation among different vehicle classes for newly constructed highway pavements. The approach accounts for different pavement types, structures, climate regions, and varying vehicle configurations. With the aid of the new M-E Design Guide, rehabilitation cost allocation can be done similarly. In terms of policy implications, the proposed approach provides an objective means to determine the equity of highway user fees, which is the ultimate goal for HCA studies.

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