TRANSYT-7F: Enhancement for Fuel Consumption, Pollution Emissions, and User Costs

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Traffic Network Study Tool Version 7F (TRANSYT-7F) is a macroscopic deterministic traffic signal system simulation and optimization computer program. The program is used to optimize the performance of urban signal systems with respect to delay, number of intersection stops, and, most significantly, fuel consumption. The fuel consumption algorithm that has been used in the TRANSYT-7F program produces estimates that are not representative of the performance of the current U.S. vehicle fleet. A new set of interrelated algorithms that consider current vehicle fleet performance is described as well as a number of other factors for estimating fuel consumption. Besides considering fuel consumption, these algorithms have been expanded in scope to include estimates of air pollutant emissions and user costs. These additions and changes will result in the expansion of the TRANSYT-7F performance data summary to cover a wider range of measures of effectiveness describing the quality of traffic signal system performance.

TRANSYT (Traffic Network Study Tool) is a traffic signal system simulation and optimization computer program. TRANSYT uses a macroscopic deterministic platoon dispersion model to simulate the flow of traffic through a street network. Version 7F of TRANSYT (TRANSYT-7F) is used extensively throughout the United States to optimize the performance of urban signal systems with respect to delay and number of intersection stops.

Besides considering delay and stops, the traffic engineer analyzing a signal system with TRANSYT-7F may also be interested in system simulation or optimization with respect to other measures of effectiveness (MOEs) such as fuel consumption, pollutant emissions, and user cost. The estimates of fuel consumption currently produced by TRANSYT-7F are based on vehicle performance data obtained in the late 1970s; therefore, they are out of date. In addition, there are some deficiencies in the fuel consumption model that cause the estimates to be inaccurate. The TRANSYT-7F program currently does not produce estimates of pollutant emissions.

A user cost model was added in Release 6 of TRANSYT-7F. This elemental user cost model considers the cost of fuel, the cost of driver and passenger time, and the cost of operating the vehicle. However, the existing model does not consider the individual components of cost associated with the operation of a vehicle.

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This paper describes a research effort that was initiated to improve and update the TRANSYT-7F fuel consumption and user cost model, as well as add a new model for producing estimates of vehicle pollutant emissions. If incorporated into TRANSYT-7F, these models will produce

1. Fuel consumption estimates that are updated and more reliable than the estimates produced by the existing TRANSYT-7F fuel consumption model;
2. Reliable estimates of vehicle pollutant emissions not currently estimated by the program; and
3. User cost estimates based on fuel consumption, pollutant emissions, driver and passenger time, and vehicle depreciation and maintenance costs.

EXISTING TRANSYT-7F FUEL CONSUMPTION MODEL

The existing fuel consumption model for TRANSYT-7F was calibrated in 1981 (*1*). That model uses the following MOEs to compute fuel consumption:

1. Total travel (vehicle-mi/hr),
2. Total delay (vehicle-hr/hr),
3. Total stops (full stops/hr), and
4. Free speed on each link (mph).

Actual vehicle fuel consumption data was collected using one test vehicle. The data were normalized to represent the 1981 U.S. vehicle fleet before being applied to the existing fuel consumption model. The data collected that were applicable to the TRANSYT-7F model included the following:

1. Fuel consumption for uniform travel speeds,
2. Fuel consumption for normal stopped idling, and
3. Excess fuel consumption (in addition to free speed consumption) resulting from a full braking stop at a normal deceleration rate from free speed, and a normal acceleration back to the same free speed.

The data were applied to an elemental model using stepwise multiple regression. Some of the limitations of this model that were pointed out at the time of its creation are listed:

1. Only one test vehicle was used to derive the relational parameters before the parameters were adjusted to represent the U.S. vehicle fleet.

2. The model does not consider the effects of
   –Traffic congestion,
   –Trucks and diesel engines,
   –Road grade and curvature,
   –Pavement surface quality, or
   –Temperature.

REQUIREMENTS FOR NEW FUEL MODEL

To develop an improved fuel consumption model for TRANSYT-7F, it is necessary to do the following:

1. Obtain updated fuel consumption data that represent the current U.S. vehicle fleet. These data must be collected with appropriate consideration given to the wide range of engine types and performance capabilities available.
2. Evaluate the relative contributions of geometric and environmental factors to overall fuel consumption and determine a method of accounting for those factors that can be addressed within the data structure and framework of TRANSYT-7F.

Each of these tasks is addressed in the discussion of the development of the proposed fuel consumption model.

Source of Fuel Consumption and Pollutant Emissions Data

This section discusses the source of the fuel consumption, pollutant emissions, and user cost data used to calibrate the models developed. A 1985 study completed by R. McGill of Oak Ridge National Laboratory for FHWA summarizes the most recent fuel consumption and pollutant emissions data available (*2*). The test procedure used combined laboratory and on-road tests using 15 vehicles. Data were collected in tabular form as a function of both acceleration and velocity. All 15 vehicles were tested for fuel consumption; 6 of them were tested for pollutant emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx).

These data fulfill the first requirement previously defined for developing a new fuel model. First, the data were collected from a set of vehicles whose performance capabilities are representative of current automotive technology. Second, the vehicles tested were selected beforehand to be representative of the wide range of performance capabilities of the current U.S. fleet. These fuel consumption data also include a representative fraction of diesel engines.

Upon completion of the tests, the consumption and emission values from all of the vehicles tested were averaged in proportion to each vehicle's contribution to the January 1986 U.S. vehicle fleet.

Geometric and Environmental Factors

Besides producing an updated fuel and pollution data set, the Oak Ridge study produced equations that describe the variation in fuel consumption and pollutant emissions as a function of roadway grade and temperature.

Roadway Grade

The effect of roadway grade is accounted for by increasing or decreasing the engine acceleration rate to counter act the acceleration due to gravity. The equation used to calculate the change in acceleration rate due to grade can be derived easily using a force balance. The effective acceleration rate due to grade is computed using the following equation:

$$A_g = 32.2(G)/[(10)(100 + G)^{1/2}]$$

where A_g equals effective engine acceleration due to grade (ft/sec^2) and G equals roadway grade (percent).

Temperature

The research that generated the new fuel consumption and pollutant emissions data also generated an approximate relationship for the effect of temperature for small cars and for medium to large cars (*2*). The correction factor is computed using the equation

$$K_t = (-0.004334)(T - 78.258) + 1$$

where K_t equals a temperature correction factor and T equals the ambient temperature in degrees Fahrenheit.

FUEL CONSUMPTION AND POLLUTANT EMISSIONS DATA REDUCTION

The fuel consumption and pollutant emissions data developed by McGill were provided in a form suitable for use in a microscopic simulation model (*2*). Because TRANSYT-7F is a macroscopic model, it was necessary to reduce the data tables to a form suitable for use in a macroscopic model. It was also desirable to fit the data to curves, since computer table lookups are far more memory-intensive and time-consuming.

The fuel consumption and pollutant emissions data were manipulated into equations that describe consumption and emission rates for the four states of vehicle motion:

1. Acceleration from an initial speed to a final speed;
2. Deceleration from an initial speed to a final speed;
3. Travel over a defined distance at a constant speed; and
4. Engine idling while the vehicle is stopped.

The equations describing the rates for the acceleration and deceleration of vehicles were obtained by applying acceleration and deceleration velocity-time profiles to the fuel consumption and pollutant emissions data. The acceleration and deceleration models were selected on the basis of their ability to predict realistic speed change distances and times over the full range of speeds normally applied to the TRANSYT-7F program. The physical equations of motions for these models are described in the following.

Acceleration Model

The nonuniform acceleration model was used for an FHWA fuel consumption-vehicle emissions-user cost study performed by Zaniewski et al. (*3*). The model expresses acceleration as a linear function of velocity.

$$A = k_1 + k_2 (V)$$

where

A = acceleration (ft/sec²),
V = velocity (ft/sec),
k_1 = initial acceleration, and
k_2 = change in acceleration due to an increase in velocity.

Using this model, the time to change from speed V_o to V_f is given by:

$$t = \{\ln[k_1 - k_2 (V_f)] - \ln[k_1 - k_2 (V_o)]\}/(-k_2)$$

where t is time to change speed (sec). The distance traveled over the time interval t from initial speed V_o is then given by

$$x = (k_1/k_2)t - (k_1/k_2^2)\{1 - \exp[-k_2(t)]\} + (V_o/k_2)\{1 - \exp[-k_2(t)]\}$$

where x is distance (ft).

In the model, k_1 is the maximum acceleration of the vehicle, and k_1/k_2 is the maximum speed obtainable. The values for k_1 and k_2 were classified by vehicle type. Values are given here for the vehicle types relevant to the fuel consumption and emissions data to be used for updating TRANSYT-7F.

	Automobile Size		
Coefficient	*Small*	*Medium*	*Large*
k_1	7.2	8.6	7.9
k_2	0.060	0.076	0.055

Using vehicle fleet mix and car type data provided by FHWA, the January 1986 U.S. vehicle fleet may be described as having 18.5 percent small cars, 20.0 percent medium cars, and 61.5 percent large cars (*1*).

Using a weighted average of the coefficients against the vehicle fleet mix, the composite coefficients obtained were 7.91 for k_1 and 0.060 for k_2. The resulting acceleration-velocity relationship is given by

$$A = 7.91 - 0.060(V)$$

The equations of motion in this acceleration model are used to predict distances and times required to reach a range of final speeds.

Deceleration Model

The linear deceleration model is used in the TEXAS Model for Intersection Traffic (*4*). The model expresses the final deceleration at zero velocity as an empirical linear function of the initial velocity before braking.

$$D_f = (K)(-6 - V_o/44)$$

where

D_f = final deceleration (ft/sec²),
V_o = initial velocity (ft/sec), and
K = empirical constant to account for observed driver behavior.

A K-value of 5.25 is used in the TEXAS Model; this was found to produce reasonable deceleration distances and times over the range of speeds normally applied to TRANSYT-7F. The slope of the deceleration versus time curve is referred to as the deceleration jerk and is given by

$$S = \tfrac{1}{2}(D_f^2)/(V_o)$$

where S is the deceleration jerk (ft/sec³).

Using this model, the time to change from speed V_o to V_f is given by

$$t = [2(V_o - V_f)/S]^{1/2}$$

where t is time (sec) and V_f is final velocity (ft/sec).

The distance traveled over the time interval t from initial speed V_o is then given by

$$x = V_o(t) + S(t^3)/6$$

The equations of motion in this deceleration model are used to predict distances and times required to decelerate from a range of initial speeds.

Data Reduction Procedure

The fuel consumption and emission rate data are expressed as a function of velocity in increments of 1 ft/sec and as a function of acceleration in increments of 1 ft/sec/sec. The acceleration model was applied to the fuel consumption data by computing the amount of time required for a vehicle to accelerate 1 ft/sec. Using the initial speed, the change in speed, and the instantaneous acceleration rate of the vehicle, the fuel consumption rate in effect over that time was obtained from the table. This consumption rate was then multiplied by the speed-change time to obtain the amount of fuel required to accelerate the vehicle 1 ft/sec. This process was repeated for all speed changes from 0 to 88 ft/sec. The cumulative sum of the consumptions from zero to any speed was thus equivalent to the amount of fuel consumed when a vehicle accelerates from zero to that desired speed. Also, by subtracting the cumulative sums from two different speeds, it was possible to obtain an estimate of the amount of fuel consumed when a vehicle accelerates from the lower speed to the higher speed.

To account for the effect of grade, it was necessary to repeat the table integration process previously described for grades between −10 and +10 percent in intervals of 2 percent. The correction for grade is applied by increasing the acceleration rate of the vehicle to compensate for hill climbing, or by decreasing the rate to compensate for gravitational accelerations in effect on negative grades. This equivalent acceleration due to grade was previously described in this paper.

A curve-fitting computer program was then used to fit least-squares curves to each of the fuel consumption curves for each grade. The program tested six different regression models and presented the results, with goodness-of-fit parameters, so the best-fitting curve could be used. The models tested included linear, transformed (exponential, power, logarithmic, and reciprocal), and parabolic (*5*). The fuel consumption for accelerations occurring on grades between these curves are computed by linear interpolation.

The same table integration routine previously described was then applied to each of the three types of pollutant emissions tables to obtain emissions as a function of speed change. Then both the fuel consumption and the pollutant emissions data were applied similarly to the deceleration model. Once again, curves describing consumption and emissions as a function of speed were obtained for the same range of roadway grades.

To describe the fuel consumption and pollutant emissions for vehicles traveling at constant speed, curves were fitted to the consumption and emissions tables for the zero acceleration case. Since the performance of a vehicle traveling at a constant speed on a grade is related to the performance of an engine accelerating or decelerating at a constant speed, additional curves were fitted to the table data for accelerations from −3 to +3 ft/sec/sec. This range of accelerations due to grade simulates the effect on the performance of a vehicle traveling on grades from −10 to +10 percent at a constant speed. Consumption and emissions for idling during stopped delay were taken as the zero velocity–zero acceleration rate from the data tables. Variables for the N tables follow:

- G = roadway grade (%),
- A_g = acceleration on grade (ft/sec²),
- V = travel speed (ft/sec),
- V_i = initial speed (ft/sec),
- V_f = final speed (ft/sec),
- F = fuel consumption rate,
- CO = carbon monoxide emissions rate,
- HC = hydrocarbon emissions rate,
- NO_x = nitrogen oxide emissions rate,
- V_{mph} = travel speed (mph),
- OIL = oil consumption rate,
- TIRE = tire wear rate (% worn),
- REP = repair visit (% visit),
- DEP = vehicle depreciation rate (% initial cost).

Table 1 lists the group of fuel consumption equations obtained as the result of this data reduction procedure. Tables 2 through 4 list the group of equations obtained for carbon monoxide, hydrocarbons, and nitrogen oxide emissions.

TABLE 1 Fuel Consumption Rate

DELAY CONSUMPTION (Gallons per Vehicle Second)

$F_{delay} = 0.00013$

ACCELERATION SPEED CHANGE CONSUMPTION (Gallons per Vehicle)

$A = 1.6570 + 0.0073607(G) + 0.0006955(G^2)$

$B = 0.30934 + 0.005019(G) - 0.001271(G^2)$

$F_{accel} = (10^B)(V_f^A - V_i^A)/100000$

DECELERATION SPEED CHANGE CONSUMPTION (Gallons per Vehicle)

$A = 1.48922 + 0.0048494(G) - 0.000278(G^2)$

$B = -0.022132 - 0.029157(G) + 0.0010894(G^2)$

$F_{decel} = (10^B)(V_i^A - V_f^A)/100000$

CONSTANT SPEED FUEL CONSUMPTION (Gallons per Vehicle Foot)

For Grades Less Than −1 Percent

$F_{const} = [14.074(e^{(0.0074057(V))})]/(100000(V))$

For Grades Between −1 and 0 Percent

$A = 14.074(e^{(0.0074057(V))})$

$B = 14.234(e^{(0.016779(V))})$

$F_{const} = [A + (B - A)(A_g + 1)]/(100000(V))$

For Grades Between 0 and 1 Percent

$A = 14.234(e^{(0.016779(V))})$

$B = 22.081(e^{(0.020016(V))})$

$F_{const} = [A + (B - A)(A_g)]/(100000(V))$

For Grades Between 1 and 2 Percent

$A = 22.081(e^{(0.020016(V))})$

$B = 23.351 + 1.0005(V) + 0.011864(V^2)$

$F_{const} = [A + (B - A)(A_g - 1)]/(100000(V))$

For Grades Greater Than 2 Percent

$A = 23.351 + 1.0005(V) + 0.011864 * V^2$

$B = 23.006 + 1.9495(V) + 0.0093498 * (V^2)$

$F_{const} = [A + (B - A)(A_g - 2)]/(100000(V))$

TABLE 2 Carbon Monoxide Emissions Rate

DELAY EMISSIONS (Grams per Vehicle Second)

$CO_{delay} = 0.003$

ACCELERATION SPEED CHANGE EMISSIONS (Grams per Vehicle)

$A = 2.43738 - 0.005583(G) - 0.000760(G^2)$

$B = -0.49326 + 0.036210(G) + 0.0002949(G^2)$

$CO_{accel} = (10^B)(V_f^A - V_i^A)/1000$

DECELERATION EMISSIONS (Grams per Vehicle)

$A = 1.54246 + 0.0051115(G) - 0.000288(G^2)$

$B = -0.751286 - 0.029621(G) + 0.0011968(G^2)$

$CO_{decel} = (10^B)(V_i^A - V_f^A)/1000$

CONSTANT SPEED CARBON MONOXIDE EMISSIONS RATE (Grams per Vehicle Foot)

For Grades Less Than −1 Percent

$CO_{const} = 3.0741(e^{(0.0093192(V))})/(1000(V))$

For Grades Between −1 and 0 Percent

$A = 3.0741(e^{(0.0093192(V))})$

$B = 3.3963(e^{(0.014561(V))})$

$CO_{const} = [A + (B - A)(A_g + 1)]/(1000(V))$

For Grades Between 0 and 1 Percent

$A = 3.3963(e^{(0.014561(V))})$

$B = 4.6927(e^{(0.031454(V))})$

$CO_{const} = [A + (B - A)(A_g)]/(1000(V))$

For Grades Between 1 and 2 Percent

$A = 4.6927(e^{(0.031454(V))})$

$B = 5.5812(e^{(0.047365(V))})$

$CO_{const} = [A + (B - A)(A_g - 1)]/(1000(V))$

For Grades Greater Than 2 Percent

$A = 5.5812(e^{(0.047365(V))})$

$B = 6.5785(e^{(0.064392(V))})$

$CO_{const} = [A + (B - A)(A_g - 2)]/(1000(V))$

VEHICLE MAINTENANCE AND USER COST DATA

Data for oil consumption, tire wear, vehicle maintenance and repair costs, and depreciation came from the 1982 study completed by Zaniewski et al. at the Texas Research and Development Foundation (*3*). Four passenger cars were tested, and the results were classified for small, medium, and large vehicles according to engine size. Then these tables were combined into one table with a proportional representation of each size of vehicle in the U.S. vehicle fleet.

The physical units for the four vehicle maintenance parameters were quarts of oil for oil consumption; percentage wear

TABLE 3 Hydrocarbon Emissions Rate

DELAY EMISSIONS (Grams per Vehicle Second)
$HC_{delay} = 0.0003$
ACCLERATION SPEED CHANGE EMISSIONS
(Grams per Vehicle)
$A = 2.0145 - 0.26268/ (G)$
$B = -0.56356 + 0.016475(G) + 0.0002783(G^2)$
$HC_{accel} = (10^B)(V_f^A - V_i^A)/10000$
DECELERATION SPEED CHANGE EMISSIONS
(Grams per Vehicle)
$A = 1.7741 + 0.0041659(G) - 0.000388(G^2)$
$B = -0.98898 - 0.028385(G) + 0.0012138(G^2)$
$HC_{decel} = (10^B)(V_i^A - V_f^A)/10000$
CONSTANT SPEED HYDROCARBON EMISSIONS RATE
(Grams per Vehicle Foot)
For Grades Less Than −1 Percent
$HC_{const} = 2.9262(e^{(0.020118(V))})/(10000(V))$
For Grades Between −1 and 0 Percent
$A = 2.9262(e^{(0.020118(V))})$
$B = 2.7843(e^{(0.015062(V))})$
$HC_{const} = [A + (B - A)(A_g + 1)]/(10000(V))$
For Grades Between 0 and 1 Percent
$A = 2.7843(e^{(0.015062(V))})$
$B = 3.7248(e^{(0.023644(V))})$
$HC_{const} = [A + (B - A)(A_g)]/(10000(V))$
For Grades Between 1 and 2 Percent
$A = 3.7248(e^{(0.023644(V))})$
$B = 4.2789(e^{(0.033437(V))})$
$HC_{const} = [A + (B - A)(A_g - 1)]/(10000(V))$
For Grades Greater Than 2 Percent
$A = 4.2789(e^{(0.033437(V))})$
$B = 5.2305(e^{(0.040708(V))})$
$HC_{const} = [A + (B - A)(A_g - 2)]/(10000(V))$

TABLE 4 Nitrogen Oxide Emissions Rate

DELAY EMISSIONS (Grams per Vehicle Second)
$NOX_{delay} = 0.0003$
ACCELERATION SPEED CHANGE EMISSIONS
(Grams per Vehicle)
$A = 1.6573 - 0.010139(G) + 0.0017341(G^2)$
$B = 0.51557 + 0.040046(G) - 0.002613 (G^2)$
$NOX_{accel} = (10^B)(V_f^A - V_i^A)/10000$
DECELERATION SPEED CHANGE EMISSIONS
(Grams per Vehicle)
$A = 1.4293 + 0.0047751(G) - 0.000276(G^2)$
$B = -0.77628 - 0.029074(G) + 0.0010873(G^2)$
$NOX_{decel} = (10^B)(V_i^A - V_f^A)/10000$
CONSTANT SPEED NITROGEN OXIDE EMISSIONS RATE
(Grams per Vehicle Foot)
For Grades Less Than −1 Percent
$NOX_{const} = 1.7325(e^{(0.011815(V))})/(10000(V))$
For Grades Between −1 and 0 Percent
$A = 1.7325(e^{(0.011815(V))})$
$B = 1.5718(e^{(0.040732(V))})$
$NOX_{const} = [A + (B - A)(A_g + 1)]/(10000(V))$
For Grades Between 0 and 1 Percent
$A = 1.5718(e^{(0.040732(V))})$
$B = 4.2279(e^{(0.050231(V))})$
$NOX_{const} = [A + (B - A)(A_g)]/(10000(V))$
For Grades Between 1 and 2 Percent
$A = 4.2279(e^{(0.050231(V))})$
$B = 1.1096(V^{1.2624})$
$NOX_{const} = [A + (B - A)(A_g - 1)]/(10000(V))$
For Grades Greater Than 2 Percent
$A = 1.1096(V^{1.2624})$
$B = 3.0515 (V^{1.1111})$
$NOX_{const} = [A + (B - A)(A_g - 2)]/(10000(V))$

of usable tread for tire wear; percentage of average maintenance or repair job for maintenance and repair costs; and percentage depreciation of initial new-car value for vehicle depreciation. The vehicle maintenance data were presented for constant speed vehicle motion and for speed changes. The constant speed data were presented as the amount of maintenance incurred when a vehicle travels 1,000 mi at a constant speed. The data covered the range of speeds from 0 to 60 mph. The speed change data were presented as the amount of maintenance incurred when a vehicle decelerates from a speed in the range of 0 to 60 mph to a full stop, then accelerates back to the initial speed. The data tables for both constant speed and speed change vehicle maintenance forms of motion were also presented as a function of roadway vertical grade.

Least-squares curves were fitted to the four vehicle maintenance parameters as a function of speed for a range of roadway grades from −10 to +10 percent. Then curves were fitted to the parameters of these curves as a function of roadway grade. Tables 5 through 8 present the equations obtained from the curve-fitting procedure.

TABLE 5 Oil Consumption

CONSTANT SPEED OIL CONSUMPTION
(Quarts per Vehicle Mile)
For Grades Greater Than 2 Percent
$A = -0.60125 - 0.26406(LOG_{10}(G))$
$B = 1.1060 + 1.0459 (LOG_{10}(G))$
$OIL_{const} = [10^B(V_{mph}{}^A)]/1000$
For Grades Between 0 and 2 Percent
$A = 13.83557 + 14.86654(G)$
$B = 0.99220 + 0.136932(G)$
$OIL_{const} = [B + A/(V_{mph})]/1000$
For Grades Between −2 and 0 Percent
$OIL_{const} = [0.99272 + 13.836/(V_{mph})]/1000$
For Grades Less Than −2 Percent
$A = - 27.693 - 16.637(G)$
$B = - 0.40799 - 3.4550/(G)$
$OIL_{const} = [B + A/(V_{mph})]/1000$
SPEED CHANGE OIL CONSUMPTION
(Quarts per Speed Change Cycle)
$OIL_{a/d} = [0.0017727 + 0.0005531 * V_{mph}]/1000$

NEW DATA INPUT REQUIREMENTS

Implementing the new fuel, pollution, and user cost models will require new data that are not currently provided for in the existing TRANSYT-7F data input cards. Most of the new data are organized onto two new data input cards that fit into the existing series of cards required to run TRANSYT-7F. The roadway grade parameter is added to one of the existing TRANSYT-7F card types.

Roadway Grade Data

The grade of each roadway link in TRANSYT-7F may be designated using one of the unused fields from the link ex-

TABLE 6 Tire Wear Rate

CONSTANT SPEED TIRE WEAR
(Percent Tread Worn per Vehicle Mile)

For Grades Greater Than −1 Percent

$$A = 10^{(-1.1894)}(G + 2)^{(-0.73580)}$$
$$B = -4.3958 + 5.0811(\mathrm{LOG}_{10}(G + 2))$$
$$\mathrm{TIRE}_{const} = [e^{(B)}e^{(A(Vmph))}]/100000$$

For Grades Between −4 and −1 Percent

$$A = e^{(-2.883183)}e^{(-0.045573(Vmph))}$$
$$B = -0.23931 - 0.12724(\mathrm{LOG}_{10}(V_{mph}))$$
$$\mathrm{TIRE}_{const} = [A + (B - A)(G + 2)]/100000$$

For Grades Less Than −4 Percent

$$A = 0.0061936 + 0.0027882(G)$$
$$B = -0.85561 - 0.27553(G)$$
$$\mathrm{TIRE}_{const} = [B + A(V_{mph})]/100000$$

SPEED CHANGE TIRE WEAR
(Percent Tread Worn per Speed Change Cycle)

$$\mathrm{TIRE}_{a/d} = 10^{(-2.78104)}(Vmph^{(1.84284)})/100000$$

TABLE 7 Maintenance and Repair Rate

CONSTANT SPEED MAINTENANCE AND REPAIR
(Percent of Visit per Vehicle Mile)

For Grades Greater Than −2 Percent

$$A = e^{(-4.56393)}(e^{(0.040463(G))})$$
$$B = e^{(1.32637)}(e^{(0.0019682(G))})$$
$$\mathrm{REP}_{const} = e^{(B)}(e^{(A(Vmph))})/100000$$

For Grades Between −4 and −2 Percent

$$A = -0.53013 + 0.13827(G)$$
$$B = -3.329245 - 25.10303(G)$$
$$\mathrm{REP}_{const} = [B + A(V_{mph})]/100000$$

For Grades Less than −4 Percent

$$A = -1.108532 + 0.0007879(G)$$
$$B = 7.9614 - 22.43846(G)$$
$$\mathrm{REP}_{const} = [B + A(V_{mph})]/100000$$

SPEED CHANGE MAINTENANCE AND REPAIR
(Percent of Visit per Speed Change Cycle)

$$\mathrm{REP}_{a/d} = 10^{(-2.88889)}(V_{mph}{}^{(2.01258)})/100000$$

TABLE 8 Vehicle Depreciation Rate

CONSTANT SPEED DEPRECIATION
(Percent Depreciation per Vehicle Mile)

$$\mathrm{DEP}_{const} = [1.4704 - 0.54925(\mathrm{LOG}_{10}(V_{mph}))]/100000$$

SPEED CHANGE DEPRECIATION
(Percent Depreciation per Speed Change Cycle)

$$\mathrm{DEP}_{a/d} = 0.0002462(V_{mph})/100000$$

tension card (Card Type 29). Fields 5 and 6 on Card Type 29 are not currently used for any purpose. The roadway grade is used to correct fuel consumption, pollution emissions, and user cost estimates for the effect of grade.

User Cost Data Input Card

This new card provides the user cost model with up-to-date unit cost information: consumer price index, gasoline price, oil price, tire price, new vehicle price, cost of an average shop maintenance and repair job, and value of travel time.

The unit cost data are applied to the user cost models so that an estimate of user cost associated with a given signalization scheme may be determined as an MOE.

Environment Data Input Card

The second new data input card is the environment data input card. This card would be required to provide correction factors for fuel consumption and pollutant emissions as well as the ambient temperature of the study area. The fuel and pollution correction factors may be used to correct fuel and pollution estimates to better represent current and local conditions. The ambient temperature is used to adjust fuel consumption and pollutant emissions for the effect of temperature.

COMPARISON OF OLD AND NEW FUEL CONSUMPTION MODELS

The fuel consumption estimates produced by the existing TRANSYT-7F fuel model were compared with those of the proposed fuel model. Table 9 shows a parametric comparison between fuel rates predicted by the two models as a function of speed. As expected, the idling fuel consumption estimate is lower for the new model. This occurred because the new fuel model was calibrated using a vehicle fleet mix with better fuel efficiency than those used to calibrate the old model.

A comparison of the constant speed fuel consumption between the two models indicates that the current TRANSYT-7F fuel model predicts fuel consumption values lower than the new model in ranges below 20 mph. The predicted fuel consumptions are nearly equal in the range of 20 to 40 mph;

TABLE 9 Comparison of Fuel Consumption Estimates

Idling Stopped Delay Fuel Consumption (Gallons per Vehicle-Hour)		
	Existing Fuel Model	Proposed Fuel Model
	0.732	0.468

Constant Speed Travel Fuel Consumption (Gallons per Mile)		
Speed (MPH)	Existing Fuel Model	Proposed Fuel Model
10	0.055	0.064
20	0.042	0.042
30	0.035	0.036
40	0.034	0.034
50	0.040	0.035
60	0.052	0.037

Extra Fuel Consumption for Stop-and-Go Speed Change Cycle (Gallons per Cycle)		
Speed (MPH)	Existing Fuel Model	Proposed Fuel Model
10	0.0014	0.0021
20	0.0052	0.0055
30	0.0120	0.0110
40	0.0210	0.0182
50	0.0330	0.0248
60	0.0480	0.0312

however, fuel efficiency for the new model is much better at speeds above 40 mph. This is consistent with trends toward fuel economy in this speed range through better vehicle aerodynamics. Figure 1 graphically displays the variation of fuel comparison with speed for both models.

A comparison of the speed change fuel consumption between the two models indicates that the newer vehicle fleet used to calibrate the new fuel model is more efficient than the older fleet only at speeds in excess of 35 mph. This improvement is also consistent with the trend toward better fuel economy at higher speeds. Figure 2 graphically displays the variation of fuel consumption with speed for both models.

IMPLEMENTATION OF NEW MODELS

This section describes considerations pertaining to the implementation of the new fuel, pollution, and user cost models as

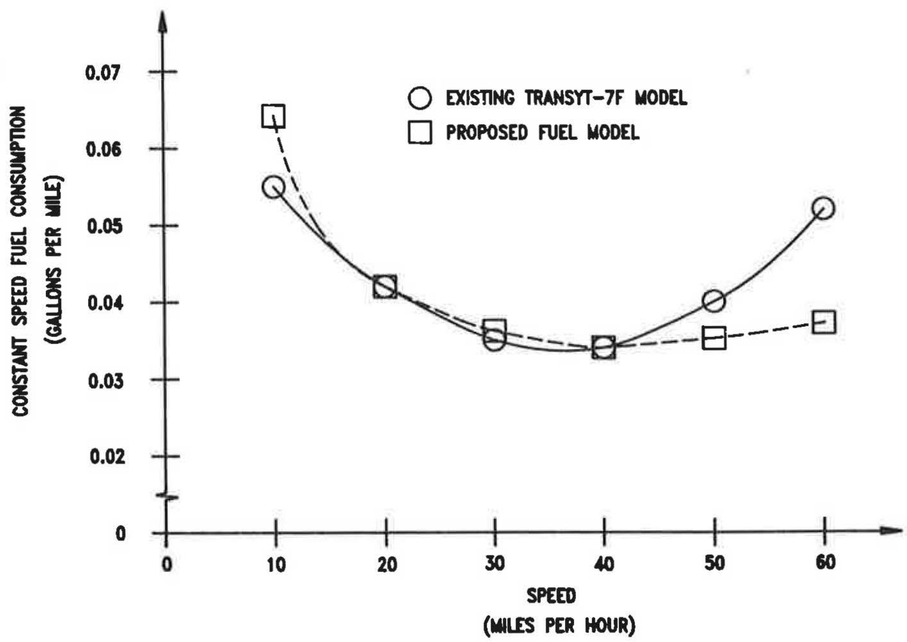

FIGURE 1 Comparison of constant speed fuel consumption.

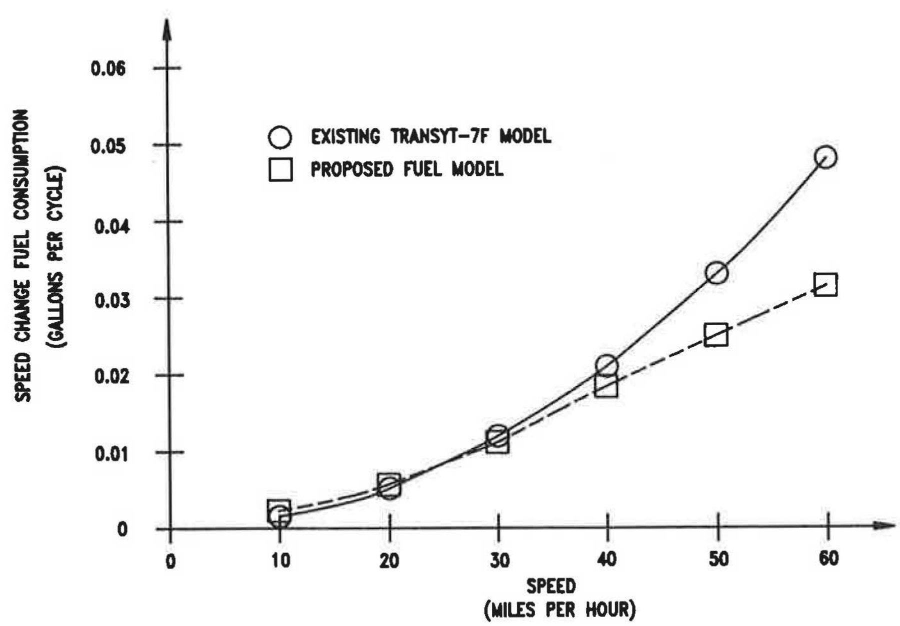

FIGURE 2 Comparison of speed change fuel consumption.

part of the TRANSYT-7F program. The new fuel, pollution, and user cost models may be easily implemented as part of the TRANSYT-7F program by coding the equations from Tables 1 through 8 into subroutines. This method of implementation would require that the following modifications be made:

1. Modify the TRANSYT-7F input utility to accept the two new data input cards and roadways grade. The input routine could be set up to generate automatically a set of default values for cost coefficients; all roadway grades could be set to a zero default unless otherwise coded by the user.
2. Modify the TRANSYT-7F program input routine to accept the two new data input cards and the roadway grade parameter.
3. Add the new fuel, pollution, and user cost equations as functions or subroutines to the TRANSYT-7F source code. Delete the existing fuel and user cost subroutines and functions.

CONCLUSIONS

New technology is leading to new patterns in fuel consumption and pollutant emissions. There is growing concern about energy conservation, urban air pollution, and economic justification of government public works improvements. Thus, the need for an updated fuel consumption model, a pollutant emissions model, and a user cost estimation model in TRANSYT-7F can be easily understood. With these models available, traffic engineers using TRANSYT-7F will have a means by which consumption, emissions, and user cost MOEs may be incorporated into signal systems timing design.

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