HVTT13 - EQUITABLE PERMIT FEE FOR OVERWEIGHT TRUCKS



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1. Abstract

This paper presents a rational approach for determination of permit fees for overweight (OW) trucks based on consumption of service life of highways. The prescribed approach uses mechanistic-empirical design philosophy for estimation of deterioration of the pavement structure. The methodology uses permanent deformation, load-related fatigue damage, and roughness scores as primary descriptors for estimation of the service life consumption for flexible pavements and punchouts and roughness measures for rigid pavements.

The experiment factorial included sections with varying structural numbers and slab thicknesses. Each of the pavement sections were simulated under different loading conditions to reflect the full spectrum of axle weights that are characteristic of single, tandem, tridem, and quad axles. This provided the basis for developing the group equivalency (GEF) and axle load factors (ALF) for individual axle groups. This enabled adoption of a modular approach towards determination of gross load equivalencies for any truck category without any restriction on axle weights or configuration.

The consumption of the service life was calculated as the additional pavement structure that would be required to accommodate the OW traffic in excess of the design traffic while ensuring the same performance. The cost incurred in the process of providing the additional structure to offset the accelerated consumption was assigned to the responsible truck fleet in proportion to the marginal load equivalency over the legal gross vehicle weight (GVW) and axle weight tolerances.

2. Introduction and Objectives

The Motor Carrier Division (MCD) of Texas Department of Motor Vehicles (TxDMV) routinely issues oversize/overweight permits to transport “non-divisible” payloads that exceed legal size or weight restrictions permitted on the state highway network. In most cases, these permits originate from ports or manufacturing units and terminate at the point of installation or the state line in case of inter-state shipments. The fee assessed for such permits is primarily an administrative fee to cover the establishment costs incurred by the highway agency and a highway maintenance fee to recover the cost associated with consumption of service life for pavements and bridges. The current fee structure that has been in effect for several years is riddled with several limitations. For example, the assessed fees are independent of the vehicle-miles traveled (VMT) and hence disproportional to the actual utilization of the transportation system by the responsible party. Furthermore, the fee structure is categorized into weight-buckets that range from 80-120 kips, 120-160 kips, 160-200 kips, and 200-255 kips (1, 2, 3, 4). This will tend to subsidize the assessed fee for heavier trucks at the cost of the lighter trucks which questions if the fee structure is equitable.

The primary revenue stream for highway agencies across the nation is the gas tax, which for Texas equals to 20 ¢/gallon. However, improved fuel efficiency and lower industrial activity during the recent economic downturn has severely affected state highway agencies and resulted in budget cuts for highway construction and maintenance. It therefore becomes necessary to look for alternate revenue streams that could potentially make up for the maintenance budget deficits faced by the highway departments. The addition of a consumption-based permit fee structure for overweight permits would help highway departments develop a self-sustaining highway maintenance fund and ease the demand on existing revenue sources for highway maintenance projects. It should be also noted that additional fees on the trucking industry will increase transportation costs which has the potential to cascade across several businesses. Furthermore, due to globalization, domestic businesses face stiff competition in the international market today. Therefore in order to ensure competitiveness of local businesses, it is necessary to ensure that the assessed fees do not burden local industries unnecessarily.

The trucking industry is vital to Texas's economy including the timber industry, farming and agriculture, and many others like it. It goes without saying that these industries contribute to the domestic economy through creation of jobs, business taxes and in many other forms. Therefore, in developing a fair and equitable fee structure, it becomes necessary that the value offered by the trucking industry is given due consideration. Due to the inherent complexity associated with quantification of socio-economic benefits associated with the specific industry, the authors advise that the subject is dealt thoroughly as part of a separate study. It is therefore emphasized that the permit fee structure suggested as part of this study is purely based on consumption of the service life of the highway infrastructure by the OW truck traffic. The proposed fee structure does not take into account the consumption of bridge service life as the scope of this study is restricted to pavements.

This study focuses on developing a permit fee structure for OW trucks on the basis of service life consumption. To that effect, the authors concentrate on determination of the load-related consumption associated with movement of truck traffic and develop a framework for determination of load equivalencies. In the following step, the associated consumption is translated to structural improvement necessary to accommodate the accelerated deterioration of highway facilities. The associated costs are apportioned on the basis of marginal load equivalencies to ensure that the assessed fees are commensurate with the respective party's usage of the highway facilities.

It should be noted that oversize loads that do not exceed legal axle weight tolerances or gross vehicle weights are excluded from the scope of this study. Hence, this study aims to provide specific guidelines regarding the permit fee for OW truck classes associated with consumption of service life for the highway infrastructure.

3. Background

This study will focus at allocating the highway construction and maintenance costs that are attributable to OW vehicles. This involves assessment of the associated consumption of service life and subsequent determination of the cost associated with structural improvements to the highway infrastructure. Hence, there are two separate components to this study: 1) assessment of the pavement consumption, and 2) determination of the cost incurred by the highway department to provide structural improvement that would compensate for the accelerated consumption of the service life of the highway infrastructure and apportioning such costs to the responsible party. It is important to note that the challenge associated with establishing a permit fee structure for OW trucks is often associated with determining the consumption of service life due to a single load. Part of this is due to atypical truck configurations that are often used in the transportation of these loads.

The concept of load equivalency between different axle loads and configurations was first introduced as part of the AASHO Road Test in the 1960s. Following the conclusion of the Road Test program, it was realized that the LEF represents a composite number that can be degenerated into partial factors to account for individual components including axle loads, configuration, tire pressure, loading rate, and temperature among others. Some of these factors, like tire pressure, was not included as part of the AASHO Road Tests or in the determination of LEFs (5, 6). This led to generalization of the LEF concept to incorporate multiple failure criteria based on mechanistic analysis of pavement structures under dynamic traffic loads and led to Equivalent Damage Factor (EDF) (7). Prozzi et al (8, 9) suggested the following relationship for determination of EDF for a particular axle load, configuration, and tire pressure:

$$EDF = GEF \times ALF \times CSF \quad (1)$$

Where,

GEF : Group Equivalency Factor,

ALF : Axle Load Factor, and

CSF : Contact Stress Factor.

Group Equivalency Factor (GEF) establishes the equivalency between different axle groups. By definition, the GEF for single axles is one. *Axle Load Factor (ALF)* is defined as the ratio between the life of the pavement under a single axle of 18kip and the life of the pavement under a single axle of different load. Typically, the ALF is approximated as four based on findings from the AASHO road tests. *Contact Stress Factor (CSF)* is the ratio between the lives of the pavement under a dual-wheel single axle with a tire pressure of 120 psi and that under a different tire pressure.

Once the load equivalencies are established, the cost associated with replenishment of the service life consumed by the OW trucks can be apportioned commensurate to the usage of the highway infrastructure by the responsible party. Li et al. (10) proposed a framework for allocating highway rehabilitation costs. The overall rehabilitation cost was divided into two separate groups – those which can be attributed to load related damage and those which are not. The authors recommended that in case of flexible, JCP and composite pavements, the load related highway rehabilitation expenditures are 28%, 78% and 38%, respectively. Martin (11) suggested load related highway rehabilitation expenditures are about 88%. The 1997 Highway Cost Allocation Study (HCAS) (12) estimated that the cost associated with load-related damage account for 84-89% of the overall rehabilitation costs in case of flexible pavements, 78-86% for JCP and 84-89% for composite pavements. It can therefore be concluded that structural improvements account for the vast majority of expenditures associated with capital improvement projects for the highway infrastructure. In addition, the varying figures suggest that site features significantly influence load-induced deterioration of highway facilities and can have a bearing on the associated costs. Hong et al. (13) showed that Class 9 trucks account for almost 80% of the consumption of pavement service life while that for Class 5 trucks it is about 10%. Timm et al. (14) adopted a similar methodology for determination of permit cost for overloaded trucks and concluded that an increase in the permitted axle volume results in an exponential increase in life cycle costs. The aforementioned studies used the M-E design procedure for determining consumption of service life by OW trucks.

4. Methodology

Tthe overall objective of the study can be sub-divided into two: 1) establishing equivalence between different truck configuration using a common benchmark, and 2) determining the cost associated with the consumption of service life. The following sub-sections detail the procedure adopted to address the aforementioned objectives and hence fulfill the scope of this study.

4.1 Determination of Load Equivalencies

OW loads vary largely in terms of their dimensions, configuration, and payloads which can result in an infinite number of possible truck configurations. To simplify the problem and make it manageable, the methodology adopted in this study uses a modular approach wherein the authors aimed at assessment of the impact of individual axles on the pavement structure. The adopted methodology allowed the authors to model any truck configuration as a combination of the individual axles. It is known that the load-induced deterioration of a pavement structure due to a particular truck configuration is equal to the sum of the damage induced by the constituent axles. The authors used AASHTOWare ME Pavement Design to evaluate the pavement deterioration resulting from different axle groups and weights. In the context of this study, two different axles are equivalent if they result in similar pavement performance at the end of the design life. Therefore, load equivalencies established as part of this study apply to axle weights and configuration, which can be added subsequently to determine the overall equivalency of any truck configuration.

In the context of this study, the authors have replaced the term EDF with Equivalent Consumption Factor (ECF) as the load equivalency is founded on the concept of equivalent consumption of pavement service life. Equation (2) shows the generic relationship between ECF and the constituent partial factors determined in this study. The partial factor, CSF, was dropped from the equation as it was held constant at 120 psi across the entire study.

$$ECF_L = GEF_L \times ALF_L \quad (2)$$

Where,

GEF_L : Group Equivalency Factor (the axle loaded to “L” lbs.), and

ALF_L : Axle Load Factor.

The rate of pavement deterioration can widely vary depending on the governing distress mechanism. Hence, load equivalencies will differ based on the distress mechanism considered. For these reasons, the authors calculated separate ECFs in case of flexible pavements using the most prominent distress mechanisms: rutting, cracking, and roughness. The same approach was adopted in the case of rigid pavements wherein the primary distress mechanisms considered were punchouts and roughness.

Following is the equation used for calculation of the ECF in the study:

$$ECF = \frac{N_{18}}{N_L} = \left(\frac{W_L}{W_{18}}\right)^{\alpha} \quad (3)$$

Where

N_{18}: number of repetitions to failure of a standard 18 kip axle; and

N_L: number of repetitions to failure of any given axle load "L".

ECF represents the relative pavement life under the imposed load with respect to the expected pavement service life for the same number of repetitions of an 18-kip standard axle. Previous studies have shown that the exponent depends on the bearing capacity of the pavement structure (15, 16). In the case of flexible pavements, the structural capacity could be represented by the structural number (SN). The SN is an abstract number that expresses the bearing capacity required for a given combination of soil support (M_R), total traffic expressed in ESALs, terminal serviceability, drainage and environmental conditions (17). In case of rigid pavements, the same can be replaced with the slab thickness. Deacon et al. (16) suggested that in theory, one should be able to develop a relationship between the exponents of the power law and the structural number in the case of flexible pavements. However, the recommendations also suggested that the structural number is not sufficient in itself to accurately describe the load equivalency factors as other factors including contact pressure, group equivalency, loading time and temperature will also have a bearing on the calculated EDF/ECF.

While the structural capacity of the pavement structure is one of the determinants for the exponent in Equation 3, others like climatic features and local conditions can also influence the ECF (16). A total of 82 flexible and 29 rigid pavement sections spread out across five different geographies in Texas with varying bearing capacity and design traffic volume were considered in order to investigate the relationship between ECF and its governing factors. Results indicated in the case of flexible pavements, the ECF calculated using rutting as the governing distress mechanism was influenced by the bearing capacity of the pavement structure. Noteworthy of mention, the SN and ALF had an inverse relationship in the case of single axles; for tandem, tridem and quad axles the relationship between these two parameters could be explained using a non-monotonic function. It was observed that the ALF reaches an asymptotic value at SN ≈ 2.5 and peaks around 4.0. However, in the case of cracking and roughness, results did not indicate any underlying relationship. As for rigid pavements, the authors did not notice any observable trend between the slab thickness and the ALF. Therefore, except for the case of rutting, the authors decided to obtain an average ALF for the sections included in this study. Table 1 summarizes the models that were developed for determining the ECF using each of the distress mechanisms for flexible and rigid pavements along with the respective GEF for single, tandem, tridem, and quad axles (18, 19).

The models presented in Table 1 can be used to calculate consumption equivalencies for single, tandem, tridem, and quad axles loaded to any given weight using each of the distress mechanisms considered. In the event where the user is interested in determining a single load equivalency for a given axle, the same may be obtained by assigning a particular weight to each of the individual load equivalencies. Although the authors used uniform weights to determine the overall ECF, others might vary them based on their engineering judgment.

Table 1: Summary of Equations Necessary for Calculating Load Equivalencies

Flexible Pavements				
Distress Mechanism	Model	GEF		
		Tandem	Tridem	Quad

Rutting	$ln(ECF) = (e^2 \times SN^{-0.43}) \times ln\left(\frac{W_L}{GEF \times W_{18}}\right)$ [Single Axles] $ln(ECF) = \left(0.26SN^{4.45}e^{-SN^{1.09}} + 3.04\right) \times ln\left(\frac{W_L}{GEF \times W_{18}}\right)$ [Tandem and Higher]	1.44	1.87	2.22
Cracking	$ln(ECF) = (-0.5n + 5.72) \times ln\left(\frac{W_L}{GEF \times W_{18}}\right)$	1.89	2.59	3.10
Roughness	$ECF = e^{0.703 \times \left(\frac{W_L}{GEF \times W_{18}} - 1\right)}$ [Single Axles] $ECF = e^{0.945 \times \left(\frac{W_L}{GEF \times W_{18}} - 1\right)}$ [Tandem and Higher]	1.57	2.21	2.41
Rigid Pavements				
Punchout	$ln(ECF) = 3.27 \times ln\left(\frac{W_L}{\text{GEF} \times W_{18}}\right)$	1.38	2.14	3.08
Roughness	$\ln(ECF) = 1.46\left(\frac{W_L}{\text{GEF} \times W_{18}} - 1\right)$	1.57	2.18	2.76

4.2 Cost Calculations

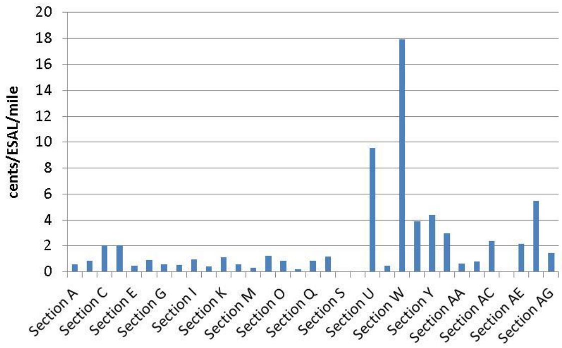
This study focuses on development of a usage-based permit fee structure wherein users of the highway network will be required to pay a fee that is commensurate with consumption of service life. In the context of this study, the authors are interested in determining permit fee for OW trucks based on their usage of the highway infrastructure. There are several approaches for allocating highway construction costs to responsible vehicle classes. Among these, the proportional method is among the notable ones. In the proportional method, highway construction costs are allocated based on a measure of consumption by individual OW truck classes.

It is understood that the pavement structure will experience accelerated deteriorated as a result of the overweight axles. The methodology adopted requires providing additional structural support to accommodate additional OW truck traffic while ensuring the same terminal distress condition. This implies increasing the structural capacity of the pavement structure, which could be achieved in several different ways, including increased thickness of the structural course or improved material quality. Given that it is a design problem, there may be several ways to increase structural capacity: increasing the thickness of the asphalt concrete, increasing the thickness of the base, blending the natural subgrade with higher quality material, or even stabilizing the base or subgrade are just a few of them. The design choice made as part of this study consists of increasing the thickness of the primary structural layer. In the case of flexible pavements, this implied increasing the thickness of the surface course or one of the underlying layers in situations where the surface course had a different function other than providing structural support. On other occasions, like in the case of rigid pavements, the same objective was addressed though increased slab thickness. In case of certain thin flexible pavement sections, provision of an asphalt overlay was considered.

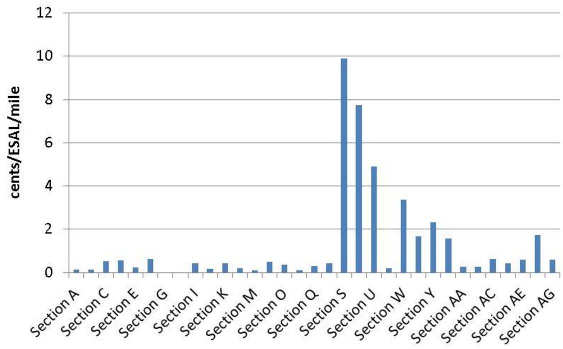
It should be noted that the increased thickness and the associated cost refers to the total highway construction cost required to accommodate the entire OW truck fleet. The overall cost was apportioned based on relative consumption of service life by individual truck classes to determine the fee structure for individual OW truck class. To that effect, the marginal ECF (allocator) over the legal GVW (58 kips on load-zoned highways (LZ); 80 kips for non-LZ facilities) or the individual axle tolerances were used for apportioning the construction costs to the responsible parties.

The study team considered a scenario where the total number of ESALs owing to the OW truck fleet equals that of the design truck volume. However, designing the pavement structure to exclusively cater to OW truck volume was not considered as it would be inappropriate because the highway facility was designed for the design truck traffic. Therefore, the additional structure necessary to accommodate the OW truck traffic (in addition to the design traffic volume) was determined and the associated costs were apportioned on the basis of marginal ECF. In the case of flexible pavements, these costs were estimated using each of the three primary distress mechanisms earlier discussed: rutting, cracking, and roughness. In the case of rigid pavements, the cost was assessed using the two distress mechanisms considered in this study, namely, punchout and roughness.

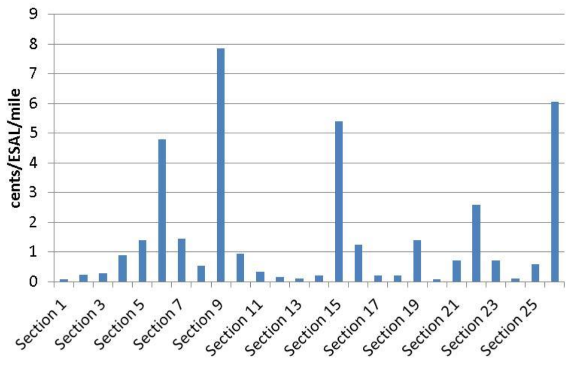
A key component of the procedure involved obtaining reliable estimates for construction costs. The particular objective was addressed by referring to TxDOT's average low bid price portal (20). In the following step, unit costs were multiplied with the total quantity of required material to determine the construction costs per lane mile. As highlighted in the previous paragraph, the allocator used in this study refers to the marginal ECF which is calculated in terms of ESAL. Together with the construction cost/lane mile and an estimated value for the allocator, it is possible to determine the apportioned fee in \$/mile/ESAL. Figure 1 highlights the calculated unit price for the permit costs for the individual flexible and rigid pavement sections using the different distress mechanisms considered in this study.



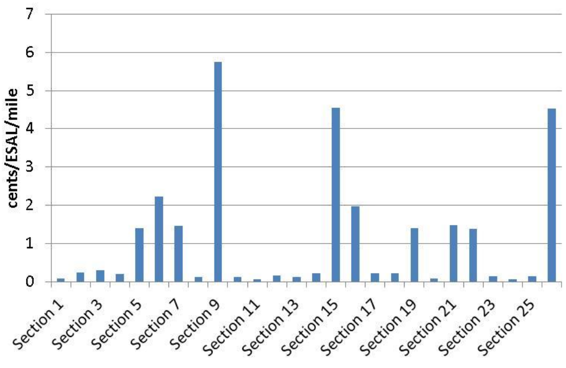
Flexible Pavements (Rutting)



Flexible Pavements (Roughness)



Rigid Pavements (Punchout)



Rigid Pavements (Roughness)

Figure 1: Pavement Costs Assessed for OS/OW Loads

The results presented in Figure 1 does not hint at any relationship between calculated fees and the functional classification or the structural number for a given highway facility. This encouraged the authors to obtain average fees irrespective of the highway facility: 1.8 cents/ESAL/mile for flexible pavements and 1.3 cents/ESAL/mile for rigid pavements. However, it should be noted that the computed costs vary over a wide range for both flexible and rigid pavement structures. In these circumstances, it is advised that a 95% confidence interval is constructed to account for the inherent variability in the data to safeguard against under-estimation (21). This resulted in increased fees of 3.7 cents/ESAL/mile for flexible pavement structures and 2.9 cents/ESAL/mile for rigid pavement structures. To put the aforementioned tariff rates into perspective, Seedah et al. estimated the VOC at $1.40 for a Class 9 truck moving an 80kip load on SH130 (22). The proposed fees if applied to the same truck would result in 14.8 cent/mile fee, which is approximately 10% of the VOC.

The permit fee structure proposed above refers to the fee that should be assessed on OS/OW loads. However, an important factor that requires further consideration is the definition of "legal load" in Texas. A truck that does not exceed a GVW of 80,000 lbs. is not subject to any fees under the current fee structure. Such rules also apply to single axles not exceeding 20,000 lbs., tandem axles not exceeding 34,000 lbs., and tridem axles not exceeding 42,000 lbs. Therefore, under the proposed fee structure, these vehicles should continue to have the same exemptions that are extended today. The researchers propose that the suggested fee structure should be considered as a marginal fee applicable to OW loads once they exceed the legal limits – and proportional to the amount that exceeds these limits.

5. Case Study

As discussed earlier, the current permit fees that are assessed on OS/OW loads have several deficiencies. The first of these being the fee structure does not depend on the traveled miles and therefore does not relate to the actual usage of the highway infrastructure. The other major drawback relates to the incongruity between the assessed fees and the actual consumption by OW trucks. Currently, the fees are assessed based on GVW while it is known that the axle weight and not the GVW that primarily determines the consumption of service life. Therefore, the new fee structure proposed as part of this research study aims to address the aforementioned limitations and develop a system that rewards/penalizes operators based on their usage of the highway infrastructure. In addition, it will also account for differences in truck configuration between trucks and incentivize operators that use axle combinations that are friendlier towards the pavement structure. Occasionally, this might require a balance between axle configuration and operating costs as it is know that additional axles will reduce the gross ECF but result in higher vehicle operating costs (VOC). The following sub-section illustrates the calculated fees according to the proposed fee structure vis-à-vis the current state-of-practice.

Typically, fees associated with single-trip permits are relatively easy to determine as the route is known, and so is the percentage of loaded VMT traveled on IH, US, SH, and FM roads. It should be noted that certain facilities may be load-zoned implying the legal GVW for these facilities drop down to 58,000 lbs. The cost associated with consumption of service life can be computed by determining the marginal consumption factors for each route segment and multiplying it with the unit cost per traveled mile for the particular facility based on their respective structural characteristics. Table 2 illustrates the consumption rates for typical truck configuration for the individual weight classes that are currently used.

The results presented in Table 2 highlight the importance of a usage-based permit fee structure. Ordinarily, a particular OW truck would be included in one of the four weight classes shown in Table 2 and the permit fees will be assessed independent of the traveled miles. However, the proposed fee structure represents a quantum shift in this regard as it calculates an equitable fee based on the VMT associated with the permit and the payload being transported and thus directly relating the assessed fee to the usage of the transportation system. The aforementioned observation is highlighted by the gross disjoint between the fees assessed under the proposed tariff structure and that already in place, which underscores the need for major reforms.

6. Conclusions

This paper presents a methodology for determining the fee structure for OW truck permits. The fee structure proposed as part of this study is based on the consumption of service life of highway facilities. It is important to take into consideration that the proposed fees are based on the accelerated deterioration that results from OW axles and does not take into consideration socio-economic aspects of imposing increased fees on the trucking industry.

The methodology adopted in this study uses a modular framework towards establishment of load equivalencies by estimating the partial factors – GEF and ALF, individually. Following their determination, the gross equivalency was computed as a product of GEF and ALF. The fact that the equivalencies are established for individual axles, allowed the study team to determine the load equivalency for any truck class without imposing restrictions on axle weights or configuration. This is particularly beneficial with OW trucks as they frequently deviate from standard truck configuration due to dimensional restrictions and effective dispersion of the load to the pavement structure.
Following the determination of the load equivalencies, the additional structure necessary to accommodate the OW trucks was determined and the associated costs were calculated. The provision of additional structural support to the pavement sections would help ensure the same terminal serviceability condition and hence offset the additional consumption of service life by OW trucks. The incurred costs were apportioned on the basis of the marginal ECF (load equivalency) already calculated.
Current mandates define GVW up to 80,000 lbs as legal with certain restrictions on individual axles and therefore not required to pay additional permit fees on the Interstate or the state highway network. In order to develop a fair and equitable fee structure for OW trucks, their respective ECF were discounted such that the permit fee assessed on individual loads is proportional to the amount that exceeds the definition of legal loads.

The foregoing sections highlight several benefits associated with the aforementioned procedure. The foremost of this includes discontinuation of a flat-fee that is assessed from OW truck operators wherein short-haulers subsidize the fees assessed from long-haulers. The adoption of the proposed fee structure will lead to an usage-based fee that is commensurate with the VMT and the payload. This represents a significant shift from the current state-of-practice wherein the assessed fees overlook the actual usage of the highway infrastructure by the truck operators. The case study further highlights the importance of a usage-based fee structure as it underscores the disparity in the fees under the proposed structure and that currently in place. The adoption of the proposed fee structure will establish equity among the responsible operators and also help secure maintenance funding that is proportional to the repair needs and help lower VOC.

Table 2: Consumption Fees for General OS/OW Single-Trip permit Weight Classes

Weight Class (kips)	Configuration	Legal Load (ESAL)	Unit Cost (Pavements)	Pavement Rate ($/mile)	Bridge Rate ($/mile)	Composite Rate ($/mile)	VMT – TxPROS (miles)**	Proposed Fee ($)	HWY Maint. Fee FY 2011 ($)
80-120	15kip Steering + 45kip Tandem + 60 kip Tridem*** = 11.5 ESAL	3.97	3.7 ¢/mile/ESAL	0.347	0.231*	0.58	9 (Min)	5.22	150
							244 (Avg.)	142	
							672 (Max)	390	
120-160	15kip Steering + 2# 42.5kip Tandem + 60kip Tridem*** = 14.6 ESAL			0.494	0.377*	0.87	5 (Min)	4.35	225
							111 (Avg.)	96.6	
							492 (Max)	428	
160-200	15kip Steering + 3# 42-kip Tandem + 59 kip Tridem*** = 17.97 ESAL			0.648	0.485*	1.13	14 (Min)	15.8	300
							91 (Avg.)	103	
							357 (Max)	403	
200-255	15kip Steering + 4# 60kip Quad*** = 22.59 ESAL			0.861	0.896*	1.76	132 (Min)	232	375
							464 (Avg.)	817	
							812 (Max)	1429	

* The consumption rate for bridges is beyond the scope of the study and its details can be found elsewhere (19).

** The VMT information for the OW trucks is based on the summary statistics obtained from the TxDMV OS/OW database.

*** The representative axle configuration chosen corresponding to the individual weight categories was also done based on statistics obtained from the OS/OW database.

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