

# **QUANTIFYING TRAFFIC OPERATIONAL IMPACTS OF NEW TRUCK CONFIGURATIONS IN THE U.S. HIGHWAY NETWORK**

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## **ABSTRACT**

Trucks of differing size and performance capabilities have different effects on traffic operations. Thus, introducing new truck types in the traffic stream to partially or completely replace other vehicle types, can potentially result in changes in traffic operational quality and capacity. This study was conducted as part of the 1997 U.S. DOT Comprehensive Truck Size and Weight Study, to evaluate the impact of new truck configurations in traffic operational quality. The objectives of the study were to develop a method for estimating changes in the total vehicle-hours (and the associated travel delay) as a function of changes in federal policy related to vehicle size and weight (and the associated Vehicle-Miles-Traveled, or VMT), and to implement it on a computerized model. It was concluded that the methodology developed provides the desired results very efficiently. The model developed has the capability to automatically provide quantitative estimates of changes in total annual vehicle delay and cost, resulting from changes in the U.S. federal policy on truck size and weight.

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## **BACKGROUND**

The use of longer and heavier combination vehicles could lead to significant productivity gains for certain portions of the motor vehicle and trucking industry. Trucks of differing size and performance capabilities have different effects on traffic operational quality, and introducing new truck types in the traffic stream to partially or completely replace other vehicle types, can potentially result in changes in capacity availability.

This paper documents the development of a methodology for quantifying the effects of proposed changes in truck size and weight policy, on the traffic operational quality of the roadway system in the U.S. This research was conducted as part of the 1997 U.S. DOT Comprehensive Truck Size and Weight Study. The objective of the research was to develop a methodology for estimating the traffic operational impacts of the proposed changes in truck configurations on the U.S. highway network. These impacts are measured in terms of changes in travel delay experienced by all drivers, and the associated costs. This study did not attempt to predict changes in truck travel, shift of vehicle-miles-traveled (VMT) or traffic volumes from one type of truck to another, neither did it consider environmental or energy issues. Questions of policy, logistics, permits and pricing are also outside the scope of this study.

## **METHODOLOGY**

A variety of performance measures such as speed, density, delay, etc., can be applied to quantify traffic operational changes. For this study, change in total vehicle-hours experienced by all vehicle types was selected as the performance measure. This is equivalent to the overall delay, and can be translated to total cost by assigning a value of time to the unit of delay. This section describes the methodology employed for calculating the anticipated changes in vehicle-hours due to the introduction of the new truck configurations and / or replacement of other truck configurations. The methodology consists of three steps:

- a) Determine the Passenger Car Equivalent (PCE) value for each of the base and proposed truck types. The PCE value can be defined as “the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions” (Highway Capacity Manual, 1994). As the definition implies, the PCE value varies as a function of highway design elements, traffic stream characteristics as well as vehicular characteristics. For the purposes of this project, equivalency was established in terms of travel speed, i.e., two traffic streams are equivalent when they result in the same travel speed for the highway segment studied.
- b) Obtain the truck substitutions that would occur under the policy scenarios considered. For each proposed new vehicle type, knowing its projected annual VMT as well as the vehicle type(s) it would be replacing and its corresponding reduction in annual VMT, one can estimate the expected traffic volume by truck type for status quo, and for the new policy scenario.
- c) Using the PCE values and the projected estimates of annual VMT by vehicle type, calculate the anticipated average traffic flows in units of passenger cars and determine the expected change in delay within a year for the U.S. highway network.

The methodology outlined above was implemented in a spreadsheet. The following sections describe the methodology in greater detail.

## **ESTIMATING PCE VALUES FOR SELECTED TRUCK CONFIGURATIONS**

The two vehicular characteristics primarily affecting traffic operational performance are the vehicle length and the weight-to-horsepower ratio (Wt/Hp). Thus, PCE values were obtained for a selected group of truck types: 3x3 “vehicle length-by-Wt/Hp” PCE matrices were developed for each highway functional class, that were subsequently used to obtain a PCE value for a vehicle of any overall length and weight-to-horsepower ratio (Wt/Hp), on a variety of roadway types. This approach implies that there is a linear relationship between PCE and vehicle length, as well as between PCE and Wt/Hp, which has been verified in previous research (Torbic, et al., 1997).

This section provides an overview of the procedures used to estimate PCE values to develop the PCE matrices, and it describes how these can be used to predict the PCE value of any truck type, and for any highway functional class.

### **PCE Calculation**

In the development of a methodology for PCE calculation, previous research on the estimation of PCE values was reviewed. There are several approaches reported in the literature for

estimating PCE values. Existing methods included either the use of simulation models or field data collection, and applied a variety of performance measures (speed, delay, time or space headways, etc.) as the basis of equivalency. In this study, simulation was selected as the preferred approach, rather than field data collection, because of the large number of geometric and traffic operational parameters, and the consideration of a large array of vehicle types. Field data collection for such a large set of possibilities would be impractical.

The basis for PCE estimation chosen for this study was traffic speed, consistent with the PCEs estimated in the Federal Highway Cost Allocation Study (FHWA, 1997, and Elefteriadou et al, 1997). Speed is a measure of performance directly related to the quality of service and it can be obtained from a variety of simulation models. In addition, it can be directly related to travel time and delay, which in turn can be translated to costs.

The approach employed by Sumner et al (1984) was selected and modified to fit the needs of this study. The methodology employed by the research team can be summarized as follows (**Figure 1**):

- Formulate a speed-flow curve for the passenger-car-only traffic stream. This is called the “Base Curve” in this study.

Identify the typical vehicle mix for the traffic stream operating on the functional class examined. Formulate a speed-flow curve for this typical vehicle mix. This is called the “Mix Curve” in this study.

- Select a vehicle type (“Subject Vehicle”) and traffic flow level, and simulate traffic operations after adding a certain volume of subject vehicles and removing the same volume of passenger cars, to determine the speed and total volume of traffic.

The PCE of the subject vehicle can then be calculated using the following equation:

$$PCE_S = \frac{1}{-p} \left[ \frac{q_B}{q_S} - \frac{q_B}{q_M} \right] + 1$$

Where:

$PCE_S$  = the PCE value of the subject vehicle

$_p$  = the proportion of subject vehicles which is added to the mix and subtracted from the base vehicles (passenger cars)

$q_B$  = the base vehicle flow at a constant speed shown by the horizontal line in Figure 1

$q_M$  = the mixed vehicle flow at this same constant speed

$q_S$  = the subject vehicle flow at this same constant speed

Using this method, base and mix curves were generated, and PCE values were calculated, using simulation models for a selected number of segment geometry types, as described in the following section.

## **PCE Matrices for Segment Geometry Types**

Given the large variety of potential vehicle types, 3x3 matrices were developed to enable the calculation of PCE values as a function of a truck's overall length and Wt/Hp. Overall length and Wt/Hp are the two vehicle characteristics having a significant effect on a vehicle's PCE.

In the U.S., there are 12 different functional highway classes. Six different "test" segment geometries were used in this study to take into account the variety of roadway geometric characteristics that affect traffic operations, such as grade and length of grade. These six geometry types were selected because they represent a wide range of roadway geometric conditions over the twelve roadway functional classes. PCE values were determined for each of these segment geometry types using the appropriate simulation model. Simulation models were selected taking into consideration the roadway geometric and operational characteristics, as well as the simulation model capabilities. Three models were selected: FRESIM, TWOPAS and NETSIM.

The FRESIM model simulates traffic operations on freeways (FRESIM 5.0, 1995) the TWOPAS model is capable of simulating traffic on two-lane highways (St. John and Harwood, 1986) and the NETSIM model is capable of simulating traffic on arterial streets (TRAF User Reference Guide, 1994). These models are all microscopic and stochastic in nature. The FRESIM and TWOPAS models were selected because they were the only stochastic and microscopic models capable of simulating operations for a variety of user-specified vehicle types on freeways and two-lane highways respectively. The NETSIM model was selected because it has been extensively validated, and it provides flexibility in studying the impact of different types of vehicles on the operation of traffic on arterial streets.

PCEs were estimated for a subject vehicle having the operating characteristics (overall vehicle length and Wt/Hp) corresponding to each of the 9 cells represented in a 3x3 matrix of length and Wt/Hp. PCE matrices for one of the six segment geometry types is provided in Table 1 for illustrative purposes.

## **Obtaining a PCE Value Using the PCE Matrices**

These 3x3 PCE matrices enable the calculation of a PCE for a truck of given overall length and Wt/Hp operating on a roadway with a given segment geometry. If the overall length or Wt/Hp of the given truck are not equal to the length or Wt/Hp values used in the PCE matrix for the given segment geometry, then linear interpolation or extrapolation is performed to obtain the PCE. Interpolation is performed if the length or Wt/Hp value of the given truck falls within the length or Wt/Hp values used in the PCE matrix, and extrapolation is performed otherwise. It must be noted that this method assumes that the PCE value is a linear function of the overall length and Wt/Hp of the vehicle. Preliminary analyses showed that this assumption is valid, since values thus interpolated are within  $\pm 1$  of the simulated value. The user is cautioned however, that extrapolation may produce erroneous results, since the values are outside the range of estimated PCEs.

**Table 1. PCEs for Rural Interstate, 2 lanes / dir., 3% grade, 3/4 mile.**

|             | Truck Length (feet) |       |       |
|-------------|---------------------|-------|-------|
|             | 40                  | 80    | 120   |
| 150         | 9.01                | 9.55  | 10.46 |
| Truck Wt/Hp |                     |       |       |
| 200         | 11.29               | 11.77 | 12.40 |
| 250         | 13.19               | 14.05 | 14.73 |

## TRUCK SUBSTITUTION ESTIMATES

The next step in the study was to obtain truck diversion estimates. As noted above, these estimates are an input to the procedure described here. The information required consists of two components:

- (1) The existing and projected annual VMT, functional class, and vehicle type.
- (2) The overall vehicle length and Wt/Hp of all truck types involved in the diversion scenario, before and after the diversion.

The annual VMT by vehicle class are used to calculate the estimated hourly volumes (vehicles per hour per lane) traveling on the roadway for a given functional class. The estimated hourly volumes are obtained by dividing VMT by lane-miles on the facility as described in the next section.

## CALCULATION OF CHANGES IN DELAY

After obtaining the PCE values and the truck substitution estimates as described above, the change in delay (vehicle-hours) and cost can be calculated using the procedure described in this section. An overview of the diversion calculations is provided in [Figure 2](#). This diagram shows the order in which calculations are performed on the spreadsheet. To obtain the change in vehicle-hours and cost to users for a given functional class, the following ten steps are performed, as shown in Figure 2.

Step 1. Find the typical hourly traffic volumes for the functional class in the one or two component segment geometries. Express this composition in terms of the following variables:

QP - Passenger Cars and Light Trucks

QM - Trucks in the traffic mix not including those involved in the diversion strategy

QT1 - Volume of trucks to be diverted (“before” trucks)

QT2 - Volume of trucks replacing the diverted trucks (“after” trucks)

These variables are the traffic stream components. In performing this step, it is assumed that the annual traffic is distributed uniformly in both time (24 hours a day, 365 days a year), and roadway space (all roadway miles and lanes of the given functional class). The annual VMT for each traffic stream component is divided by the number of lane-miles for the given functional class, and by  $24 \times 365$  to obtain hourly volumes per lane. If a functional class has two component segment geometries, as indicated in Table 1, then the lane-miles and VMT are divided evenly between the two component segment geometries.

Step 2. Using the PCE matrices, calculate the PCE of the “before” trucks, and the “after” trucks for each segment geometry defined as follows:

PCE1 = PCE of the “before” trucks (only those to be replaced)

PCE2 = PCE of the “after” trucks (only those replacing the “before” trucks)

PCE1 and PCE2 are obtained for each segment geometry type by linearly interpolating based on length and Wt/Hp using the PCE matrix for the respective segment geometry type.

Step 3. Calculate the volume of all vehicles in the traffic mix before the diversion.

$$QPM = QP + QM + QT1$$

Step 4. Using this volume, QPM, and the “Mix Curve” generated by the traffic simulations, determine  $S_{\text{BEFORE}}$  (average traffic speed before the diversion scenario). This step is shown in [Figure 3](#).

Step 5. Using  $S_{\text{BEFORE}}$  and the “Base Curve”, determine the equivalent volume  $Q_{\text{BEFORE}}$  resulting in this same speed if the traffic were all passenger cars and no trucks. This step of the procedure is illustrated in [Figure 4](#).

Step 6. Find the change in PCE units due to the diversion strategy:

$$DPCE = PCE2 * QT2 - PCE1 * QT1$$

Note that DPCE will be negative if the diversion strategy improves the traffic flow, positive otherwise.

Step 7. Find the equivalent all-passenger-car volume after the diversion,  $Q_{\text{AFTER}}$ .

$$Q_{\text{AFTER}} = Q_{\text{BEFORE}} + DPCE$$

This step is illustrated in [Figure 5](#).

Step 8. Using the value for  $Q_{\text{AFTER}}$  obtained in Step 7, and the “Base Curve” determine  $S_{\text{AFTER}}$ , the average traffic speed after the diversion scenario is implemented. This step is illustrated in [Figure 6](#).

Step 9. Calculate the change in vehicle-hours due to the diversion scenario on the segment geometry type(s) for the given functional class, as shown below:

$$VH_{ADDED} = VH_{AFTER} - VH_{BEFORE}$$

Where:  $VH_{BEFORE} = VMT_{BEFORE} / S_{BEFORE}$

$$VH_{AFTER} = (VMT_{BEFORE} + VMT_{ADDED}) / S_{AFTER}$$

[Units:  $VMT / SPEED = \text{veh-miles} / (\text{miles} / \text{hour}) = \text{veh-hours}$ ]

**Step 10.** If the functional class contains two segment geometries, add the delay calculated for the two component segment geometry types in Step 9. If the functional class contains only one segment geometry type, then the delay calculated in Step 9 is also the delay for the functional class. Calculate the cost by multiplying the delay value (vehicle-hours) by the estimated value of time (\$13.16 per vehicle-hour was used in this study).

## THE DELAY\$ MODEL

A spreadsheet program, DELAY\$.XLS, was developed to automatically estimate the delay changes resulting from a given truck diversion scenario. The following inputs are necessary to use the spreadsheet:

- Status quo annual VMT for all vehicle classes
- Diversion annual VMT for all vehicle classes
- Vehicle classes involved in the diversion strategy
- “Before” and “after” vehicle length and Wt/Hp
- Unit value of time per vehicle-hour (\$)

The spreadsheet produces the following outputs:

- Change in delay on the functional class (vehicle-hours per year)
- Change in user cost on the functional class (\$ per year)

The procedure to obtain the change in vehicle-hours, is conducted separately for each roadway functional classes involved in the implementation scenario. An overall change in vehicle-hours can be calculated by adding the values for change in vehicle-hours for the 12 functional classes. The cost in dollars can be found by multiplying vehicle-hours by an estimated value of time.

## CONCLUSIONS AND RECOMMENDATIONS

In this study, a methodology was developed for quantifying the traffic operational impact of various truck configurations on the roadway system. To achieve the objectives of this study, PCE values were estimated for a variety of truck types and on a variety of roadway types, using simulation. Traffic speed was selected as the basis of equivalency, to be consistent with the PCE values estimated as part of the Federal Highway Cost Allocation Study. The estimated PCE values demonstrated that for traffic operational purposes, the Wt/Hp becomes more critical than the overall vehicle length as the upgrade increases in length or slope.

A spreadsheet model (DELAY\$) was developed to estimate the changes in traffic operational quality that result from changes in the vehicle size and weight policy. Estimates of these changes are provided both in terms of delay (vehicle-hours) and in cost (dollars). The DELAY\$ model inputs include annual VMT for the status quo and for the policy scenario examined by vehicle type, region of the country and facility type, as well as the overall vehicle length and Wt/Hp of all truck types involved in the diversion scenario, before and after the diversion. The user must input the unit value of time per vehicle - hour (\$). The model developed in this study, quantifies the impacts on traffic operational quality as a function of changes in federal truck size and weight policy. As noted in previous sections of this paper, the changes estimated by employing a number of assumptions:

- The annual VMT by vehicle class is homogeneously distributed spatially (across all lane-miles) and temporally (24 hours, 365 days per year). The method developed here however, could be employed for estimating changes in operational quality in portions of the highway network, or for portions of the time. For example, one could estimate operational impacts for peak vs. non-peak hours. At the time this study was conducted, VMT estimates for peak vs. non-peak hours were not available.
- The national road mileage by functional highway class were taken from *Highway Statistics* (FHWA, 1993).
- One or two segment geometries are assumed for each functional class. For functional classes with two segment geometries, the VMT and roadway mileage are both assumed to be split evenly between the two segment geometry components. As noted above, roadway geometric characteristics by functional class were not available at the time this study was conducted.



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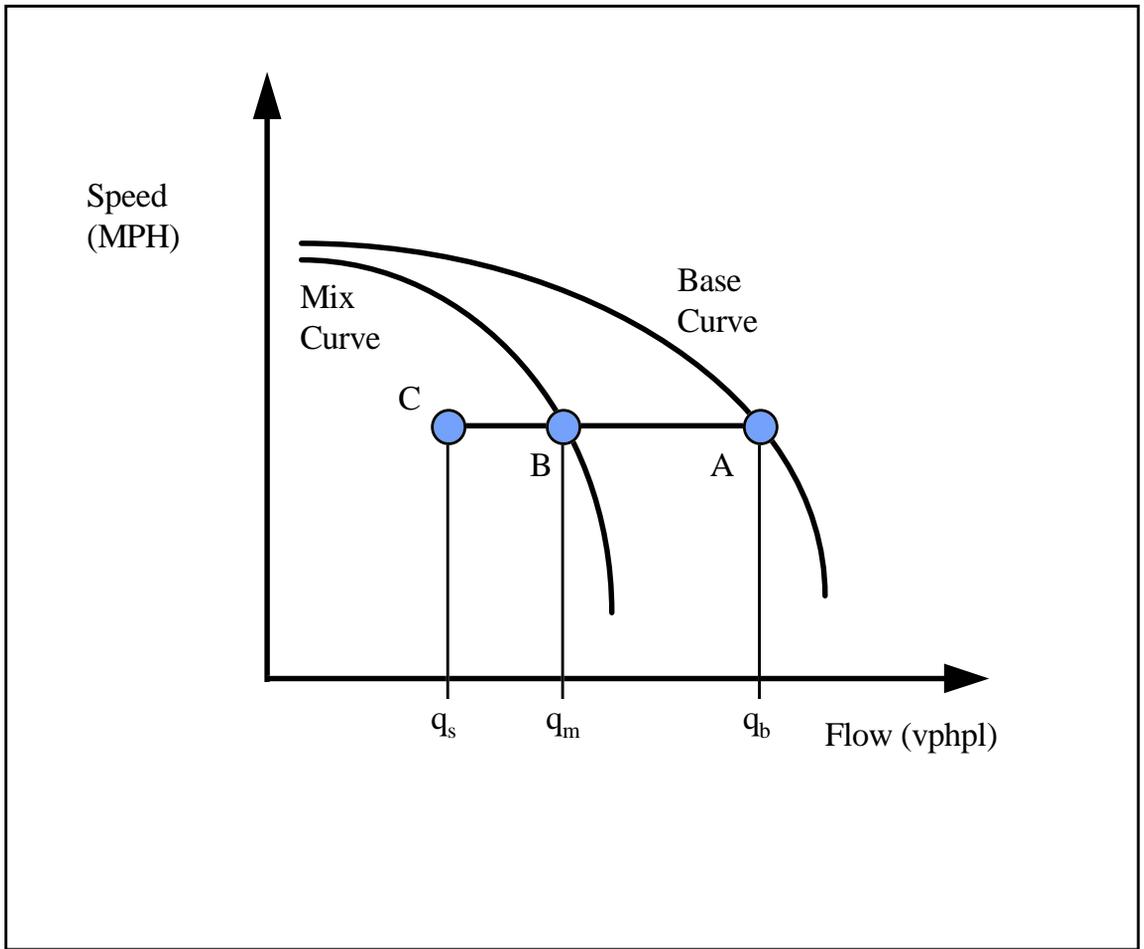


## AUTHOR BIOGRAPHIES

**Dr. Lily Elefteriadou** is an assistant professor at the civil engineering department of The Pennsylvania State University. She is also a research associate at the Pennsylvania Transportation Institute. She is currently teaching graduate and undergraduate courses in traffic operations and traffic flow theory, while working on various research projects related to highway capacity and design, traffic flow theory and simulation. She is a member of the Vehicle Size and Weight TRB committee, and a member of the Freeway Subcommittee and the Arterials Subcommittee, Highway Capacity and Quality of Service Committee of the Transportation Research Board. She was the principal investigator in the Treatment of Design and Operational Characteristics for the Federal Highway Cost Allocation, and the Evaluation of Limitations in Roadway Geometry and Impacts on Traffic Operations for Proposed Changes in Truck Size and Weight Policy, both projects conducted for Battelle/FHWA. Prior to joining the Pennsylvania State University, she was working for Garmen Associates, a New Jersey transportation consulting firm.

**Mr. Nathan Webster** is currently employed at Lee Engineering, a New York-based consulting firm. He completed his M.S. in Civil Engineering at Penn State University in August 1997. While a graduate student, he was working with Dr. Elefteriadou on a variety of research projects, including the Treatment of Design and Operational Characteristics for the Federal Highway Cost Allocation, and the Evaluation of Limitations in Roadway Geometry and Impacts on Traffic Operations for Proposed Changes in Truck Size and Weight Policy, both projects conducted for Battelle/FHWA. His thesis involved the development of PCE values for basic freeway segments as a function of traffic density.

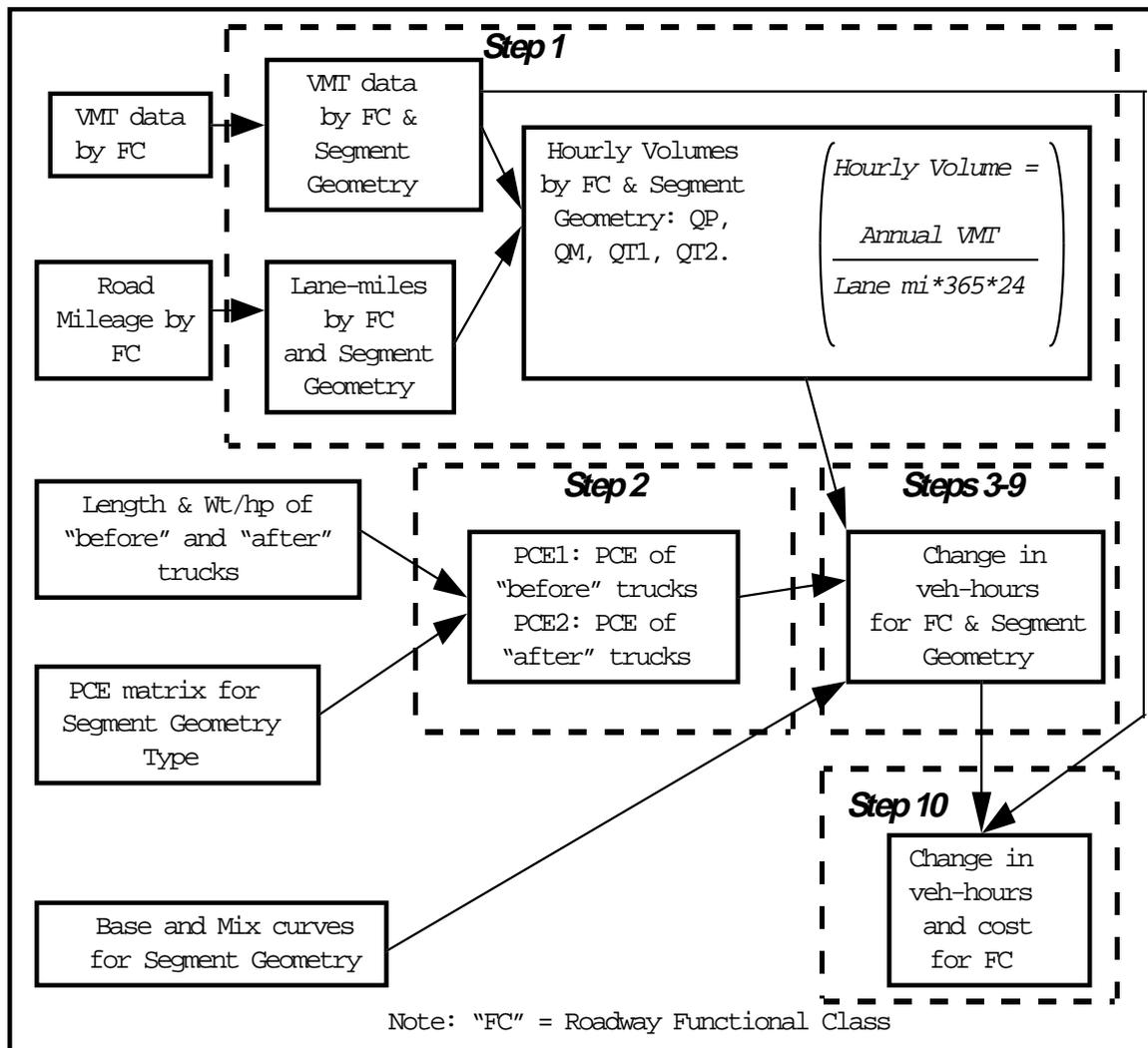




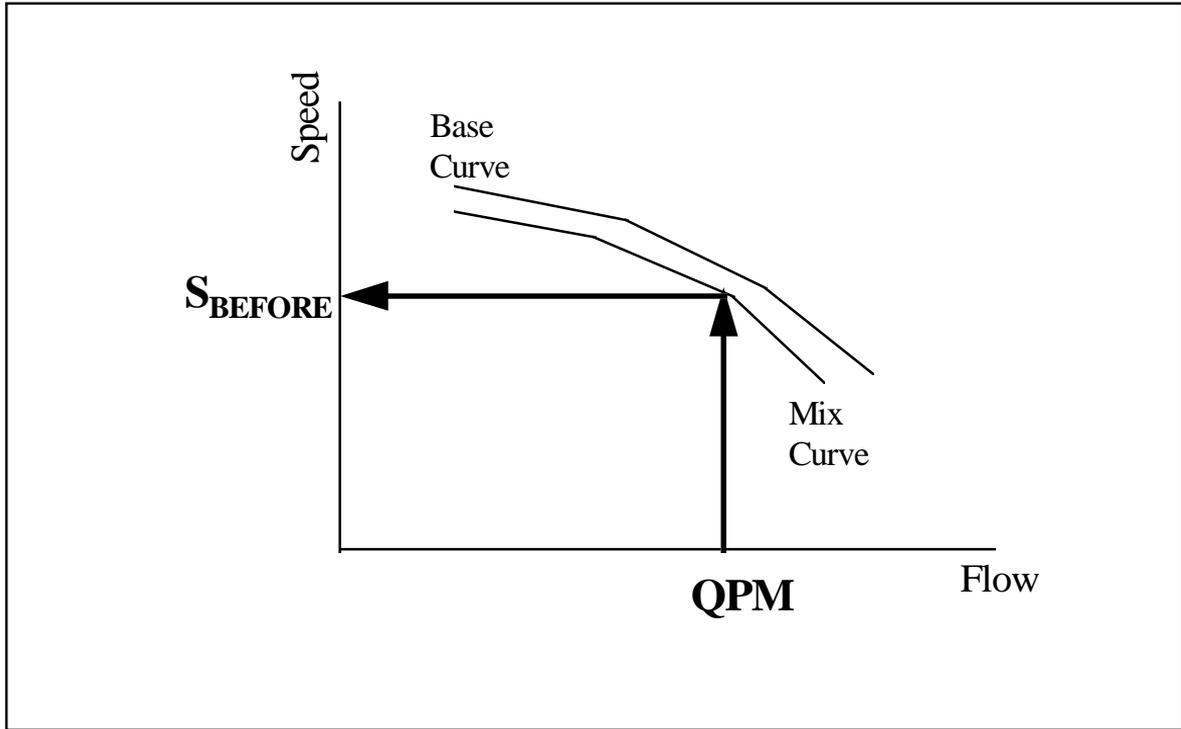
*Figure 1 - Method of PCE calculation*

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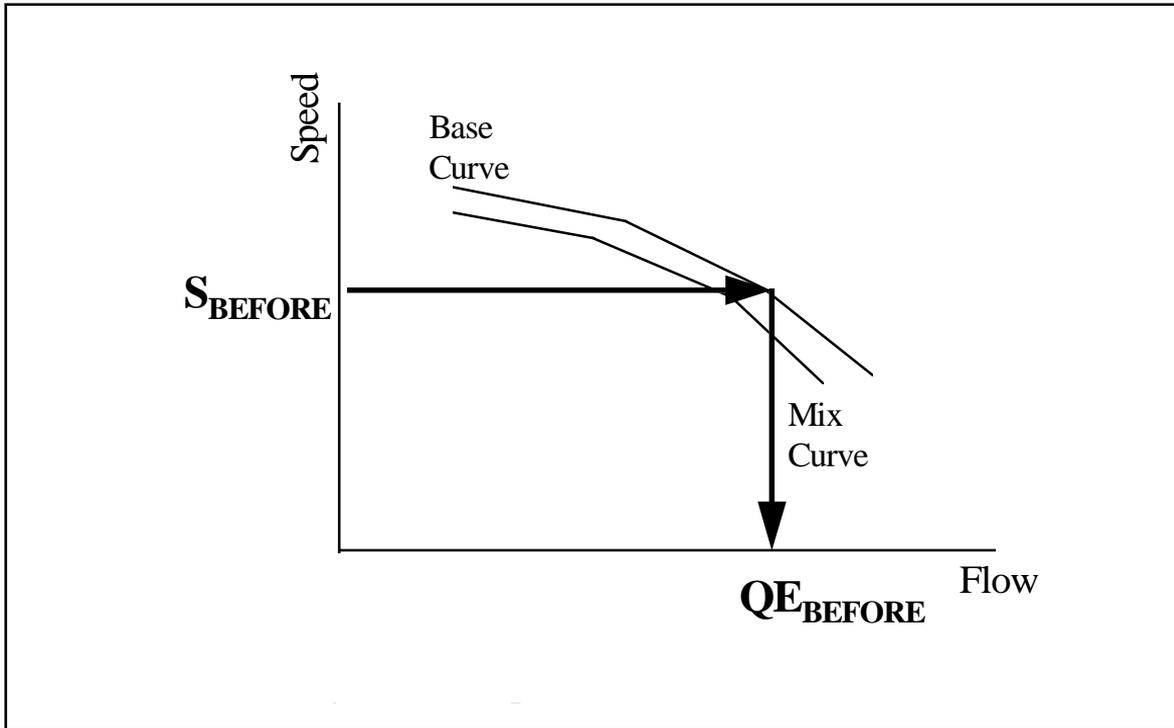
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**Figure 6-2. Diversion Calculations Overview.**



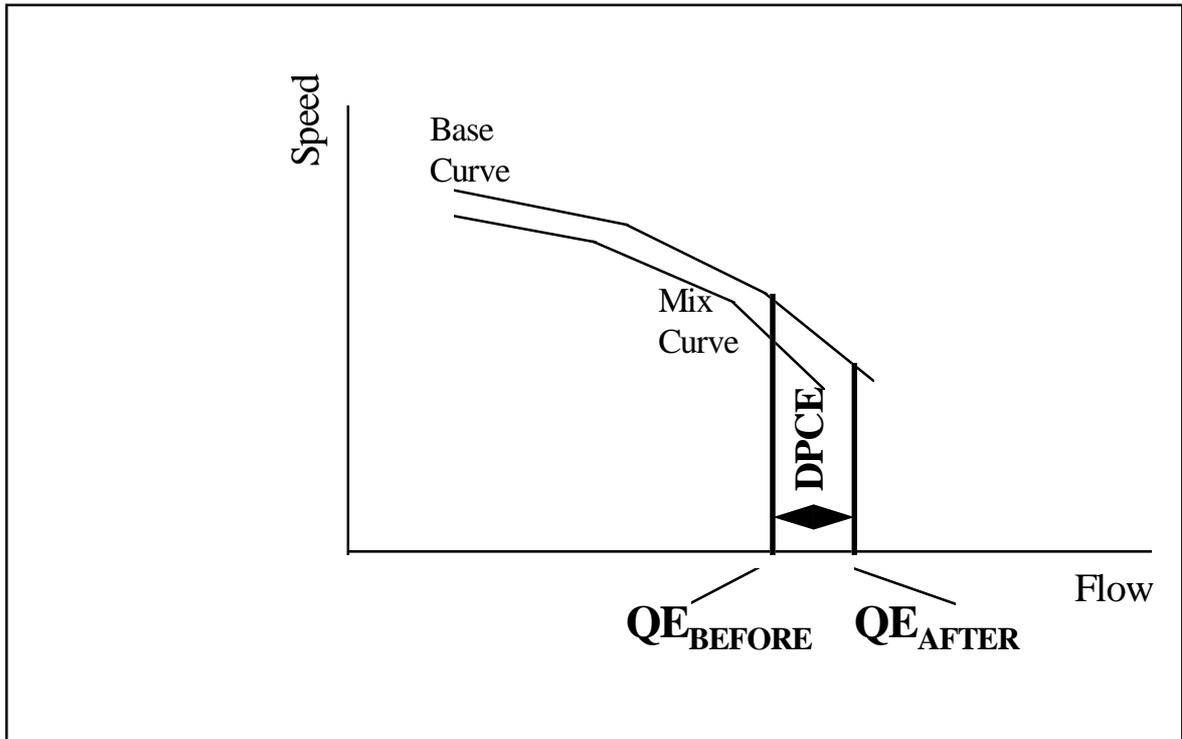
*Figure 3 - Step 4 of the Procedure*



*Figure 4 - Step 5 of the Procedure*

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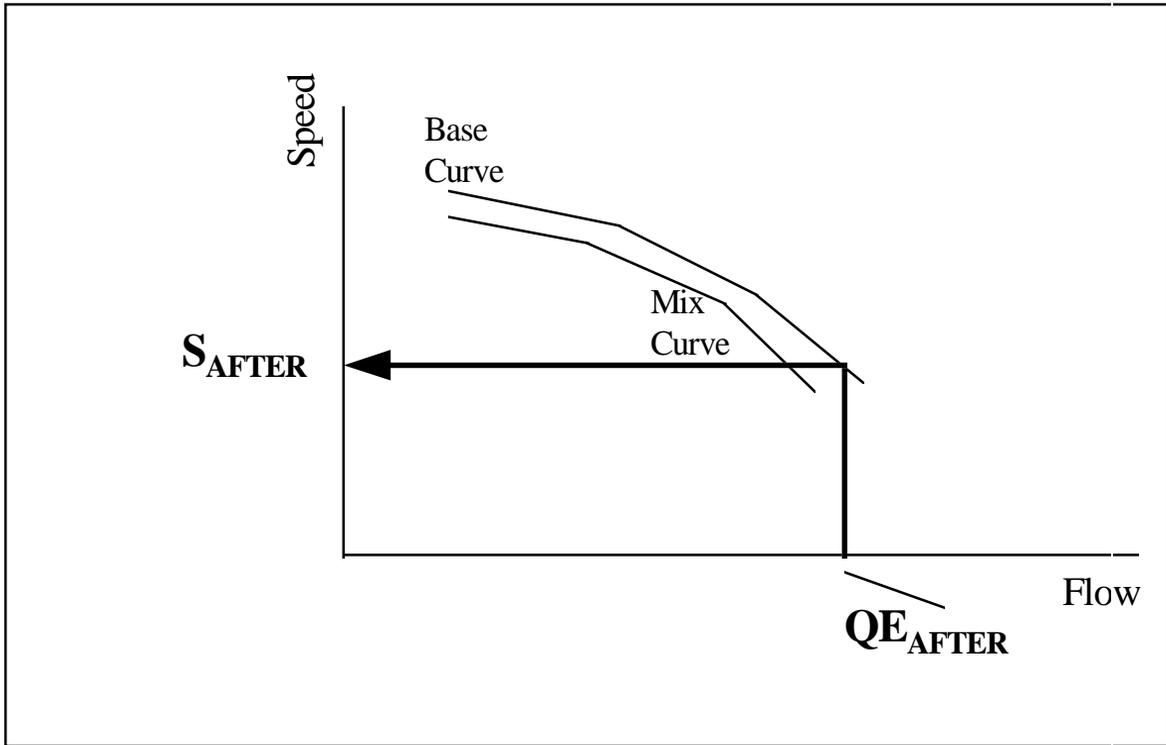
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*Figure 5 - Step 7 of the Procedure*

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*Figure 6 - Step 8 of the Procedure*

