Accounting for the Impact of Heavy Truck Traffic in Volume–Delay Functions in Transportation Planning Models

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Truck traffic accounts for a substantial fraction of the traffic stream in many regions and is often the source of localized traffic congestion. This paper presents the analysis and findings that recommend updated volume–delay relationships for transportation planning models that account for total volume, roadway capacity, and the mix of heavy truck traffic. The traditional Bureau of Public Roads function representing the speed–flow relationships for roadway facilities is modified to include the impact of truck traffic specifically. Several new speed–flow functions based on microsimulation results for freeways and urban arterials have been developed.

Truck traffic accounts for a substantial fraction of the traffic stream in many regions and is often the source of localized traffic congestion. Use of travel demand models to identify transportation projects that can best improve air quality and mobility requires the effective treatment of trucks in travel demand forecasting. Many urban areas now include the explicit treatment of truck trip making as part of the overall modeling process.

Led by the Florida Department of Transportation (FDOT), the metropolitan planning organizations (MPOs) in the Tampa Bay, Florida, area have worked together to improve truck modeling by empirically measuring the quantity and impact of truck traffic in the region through a series of local surveys, traffic counts, and data mining activities (*1*). Through these efforts, much has been learned about truck trip generation, distribution, and route choice. However, it has been difficult to measure the impact of truck traffic on overall traffic flow. To better understand the impact of truck traffic on overall system performance, the MPOs and FDOT initiated a project to examine this issue.

MODELING ISSUES FOR TRUCK TRAFFIC ASSIGNMENT

In developing a refined truck trip assignment methodology, the following issues were identified by the MPO technical staff to be considered and addressed:

- Route choice flexibility. It is frequently assumed that trucks have little flexibility in route choice. Thus, a common practice is to execute a single all-or-nothing preassignment of trucks at the beginning of the traffic assignment process (*2, 3*). This means that trucks will not be able to respond to building congestion as auto trips are assigned to the network by seeking alternate, less-congested routes in later iterations. Whether this is still a valid assumption or if trucks now have more flexibility in route choice should be considered.
- Impact of signals, stops, and delays. Local interviews with both trucking company officials and truck drivers revealed that one of the most important considerations for truck route choices is continuity of flow and avoidance of stops and delays. Although this is true for all trucks, it is especially true for heavy trucks.
- Impact on available capacity. A single truck will absorb much more of the available capacity on a roadway than will an auto. In part this is simply because trucks take up more space. In addition, most drivers will maintain more space between their vehicle and a truck than between their vehicle and another auto. This is particularly true on higher-speed roadways, where drivers have greater safety concerns.
- Impact on congested speeds. A given volume of trucks on a roadway often will result in a much greater deterioration of congested speeds than a similar volume of autos. This is because generally a truck takes much longer to accelerate and decelerate than does an auto.

Review of available practice and research indicates that many of these issues are addressed in some way in many model applications. The *Highway Capacity Manual* (*4*) and the *Quick Response Freight Manual* (*5*) suggest use of a passenger-car-equivalent approach to account for heavy truck impact on capacity and speeds. This is the most common approach used in urban area models. The recommended factor for flat grades (such as central Florida) is 1.5 or 2.0, depending on the specific type of vehicle. Although this recognizes the impact of truck size, it does not reflect facility-specific differences that would be expected because of stops, signals, and delays, at which truck acceleration and deceleration characteristics would be most notable.

Another consideration in the evaluation process was the interaction of total traffic that results in congestion. The most common approach to reflecting the overall impact of congestion in travel demand models is the Bureau of Public Roads (BPR) type curve (*6*). One advantage of the BPR curve is that the parameters of the curve can be calibrated to reflect locally observed volume–delay relationships that may vary depending on roadway class and driver behavior. A disadvantage of the standard BPR formulation is that it does not recognize the mix of traffic and how that mix can contribute to congestion.

Beginning in 2001, FDOT undertook a review of methodologies to collect local data regarding truck traffic impact. Initially, field data were to be collected from selected locations around the region to estimate an updated set of BPR-type volume–delay functions for selected

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classes of roadways. However, the number of variables that would have to be controlled for in such an estimate, such as weather, driver mix, time of day, day of week, and lighting, made such a study prohibitively expensive. A large sample size would be needed to properly account for all these variables, and it would be difficult to measure many of them.

After looking at the cost and likely reliability of field data collection, the management team decided to look at microsimulation as a way to measure the changes in operating speed that would result from changes in the mix of truck and passenger car traffic. Since many validated CORSIM models in the region had been calibrated to local traffic flows and speeds, these could offer a way to quickly test changes in the mix of traffic that could control for variables such as driver behavior that would be uncontrollable in the field. And since microsimulation models account for size, acceleration, deceleration, and lane-changing behavior, they would be able to account for the speed and capacity effects of changes in the mix of traffic.

This paper documents the development of a truck trip assignment methodology for use in the urban travel demand forecasting process. CORSIM simulation results were used to develop the speed–flow relationships with the impact of truck traffic. The speed–flow relationships were developed for freeways and different categories of urban arterials. The simulated speed was first plotted against the simulated volume for a given truck percentage. General observations were made about the underlying relationships among the relevant variables. Detailed statistical analyses were then performed to determine the best-of-fit functional forms and their associated coefficients. The general observations, proposed functional forms, and resulting properties of the speed–flow functions for each of the roadway categories are presented in detail.

SPEED–FLOW FUNCTIONS WITH TRUCK IMPACT FOR FREEWAYS

Freeways are multilane, divided highways having full control of access and egress. They can be located in rural areas, at or near urban fringes, in urbanized areas, or near downtown areas. The posted speeds for freeways in Florida normally range from 55 to 70 mph. The freeway is the only highway facility that provides completely uninterrupted flow: the traffic is not interrupted by at-grade intersections, signals, or other fixed causes of periodic delay.

For the purpose of this study, the freeway segment for the CORSIM simulation has three lanes in each direction. The free-flow speed is assumed to be 70 mph. A total of 26 simulation runs was performed for the freeway segment, each run representing a different truck percentage. The truck percentages range from 0% to 50% with a 2% increment.

General Observation of CORSIM Simulation Results for Freeways

Figure 1 illustrates the CORSIM simulation results for the freeway segment. The *x*-axis represents the simulated volumes in vehicles per hour per lane (vphpl); the *y*-axis represents the resulting congested

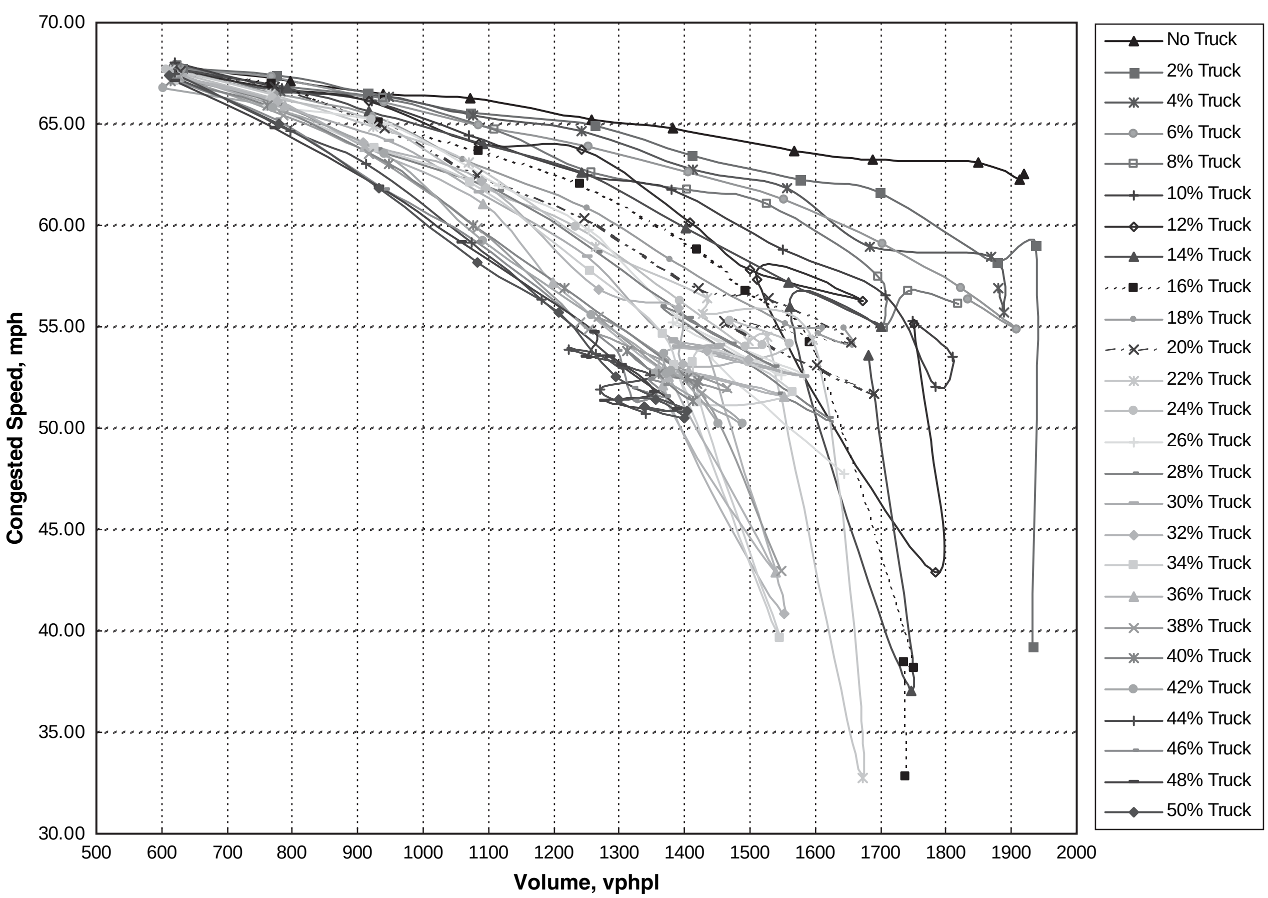

FIGURE 1 Simulated speeds versus volumes with different truck percentages for freeways.

speeds in miles per hour. Several general observations can be made of the charted CORSIM simulation results. First, the travel speed decreases as the total volume of the freeway increases. For instance, Figure 1 shows a general downward turn from above 65 mph to below 55 mph as the volume increases. Second, the driving speed decreases as the percentage of trucks increases.

As shown in Figure 1, at a volume of 1,400 vphpl, when there are no trucks on the road, the speed is approximately 64 mph; however, when the total traffic includes 50% trucks, the speed is approximately 51 mph. The truck impact on the travel speed tends to be much greater when the traffic volume is higher. For example, at a volume of approximately 600 vphpl, the travel speed for a traffic stream having no trucks is approximately 68 mph; the travel speed for a traffic stream consisting of 50% trucks is slightly more than 67 mph. The difference in speed between the two traffic streams is less than 1 mph. However, when the traffic volume increases to 1,200 vphpl, the travel speeds of the two traffic streams decrease to 65 mph and 56 mph, respectively. The difference in speed increases to 9 mph.

The simulated congested speed shows a somewhat erratic pattern when traffic volume is high. In some cases, the congested speed is significantly lower than what the trend would otherwise indicate. In other cases, slower speed is observed where traffic volume is low. This is because the CORSIM simulation attempts to replicate the real-world traffic operating conditions. In reality, when traffic volume approaches capacity, there is a sudden drop in operating speed. The traffic flow becomes very unstable under these circumstances.

The unstable pattern shown in Figure 1 when volumes approach capacity makes sense from a traffic engineering point of view. However, the volumes observed under these conditions do not represent the true demand for the roadway facility. The simulated speeds and volumes for these cases will be excluded from the analysis.

Proposed Functional Form for Freeways

The speed–flow relationship traditionally has been represented by the BPR function in transportation planning models. This curve was developed on the basis of the 1965 *Highway Capacity Manual.* The functional form of the BPR curve is as follows:

$$S = \frac{S_0}{1 + \alpha(V/C)^{\gamma}} \tag{1}$$

where

S = congested speed (mph);
S_0 = free-flow speed (mph);
V = volume [passenger car units per hour per lane (pcu/hr/l)];
C = capacity (pcu/hr/l); and
α, γ = coefficients for freeways, $\alpha = 0.15$, $\gamma = 4.00$.

The BPR curve is parabolic in shape, and speed is fairly sensitive to increasing flows. The curves presented in Figure 1 bear much resemblance to the standard BPR curve. In other words, for a given truck percentage, the relationship between congested speed and volume should be similar to the BPR function. To reflect the impact of truck traffic on the speed–flow relationship, a second term related to the truck percentage needs to be introduced into the equation. If this term is denoted by $f(T)$, meaning a function of truck percentage (T), then the speed–flow relationship with truck impact will have the following functional form:

$$S = \frac{S_0}{1 + \alpha f(T)(V/C)^{\gamma}} \tag{2}$$

where

α, γ = coefficients to be determined;
T = proportion of trucks in the traffic mix, in decimals; and
$f(T)$ = function of T to be specified.

Function $f(T)$ should possess the following two properties. First, $f(T) = 1$ when $T = 0$. This ensures that when there are no trucks in the vehicle mix, that is, when $T = 0$, the proposed functional form remains consistent with the standard BPR functional form. Second, $f(T)$ increases when T increases. This ensures that the proposed functional form reflects the CORSIM simulation results shown in Figure 1. As discussed earlier, travel speed decreases as truck percentage increases at a give volume. Since $f(T)$ is inversely related to the congested speed S in the proposed function, an increase in $f(T)$ will cause a decrease in speed.

A number of different functional forms for $f(T)$ were tested, and a curve estimation analysis was performed by using the SPSS software package. It was determined from the analysis that a power function in the form of $(1 + T)^{\beta}$ satisfies both preceding conditions. In addition, the simple functional form allows for easy calibration and easy modification of the standard BPR function if it is implemented in the traditional travel demand estimation models. To summarize, the proposed functional form to represent the speed–flow relationship for freeways is as follows:

$$S = \frac{S_0}{1 + \alpha f(T)^{\beta}(V/C)^{\gamma}} \tag{3}$$

where α, β, and γ are coefficients to be determined.

Determination of Coefficients

To determine the coefficients α, β, and γ, the proposed functional form was first transformed as follows:

$$\log_{10}\left(\frac{S_0}{S} - 1\right) = \log_{10}\alpha + \beta\log_{10}(1 + T) + \gamma\log_{10}(V/C) \tag{4}$$

where

$Y = \log_{10}\left(\frac{S_0}{S} - 1\right)$,
$A = \log_{10}\alpha$,
$X_1 = \log_{10}(1 + T)$, and
$X_2 = \log_{10}(V/C)$.

Then Equation 4 becomes the standard two-dimensional linear equation as follows:

$$Y = A + \beta X_1 + \gamma X_2 \tag{5}$$

A multiple linear regression analysis was performed where $\log_{10}[(S_0/S) - 1]$ is the dependent variable and $\log_{10}(1 + T)$ and $\log_{10}(V/C)$ are the independent variables. The freeway lane capacity C used in the analysis was determined from the *1998 Level of Service Handbook* (*7*). According to the handbook, the generalized peak hour directional volume for a six-lane Group 1 freeway (within an urbanized area with a population more than 500,000 and leading to or passing within 5 mi of a city central business district) is 6,270 vehicles per hour when the level of service is E. Therefore, the capacity for each lane for a three-lane freeway segment is one-third the directional hour volume, or 2,090 vphpl. The three coefficients determined from the regression analysis are –0.548 for constant, 3.018 for β, and 2.249 for γ, respectively. Since the value –0.548 is the logarithm of α, α can be calculated as follows:

$$\alpha = 10^{-0.548} = 0.283 \tag{6}$$

With the coefficients determined, the speed–flow relationships with truck traffic for freeways can be represented by the following equation:

$$S = \frac{S_0}{1 + 0.283(1+T)^{3.018}(V/C)^{2.249}} \tag{7}$$

To measure how well the speed–flow curve developed from the regression analysis fits the CORSIM simulation data, a number of statistics commonly used to determine the goodness of fit of the regression equations were evaluated. The coefficient of determination or R^2 measures the strength of the association between the independent variable and the dependent variables. The R^2 value for the regression analysis is 0.953, indicating a strong relationship exists among the congested speed, traffic volume, and proportion of trucks in the traffic mix.

Properties of Freeway Speed–Flow Curves

Even with the introduction of the new term T (proportion of trucks in the traffic mix), the newly developed speed–flow equation is still considered a variation of the standard BPR function. The most appealing feature of this type of equation is its simplicity. Traffic forecasting models must be able to analyze thousands of links in each model run. Use of a simple equation rather than a complex procedure to estimate link speed can reduce processing time. Also, the simple data requirements of the speed–flow curve will facilitate data entry for modelers and planners.

The traffic forecasting models generally require that travel time be a monotonically increasing function of volume to ensure that a single user equilibrium solution can be found for the traffic assignment problem. Given that travel speed is the inverse of travel time, this means that the travel speed needs to be a monotonically decreasing function of volume. As discussed earlier, the functional form of the freeway speed–flow curve satisfies this condition. This is even more evident when the congested speed is plotted against flow, as shown in Figure 2.

Some interesting properties of the speed–flow curves may be explored through some special values of truck percentage (T) and volume-to-capacity ratio (V/C). First, the functional form performs reasonably under certain extreme conditions. For example, when V is close to zero, or $V \rightarrow 0$, indicating a near free flow condition, the congested speed estimated from the equation is close to the free-flow speed, or $S \rightarrow S_0$. Also, when $T = 0.00$, meaning there are no trucks in traffic mix, the functional forms becomes the standard BPR function, although the values of coefficients are different.

Second, as compared to the standard BPR function, the congested speed estimated from the freeway speed–flow curve is much lower when volume is at capacity, that is, $V/C \rightarrow 1$, and the difference increases as the truck percentage increases. This is because the multiplier of the term $(V/C)^{\gamma}$ in Equations 1 and 7 represents the percent drop in speed from the free–flow speed. For the standard BPR function represented by Equation 1, the multiplier is 0.15, indicating there is a 15% drop in speed when the volume approaches capacity. For the newly developed speed–flow curve represented by Equation 7, this

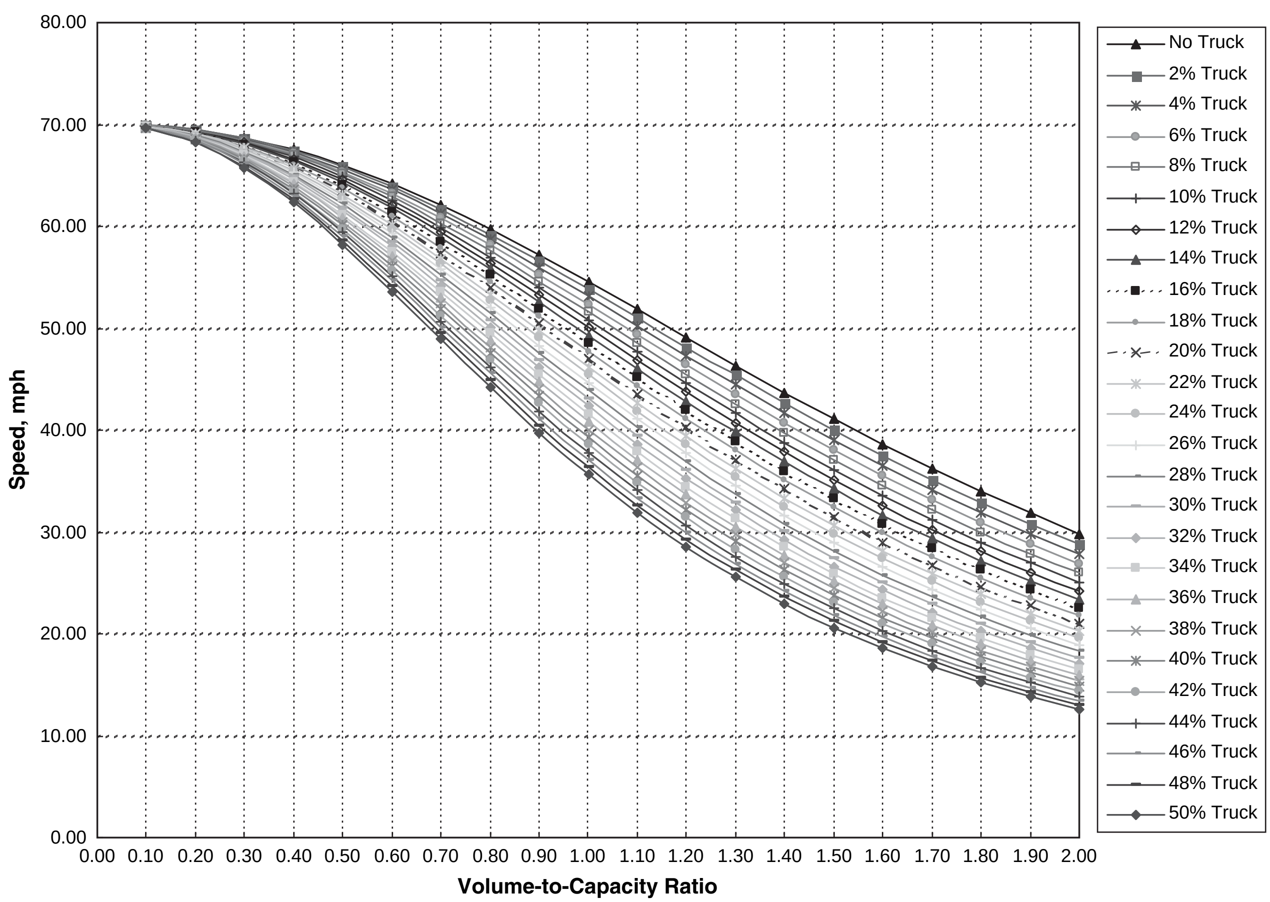

FIGURE 2 Freeway speed–flow relationships (Eq. 7) with different truck percentages.

multiplier is $0.283(1 + T)^{3.018}$, a monotonically increasing function of T, which means the estimated speed will drop at least 28.3% when the V/C ratio is close to 1.

Finally, a smaller value of exponent of (V/C) ($\gamma = 2.249$) in the speed–flow equation indicates that the speed is sensitive to changes in traffic flow. However, the speed drop when V/C gets close to 1.0 is not as abrupt as the standard BPR function, where the exponent of (V/C) is 4.0.

SPEED–FLOW FUNCTIONS WITH TRUCK IMPACT FOR URBAN ARTERIALS

Urban arterials are signalized roadways that serve primarily through traffic and provide access to abutting properties as a secondary function. The spacing between the signalized intersections normally does not exceed 2 mi, and turning movements at intersections are usually less than 20% of total traffic. On the basis of signal density, urban arterials are divided into the following four classes:

Class I. Arterials in nonrural areas with speed limits of at least 45 mph and fewer than two signals per mile;

Class II. Arterials with speed limits of 35 to 45 mph and two to four and a half signals per mile;

Class III. Arterials with speed limits of 30 to 40 mph and at least four and a half signals per mile; and

Class IV. Arterials in the downtowns of cities in urbanized areas with a population greater than 750,000 with speed limits from 25 to 30 mph and more than six signals per mile.

The development of speed–flow relationships for urban arterials follows the same procedure as freeways. A roadway segment is set up for each of the four classes of arterials. Each roadway segment has three lanes in each direction. All intersections are assumed to be controlled by pretimed signals. The signal cycle length, phasing, and splits are fixed in all cases. Similar to freeways, CORSIM simulation runs were performed for different truck percentages ranging from 0% to 50% with a 2% increment.

CORSIM Simulation Results for Urban Arterials

The CORSIM simulation results for Classes I to IV urban arterials are illustrated in Figures 3 to 6. In general, the speed changes for urban arterials related to changes in traffic volume and truck percentage show a similar pattern to freeways. Like the freeway CORSIM simulation results, an increase in traffic volume or truck percentage will cause the travel speed to decrease. However, the impact of trucks on travel speed for arterials is not as significant as that for freeways. This is particularly true for Classes III and IV urban arterials, as demonstrated in Figures 5 and 6. The overlapping curves for different truck percentages at low volumes as shown in these figures suggest that the truck impact on travel speed tends to be minimal.

When developing speed–flow curves for urban arterials, it is important to note that unlike freeways, traffic flows on urban arterials are interrupted flows caused by traffic signals and other traffic control devices. Traffic signal phasing and timing have as much impact, if not more, on the average speed of the traffic flow as does the traffic volume or the percentage of trucks in the traffic mix.

Proposed Functional Form for Urban Arterials

Several possible functional forms to represent the speed–flow relationships for arterials were explored. The same functional form for

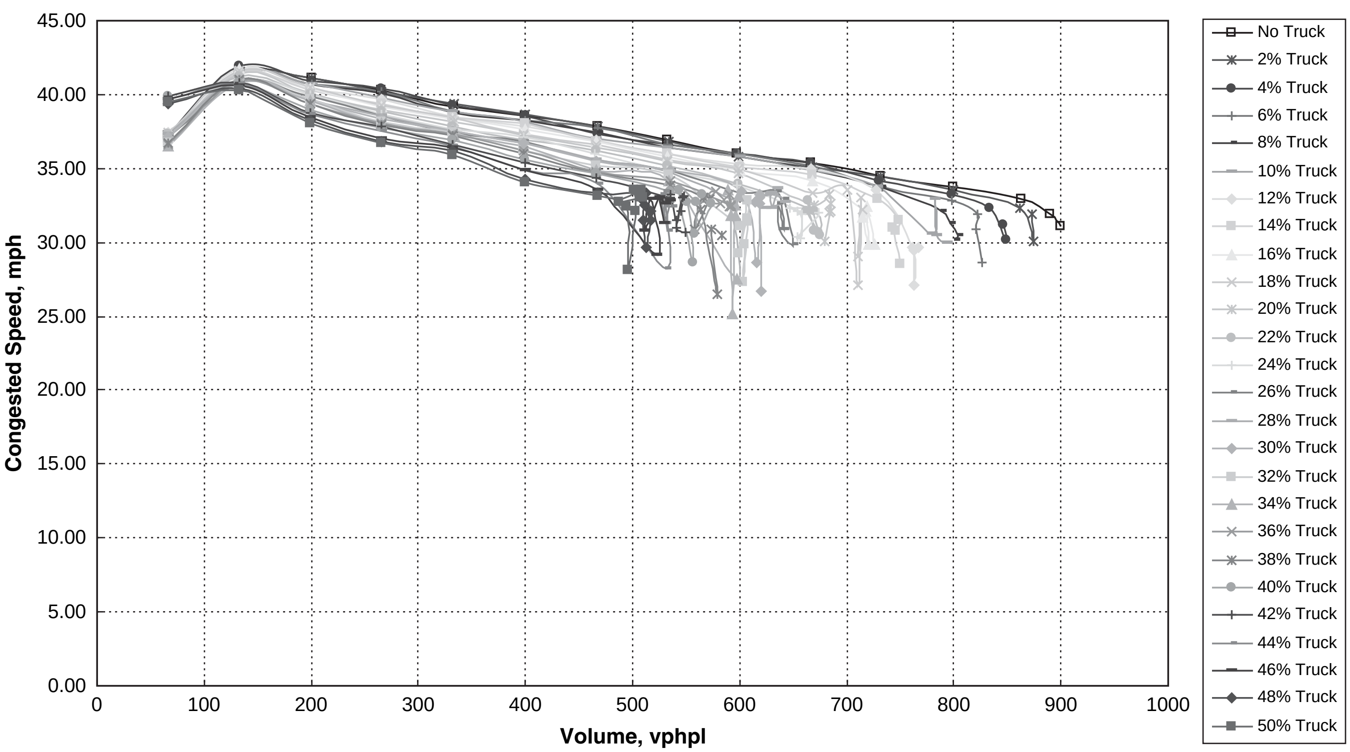

FIGURE 3 Simulated speeds versus volumes with different truck percentages for Class I arterials (free-flow speed, 50 mph; signal density, one signal per mile).

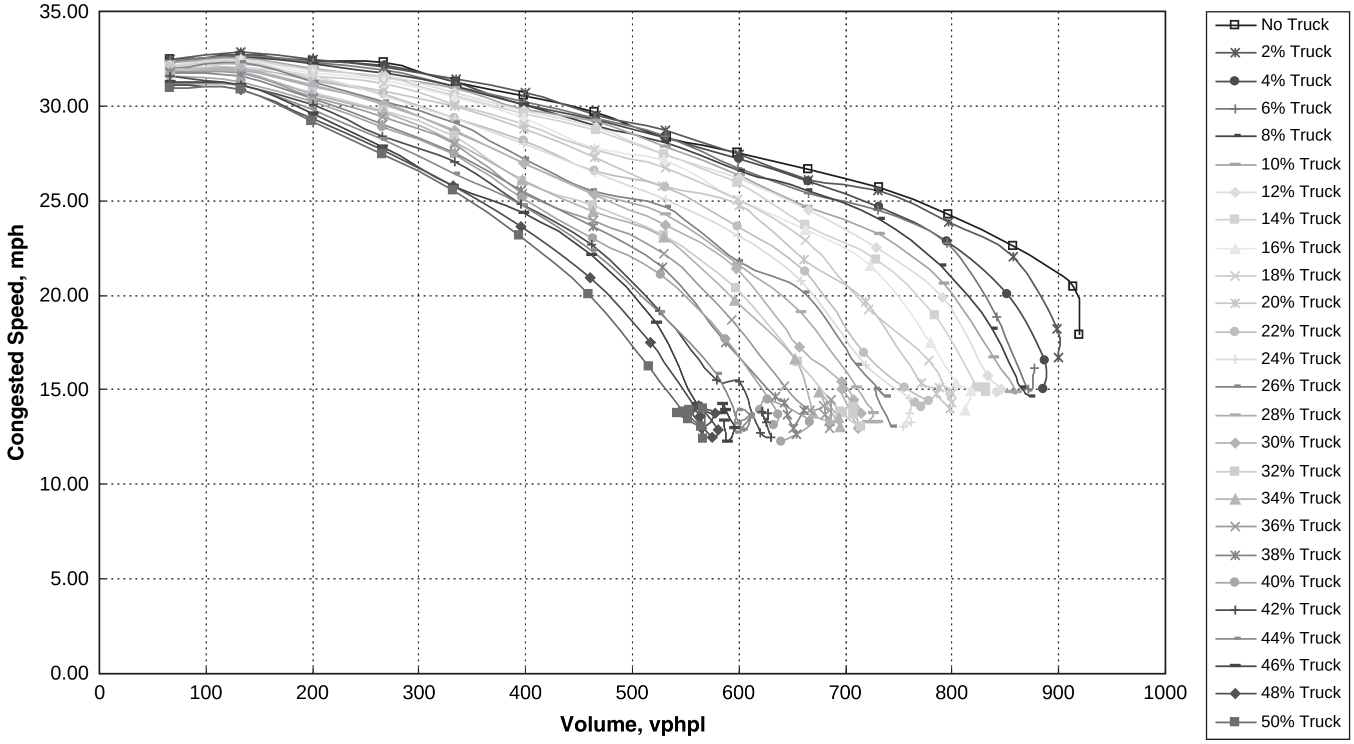

FIGURE 4 Simulated speeds versus volumes with different truck percentages for Class II arterials (free-flow speed, 40 mph; signal density, three signals per mile).

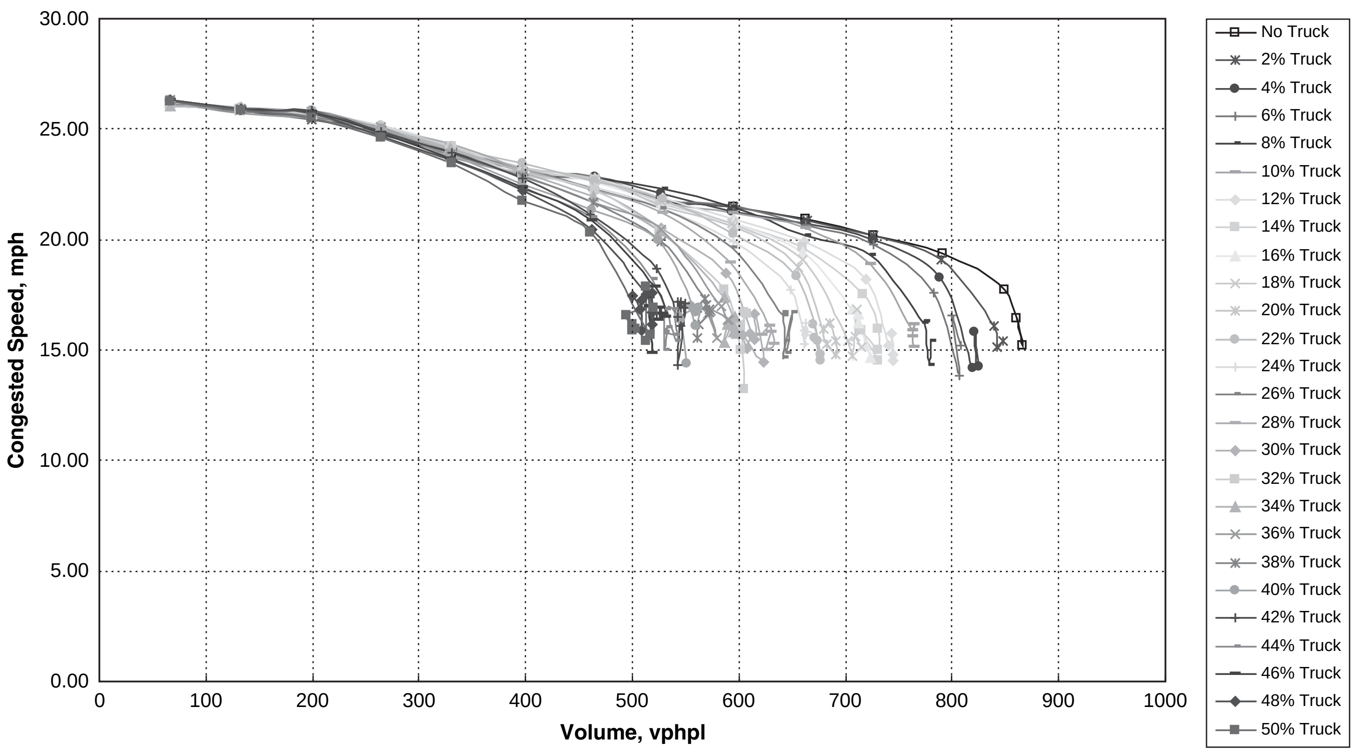

FIGURE 5 Simulated speeds versus volumes with different truck percentages for Class III arterials (free-flow speed, 35 mph; signal density, four signals per mile).

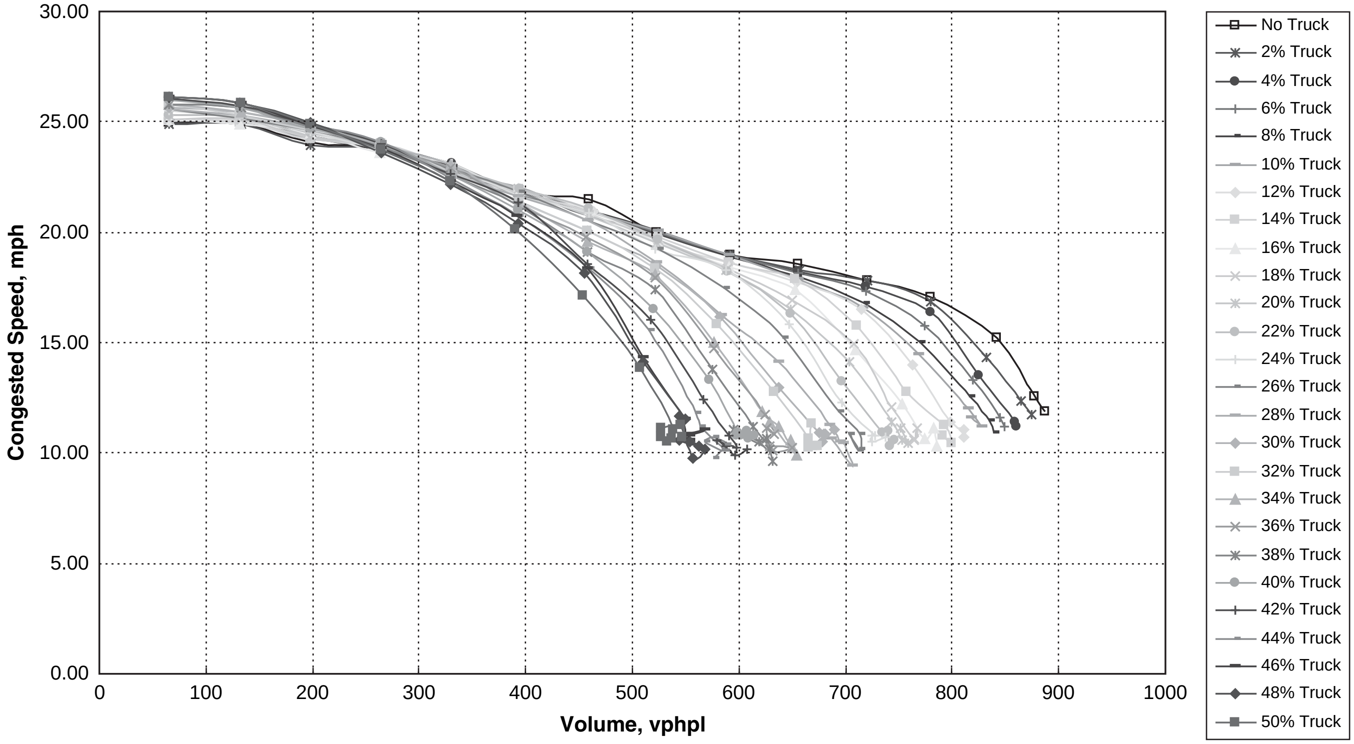

FIGURE 6 Simulated speeds versus volumes with different truck percentages for Class IV arterials (free-flow speed, 30 mph; signal density, five signals per mile).

freeways as based on the original BPR function initially was appealing. However, a closer examination of the properties of the equation revealed a potential flaw of the functional form. In particular, when traffic volume is close to free-flow conditions, or $V/C = 0$, the estimated speed from the equation is equal to free-flow speed, or $S = S_0$. This is true for freeways but may not be the case for arterials simply because of the delays caused by traffic signals.

To remedy the problem, it is necessary to introduce a different term with respect to V/C into the equation. The best possible relationship between the speed and the V/C ratio is determined by a curve estimation analysis that uses the SPSS software package. The average travel speed (S) is first transformed to ($S_0/S - 1$), denoted by SSMINUS1. The curve estimation analysis is then performed by using SSMINUS1 as a dependent variable and V/C (denoted by VC) as an independent variable. Four possible functional forms (linear, logarithm, inverse, and exponential functions) are tested, and the results show that the exponential function provides the best fit of the observed data as indicated by the highest R^2 value of 0.744.

On the basis of the curve estimation analysis results, the functional form representing the speed–flow relationships for urban arterials is as follows:

$$S = \frac{S_0}{1 + \alpha(1 + T)^{\beta}\gamma^{(V/C)}} \tag{8}$$

Determination of Coefficients

To determine the coefficients in Equation 8, the functional form first must be transformed as follows:

$$\log_{10}\left(\frac{S_0}{S} - 1\right) = \log_{10}\alpha + \beta\log_{10}(1 + T) + (V/C)\log_{10}\gamma \tag{9}$$

where $B = \log_{10}\gamma$.

Then Equation 9 becomes the standard two-dimensional linear equation as follows:

$$Y = A + \beta X_1 + BX_2 \tag{10}$$

The values of A, β, and B are determined by performing multiple linear regression analysis by using $\log_{10}[(S_0/S) - 1]$ (or Y) as a dependent variable and $\log_{10}(1 + T)$ (or X_1) and V/C (or X_2) as dependent variables. Similar to freeways, the lane capacities for different classes of arterials are determined from the *1998 Level of Service Handbook* (*7*). These values, together with the coefficients determined from regression analyses, are provided in Table 1.

From Table 1, the speed–flow curves for urban arterials can be summarized as follows:

$$\text{Class I: } S = \frac{S_0}{1 + 0.136(1 + T)^{1.234}5.058^{(V/C)}} \tag{11}$$

TABLE 1 Coefficients Determined from Regression Analyses

Arterial	Capacity, vphpl	A	β	B	$\alpha = 10^A$	$\gamma = 10^B$
Class I	930	–0.865	1.234	0.704	0.136	5.058
Class II	910	–1.139	3.140	1.231	0.073	17.022
Class III	880	–0.711	1.105	0.845	0.195	6.998
Class IV	850	–1.132	1.989	1.328	0.074	21.281

TABLE 2 Goodness-of-Fit Statistics for Urban Arterials

Arterial	Coefficient of Determination (R^2)	Standard Error of Estimate (SEE)	F Statistic
Class I	0.912	0.0462	1861.031
Class II	0.918	0.0943	2018.861
Class III	0.872	0.0776	1318.323
Class IV	0.887	0.1258	1524.972

$$\text{Class II: } S = \frac{S_0}{1 + 0.073(1+T)^{3.140}17.022^{(V/C)}} \tag{12}$$

$$\text{Class III: } S = \frac{S_0}{1 + 0.195(1+T)^{1.105}6.998^{(V/C)}} \tag{13}$$

$$\text{Class IV: } S = \frac{S_0}{1 + 0.074(1+T)^{1.989}21.281^{(V/C)}} \tag{14}$$

The statistics commonly used to measure the goodness of fit are summarized in Table 2. The high R^2 values show that there is strong association between average travel speed on the one hand and truck percentage and traffic volume on the other hand. The low standard error of the estimate values indicate that the speed–flow curves can be used to estimate the average travel speed for urban arterials with a high level of accuracy. Finally, the high values of F statistics provide further evidence that the regression equations are statistically significant.

Properties of Urban Arterial Speed–Flow Curves

The speed–flow curves for urban arterials share some common characteristics with those of freeways. For any given truck percentage, these curves maintain the simplicity of a single differentiable, monotonically decreasing function, which makes it easier to implement the equations in the transportation planning models. The speed–flow curves for urban arterials are shown in Figures 7 to 10.

The coefficient α in the generalized speed–flow function in Equation 8 represents the drop in speed from the free-flow speed when traffic is light and when there are no trucks present. As mentioned, the speed drop is caused mainly by the delays caused by traffic signals. For example, in the case of a Class I urban arterial, α is equal to 0.136, which means the average speed will drop by 13.6% from free-flow speed even if the traffic volume is very low. Although α is a facility-specific parameter, its value is influenced more by traffic timings at individual intersections and how well the signals are coordinated along the corridor.

The coefficient β in Equation 8 is an indication of how sensitive the travel speed is to the presence of trucks in the traffic mix. The higher the value of β, the greater impact the trucks will have on the average

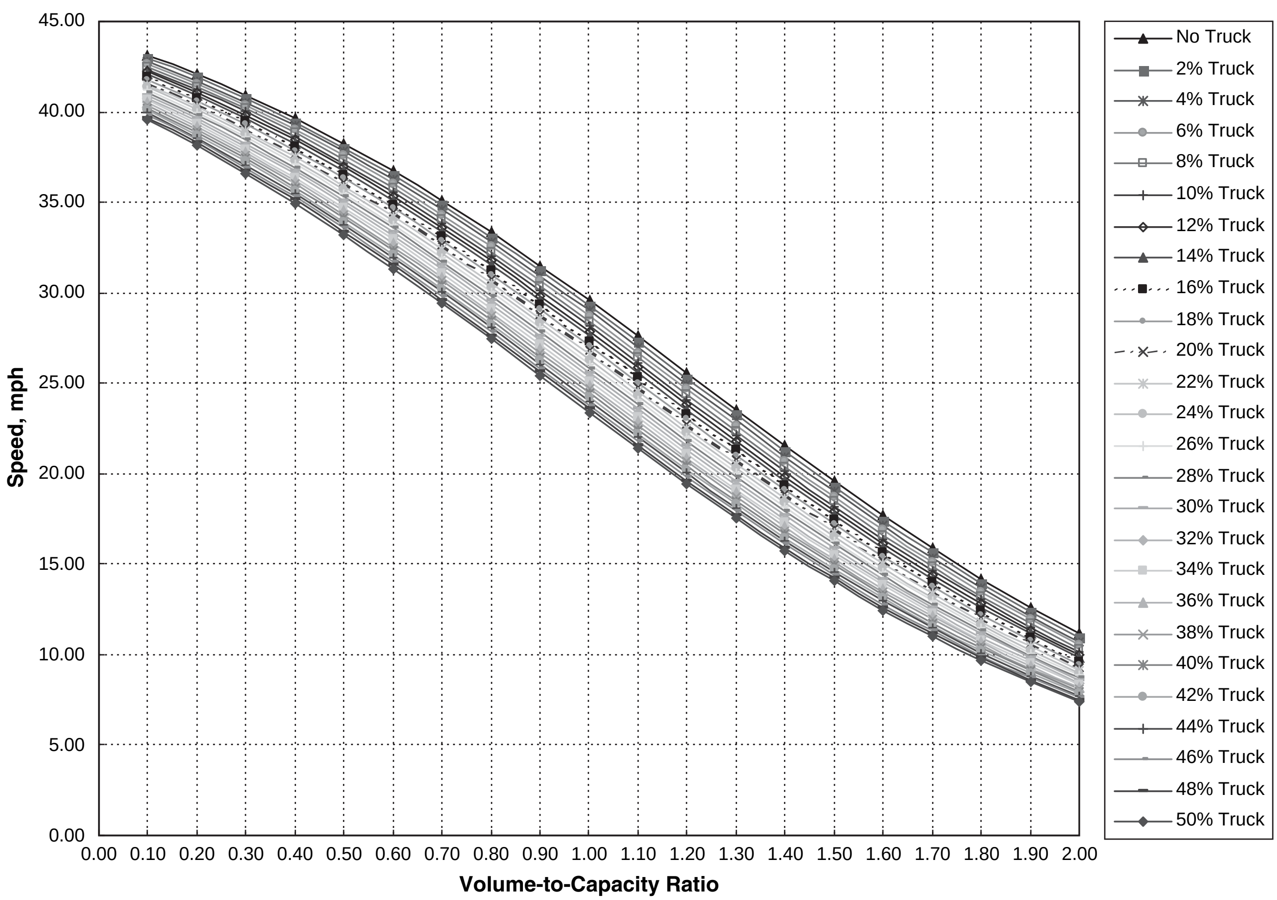

FIGURE 7 Class I urban arterial speed–flow relationships (Eq. 11) with different truck percentages (free-flow speed, 50 mph; signal density, one signal per mile).

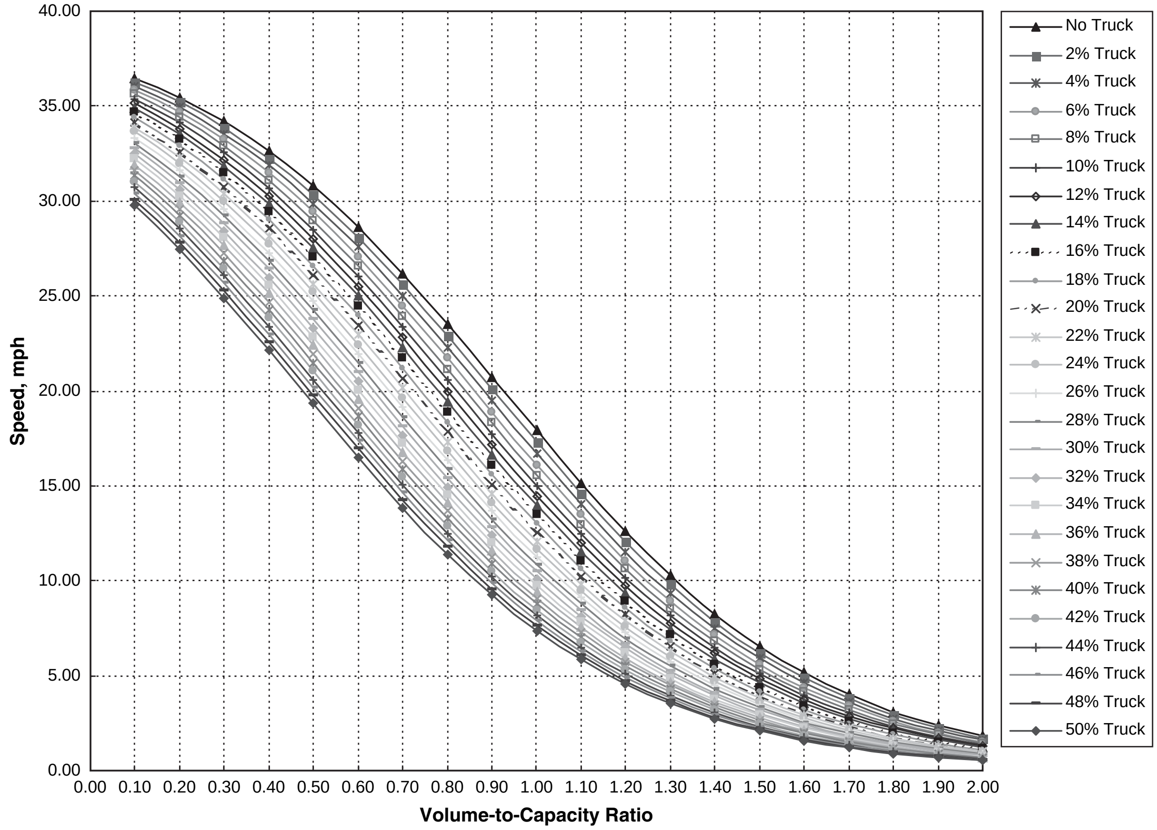

FIGURE 8 Class II urban arterial speed–flow relationships (Eq. 12) with different truck percentages (free-flow speed, 40 mph; signal density, three signals per mile).

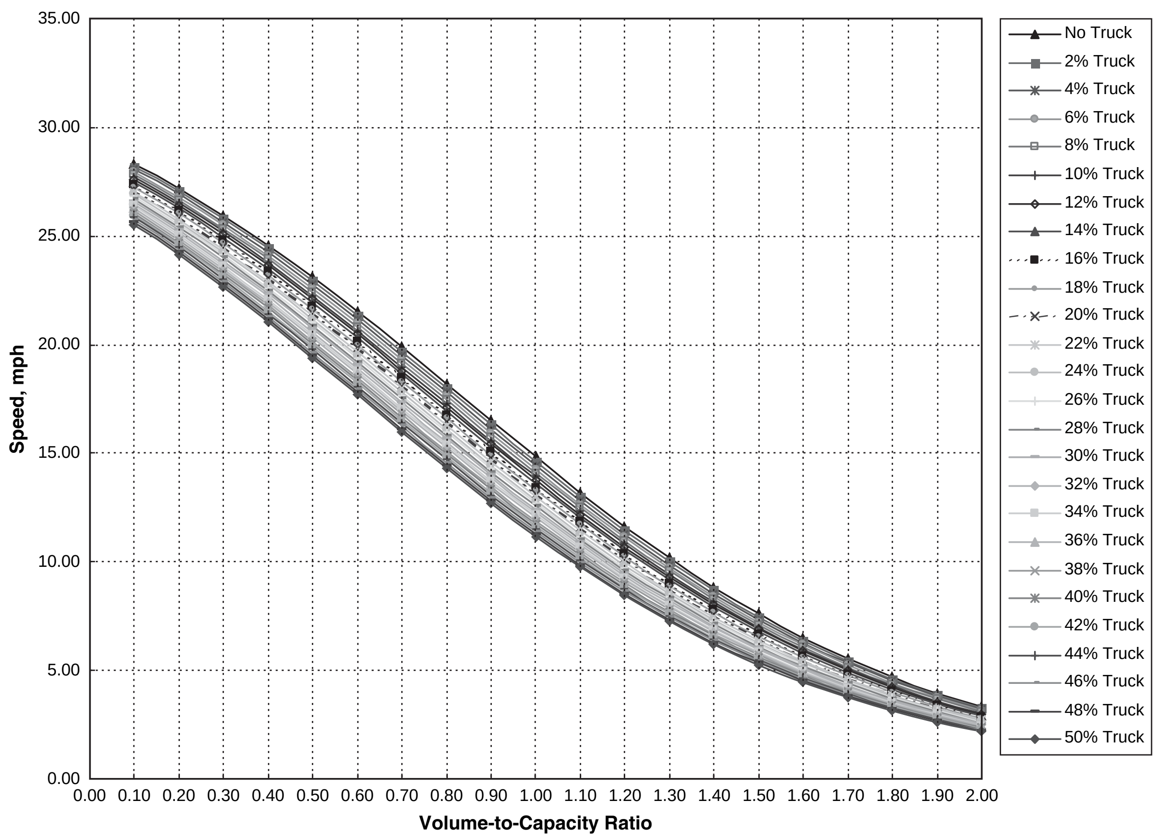

FIGURE 9 Class III urban arterial speed–flow relationships (Eq. 13) with different truck percentages (free-flow speed, 35 mph; signal density, four signals per mile).

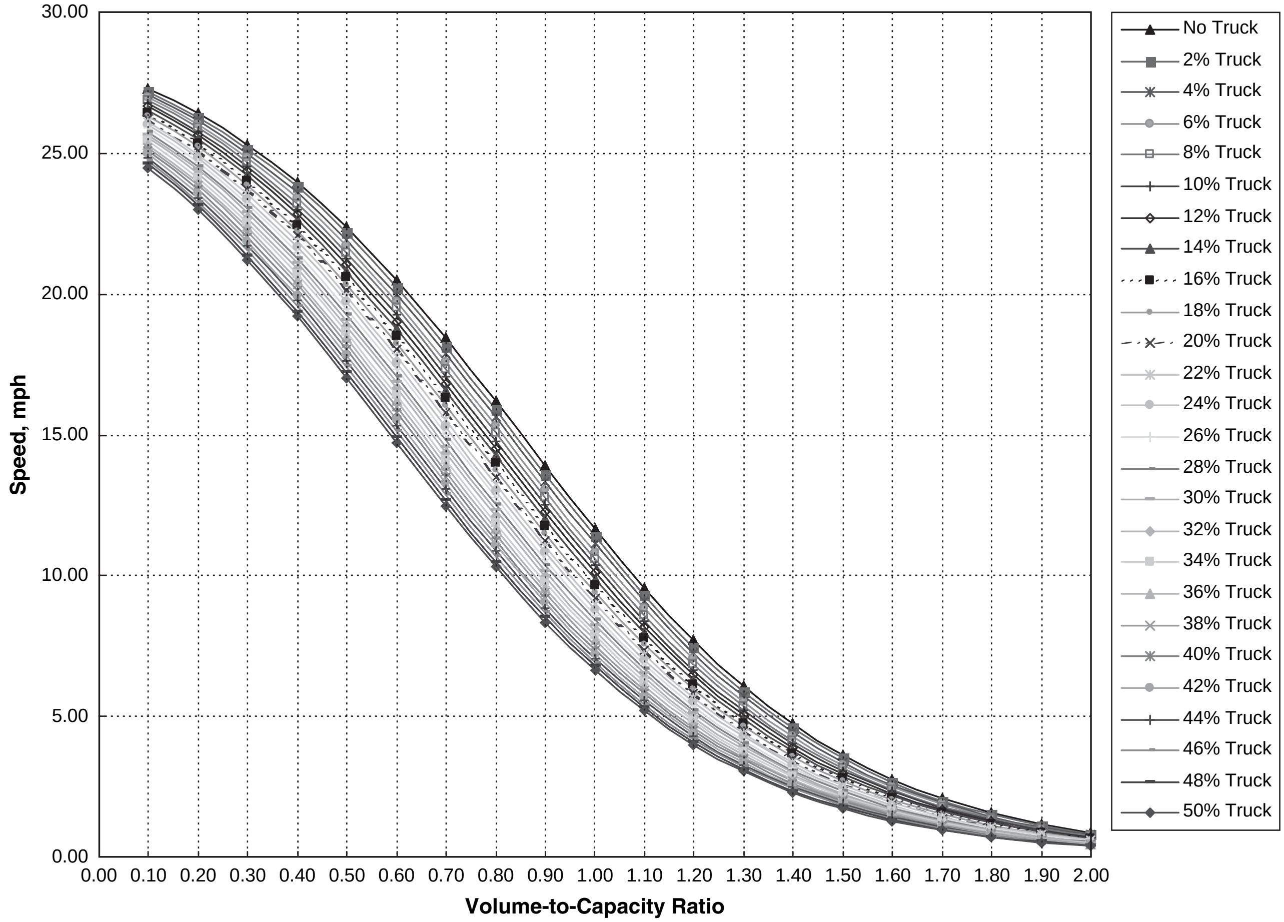

FIGURE 10 Class IV urban arterial speed–flow relationships (Eq. 14) with different truck percentages (free-flow speed, 30 mph; signal density, five signals per mile).

travel speed. In addition, the value of β is inversely related to that of α. As shown in Table 1, the values of β equal 1.234 and 1.105 for Classes I and III urban arterials, respectively. These numbers are lower than those of Classes II and IV urban arterials, which are 3.140 and 1.989, respectively. However, the respective α values for Classes I and III urban arterials are 0.136 and 0.195, which are much higher than the respective α values of 0.073 and 0.074 for Classes II and IV urban arterials. This phenomenon is not surprising given that α represents the delays caused by traffic signals. When α is low, meaning the speed drops caused by signals are low, the impact of trucks on the speed becomes more significant.

Finally, the coefficient γ in Equation 8 indicates how quickly the average speed will drop when traffic volume increases. A higher value of γ indicates a steeper drop in speed when volume increases.

CONCLUSIONS

This paper presented an updated delay calculation methodology developed for use in the urban travel demand forecasting process. The traditional BPR function representing the speed–flow relationships for roadway facilities is modified to specifically include the impact of truck traffic. Several new speed–flow curves were developed on the basis of CORSIM simulation results for freeways and urban arterials. Initial testing in the TRANPLAN and Cube Voyager implementations of the Tampa Bay regional planning model suggest this approach will yield improved traffic assignments and estimates of roadway operating speeds.

The resulting speed–flow relationships for the roadway facilities are given in Equation 7 for freeways and in Equations 11 to 14 for urban arterials.

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