Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 2(6):236-241

Development of a Weight-Distance Permit Fee Methodology for Overweight Trucks in Virginia

Brian K. Diefenderfer[1+], Audrey K. Moruza[2], Michael C. Brown[1], Daniel S. Roosevelt[3]
E. Cris Andersen[4], Amy A. O'Leary[5], and Jose P. Gomez[6]

Abstract: Following the 2007 Virginia legislative session, the Virginia Transportation Research Council was tasked with providing the Virginia Department of Transportation (VDOT) and the Virginia Department of Motor Vehicles with a practical methodology for assessing permit fees for overweight trucks in Virginia based on engineering principles. It was imperative that the methodology be practical and be readily implemented by the state agencies. These fees were intended to partially recover additional pavement maintenance attributable to overweight vehicles. This study describes the methodology developed to divide VDOT's maintenance budget into either load-related or not load-related categories and to distribute the costs across vehicle classifications. Budget allocations attributable to vehicle characteristics were divided into six categories, while all other maintenance costs were considered common to all vehicle classes and were disregarded in this analysis. The study developed a per mile axle-load-related cost based on data from weigh-in-motion stations located around the state. From this, a permit fee can be calculated. The study also shows an example of how the methodology was applied to determine a damage-related fee for a particular vehicle type, the owners of which were seeking legislation to permit higher axle- and gross-weight allowances from the 2007 Virginia General Assembly.

***Key words**: Budgets; Legislation; Maintenance; Pavements; Truck weight.*

Introduction

Following the 2007 Virginia legislative session, the Virginia Transportation Research Council (VTRC) was tasked with providing the Virginia Department of Transportation (VDOT) and the Virginia Department of Motor Vehicles (DMV) with a methodology for assessing overweight hauling permit fees for overweight trucks in Virginia based on engineering principles. It was imperative that the methodology be practical and could be readily implemented by the state agencies. These permit fees were intended to partially recover additional pavement maintenance attributable to overweight vehicles. To assess the additional costs that overweight vehicles contribute to maintenance expenditures, a detailed methodology was developed to divide VDOT's fiscal year (FY) 2007 maintenance budget between load-related and not load-related categories and to distribute the load-related costs across vehicle classifications according to estimated cost responsibility. Although the methodology initially divided the load-related costs of the budget into six categories to attempt to capture all load-related maintenance activities, costs in the budget resulting from axle loads were ultimately the focus of this methodology. These costs were allocated using data obtained from in-lane weigh-in-motion (WIM) devices located around the state on interstate and primary routes. Residual costs (not load-related) were considered common to all vehicle classes and were disregarded in the present analysis.

To assess the loading from vehicles, this study made use of data from in-lane WIM sensors. WIM sensors have been installed on both interstate and primary routes at 15 sites within Virginia, continuously collecting an array of data, including the date and time a vehicle passes, the vehicle speed, the gross vehicle weight, individual axle weights, and axle spacing. From those data, vehicle classifications are assigned by algorithm. These data ultimately allowed the study team to (1) estimate the portion of load-related maintenance allocations attributable to heavy vehicles on the basis of their configurations and axle loading, and (2) develop a fee calculation that linked the loading characteristics of a vehicle to its vehicle class's share of load-related maintenance costs.

Previous studies of the impact of overweight vehicles on highway assets in Virginia were hindered by the lack of available data on recurring maintenance costs and factors to allow for the allocation of these costs to specific vehicle classifications. As such, an accurate estimate of the cost to maintain the roadway infrastructure was previously unknown to VDOT, since the condition of the system was not known with statistical accuracy and therefore maintenance allocations were not based solely on need. The share of the impact on the highway infrastructure by vehicle classification could be estimated, but major components in the estimate were based on the registered weight of vehicles and did not take into consideration that vehicle weights vary within each classification

[1] PhD, P.E., Research Scientist, Virginia Transportation Research Council, Charlottesville, VA 22903, USA.
[2] Associate Research Scientist, Virginia Transportation Research Council, Charlottesville, VA 22903, USA.
[3] P.E., Research Scientist, Virginia Transportation Research Council, Charlottesville, VA 22903, USA.
[4] Assistant District Administrator - Business, Retired, Virginia Department of Transportation, VA, USA.
[5] PhD, Associate Director, Virginia Transportation Research Council, Charlottesville, VA 22903, USA.
[6] PhD, P.E., Associate Director, Virginia Transportation Research Council, Charlottesville, VA 22903, USA.
[+]Corresponding Author: E-mail brian.diefenderfer@vdot.virginia.gov
Note: Submitted June 17, 2009; Revised August 10, 2009; Accepted August 11, 2009.

Table 1. Distribution of VDOT FY 2007 Maintenance Budget.

Item	Allocation, $ (millions)
Assets	
Pipes and Drainage	51.9
Roadside	85.1
Traffic Control and Direction	80.3
Pavements	316.4
Structures and Bridges	54.3
Special Facilities*	12.5
Asset Subtotal	600.6
Cost Centers Subtotal	349.1
Federal-Aid Subtotal	178.2
Total	1,127.9

*Includes rest areas and waysides, pedestrian and river/mountain tunnels, traffic management systems, ferries, parking lots/decks, bus stops/shelters, and movable bridges.

and that damage to some assets (e.g., pavements) depends on axle loading rather than gross vehicle weight.

In 2005, VDOT adopted a needs-based budgeting process that made additional data available for cost analysis and offered a logical option for determining load-related costs for maintenance. The needs-based budget distributes funds to various assets (e.g., pavements, structures, signs, etc.) by activities (e.g., paving, patching, overlays, etc.), and to cost centers, which capture VDOT expenditures that cannot otherwise be coded according to the route-asset-activity structure (e.g., incident management, preparation for snow removal, etc.). The budget relies on a condition assessment of assets from which the cost to maintain the assets over the budget period is estimated. These estimates were taken by the authors to represent the "true" cost of the damage incurred by these assets over the 2007 budget period following recommendation by VDOT's Maintenance Division. Ex post maintenance expenditures were not considered as the true maintenance cost as they are often directed by unforeseen events (e.g., floods) and delays that result in changed priorities and deferral of needed maintenance activities.

Methodology

The methodology developed in this study began with allocating VDOT's FY 2007 maintenance budget into load-related and not load-related categories. Following this allocation, the load-related costs of the budget were divided among the 13 Federal Highway Administration (FHWA) vehicle classifications based on a vehicle class's estimated share of Equivalent Single Axle Load (ESAL)-vehicle miles traveled (VMT) (i.e., ESAL-miles traveled) during the budget period. Following this, the methodology was applied to determine a damage-related fee for a particular vehicle type, the owners of which were seeking legislation to permit higher axle- and gross-weight allowances from the 2007 Virginia General Assembly.

Allocation of Load-Related and Not Load-Related Activities

In 2005 VDOT adopted a needs-based budgeting process that relies both on a condition assessment of assets and historic deterioration rates to estimate the cost to maintain the assets. VDOT's maintenance budget for FY 2007 was approximately $1.13 billion (including federal-aid monies); a more detailed breakdown is shown in Table 1.

The maintenance budget was subdivided first by determining which maintenance activities were load-related. Then, a panel of engineers within the study group was convened to estimate the percentage of each load-related maintenance expense that could be attributed to one of six vehicle characteristics identified as follows:

1. Axle load: damage caused by the load carried on each axle of the vehicle;
2. Number of axles: wear caused by tire action;
3. Vehicle-induced moment: repairs necessitated by loading on structural elements;
4. Truck-only: wear resulting from vehicle size;
5. Non-truck: wear not attributable to heavy vehicles; and
6. Bus-only: repairs of assets that primarily serve buses.

Any residual maintenance activities not considered to have been caused by one of these specific vehicle characteristics was considered a cost common to all roadway users. Given the lack of scientific study relating the other vehicle characteristics to maintenance expenditures, "axle load" was the only vehicle characteristic considered in this study. A methodology to attribute bridge maintenance costs to vehicles (based on vehicle-induced moment) is still under development and is therefore excluded here.

Calculating Load-Related Maintenance Costs

The methodology used to divide the maintenance budget was developed with the assumption that the sources of damage repaired by maintenance allocations are the result of either vehicle characteristics (some of which are load-related) or the environment (not load-related). Other sources of damage were considered to be negligible or the methodology to quantify their costs was not firmly established. The study team used an expert panel made up of VTRC scientists involved in pavement, structures, and maintenance research to attribute costs to load-related and not load-related damage as follows:

1. The study team reviewed all budgeted activities for maintenance of assets and designated those activities that respond, in whole or in part, to the six vehicle characteristics listed above.
2. The study team assigned the cause of the maintenance activity within each asset category (as shown in Table 1) to one of the vehicle characteristics. Remaining maintenance costs were considered common costs and were disregarded in this study.
3. Each member of the expert panel independently estimated the percentage of costs to be allocated for each of the maintenance activities that respond to the vehicle characteristics. The panel then compared their findings and discussed to reach consensus. Only the resulting percentages attributed to axle loading were used to determine the load-related cost shares for each asset category by activity.
4. The study team individually reviewed cost center allocations (expenditures which are not specific to assets) to identify axle-load-related expenses.

Table 2. VDOT FY 2007 Maintenance Budget Attributed to Vehicle Characteristics.

Item	$ (Thousands)	
	All Vehicle Characteristics	Axle Load Only
Assets		
Pipes and Drainage	13.8	13.8
Roadside	210.9	210.9
Traffic Control and Direction	8,729.7	0
Pavements	121,191.3	121,191.3
Structures and Bridges	9,956.7	0
Special Facilities	310.4	142.5
Asset Subtotal	140,412.8	121,558.5
Cost Centers Subtotal	22,757.4	18,418.2
Federal-Aid Subtotal	48,273.1	34,946.2
Total	211,443.4	174,923.0

5. As federal-aid funds allocated to maintenance in FY 2007 were distributed after the start of the fiscal year, the study team reviewed each federal project, determined the asset category involved and estimated the axle-load-related allocation percentage. For guidance, the study team used the matrix of percentages developed by the expert panel in Step 3.

Table 2 shows the resulting distribution of load-related costs for all load-related vehicle characteristics and those for axle load only.

Distribution of Axle-Load-Related Costs to Vehicle Classes

Although the study team searched for existing or new cost-allocating methodologies based on the vehicle characteristics identified in this study, the attribution of highway asset deterioration to vehicle characteristics other than axle loading remains actively researched and debated and thus did not meet the mandate that the study be readily implemented. In the case of the axle load category, however, a wealth of objective research has documented the deterioration of pavements attributable to this cause. From an engineering perspective, it is well-established that higher axle loads increase the damage done to pavements, resulting in the need for more frequent pavement repair and rehabilitation and imposing considerable indirect costs on the public because of travel delay and accidents in work zones.

Engineering research over the past 50 years has conclusively demonstrated that as axle loads increase, pavement damage increases exponentially [1-6]. As seen in Table 2, the estimated share of axle-load-related costs was approximately 83 percent of all costs attributed to vehicle characteristics. As the study progressed, the small relative contribution of the other vehicle characteristics to total load-related damage costs, as well as the lack of methods based on those load types to distribute costs to vehicle classes, led the study team to adopt the axle-load vehicle characteristic as the only criterion for calculation and distribution of load-related damage costs.

Costs Related to Axle Load

To quantify the effects of axle loading, the study team used ESALs as the metric for comparing the relative damage caused by each vehicle class. The ESAL is an empirical relationship used to describe the amount of pavement damage caused by each pass of a given axle as compared to a standard 18,000-lb (80-kN) single axle [7]. The ESAL concept was developed during the American Association of State Highway Officials (AASHO) Road Test of the late 1950s and early 1960s and is commonly used in pavement design as a descriptor of vehicles in terms of the damage they cause [8]. In addition, this methodology is the current design standard followed by VDOT [9].

To measure vehicle axle loading, this study made use of data from in-lane WIM sensors. WIM sensors are installed at fifteen sites on both interstate and primary routes in Virginia [10]. They continuously collect an array of data including date and time a vehicle passes, vehicle speed, gross vehicle weight (GVW), individual axle weights, and axle spacing. From these data a vehicle classification is assigned by algorithm. The present study used WIM data collected during one 7-day period (Sunday through Saturday) per month from January 2005 through March 2007. The sample dates were chosen to avoid national or local holidays. Since some WIM sites had only recently been installed, data used within this study were collected for an average of approximately 15 months at each site (the periods of data collection ranged from 3 to 27 months).

From the WIM data, an average ESAL value for each vehicle class was determined for both primary and interstate routes. Vehicles were classified by type according to the FHWA's Guide to Long-Term Pavement Performance (LTPP) Traffic Data Collection and Processing, which assigns vehicle classifications 1 through 3 to passenger vehicles, 4 to buses, and 5 through 13 to trucks based on their configurations [11]. Since Virginia has no WIM sensors on secondary routes, the ESAL values for secondary routes were assumed to be equal to those for primary routes. The average ESAL values allowed estimation of the damage caused by each vehicle class and were used to develop a more equitable distribution of maintenance costs among classes.

ESAL values, however, are not solely dependent on vehicle characteristics. When flexible pavements are considered, the average ESAL value for each vehicle class varies depending on the structural number and terminal serviceability of the pavement. The structural number is indicative of a pavement's structural capacity, and the terminal serviceability represents the condition value (on a scale of 0 to 5) at which the pavement is considered failed [7]. Representative structural numbers for interstate, primary, and secondary routes were assumed to be 6.0, 4.75, and 3.3, respectively. Terminal serviceability values for interstate, primary, and secondary routes of 3.0, 2.85, and 2.85, respectively, were obtained from VDOT's Guidelines for 1993 American Association of State Highway and Transportation Officials (AASHTO) Pavement Design, the department's design standard for use with the 1993 AASHTO pavement design guide [9].

From these assumptions, a weighted average ESAL value (weighted by relative shares of interstate, primary, and secondary route miles traveled in 2007) for each FHWA vehicle classification was developed, as shown in Table 3. Average ESAL values for FHWA Class 4 through Class 13 were taken from the WIM data; ESAL data for FHWA Class 1 through 3 were assumed based on VDOT guidelines [9].

Table 3. Average ESAL by Roadway Classification.

FHWA Classification	Description	Average ESAL Primary/Secondary	Average ESAL Interstate	Weighted Average ESAL**
01	Motorcycles	0.0002*	0.0002*	0.0002
02	Passenger Cars	0.0002*	0.0002*	0.0002
03	2 Axle, 4 Tire Single Unit Vehicles	0.0002*	0.0002*	0.0002
04	Buses	0.3194	0.4050	0.3490
05	2-Axle, 6 Tire Single Unit Trucks	0.3497	0.2427	0.3182
06	3-Axle Single Unit Trucks	0.6848	0.4210	0.6020
07	4 or More Axle Single Unit Trucks	1.5571	1.3133	1.4976
08	4-Axle or Fewer Single Trailers	0.4669	0.4592	0.4637
09	5-Axle Single Trailers	1.0677	1.0455	1.0520
10	6 or More Axle Single Trailers	1.1429	1.0908	1.1196
11	5-Axle or Fewer Multi-Trailers	1.1725	1.5087	1.4410
12	6-Axle Multi-Trailers	0.7128	0.7998	0.7893
13	7 or More Axle Multi-Trailers	2.8996	1.4910	1.8147

*Assumed based on VDOT's Guidelines for 1993 AASHTO Pavement Design [9].
**Weighted based on daily vehicle miles traveled (DVMT) for each administrative classification.

Table 4. 2007 Daily Vehicle Miles Traveled (DVMT) by Vehicle and Roadway Classification.

FHWA Class	Secondary	Primary	Interstate	Total	% of Total
01	161,237	365,324	218,799	745,360	0.3
02	55,210,215	71,061,399	47,535,289	173,806,903	77.3
03	7,495,630	17,349,536	9,984,377	34,829,543	15.5
04	271,691	553,313	435,516	1,260,520	0.6
05	393,656	840,478	514,142	1,748,275	0.8
06	237,415	625,405	394,680	1,257,500	0.6
07	60,179	161,749	71,596	293,524	0.1
08	84,046	316,065	295,770	695,881	0.3
09	201,123	2,605,762	6,748,732	9,555,617	4.2
10	17,914	85,092	83,064	186,069	0.1
11	1,732	72,254	293,672	367,658	0.2
12	329	14,280	106,773	121,382	0.1
13	9	167	591	767	0.0
Total	64,135,176	94,050,824	66,683,000	224,869,000	

Vehicle classes were considered responsible for pavement damage in proportion to both vehicle class average weighted ESAL values and extent of travel on the road system. Therefore, load-related maintenance costs were apportioned among vehicle classes by calculating vehicle class shares of total daily ESAL-miles (weighted average ESALs × DVMT).

The proportion of the maintenance budget related to axle loads was distributed to vehicle classes in the same proportions as ESAL-miles were generated by FHWA vehicle classes in 2007, using VDOT's DVMT data by vehicle classification [12]. Table 4 presents the DVMT information for FY 2007 distributed by vehicle and roadway classification. Table 5 presents estimated daily ESAL-miles by vehicle class and shares by vehicle class.

Application of Methodology

Following the 2007 Session of the Virginia General Assembly, VDOT, and DMV were tasked with developing a methodology to quantify the additional maintenance costs associated with overweight vehicles delivering petroleum products (tank wagons) for the purpose of designing a permit fee which could equitably recover some of those added costs. Senate Bill 1321 (SB 1321) of the 2007 Session of the Virginia General Assembly (Virginia *Acts of Assembly*, Ch. 738; *Code of Virginia* § 46.2-1141.1) enables owners or operators of petroleum tank wagons to apply for overweight permits from the Commissioner of the Virginia Department of Motor Vehicles. These vehicles with tanks less than 6,000 gallon capacity are used to deliver petroleum products to homes or businesses. Tank wagons are defined in Virginia as two-axle, six-tire vehicles (Code of Virginia § 58.1-2201), meeting the definition of a Class 5 vehicle.

Tank wagons traveling without overweight permits were previously subject to upper limits of 20,000*lb* (89*kN*) on a single axle and 32,000*lb* (142*kN*) GVW. Prior to the enactment of SB 1321, tank wagon owners who wished to transport a number of gallons of product that would result in the vehicle exceeding 32,000*lb* (142*kN*),

Table 5. 2007 Daily ESAL-Miles by Vehicle Class.

FHWA Class	Daily ESAL-Miles	% of Total
01	149	0.0
02	34,761	0.3
03	6,966	0.1
04	439,906	3.5
05	556,296	4.4
06	757,024	6.0
07	439,585	3.5
08	322,650	2.6
09	10,052,905	79.9
10	208,325	1.7
11	529,806	4.2
12	95,806	0.8
13	1,392	0.0
Daily Total	13,445,573	
Annual Total	4,907,634,143	

GVW could obtain a 5 percent overload permit for $200 (*Code of Virginia*§ 46.2-1129 et seq.), subject to a single-axle weight limit of 21,000*lb* (93*kN*) and a GVW limit of 33,000*lb* (147*kN*). Under SB 1321, vehicles of this type would be allowed to obtain an overweight permit to increase the allowable weight on a single axle by 4,000*lb* (18*kN*) (24,000*lb* (107*kN*) maximum) for a maximum allowable GVW of 36,000*lb* (160*kN*) for a permit fee that would ideally recover some of the added damages.

To estimate the maintenance cost impact of the additional loading allowed by SB 1321, the methodology described above was applied narrowly to a hypothetical vehicle fitting the description of the tank wagon vehicle yet carrying the higher proposed weight allowances. Three pieces of information were needed to estimate a damage-based fee for the heavier tank wagon: (1) the increase in typical ESAL value of the tank wagon at the higher weight allowances over its former typical ESAL value, (2) the DVMT for such a vehicle, and (3) the load-related maintenance cost (restricted to costs attributable to axle loads) per ESAL-mile traveled in 2007.

Calculation of the load-related maintenance cost per ESAL-mile traveled was relatively straightforward. Total estimated axle-load-related maintenance costs for FY 2007 are shown in Table 2 as $174 million. Total annual ESAL-miles (for all vehicle classes) are shown in Table 5 as 4.9 billion. From this, the estimated maintenance cost per ESAL-mile can be found by dividing the total maintenance cost related to axle load ($174,922,958) by the total annual ESAL-miles traveled (4,907,634,143); a maintenance cost of $0.0356 per ESAL-mile was calculated for FY 2007.

Calculating the change in typical ESAL values needs to reflect a realistic operating weight distribution for a tank wagon, one that does not presume operation at maximum weight limits at all times. To estimate a realistic operating ESAL value for a tank wagon, the following steps were taken.

1. Calculate the current average ESAL of a tank wagon (i.e., prior to the higher weight allowances specified in SB 1321). As a tank wagon is defined as FHWA Class 5 (two-axle, six tire), the average ESAL value for a Class 5 vehicle from the WIM data was used. This value is shown in Table 3 as 0.3182.
2. Determine the current average ESAL of a tank wagon compared to the current maximum ESAL expected. Assuming typical Class 5 vehicle loading to be 12,000*lb* (53*kN*) on the steering axle and 20,000*lb* (89*kN*) on the rear axle, the current maximum Class 5 ESAL value expected was calculated to be 1.4643[1] (computed as a weighted average considering the structural number, serviceability, and DVMT of Class 5 on each roadway classification using equations found in the AASHTO Guide for Design of Pavement Structures [8]). An "operating weight factor" calculated as the ratio of the current average Class 5 ESALs (0.3182) to the current maximum ESALs (1.4643), or 21.73%, suggests that the average Class 5 vehicle travels at 21.73 % of the maximum expected Class 5 ESAL value. The tank wagon was assumed to have the same operating weight factor as other Class 5 vehicles. This assumption was necessary in lieu of more vehicle specific data.
3. Determine the new maximum tank wagon ESAL value given the higher axle weight allowed to tank wagons in SB 1321. The new maximum tank wagon ESAL value was calculated similarly to the current maximum Class 5 ESAL value of Step 2 and was determined to be 2.7757, assuming the additional 4,000*lb* (18*kN*) was placed on the rear axle.
4. Calculate the new average tank wagon ESAL value given the higher axle weight allowed to tank wagons in SB 1321. When the new maximum tank wagon ESAL value (2.7757) was multiplied by the "operating weight factor" of 21.73%, a new average tank wagon ESAL value was found to be 0.6032.
5. Calculate the increase in average tank wagon ESAL values (i.e., the difference in average ESALs prior to and after SB 1321). Calculated as the difference between the current average ESAL (0.3182) and the new average ESAL (0.6032), the increase was found to be 0.2850.
6. Calculate a blanket annual fee for a tank wagon traveling under the provisions of SB 1321. This fee was calculated by finding the product of average tank wagon ESALs under SB 1321 (0.2850) and the estimated axle-load-related maintenance cost per ESAL-mile in 2007 ($0.0356), and then multiplying by the estimated annual tank wagon mileage. Annual mileage of 26,000*mi.* (41,840*km*) was assumed based on results of interviews with several petroleum hauling companies across Virginia (the estimates ranged from 20,000 to 40,000*mi.* (32,190 to 64,370*km*)). From this, the annual blanket permit fee for tank wagons loaded according to the higher axle-weight provisions of SB 1321 was calculated to be approximately $265 per year.

Implementation

During the 2008 session of the Virginia General Assembly, House Bill 1551 was approved, which directed VDOT and DMV to review the fee structure for all overweight vehicles. In addition, a 1-year overweight permit fee for tank wagons was set at $265 in accordance with the findings related to SB 1321.

[1] *The procedure at the time excluded consideration of ESALs contributed by the steering axle because it was assumed that only rear axle loading would change under the proposed tank wagon legislation.*

A new fee structure governing all overweight vehicles will be established following a review as outlined in the House Bill (HB) 1551. The fee methodology documented here will serve as the foundation for further research in recovery of damage-related costs attributable to overweight vehicles.

Discussion

Development of overweight permit fees for other vehicles or in subsequent years following the above methodology should be considered as a dynamic process. As load-related costs in the maintenance budget vary for a future fiscal year, estimated maintenance cost per ESAL-mile of travel on the state's roadways could vary as well, depending on annual miles traveled by the class. In summary, the estimates of maintenance cost shares, and therefore damage-related overweight fees, are sensitive to (1) maintenance budgets, (2) vehicle class annual mileage as a share of all vehicle mileage, and (3) trends in heavy vehicle operating weights as shown in WIM data. Given the likelihood of independent variability among these factors, the annual variability of a permit fee resulting from this methodology will be an important determinant of whether the methodology gains support outside of this research. Therefore the authors suggest that new data be used and applied to the developed methodology to determine if the overweight permit fees in future years are stable year-to-year, incrementally variable, or widely variable.

Additionally, even if businesses are willing to pay damage-based fees to operate heavier vehicles, more frequent pavement maintenance resulting from higher axle weights (although funded with damage-based fees) will impose added costs on all motorists in the form of more work zones and longer queuing delays. These potentially significant costs of more frequent maintenance operations could not be included in the methodology of this study.

Conclusions

Through this study, the following conclusions are derived:

- The load-related maintenance cost per ESAL-mile was calculated to be $0.0356. This value was determined using VDOT data for FY 2007. This cost is irrespective of the vehicle type.
- The annual additional maintenance cost for a tank wagon operating with the heavier axle load allowed under SB 1321 was calculated as approximately $265, assuming an annual mileage of 26,000*mi.* (41,840*km*). This fee reflects only the marginal maintenance cost attributable to an additional 4,000*lb* (18*kN*) on a single axle of a tank wagon truck.
- The authors anticipate that the fee methodology developed in this study could be applied by VDOT and other departments of transportation to an expanded pool of overweight permit applicants in order to capture a portion of increased maintenance costs due to overweight vehicles.

Acknowledgments

The study team acknowledges the valuable assistance provided by Rob Hanson of VDOT's Operations Planning Division; Keri Pomeroy, Alan Brasili, Raja Shekharan, Tanveer Chowdury, and Jim Cline of VDOT's Maintenance Division; F. Hamlin Williams of VDOT's Traffic Engineering Division; William Childress of the Virginia DMV; James Saklas of the FHWA's Office of Transportation Policy Studies; Doug Quarles of Quarles Petroleum Company, Fredericksburg, Virginia; Michael J. O'Connor of the Virginia Petroleum, Convenience, and Grocery Association, Richmond, Virginia; Warren Dekker and Bryan Smith of the University of Virginia's Department of Civil & Environmental Engineering; and David Mokarem, Jim Gillespie, Ken Winter, Pat DeSalvo, and Misty Boos of VTRC.

References

1. Highway Research Board, (1952). Final Report on Road Test One MD, *Special Report 4*, Highway Research Board, Washington, DC, USA.
2. Highway Research Board, (1955). The WASHO Road Test, Part 2: Test Data Analysis and Findings, *Special Report 22*, Highway Research Board, Washington, DC, USA.
3. Highway Research Board, (1962). The AASHO Road Test, Report 5: Pavement Research, *Special Report 61E*, Highway Research Board, Washington, DC, USA.
4. Lee, K.W. and Peckham, W.L., (1990). Assessment of Damage Caused to Pavements by Heavy Trucks in New England, *Transportation Research Record*, No. 1286, pp. 164-172.
5. Gillespie, T.D., Karamihas, S.M., Sayers, M.W., Nasin, M.A., Hansen, W., Ehsan, N., and Cebon, D., (1993). Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance, *NCHRP Report 343*, Transportation Research Board, Washington, DC. USA.
6. Freeman, T.E. and Clark, T.M., (2002). Performance of Pavements Subject to Higher Truck Weight Limits in Virginia, *Transportation Research Record*, No. 1806, pp. 95-100.
7. Huang, Y.H., (2004). *Pavement Analysis and Design*, 2nd Edition, Prentice Hall, Inc., Englewood Cliffs, NJ, USA.
8. American Association of State Highway and Transportation Officials, (1993). *Guide for Design of Pavement Structures*, Washington, DC, USA.
9. Virginia Department of Transportation, Materials Division, (2000). *Guidelines for 1993 AASHTO Pavement Design*, Richmond, VA, USA.
10. Cottrell, B.H., Jr. Schinkel, T.O., and Clark, T.M., (2002). A Traffic Data Plan for Mechanistic-Empirical Pavement Designs (2002 Pavement Design Guide), *Publication VTRC 04-R3*, Virginia Transportation Research Council, Charlottesville, VA, USA.
11. FHWA, (2001). *Guide to LTPP Traffic Data Collection and Processing*, FHWA, U.S. Department of Transportation, Washington, DC, USA.
12. Virginia Department of Transportation, (2007). 2007 Traffic Data Daily Vehicle Miles Traveled, *Report 220-DVMT* by Federal Vehicle Class, Richmond, VA, USA, http://www.virginiadot.org/info/ct-TrafficCounts-VMT2007.asp, Accessed July 24, 2008.