A TIERED VMT-BASED SYSTEM FOR HIGHWAY FINANCING

Vinod Vasudevan, Ph.D., P.E.
Associate Research Engineer & Program Manager
Transportation Research Center
University of Nevada, Las Vegas
4505 S. Maryland Parkway, Box 454007, Las Vegas, NV 89154-4007 USA
Tel.: (702) 895 1594; Fax: (702) 895 4401
vinod.vasudevan@unlv.edu

Shashi S. Nambisan, Ph.D., P.E.
Director, Institute for Transportation
Professor of Civil Engineering
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664 USA
Tel: (515) 294-5209
E-mail: shashi@iastate.edu

Pushkin Kachroo, Ph.D., P.E.
Director, Transportation Research Center
Professor of Electrical & Computer Engineering
University of Nevada, Las Vegas
4505 S. Maryland Parkway, Box 454007, Las Vegas, NV 89154-4007 USA
Tel.: (702) 895 4926; Fax: (702) 895 4401
pushkin@unlv.edu

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A Tiered-VMT Based System for Highway Financing
Vinod Vasudevan¹, Shashi Nambisan², Pushkin Kachroo³

ABSTRACT
The development and maintenance of highway infrastructure in the US is becoming an important challenge due to increasing costs and revenues that are not adequate to meet the costs. Traditionally, fuel taxes have provided a significant portion of the revenues for the highway network. However, the increased sales of hybrid and alternate fuel vehicles along with stricter policies on improving fuel efficiencies pose a high risk of reducing revenue for highway funding. On the other hand, construction and maintenance cost increase significantly over the years. This makes the issues associated with highway financing a challenging process. User fee based on vehicle miles travelled (VMT) is one of the options considered by various agencies across the country. In this paper a modification of the VMT based user fee, a tiered system, is discussed. Here, definition of tier based system and its advantages are illustrated using revenue for highway trust fund as an example.

INTRODUCTION
The global economy is pressuring countries to upgrade their transport infrastructure so as to remain competitive, gain advantage, or to keep from falling behind. Providing a high quality of road transport service in the US is challenging because of the inability to keep the system capacity on pace with the increases in demand. Along with the eroding quality of the transport and civil infrastructure in the US, is challenging the economic vitality and global leadership role of the US (1).

Highway programs derive a portion of their funding from user fees such as taxes and charges levied on vehicles and their operators in relation to their use of roads. The motor fuel excise tax, also known as gasoline tax or fuel tax is one of the major contributors of such road user fees. The federal excise tax revenue generated from this tax increased from $125 Million in 1933 to $21 Billion in the year 2002 (2). More than one-third of the $133 billion in total U.S. revenue available for highway spending in 2001 came from federal and state gas taxes. State gas taxes alone made up 21.6 percent of all highway revenues that year (3). In 2004, fuel tax accounted for about 64 percent of the highway user fee revenue (TRB, 2006). Other major contributors of highway user fees include vehicle registration fees, excise taxes on truck sales, and tolls. About 80 percent of the highway user fee is dedicated to highway spending (4).

When gas tax revenues over time are considered, it is seen that after years of steady growth, federal and state gas tax receipts stabilized in the late 1990s. When accounting for inflation, federal and state gas tax revenues are actually declining (3). The federal fuel tax on gasoline has
been based on a fixed amount per gallon of fuel sold, and not as a percentage of the sale price of gasoline. Thus, changes in automotive technologies, fuel prices, and new energy regulations could cause significant reductions in fuel consumption and hence a severe reduction in fuel tax revenues. This will affect the current system of highway financing. Boarnet (5) explains that in the current system travel on most of the highways is essentially free to the drivers. The author emphasizes that similar to the use of any free good, the lack of a price will encourage inefficient consumption. A decrease in revenues coupled with increases in construction, operations, and maintenance costs for highways will make the future for highway funding one of the most critical issues in infrastructure development and maintenance in the US. Several studies (6, 7, 8, 9) state that the gasoline tax based system needs to be restructured, and they identified potential alternatives. Recent articles address transportation infrastructure costs, revenue sources, and funding mechanisms (10, 11, 12, 13, 14, 15, 16). Several articles by Wachs and his coauthors (17, 18, 19, 20, 21, 22) address several aspects related highway financing challenges and options, and strategies for pursuing the same. Some studies (20, 21, 23) in the US recommend adopting a VMT based user fee system for maintenance and improvement of roadway infrastructure. Under this concept the users pay based on their usage. In spite of several challenges, the user fee based on VMT promises to be an equitable system for generating revenues needed to maintain and improve the roadway network. The simple flat VMT-based user fee system would consist of a user fee per vehicle mile of travel; the cost to the operator of a vehicle for using the road system would be this “unit rate per VMT” multiplied by the total VMT. One of the challenges of this simple flat VMT-based user fee system is that the “unit rate per VMT” user fee is insensitive to important factors such as the type of vehicle, axle load, the extent of road usage, and spatial and temporal use characteristics. Many approaches can be used to address these factors.

This paper addresses the specific issue of evaluating a “unit rate per VMT” charge (or user fee) based on the extent of use of the road network. The extent of use of the road network is quantified in term of total annual VMT for a vehicle. The concept of establishing “unit rate per VMT” user fee based on a tier system is proposed herein. The tier-based approach is similar to that adopted by utilities such as water, and electric power. In such a system, the “unit rate per VMT” of user fee would be the lowest at the lowest annual VMT. The “unit rate per VMT” for each tier would be greater than that for the VMT in the lower tier – i.e., the marginal cost to the user increases as they exceed the VMT in each tier. The rationale for this approach include considerations such as addressing fixed costs that owners and operators of the road network incur regardless of usage, and then incrementally recovering costs based on actual “consumption” or usage; to encourage vehicle owners to reduce their vehicles’ annual VMT, and in turn reducing demands on the network (i.e., reducing congestion) and also the accompanying fuel consumption and emissions.

**OBJECTIVE**

The objective of this paper is to develop and demonstrate a tiered VMT-based system for generating revenues needed for highway systems. If adopted properly, besides generating adequate funds for highway systems, such a tiered system is also expected to encourage people to drive less by providing incentives to those who drive less. This, in turn, would help reduce traffic congestion, fuel consumption, and vehicular emissions.

**METHODOLOGY**
The approach is to replace the gasoline taxes with “unit rate per VMT” charges so as to generate the same annual revenue as that obtained from the gasoline taxes based on the same annual VMT. The first step in estimating revenues for a VMT-based tiered system is to estimate the average "unit rate per VMT" (AveC) charge for the year considered (j) As a starting point, this could be calculated based on historical information on total annual revenue generated from gasoline tax (AnnRev) and annual VMT (AnnVMT) as follows:

\[ AveC_j = \frac{AnnRev_j}{AnnVMT_j} \]

FHWA publishes highway statistics, which provide the information required to estimate charge per VMT for past years (24).

The next step is to define the tiers. Defining tiers includes establishing the number of tiers to be used, estimating the proportion of total annual VMT that would fall within each tier, estimating the proportion of vehicles that would be included in each tier, and the “unit rate per VMT” user fee or charge for each tier. It is important to ensure that the tier system is designed in such a way that the total system wide revenues generated at least equal AnnRev. The final step is to estimate the revenue that could be realized if the tiered VMT-based system were adopted. The total revenue generated for a tiered system with \( n \) tiers could be estimated as follows:

Let

\[
A = \text{total registered vehicles in the year considered}, \\
B = \text{average VMT per vehicle for the year considered}, \\
C = \text{average “unit rate per VMT” charge for the year considered} = AveC \\
n = \text{the total number of tiers used} \\
p_1, p_2, p_3, \ldots, p_n = \text{the proportion of registered vehicles in each tier}, \\
s_1, s_2, s_3, \ldots, s_n = \text{the proportion of “unit rate per VMT” (AveC) applied for each tier, and} \\
t_1, t_2, t_3, \ldots, t_n = \text{the proportion of the yearly average VMT for vehicles in each tier,} \\
\]

with a constraint:

\[
\sum_{i=1}^{n} p_i = 1
\]

Revenue generated by vehicles in Tier 1,

\[
\begin{align*}
   r_1 &= (A \cdot t_1) \cdot (B \cdot p_1) \cdot (C \cdot s_1) = A.B.C.p_1.t_1.s_1 \\
\end{align*}
\]

Revenue generated by vehicles in Tier 2,

\[
\begin{align*}
   r_2 &= (A \cdot t_1) \cdot (B \cdot p_2) \cdot (C \cdot s_1) + [A \cdot (t_2 - t_1)] \cdot (B \cdot p_2) \cdot (C \cdot s_2) \\
         &= A.B.C.p_2.[t_1.s_1 + (t_2 - t_1).s_2] \\
\end{align*}
\]

Revenue generated by vehicles in Tier 3,

\[
\begin{align*}
   r_3 &= (A \cdot t_1) \cdot (B \cdot p_3) \cdot (C \cdot s_1) + [A \cdot (t_2 - t_1)] \cdot (B \cdot p_3) \cdot (C \cdot s_2) + [A \cdot (t_3 - t_2)] \cdot (B \cdot p_3) \cdot (C \cdot s_3) \\
         &= A.B.C.p_3.[t_1.s_1 + (t_2 - t_1).s_2 + (t_3 - t_2).s_3] \\
\end{align*}
\]

Revenue generated by vehicles in Tier \( n \),
\[ r_n = (A \cdot t_1) \cdot (B \cdot p_n) \cdot (C \cdot s_1) + [A \cdot (t_2 - t_1)] \cdot (B \cdot p_n) \cdot (C \cdot s_2) + [A \cdot (t_3 - t_2)] \cdot (B \cdot p_n) \cdot (C \cdot s_3) + \ldots + [A \cdot (t_n - t_{n-1})] \cdot (B \cdot p_n) \cdot (C \cdot s_n) \]

\[ = A \cdot B \cdot C \cdot p_n \cdot [t_1 \cdot s_1 + (t_2 - t_1) \cdot s_2 + (t_3 - t_2) \cdot s_3 + \ldots + (t_n - t_{n-1}) \cdot s_n]. \quad (4) \]

Total revenue generated for any year \( j \), \( R_j = \sum_{i=1}^{n} r_i \) \quad (5)

The revenue generated for any year could be estimated using equations 1 to 5. For a given tier system, the parameters \( p, s, \) and \( t \) remain unchanged across all years. However, values of the number total registered vehicles, “unit rate per VMT” to be charged, and average VMT per vehicle need to be estimated for the year considered. The number of total registered vehicles and values of average VMT per vehicle could be estimated using historical data and “unit rate per VMT” could using these data as previously defined. Further, in order to address concerns related to inflation, these estimates could be adjusted indexing the base year rates with standard indices such as Consumer Price Index (CPI) and Producer Price Index (PPI) for roadway construction (26).

**ILLUSTRATION USING THE HIGHWAY TRUST FUND**

The concepts described in the previous section are illustrated using the Highway Trust Funds (HTF) revenues from federal gasoline taxes. This assumes that the tier-based system for VMT would replace the existing gasoline tax system. By doing so, the new system needs to generate, at a minimum, the amount historically generated by the gasoline tax.

Table 1 shows a five-tier system to illustrate a tiered VMT-based system for highway funding. As noted previously, let \( \text{AnnVMT} \) be the average annual VMT of the base year, and the \( \text{AveC} \) be the average cost per VMT for the base year. Tier 1 consists of vehicles driven less than or equal to 80 percent of the average VMT per vehicle (B) for that year. It is assumed that the average VMT recorded by vehicles within this tier would be equal to 55 percent of B.

In order to estimate the revenue generated, it is necessary to determine the percent of registered vehicles that make up each of the tiers. Although when implemented, this has to be determined based on real data, for illustration purposes percent of vehicle registered in various tiers are assumed as shown in table 1. In this case for tier 1, it is assumed that 60 percent of all registered vehicles drive less than 80 percent of the average VMT, B. The next item to be defined is the proportion of the average cost per VMT (AveC) to be charged for each tier. In this study, the estimated VMTs within tier 1 are charged at 55 percent of the estimated AveC (which here has deliberately been set to equal t1 for this tier).

It is important to note that the total charge adds up to a value of at least 1.000C, for the tier system to generate sufficient revenue for the scenario considered. Otherwise, this would mean that the tier based system would generate lesser revenue than the previous option, the VMT based usage fee without tier. Therefore once the average annual VMT/vehicle (B), average cost per VMT (C), and percent of total registered vehicles within each of the tiers are identified from real data, the percent charge per tier needs to be adjusted so that the total charge is over 1.000C.
Table 1: Illustration of the VMT-based Tiered System

<table>
<thead>
<tr>
<th>Tier</th>
<th>Range of VMT</th>
<th>Average VMT</th>
<th>% Total reg. vehicles</th>
<th>% Unit rate per VMT</th>
<th>Fraction of total revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of B</td>
<td>t₁ (% of B)</td>
<td>p₁ (% of A)</td>
<td>s₁ (% of C)</td>
<td>t₁ · p₁ · s₁</td>
</tr>
<tr>
<td>Tier 1</td>
<td>≤ 0.8</td>
<td>55%</td>
<td>60%</td>
<td>55%</td>
<td>0.182</td>
</tr>
<tr>
<td>Tier 2</td>
<td>0.8 - 1.2</td>
<td>100%</td>
<td>20%</td>
<td>100%</td>
<td>0.200</td>
</tr>
<tr>
<td>Tier 3</td>
<td>1.2 - 1.5</td>
<td>135%</td>
<td>10%</td>
<td>145%</td>
<td>0.196</td>
</tr>
<tr>
<td>Tier 4</td>
<td>1.5 - 2.0</td>
<td>175%</td>
<td>5%</td>
<td>190%</td>
<td>0.166</td>
</tr>
<tr>
<td>Tier 5</td>
<td>&gt; 2.0</td>
<td>220%</td>
<td>5%</td>
<td>240%</td>
<td>0.264</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>100%</strong></td>
<td></td>
<td></td>
<td><strong>1.008</strong></td>
</tr>
</tbody>
</table>

Thus, from Table 1 the following can be noted:

- the upper bound of the annual VMT for Tier 1, UB₁ = 0.8 B
- the average annual VMT for vehicles in Tier 1, t₁ = 0.55 B
- the fraction of total registered vehicles in Tier 1, p₁ = 0.6
- the fraction of AveC VMT to be charged for vehicles in Tier 1, s₁ = 0.55

- the lower bound of the annual VMT for Tier 2, LB₂ = 0.8 B
- the upper bound of the annual VMT for Tier 2, UB₂ = 1.2 B
- the average annual VMT for vehicles in Tier 2, t₂ = 1.0 B
- the fraction of total registered vehicles in Tier 2, p₂ = 0.2
- the fraction of AveC VMT to be charged for vehicles in Tier 2, s₂ = 1.0

The application of the incremental marginal costs at each tier is as follows: for any user with a particular VMT, first 80 percent of the average VMT will be charged at 55 percent of the estimated charge per mile (AveC), the next 40 percent (i.e. from proportions 0.8 to 1.2) will be charged at 100 percent of AveC, the next 30 percent (from proportions 1.2 to 1.5) charged at 145 percent of AveC, and so on. In this example, the increase in marginal cost for sᵢ between successive steps in the tiered system is at a rate greater than the increase in the average annual VMT between the corresponding tiers. The extent of these increases and also the values of the parameters tᵢ and pᵢ can be debated, and beyond the scope of discussion in this paper.

**Estimate Financing Needs for the Future**

Once the tiers are defined, the next step is to estimate charge per VMT that needs to be charged for each tier annually. The American Association of State Highway and Transportation Officials published a report (25), with information on future revenue requirements for the highway infrastructure and transportation infrastructure in the US for the years from 2005 to 2021. This report shows the required funding for two scenarios:

a) maintain the existing systems, and
b) improve the system for future demands.
These estimates are based on an assumption that the historical split between the federal and state/local share of surface transportation capital costs is maintained. For illustration purposes, the analysis horizon for this paper is 2025, and the data obtained from AASHTO are projected to the year 2025. This report shows that in the year 2025 $84.1 Billion would be required to maintain the US highway system, as compared to $119.1 Billion to improve the highway facilities. The corresponding figures for the overall road transportation systems (including public transportation systems) are $98.5 Billion and $139.8 Billion respectively. Since the public transportation systems are integral part of the transportation infrastructure, it is important to include their needs also in the planning process.

Although the AASHTO report provides information regarding the required revenues for the future years, only a portion of it is expected to be generated directly from gasoline taxes, the remaining coming from other sources, such as diesel tax, sales tax on trucks, heavy vehicle use tax, and tax on truck tires. A report by the Congressional Budget Office (27) projects the Highway Trust Fund revenues for five years 2005-09. Table 2 shows the sources of revenue for each year from 2005 to 2009. This table shows that for each of the years considered, about 65 percent of Highway Trust Fund revenues are generated from Gasoline taxes. Therefore, assuming that the revenue structure remains the same, revenues from gasoline taxes or similar user fee should account for 65 percent of required funding in a future year. Table 3 shows the revenues required from gasoline taxes to serve the future transportation needs assuming that its proportional contribution to the Highway Trust Fund would remain the same at 65 percent.

Table 2: Sources of Highway Trust Fund

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>2005</th>
<th>%</th>
<th>2006</th>
<th>%</th>
<th>2007</th>
<th>%</th>
<th>2008</th>
<th>%</th>
<th>2009</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline and Gasohol Tax</td>
<td>$25.5</td>
<td>66.9%</td>
<td>$26.3</td>
<td>65.6%</td>
<td>$27.0</td>
<td>65.5%</td>
<td>$27.7</td>
<td>65.5%</td>
<td>$28.4</td>
<td>65.3%</td>
</tr>
<tr>
<td>Diesel Tax</td>
<td>$9.3</td>
<td>24.4%</td>
<td>$10.0</td>
<td>24.9%</td>
<td>$10.4</td>
<td>25.2%</td>
<td>$10.7</td>
<td>25.3%</td>
<td>$11.1</td>
<td>25.5%</td>
</tr>
<tr>
<td>Retail Sales tax on Trucks</td>
<td>$2.6</td>
<td>6.8%</td>
<td>$3.1</td>
<td>7.7%</td>
<td>$3.1</td>
<td>7.5%</td>
<td>$3.2</td>
<td>7.6%</td>
<td>$3.3</td>
<td>7.6%</td>
</tr>
<tr>
<td>Heavy Vehicle Use Tax</td>
<td>$1.2</td>
<td>3.1%</td>
<td>$1.2</td>
<td>3.0%</td>
<td>$1.2</td>
<td>2.9%</td>
<td>$1.3</td>
<td>3.1%</td>
<td>$1.3</td>
<td>3.0%</td>
</tr>
<tr>
<td>Tax on Truck Tires</td>
<td>$0.5</td>
<td>1.3%</td>
<td>$0.5</td>
<td>1.2%</td>
<td>$0.5</td>
<td>1.2%</td>
<td>$0.5</td>
<td>1.2%</td>
<td>$0.5</td>
<td>1.1%</td>
</tr>
<tr>
<td>Refunds</td>
<td>-$1.0</td>
<td>-2.6%</td>
<td>-$1.0</td>
<td>-2.5%</td>
<td>-$1.0</td>
<td>-2.4%</td>
<td>-$1.1</td>
<td>-2.6%</td>
<td>-$1.1</td>
<td>-2.5%</td>
</tr>
<tr>
<td>Total</td>
<td>$38.1</td>
<td>100%</td>
<td>$40.1</td>
<td>100%</td>
<td>$41.2</td>
<td>100%</td>
<td>$42.3</td>
<td>100%</td>
<td>$43.5</td>
<td>100%</td>
</tr>
</tbody>
</table>

Adapted from CBO (2006)

Estimating Revenue from the VMT-Based Tiered System

For the year 2009, AASHTO estimates that $40.2 Billion would be required from user fees to maintain the transportation infrastructure. The estimated VMT for the year 2009 is about 2,923 Billion. The estimated average “unit rate per VMT” to be charged to users is obtained as the ratio of the required funding to the estimated VMT. In this case it is equal to $0.0138. The same process is repeated for funding required for improvements and these rates adjusted for inflation...
based on CPI and PPI. Each of these estimates is again subdivided into three scenarios each; a) keeping the “unit rate per VMT” charge unchanged over time, b) adjusting annually the “unit rate per VMT” charge for inflation based on CPI, and c) adjusting annually the “unit rate per VMT” charge for inflation based on PPI. Based on the Bureau of Labor Statistics data (12) the CPI and PPI rates used in this study are 2.6 percent 4.6 percent respectively. Table 4 shows the estimated average unit rate per VMT for each the years for various adjustment scenarios from the year 2009 to 2025.

Table 3: Estimated Total Revenues Required for the Future Road Transportation Needs (in $ Billions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Requirement to Maintain Highway</th>
<th>Requirement to Maintain Total</th>
<th>Requirement to Improve Highway</th>
<th>Requirement to Improve Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>$ 30.3</td>
<td>$ 36.0</td>
<td>$ 42.6</td>
<td>$ 51.1</td>
</tr>
<tr>
<td>2006</td>
<td>$ 31.2</td>
<td>$ 37.1</td>
<td>$ 43.9</td>
<td>$ 52.6</td>
</tr>
<tr>
<td>2007</td>
<td>$ 32.1</td>
<td>$ 38.2</td>
<td>$ 45.2</td>
<td>$ 54.2</td>
</tr>
<tr>
<td>2008</td>
<td>$ 33.0</td>
<td>$ 39.2</td>
<td>$ 46.5</td>
<td>$ 55.6</td>
</tr>
<tr>
<td>2009</td>
<td>$ 33.8</td>
<td>$ 40.2</td>
<td>$ 47.6</td>
<td>$ 57.1</td>
</tr>
<tr>
<td>2010</td>
<td>$ 34.6</td>
<td>$ 41.2</td>
<td>$ 48.8</td>
<td>$ 58.4</td>
</tr>
<tr>
<td>2011</td>
<td>$ 35.4</td>
<td>$ 42.1</td>
<td>$ 49.9</td>
<td>$ 59.8</td>
</tr>
<tr>
<td>2012</td>
<td>$ 36.2</td>
<td>$ 43.1</td>
<td>$ 51.1</td>
<td>$ 61.2</td>
</tr>
<tr>
<td>2013</td>
<td>$ 37.4</td>
<td>$ 44.5</td>
<td>$ 52.8</td>
<td>$ 63.1</td>
</tr>
<tr>
<td>2014</td>
<td>$ 38.7</td>
<td>$ 45.9</td>
<td>$ 54.5</td>
<td>$ 65.1</td>
</tr>
<tr>
<td>2015</td>
<td>$ 40.0</td>
<td>$ 47.4</td>
<td>$ 56.4</td>
<td>$ 67.1</td>
</tr>
<tr>
<td>2016</td>
<td>$ 41.3</td>
<td>$ 48.9</td>
<td>$ 58.2</td>
<td>$ 69.3</td>
</tr>
<tr>
<td>2017</td>
<td>$ 42.7</td>
<td>$ 50.4</td>
<td>$ 60.2</td>
<td>$ 71.5</td>
</tr>
<tr>
<td>2018</td>
<td>$ 44.1</td>
<td>$ 52.0</td>
<td>$ 62.2</td>
<td>$ 73.8</td>
</tr>
<tr>
<td>2019</td>
<td>$ 45.6</td>
<td>$ 53.7</td>
<td>$ 64.3</td>
<td>$ 76.1</td>
</tr>
<tr>
<td>2020</td>
<td>$ 47.1</td>
<td>$ 55.4</td>
<td>$ 66.4</td>
<td>$ 78.5</td>
</tr>
<tr>
<td>2021</td>
<td>$ 48.6</td>
<td>$ 57.1</td>
<td>$ 68.6</td>
<td>$ 81.0</td>
</tr>
<tr>
<td>2022</td>
<td>$ 50.0</td>
<td>$ 58.8</td>
<td>$ 70.8</td>
<td>$ 83.4</td>
</tr>
<tr>
<td>2023</td>
<td>$ 51.5</td>
<td>$ 60.5</td>
<td>$ 72.9</td>
<td>$ 85.8</td>
</tr>
<tr>
<td>2024</td>
<td>$ 53.1</td>
<td>$ 62.2</td>
<td>$ 75.1</td>
<td>$ 88.3</td>
</tr>
<tr>
<td>2025</td>
<td>$ 54.7</td>
<td>$ 64.1</td>
<td>$ 77.4</td>
<td>$ 90.8</td>
</tr>
</tbody>
</table>

Source: Adapted from AASHTO (2007d)
Using the VMT estimates and the number of registered vehicle estimates based on Highway Statistics data (9), the tier system defined in Table 1, and the estimated average “unit rate per VMT,” the appropriate charge per VMT for each tier \( s_i \) is determined. Table 5 shows the revenues for each year for all tiers for the “rate to maintain 2009” scenario. Here, the average VMT per registered vehicle is calculated based on the estimated number of registered vehicles and the estimated VMT for each year. Then the revenue generated is estimated for each tier using the estimated average “unit rate per VMT,” and equations 1 to 5. Figure 1 shows this information along with the revenue generated for other various scenarios considered. From this figure, it is clear that all options, except the one to hold constant the 2009 unit rate per VMT, would generate the funds needed to maintain the transportation systems (as estimated by AASHTO). On the other hand, in order to generate funding required to improve the system, the unit rate per VMT should be adjusted annually based on either CPI or PPI, and each would generate significantly greater revenues. In these cases, in order to avoid generating significant surpluses, either the CPI and PPI indices need to be scaled down or the appropriate charge per VMT for each tier \( s_i \) be reduced.

**SENSITIVITY ANALYSIS**

Estimates of the revenues that could be realized from the tiered VMT-based system of user charges depend on the definition of tiers (i.e., lower and upper bounds) and on the values of the parameters or variables used. Any changes to these items could result in changes to revenue estimates. It is therefore, important to study sensitivity of the revenue estimates to each of these items. Sensitivity of a variable \( y_i \) to the revenue of any year \( j \) \( (R_j) \), in general can be defined as,

\[
S_{y_i}^{R_j} = \frac{\partial R_j}{\partial y_i} = \frac{\partial R_j}{\partial y_i} \cdot \frac{y_i}{R_j}
\]  

(6)

Where \( y = p, t, or s; and i = 1 to 5 \)

In order to estimate sensitivity of any of the variables, for the present tier system, the first step is to calculate the rate of change of revenue \( (R_j) \) to the variable considered \( (y_i) \), holding all other independent variables constant. This partial derivative is multiplied by the fraction of variable and the revenue to obtain sensitivity of that variable at the defined tier system.

**Sensitivity of the Proportion of Registered Vehicles in Each Tier**

To estimate sensitivity of \( R \) with respect to various variables, partial derivative of \( R \) is calculated with respect to these variables are determined. These are provided in equations 7 to 10

\[
\frac{\partial R}{\partial p_1} = A.B.C.s_1.t_1
\]

(7)

\[
\frac{\partial R}{\partial p_2} = A.B.C.s_1.t_1 + A.B.C.s_2.(t_2 - t_1)
\]

(8)

\[
\frac{\partial R}{\partial p_3} = A.B.C.s_1.t_1 + A.B.C.s_2.(t_2 - t_1) + A.B.C.s_3.(t_3 - t_2)
\]

(9)
Table 4: Estimated Average Unit Rate per VMT

<table>
<thead>
<tr>
<th>Year</th>
<th>Unit Rate per VMT to Maintain the System</th>
<th>Unit Rate per VMT to Improve the System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009 Rate held constant</td>
<td>2009 Rate Adjusted for CPI</td>
</tr>
<tr>
<td>2009</td>
<td>$ 0.0138</td>
<td>$ 0.0138</td>
</tr>
<tr>
<td>2010</td>
<td>$ 0.0138</td>
<td>$ 0.0141</td>
</tr>
<tr>
<td>2011</td>
<td>$ 0.0138</td>
<td>$ 0.0145</td>
</tr>
<tr>
<td>2012</td>
<td>$ 0.0138</td>
<td>$ 0.0149</td>
</tr>
<tr>
<td>2013</td>
<td>$ 0.0138</td>
<td>$ 0.0152</td>
</tr>
<tr>
<td>2014</td>
<td>$ 0.0138</td>
<td>$ 0.0156</td>
</tr>
<tr>
<td>2015</td>
<td>$ 0.0138</td>
<td>$ 0.0160</td>
</tr>
<tr>
<td>2016</td>
<td>$ 0.0138</td>
<td>$ 0.0165</td>
</tr>
<tr>
<td>2017</td>
<td>$ 0.0138</td>
<td>$ 0.0169</td>
</tr>
<tr>
<td>2018</td>
<td>$ 0.0138</td>
<td>$ 0.0173</td>
</tr>
<tr>
<td>2019</td>
<td>$ 0.0138</td>
<td>$ 0.0178</td>
</tr>
<tr>
<td>2020</td>
<td>$ 0.0138</td>
<td>$ 0.0182</td>
</tr>
<tr>
<td>2021</td>
<td>$ 0.0138</td>
<td>$ 0.0187</td>
</tr>
<tr>
<td>2022</td>
<td>$ 0.0138</td>
<td>$ 0.0192</td>
</tr>
<tr>
<td>2023</td>
<td>$ 0.0138</td>
<td>$ 0.0197</td>
</tr>
<tr>
<td>2024</td>
<td>$ 0.0138</td>
<td>$ 0.0202</td>
</tr>
<tr>
<td>2025</td>
<td>$ 0.0138</td>
<td>$ 0.0207</td>
</tr>
</tbody>
</table>

Sensitivity of $p_1$ could be estimated from equation 5 as,

\[
S_{p_1}^R = \frac{\partial R}{\partial p_1} \cdot \frac{p_1}{R} \tag{11}
\]

The value of the sensitivity for the tier system defined in table 1, could be calculated by substituting values of $A$, $B$, $C$, $s_i$, and $t_i$ in equation 11. Following the same process, the sensitivity of $p_2$, $p_3$, and $p_4$ could also be estimated. The results of these calculations show that
Table 5: Estimating Revenues for VMT-based Tier System

<table>
<thead>
<tr>
<th>Year</th>
<th>Est. Reg. Vehicles (Millions)</th>
<th>Estimated VMT / Reg. Vehicle (Millions)</th>
<th>Ave. Unit Rate per VMT</th>
<th>Estimated Revenue Generated by Tier (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tier 1</td>
</tr>
<tr>
<td>2009</td>
<td>236.58</td>
<td>2,923,219</td>
<td>12,356</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2010</td>
<td>237.76</td>
<td>2,968,323</td>
<td>12,484</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2011</td>
<td>238.95</td>
<td>3,014,122</td>
<td>12,614</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2012</td>
<td>240.14</td>
<td>3,060,629</td>
<td>12,745</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2013</td>
<td>241.35</td>
<td>3,107,852</td>
<td>12,877</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2014</td>
<td>242.55</td>
<td>3,155,805</td>
<td>13,011</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2015</td>
<td>243.76</td>
<td>3,204,497</td>
<td>13,146</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2016</td>
<td>244.98</td>
<td>3,253,940</td>
<td>13,282</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2017</td>
<td>246.21</td>
<td>3,304,147</td>
<td>13,420</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2018</td>
<td>247.44</td>
<td>3,355,128</td>
<td>13,559</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2019</td>
<td>248.68</td>
<td>3,406,895</td>
<td>13,700</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2020</td>
<td>249.92</td>
<td>3,459,462</td>
<td>13,842</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2021</td>
<td>251.17</td>
<td>3,512,839</td>
<td>13,986</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2022</td>
<td>252.43</td>
<td>3,567,040</td>
<td>14,131</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2023</td>
<td>253.69</td>
<td>3,622,078</td>
<td>14,278</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2024</td>
<td>254.96</td>
<td>3,677,964</td>
<td>14,426</td>
<td>$0.0138</td>
</tr>
<tr>
<td>2025</td>
<td>256.23</td>
<td>3,734,713</td>
<td>14,576</td>
<td>$0.0138</td>
</tr>
</tbody>
</table>
Figure 1: Comparison of Revenue Estimates from a Tiered VMT-based system

<table>
<thead>
<tr>
<th>Year</th>
<th>Improve System: 2009 Rate Adj. PPI</th>
<th>Improve System: 2009 Rate Adj. CPI</th>
<th>Improve System: 2009 Rate Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>$50</td>
<td>$60</td>
<td>$70</td>
</tr>
<tr>
<td>2010</td>
<td>$60</td>
<td>$70</td>
<td>$80</td>
</tr>
<tr>
<td>2011</td>
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</tr>
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<td>$90</td>
<td>$100</td>
</tr>
<tr>
<td>2013</td>
<td>$90</td>
<td>$100</td>
<td>$110</td>
</tr>
<tr>
<td>2014</td>
<td>$100</td>
<td>$110</td>
<td>$120</td>
</tr>
<tr>
<td>2015</td>
<td>$110</td>
<td>$120</td>
<td>$130</td>
</tr>
<tr>
<td>2016</td>
<td>$120</td>
<td>$130</td>
<td>$140</td>
</tr>
<tr>
<td>2017</td>
<td>$130</td>
<td>$140</td>
<td>$150</td>
</tr>
<tr>
<td>2018</td>
<td>$140</td>
<td>$150</td>
<td>$160</td>
</tr>
<tr>
<td>2019</td>
<td>$150</td>
<td>$160</td>
<td>$170</td>
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<tr>
<td>2020</td>
<td>$160</td>
<td>$170</td>
<td>$180</td>
</tr>
<tr>
<td>2021</td>
<td>$170</td>
<td>$180</td>
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</tr>
<tr>
<td>2022</td>
<td>$180</td>
<td>$190</td>
<td>$200</td>
</tr>
<tr>
<td>2023</td>
<td>$190</td>
<td>$200</td>
<td>$210</td>
</tr>
<tr>
<td>2024</td>
<td>$200</td>
<td>$210</td>
<td>$220</td>
</tr>
<tr>
<td>2025</td>
<td>$210</td>
<td>$220</td>
<td>$230</td>
</tr>
</tbody>
</table>
the sensitivity of the revenue estimates on the proportion of registered vehicles in each tier defined in Table 1 are:

\[ S_{p_1}^R = 0.2398, \quad S_{p_2}^R = 0.1799, \quad S_{p_3}^R = 0.2031, \quad S_{p_4}^R = 0.2013 \]

Thus, for the adopted tier system, the sensitivity of revenues to the proportion of vehicles registered in each of the tiers is relatively the same. So, a change in the value of any of these variables will have relatively similar impacts on the revenue generated.

**Sensitivity of the Proportion of the Average Unit Rate per VMT**

The sensitivity of the revenue estimates to each tier’s proportion of the average unit rate/VMT \( (s_i) \) is calculated using a similar process to that used for the proportion of registered vehicles in each tier.

\[
\frac{\partial R}{\partial s_1} = A.B.C.t_1.(p_1 + p_2 + p_3 + p_4 + p_5)
\]

\[ = A.B.C.t_1 \sum_{i=1}^{5} p_i \]

\[ (12) \]

\[
\frac{\partial R}{\partial s_2} = A.B.C.(t_2 - t_1).(p_2 + p_3 + p_4 + p_5)
\]

\[ = A.B.C.(t_2 - t_1) \sum_{i=2}^{5} p_i \]

\[ (13) \]

\[
\frac{\partial R}{\partial s_3} = A.B.C.(t_3 - t_2).(p_3 + p_4 + p_5)
\]

\[ = A.B.C.(t_3 - t_2) \sum_{i=3}^{5} p_i \]

\[ (14) \]

\[
\frac{\partial R}{\partial s_4} = A.B.C.(t_4 - t_3).(p_4 + p_5)
\]

\[ = A.B.C.(t_4 - t_3) \sum_{i=4}^{5} p_i \]

\[ (15) \]

\[
\frac{\partial R}{\partial s_5} = A.B.C.(t_5 - t_4).p_5
\]

\[ (16) \]

The sensitivity of \( s_1 \) is estimated from equation 5 as,

\[ S_{s_1}^R = \frac{\partial R}{\partial s_1}. \frac{s_1}{R} \]

\[ (17) \]

The sensitivity of the revenue estimates on the proportion of average unit rate per VMT for the five tiers are as follows:

\[ S_{s_1}^R = 0.4796, \quad S_{s_2}^R = 0.2098, \quad S_{s_3}^R = 0.1364, \quad S_{s_4}^R = 0.0989, \quad S_{s_5}^R = 0.0752 \]

These values indicate that, for the given tier definition, the sensitivity of proportion of average unit rate per VMT in tier 1 is greater than that of each of the other tiers. This also shows
that the sensitivity of charge/VMT decreases from tier 1 to tier 5, with tier 5 showing the lowest sensitivity to the revenue generated.

**Sensitivity of Proportion of Yearly Average VMT in each Tier**

The sensitivity of the revenue estimates to each tier’s proportion of the average annual VMT \( t_i \) is calculated similar to how the other sensitivities were calculated.

\[
\frac{\partial R}{\partial t_1} = A.B.C.s_1(p_1 + p_2 + p_3 + p_4 + p_5) - A.B.C.s_2(p_2 + p_3 + p_4 + p_5)
\]
\[
= A.B.C.(s_1 \sum_{i=1}^{5} p_i - s_2 \sum_{i=2}^{5} p_i)
\]

(18)

\[
\frac{\partial R}{\partial t_2} = A.B.C.s_2(p_2 + p_3 + p_4 + p_5) - A.B.C.s_3(p_3 + p_4 + p_5)
\]
\[
= A.B.C.(s_2 \sum_{i=2}^{5} p_i - s_3 \sum_{i=3}^{5} p_i)
\]

(19)

\[
\frac{\partial R}{\partial t_3} = A.B.C.s_3(p_3 + p_4 + p_5) - A.B.C.s_4(p_4 + p_5)
\]
\[
= A.B.C.(s_3 \sum_{i=3}^{5} p_i - s_4 \sum_{i=4}^{5} p_i)
\]

(20)

\[
\frac{\partial R}{\partial t_4} = A.B.C.s_4(p_4 + p_5) - A.B.C.s_5 p_5
\]
\[
= A.B.C.(s_4 \sum_{i=4}^{5} p_i - s_5 p_5)
\]

(21)

\[
\frac{\partial R}{\partial t_5} = A.B.C.s_5 p_5
\]

(22)

The sensitivity of \( t_1 \) is estimated from equation 5 as,
\[
S_{t_1}^R = \frac{\partial R}{\partial t_1} \cdot \frac{t_1}{R}
\]

(23)

The sensitivity of revenue estimates on the proportion of annual average VMT for each tier is as follows:
\[
S_{t_1}^R = 0.1374, \quad S_{t_2}^R = 0.0270, \quad S_{t_3}^R = 0.0214, \quad S_{t_4}^R = 0.0140, \quad S_{t_5}^R = 0.0107
\]

These values indicate that similar to the unit rate/VMT for the tiers, the sensitivity of the proportion of annual average VMT in tier 1 is significantly greater than the proportion of annual VMT those in the other tiers. This also shows that the sensitivity decreases from tier 1 to tier 5.

**DISCUSSIONS AND CONCLUSIONS**

VMT based user fee systems have been proposed as equitable mechanisms to charge users for their usage of roadway systems. Studies show that adopting a VMT based user fee system could
generate adequate revenues to maintain or improve the transportation infrastructure. A common approach used in this regard has been a flat charge levied per VMT for each vehicle. This paper proposed a tiered VMT-based system, which is a modified version of the flat VMT-based system. Under this concept, the transportation infrastructure is considered as a utility, similar to electricity or water. Similar to these utilities, the transportation (road) system could have a reverse telescopic unit cost structure based on consumption. Unit rates are set in tiers. The unit rate is defined as average unit rate per VMT, with the unit rate per VMT being the lowest in the first tier. The marginal cost for consumption (i.e., annual VMT) beyond each tier is subjected to a higher unit rate per VMT than that tier’s unit rate per VMT. An illustrative system was presented herein along with a quantitative example to apply the system. Key consideration in establishing such a system include the definition of the lower and upper bounds of annual VMT per vehicle, the percent of the vehicle fleet that would come within each of these tiers, the average annual VMT per vehicle in each tier, the average unit as well as the target revenue to be generated. Sensitivity analyses show that for the given tier definition, as may be expected, the revenue generated is more sensitive to the unit rate /VMT on tiers than other variables.

Advantages of the Tiered VMT based System
Studies report that a user fee system based on VMT is more equitable than a fuel tax based user fee, especially for hybrid vehicles and alternate fuel vehicles. The VMT based charges are based on actual usage and equally for various types of users, locales, be it rural or urban or by facility type, such as, freeways, arterials, or local streets. Thus it is thought to be a fairer system. A tiered VMT-based system exhibits some additional advantages as well. Using the tier based system rewards users who drive less. By doing so, there could be a reduction in the overall vehicular travel demand. This could reduce traffic congestion, fuel consumption an associated vehicular emissions. Public acceptance of this system could be expedited if it were marketed as being similar to the mechanism used by the other utilities such as water and electricity which have comparable rate structures in many areas. In addition to implementing a fair method to generate revenues needed to maintain and improve the transportation system operation, earning this acceptance, and the resultant behavioral changes and their impacts on the transportation system and quality of lives of the populace, would be significant accomplishments of this program.

Drawbacks of the Tiered VMT-based System
Despite the advantages discussed, a user fee based on VMT is the most challenging among all other options discussed. Further, adding the tiered structure further complicates the public acceptance process. There are significant implementation challenges that need to be overcome including easy verification of consumption and providing payment / collection mechanisms. The VMT based tax structure is prone to evasion of privacy, if not adopted properly. In order to collect user fees based on VMT, there need to be several changes made to the vehicles and the revenue collection system. These changes would be expensive and could create public resistance. When compared to the existing system of collecting user fee as gasoline taxes, the revised system would require a lot more capital investment and these costs must be included in the estimates of required funding. Identifying tiers and their proportionate charges are keys to balancing the user concerns and also to accurately estimating revenue. Therefore, it has to be implemented carefully.
REFERENCES


