AN ABSTRACT OF THE THESIS OF

William Curtis Cantwell for the degree of Master of Science

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Title: AN ANALYTICAL MODEL FOR PREDICTING TRUCK PERFORMANCE ON INTERSTATE HIGHWAYS

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John G. Mingle

This thesis describes a Truck Performance Simulation Model developed for use in a United States Department of Transportation university research project entitled "The Energy, Economic and Environmental Consequences of Increased Vehicle Size and Weight." The performance of the truck is found by specifying its engine, driveline and tire characteristics and evaluating its ability to overcome the resistances encountered while traveling on a highway section of specified horizontal and vertical alignment. Fuel consumption, exhaust gaseous emissions, distance, velocity and acceleration are calculated for time intervals which vary in length with the road terrain encountered.

The simulation logic is described and suggested methods for testing and validating the accuracy of the truck simulation technique used are presented.

An Analytical Model for Predicting Truck Performance on Interstate Highways

by

William Curtis Cantwell

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AN ANALYTICAL MODEL FOR PREDICTING TRUCK PERFORMANCE ON INTERSTATE HIGHWAYS

I. INTRODUCTION

During the 1976-1977 school year, a university research project, funded by the United States Department of Transportation (USDOT), was conducted at Oregon State University. This project entitled "The Energy, Economic and Environmental Consequences of Increased Vehicle Size and Weight," developed a decision model that could be used to evaluate the total effect of larger and heavier trucks on the road system (1).[1] The purpose of this decision model was to see whether the use of such vehicles would be energy and cost effective and to investigate operational and environmental consequences resulting from their use (2).

This decision model required a means of predicting the performance of trucks of various configurations over specified highway sections. Although truck performance simulation programs have been developed in the past, these programs are either proprietary in nature or were found to be unsuitable for the USDOT decision model. Therefore, it became necessary to develop a vehicle simulation program in order to accomplish the project objectives.

The Truck Performance Simulation program developed is a time-based computer model. It evaluates the total resistance that the vehicle must overcome on a highway section of specified horizontal and vertical alignment. The resistances encountered are tire rolling

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[1] Numbers in parentheses designate references in the Bibliography.

resistance, air resistance, grade resistance and cornering resistance. The performance of the truck is then found by specifying its engine, driveline and tire characteristics (e.g., maximum brake horsepower, brake specific fuel consumption, tire size and type) and, then, evaluating its ability to overcome these resistance forces. Fuel consumption, exhaust gaseous emissions, distance, velocity and acceleration are then determined for a specified time interval. The length of each time interval varies with the severity of the terrain encountered.

In the USDOT decision model, the Performance Model is a portion of a traffic operations subsystem which also analyzes the truck's effect on other vehicles in the traffic stream. The traffic operations component estimates the capacity of the roadway resulting from reduced truck speeds on hilly terrain and speed changes due to traffic conditions. The traffic stream speed is an input to the Truck Performance Model (2). However, for this thesis, the Performance Program has been removed from the traffic operations subsystems. This has required the use of supporting subroutines not found in the USDOT decision model. These subroutines will be identified as the program is described.

The Truck Performance Model is written in Fortran IV. and has been designed to run on the CDC Cyber 70 computer at Oregon State University. However, only minor modifications should be necessary to run the program on another computer of similar size and capabilities.

II. TRUCK PERFORMANCE SIMULATION

A general flowchart for the Truck Performance Model is shown in Figure 1. A copy of the computer program is given in Appendix 1. The data input to the USDOT model is handled by the main program and is supplied to the Performance Model using labeled COMMON areas. In the version described in this thesis, the data is read by the executive program TSTTRK. The USDOT portion of the model begins with subroutine TRKOPS. Subroutine TRKOPS initializes variables and calls the other subroutines of the program.

A. Data Required

The specific truck data required to use the Truck Performance Simulation Program is listed in Table 1. Most of these data are readily available from manufacturers of custom truck tractors. Engine fuel consumption data must be requested from the engine manufacturer.

Data for the roadway over which the simulation is to occur must also be obtained. For the Performance Model, the roadway is divided into vertical road sections of constant grade or constantly changing grade as shown in Figure 2. The speed restrictions due to horizontal alignment (e.g., highway curves) are added to the vertical road section in which they occur. The specific roadway data required are listed in Table 2. Also listed are the weather data required by the Truck Performance Program.

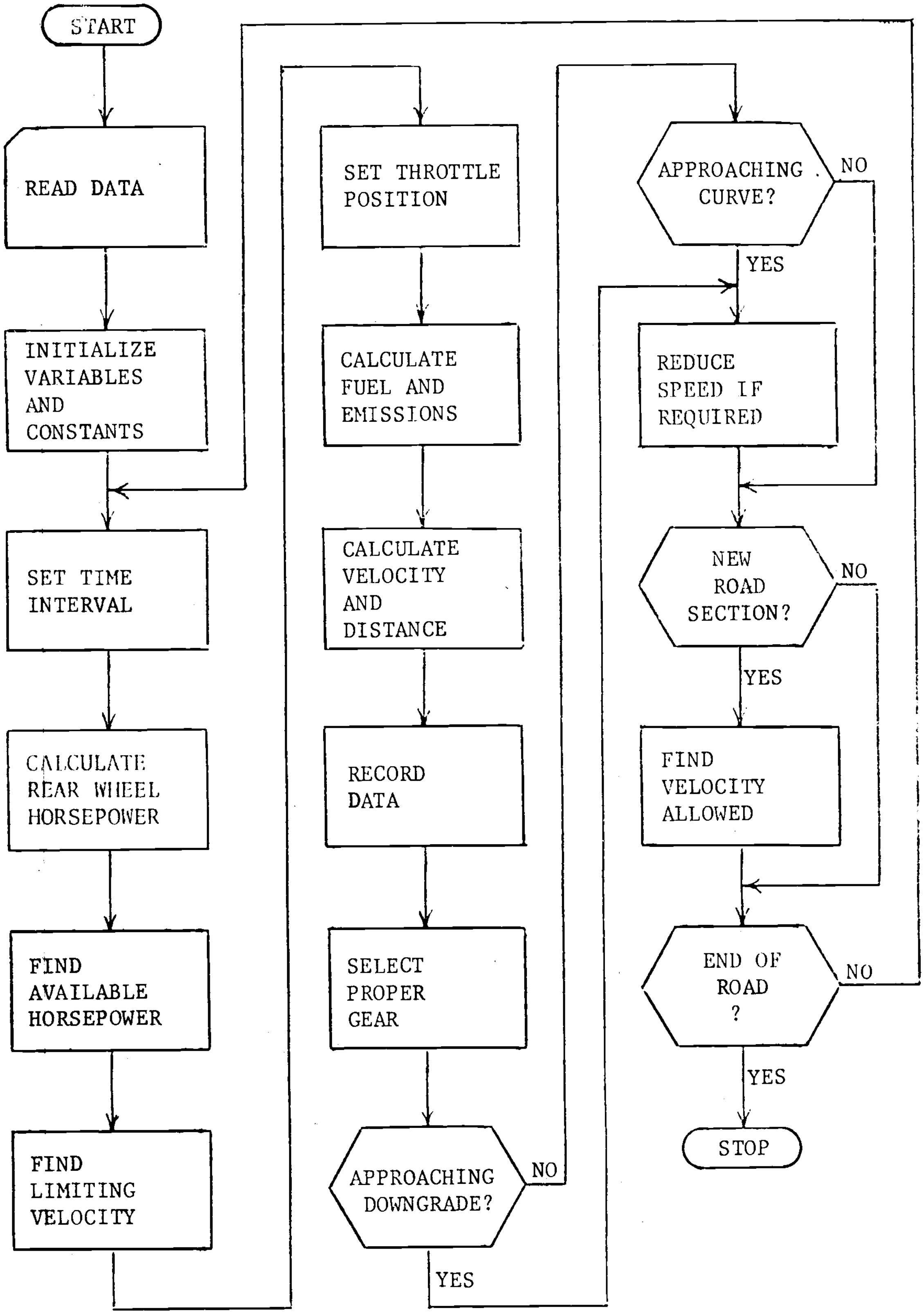

Figure 1. General Flowchart for the Truck Performance Model

TABLE 1. TRUCK DATA REQUIRED FOR PROGRAM TSTTRK

DESCRIPTION	PROGRAM NAME
ENGINE DETAIL	ENGINE(I)
Displacement, cubic inches	(1)
Maximum horsepower engine speed, rpm	(2)
Accessory horsepower	(3)
Lower shift limit, rpm	(4)
Upper shift limit, rpm	(5)
Lowest allowed engine speed, rpm	(6)
Maximum engine speed (red-line), rpm	(7)
Maximum engine horsepower	(8)
FUEL PERFORMANCE MAP, lb/bhp-hr	BSFC (I,J)
Horsepower, J	Up to J = 70
Engine rpm, I	Up to I = 20
MAXIMUM HORSEPOWER CURVE	BHPMAX (K)
Engine rpm, K	Up to K = 20
DRIVELINE DETAIL	
Number of gears	NOGEAR
Rear axle ratio	AXLRTO
Driveline loss terms	DRLOSS(L)
Full throttle efficiency	(1)
Viscous loss factor	(2)
Transmission gear ratios	GEARNO(M)
First gear	(1)
Second gear	(2)
. . . . Final gear	Up to M = 15

TABLE 1. TRUCK DATA REQUIRED FOR PROGRAM TSTTRK (Continued)

DESCRIPTION	PROGRAM NAME
TIRE AND RIM DETAIL	TIRRIM(N)
Tire outside diameter, inches	(1)
Tire weight, pounds	(2)
Static loaded radius, inches	(3)
Drive tire revolutions per mile	(4)
Total number of tires	(5)
Nominal rim diameter, inches	(6)
BRAKE SPECIFIC EMMISSION RATE, gm/bhp-hr	TKBSER(I)
Hydrocarbons	(1)
Carbon monoxide	(2)
Oxides of nitrogen	(3)
TRUCK CONFIGURATION DETAIL	
Total vehicle weight, pounds	GCW
Overall width, feet	WIDTH
Overall height, feet	HEIGHT
Air drag coefficient	DRAGCO

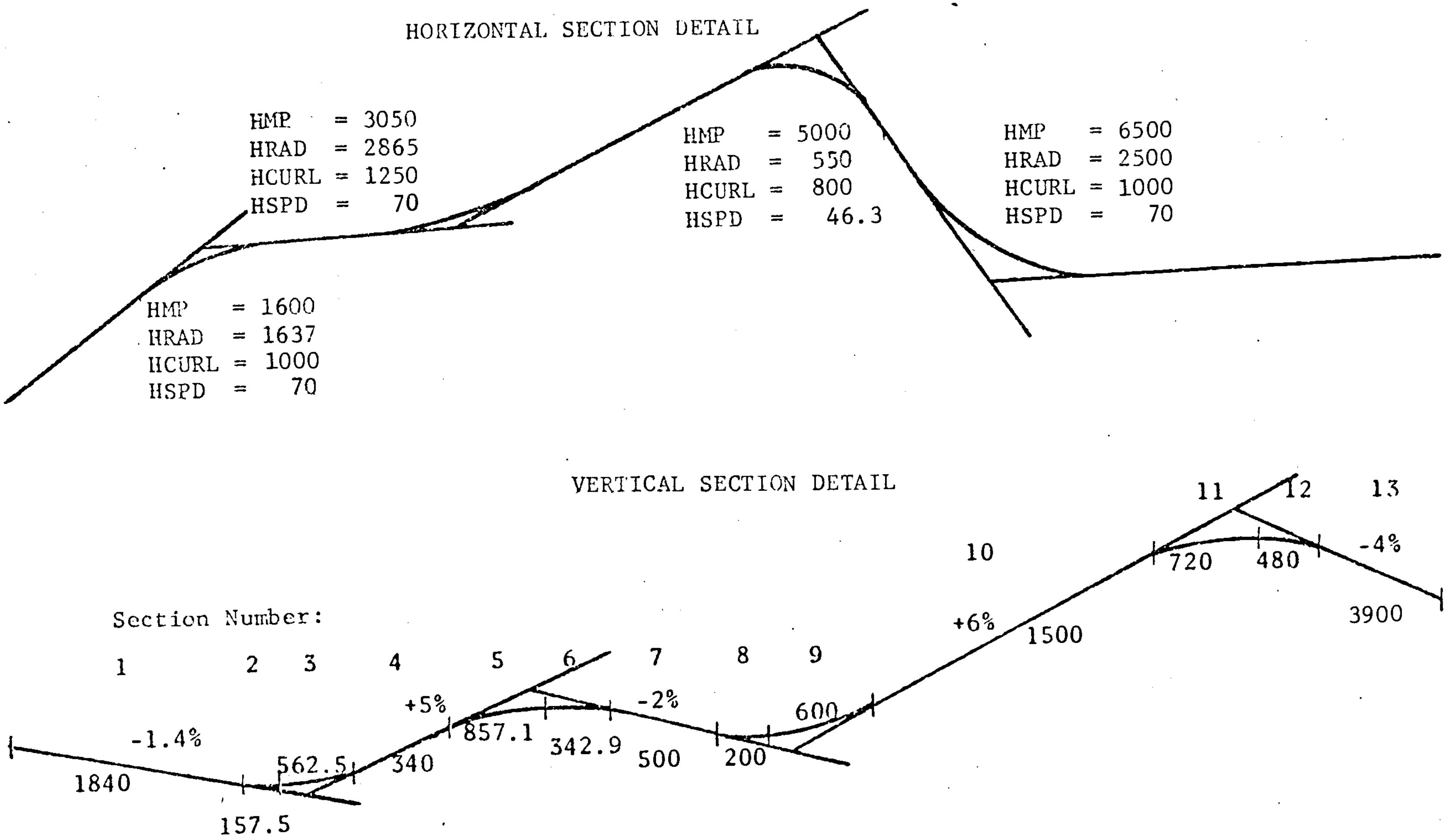

Figure 2. Sample Roadway Section

TABLE 2. ROAD AND WEATHER DATA REQUIRED FOR PROGRAM TSTTRK

DESCRIPTION	PROGRAM NAME
VERTICAL SECTION DETAIL	
Mile post at end of section, ft	VMP(i)
Constant grade, percent/100	GR(i)
Length, ft	LENG(i)
Radius of curve, ft	VCRAD(i)
Rate of change of grade, percent/100	R(i)
Number of vertical sections	NVERT
	i = 1 to NVERT
HORIZONTAL SECTION DETAIL	
Mile post at beginning of curve, ft	HMP(i)
Radius of curve, ft	HRAD(i)
Length of curve, ft	HCURL(i)
Maximum velocity allowed, mph	HASPD(i)
Curve warning mile post, ft	MPLA(i)
Number of horizontal sections	NCURVE
	i = 1 to NCURVE
WEATHER INFORMATION	WETHER(j)
Wind direction, degrees clockwise from North	(1)
Wind velocity, mph	(2)
Ambient air temperature, °F	(3)
Atmospheric pressure, in. Hg.	(4)
Water vapor pressure, in. Hg.	(5)
PAVEMENT DETAIL	
Static rolling resistance coefficient	CS
Dynamic rolling resistance coefficient, $1/mph^{-1}$	CV
Tire and pavement interaction coefficient	CP
POSTED SPEED LIMIT	SPDLMT

B. Beginning the Simulation

The program design can best be shown by describing the subroutines as they are called by subroutine TRKOPS. As an aid to the reader, the variable names used in the equations given are those used in the computer program. Also, as variables are defined, their computer names are shown in parentheses. A glossary of variable names is given in Appendix 2.

The truck is allowed to enter the first vertical road section (NOVSEC) at the maximum allowed velocity (VELALL). Because only freeway or primary road sections are used in the program, no provision has been made for starting and stopping the vehicle. If the truck comes to a stop during the simulation, an error message is relayed and the program is terminated.

There are several velocity constraints that may limit a truck's maximum velocity on a road section. The maximum allowed speed for the truck, which is determined by the transmission and rear axle gear ratios and the engines maximum (red-line) speed (TRKMAX), places an upper limit on velocity. The traffic stream speed (SPD) may also place an upper limit on truck velocity. (This variable is supplied by the traffic operations subsystem in the USDOT decision model when subroutine STRMSP is called. In the Performance Model described here, a constant speed is the input when STRMSP is called.) The posted speed may put an additional restraint on the allowed truck velocity (SPDLMT).

Subroutine ALLVEL finds the smallest of the velocity constraints described above and defines this as the maximum allowed velocity

(VELALL) on the vertical road section. A flowchart for this subroutine is shown in Figure 3. Subroutine ALLVEL is called at the beginning of each new vertical road section (NOVSEC).

Other speed-limiting factors are the road geometrics. Horizontal curves and downgrades may require reduced speeds in order to maintain safe operating conditions. The velocity required for these road conditions (VELMAX) is found by Subroutines DWNHILL and HRZCRV which are described later. The variables VELMAX and VELALL are compared and the smallest velocity becomes the limiting velocity (VELLMT). The truck is allowed to accelerate to this velocity if it is capable of doing so.

Subroutine GRSLCT is now called to find the gear suitable for the road geometrics initially encountered. This subroutine will be described in a later section.

C. The Performance Prediction Loop

The performance simulation loop begins when the time interval is set. The various subroutines are then called to obtain and to store the data for the time interval. This procedure is repeated for each new time interval until the end of the highway data is encountered.

1. Setting the Time Interval

The length of each time interval is found by subroutine VOTIME. A general flowchart for this subroutine is shown in Figure 4. The logic used in this subroutine is similar to that described by Klokkenga (4) and used by Cummins Engine Company in their Vehicle Mission

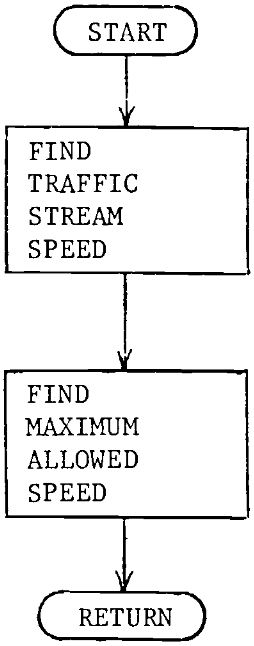

Figure 3. General Flowchart for Subroutine ALLVEL

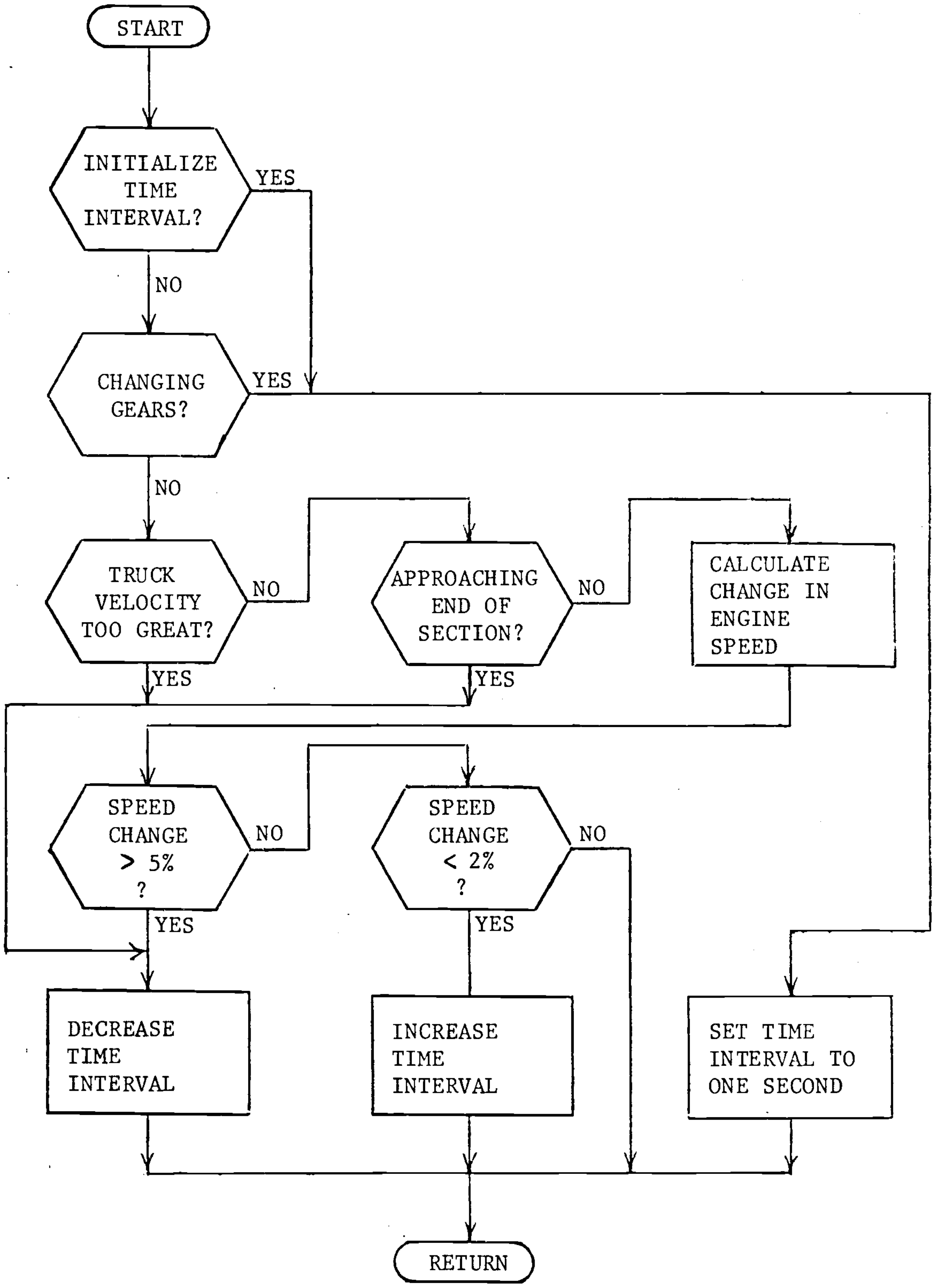

Figure 4. General Flowchart for Subroutine VOTIME

Simulation (VMS).[2]

The length of the time intervals are a function of road conditions and truck performance. On long vertical sections where little or no change in terrain is encountered, the length of each successive time interval (TIMINT) becomes larger unitl a maximum of thirty seconds is reached. However, if road conditions begin to change rapidly, the length of each successive time interval decreases until a minimum of one second is reached.

The following situations or road conditions will cause a decrease in the length of successive time intervals:

(1) A gear change takes place. In this case, the time interval is set to one second.

(2) The vehicle road velocity (VORVEL) exceeds the velocity allowed (VELALL) by at least two miles per hour.

(3) There is a change in engine speed (CNGRPM) of more than five percent between successive time intervals.

(4) The truck brakes for a downgrade or curve.

(5) The end of the vertical road section is impending.

The length of successive time intervals increases if the change in engine speed is less than two percent between successive time intervals or if the above ennumerated conditions are not encountered.

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[2]Vehicle Mission Simulation and VMS are trademarks of Cummins Engine Company.

2. Calculating the Required Rear Wheel Horsepower

A truck traveling on a road section is subjected to certain forces. These forces are shown in Figure 5 (5). The summation of the resistance forces is the amount of force, or tractive effort, that must be exerted by the truck in order to maintain a constant velocity.

Carl C. Saal developed an analytical method for predicting tractive effort (6). His work was later used in the development of the SAE Truck Ability Prediction Procedure (7). Later, Gary L. Smith, in a special paper published by the Society of Automotive Engineers, refined these truck performance prediction procedures (8). The equations given by Smith are those used by Subroutine WHLBHP to find the required tractive effort horsepower. A flowchart for this subroutine is shown in Figure 6.

a. Tire Rolling Resistance

The tire rolling resistance (ROLRES) in pounds-force, is estimated using the relationship

$$ROLRES = (GCW)(CP)\ [(CS) + (CV)(VORVEL)] \qquad [1]$$

where GCW = the vehicle gross combination weight (total vehicle weight), in pounds,

CS = the static rolling resistance coefficient,

CV = the dynamic rolling resistance coefficient, in mph^{-1},

and CP = the tire and pavement interaction coefficient.

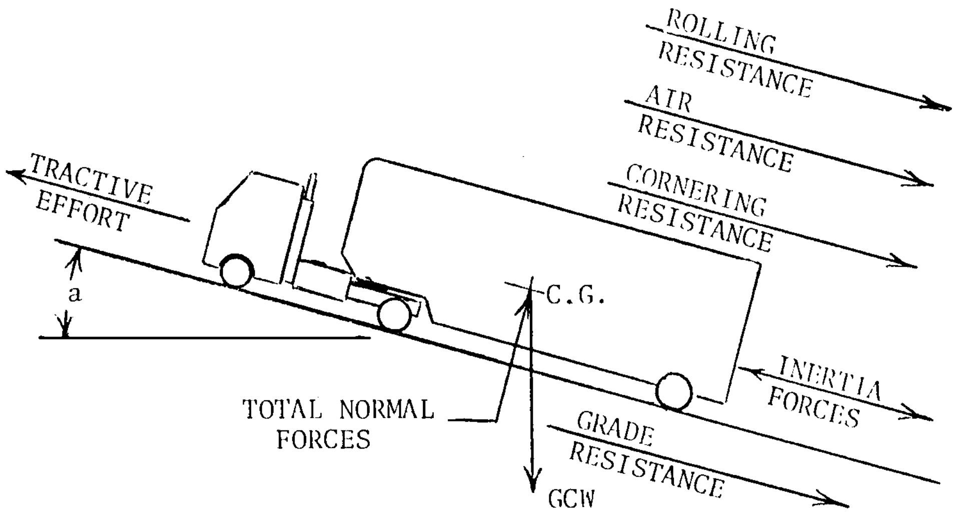

Figure 5. Truck Free Body Diagram

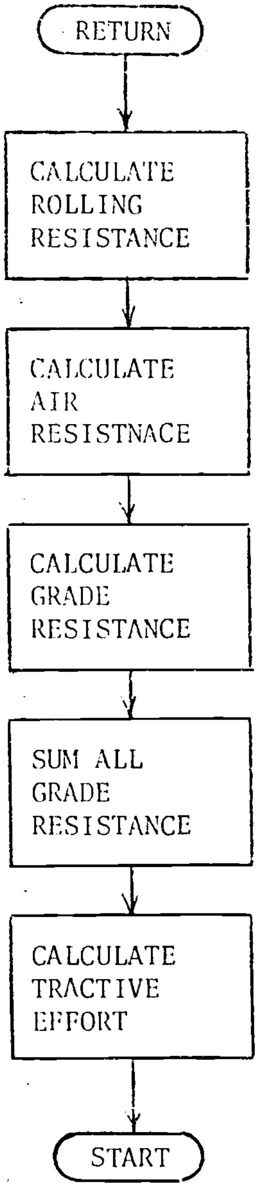

Figure 6. General Flowchart for Subroutine WHLBHP

The values of these coefficients are determined experimentally using acceleration and coast-down data from actual vehicles. Values for the bracketed portion of Equation [1], as calculated by several investigators (9), are plotted in Figure 7. These curves suggest that the rolling resistance is not only dependent upon velocity, but also varies with tire size, type and width. The values of the coefficients suggested by Klokkenga (10) are used in Subroutine (WHLBHP. They are listed in Table 3.

b. Air Resistance

Another force acting upon the truck is that caused by air resistance (AIRRES). This force can be estimated using the equation (11)

$$\text{AIRRES} = \text{ARFKTR} \left[\frac{\text{WETHER}(4)}{459.67 + \text{WETHER}(3)}\right] [\text{VORVEL} + \text{WETHER}(2)]^2 \quad [2]$$

where ARFKTR = an air resistance coefficient, in (in. Hg.-mph^2)/(F - ft^2),

VORVEL = truck velocity in mph,

WETHER(2) = headwind velocity, in mph,

WETHER(3) = ambient air temperature, in °F,

and WETHER(4) = atmospheric pressure, in Hg.

This equation assumes that air resistance is proportional to dynamic pressure which varies with the square of the velocity. It corrects for ambient air temperature and pressure conditions (12).

A program refinement would be to use the head wind component of the wind velocity vector. The magnitude of this component would

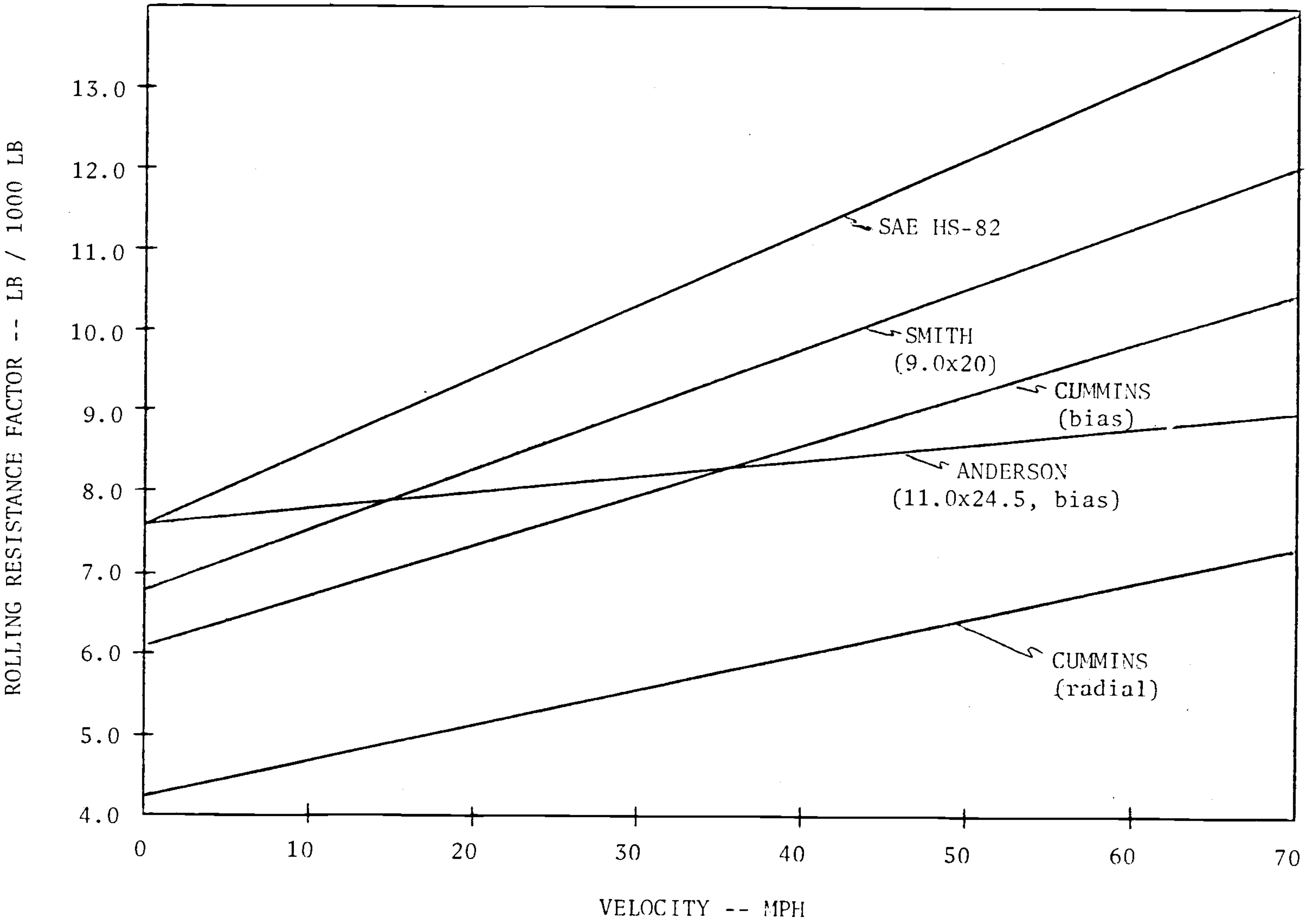

Figure 7. Comparison of Rolling Resistance Factors (9)

TABLE 3. VALUES OF COEFFICIENTS FOR CALCULATING ROLLING RESISTANCE (AFTER(10))

Tire Type	CS	CV
Bias ply	0.0059	0.000026
Radial ply	0.0043	0.000016

Road Type	CP	
	Bias	Radial
Smooth concrete Smooth asphalt with solid base	1.00	0.70
Rough concrete Rough asphalt with solid base Smooth asphalt with soft base	1.20	0.84
Rough asphalt with soft base	1.50	1.05
Packed dry gravel or dirt	2.00	1.40

vary with changes in horizontal alignment of the highway. Calculations by Smith show that the resistance caused by side winds of reasonable magnitude are negligible (13).

The air resistance coefficient (ARFKTR) is calculated in the initialization segment of Subroutine TRKOPS using the equation (14)

$$ARFKTR = (0.044258)(DRAGCO)(WIDTH)(HEIGHT - .75) \qquad [3]$$

where DRAGCO = an air drag coefficient, in (in. Hg. - mph^2) /°F

WIDTH = overall truck width, in feet,

and HEIGHT = overall truck height, in feet.

The air drag coefficient is determined from road tests or from wind tunnel tests. Typical values suggested by Klokkenga are 0.7 for a truck semi-trailer combination, 0.77 for double and triple combinations and loaded flat-bed trucks and 1.00 for car haulers (15).

c. Grade Resistance

On a grade section, a truck encounters a grade force (GRDRES) which is equal to the component of vehicle weight acting downhill. This is calculated using the relationship

$$GRDRES = [(GCW)(\sin(a)] \qquad [4]$$

where a = angle of incline, in radians, as shown in Figure 5.

In practice, the grade is designated by the ratio of the climbed height, h, to the projected horizontal distance, s. Also, the grade (GR) is expressed as a percentage. Therefore,

$$GR = h/s\ (100) \quad \tan(a) \qquad [5]$$

For small angles the sine of the angle is approximately equal to its tangent. Therefore,

$$GRDRES \approx (GCW)[\tan(a)] = \frac{(GCW)(GR)}{100} \qquad [6]$$

For grades of less than six percent, the error introduced by this approximation is less than two percent (16).

For grades that are not constant, a rate of change of grade per hundred feet (R) is used in the Truck performance Model. For these sections

$$GRDRES = (GCW)\ [GR + (VODIST)(R)] \qquad [7]$$

where VODIST = The total distance traveled in the graded section, in feet. It should be noted that the grade force is a resistance force on upgrades, but acts in the direction of travel on downgrades.

d. Cornering Resistance

Another resistance force is encountered by a truck when it is turning or while on a banked or highly crowned road section. This force results from the tangential component of the cornering force. The general equation for predicting this force, as suggested by Smith (17) is

$$CNRFRC = CORFCT \left\{ \left[\sum_{i=1}^{K} \frac{(FRCOEF)\ [TANDWT(i)]\ [TANLNG(i)]}{2\ (HRAD)} \right] + \frac{1}{[TIRRIM(5)][TIRRIM(8)]} \left[\frac{(GCW)(VORVEL)^2}{(113.21)(HRAD)} \right]^2 \right\} \quad [8]$$

where CORFCT = the correction factor for road bank angle,

K = the number of tandem axles,

FRCOEF = the tire drag coefficient between the axles on the tandem,

TANDWT(i) = the weight on tandem 'i', in pounds,

TANLNG(i) = the distance between axles of tandem 'i', in feet,

HEAD = the horizontal curve radius, in feet,

TIRRIM(5) = the total number of tires on the truck,

and TIRRIM(8) = the average tire cornering stiffness, in lb/deg.

The correction factor for bank angle is calculated from the equation

$$CORECT = 1 - \left[\frac{(14.95)(HRAD)(E)}{(VORVEL)^2} \right] \quad [9]$$

where E = the bank angle or superelevation of the road surface, in ft/ft.

The procedure for finding the bank angle is shown in Figure 8.

e. Total Truck Resistance

The amount of power required to overcome the rolling, grade and cornering forces is illustrated in Figure 9. Since the cornering

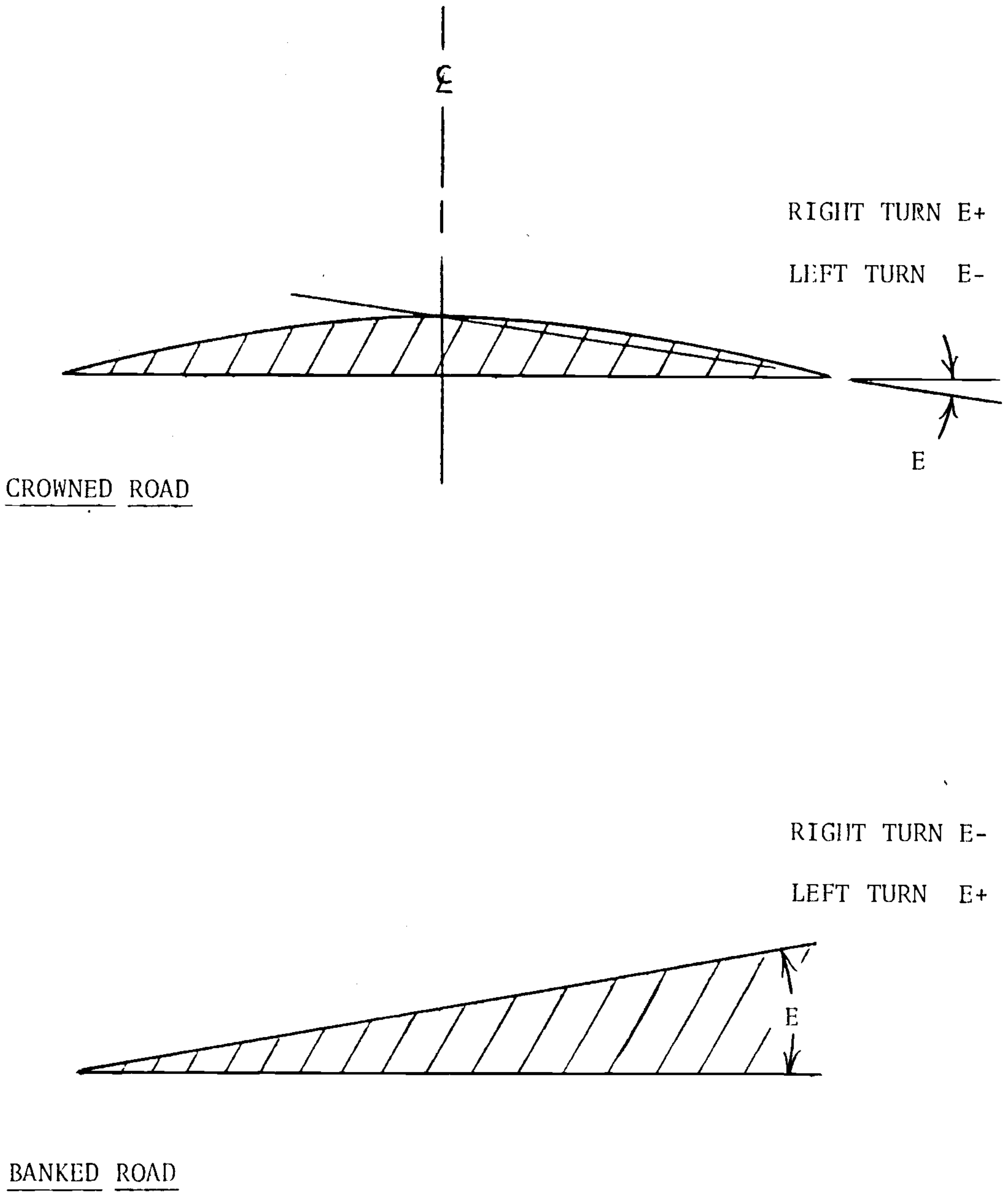

Figure 8. Determining the Bank Angle

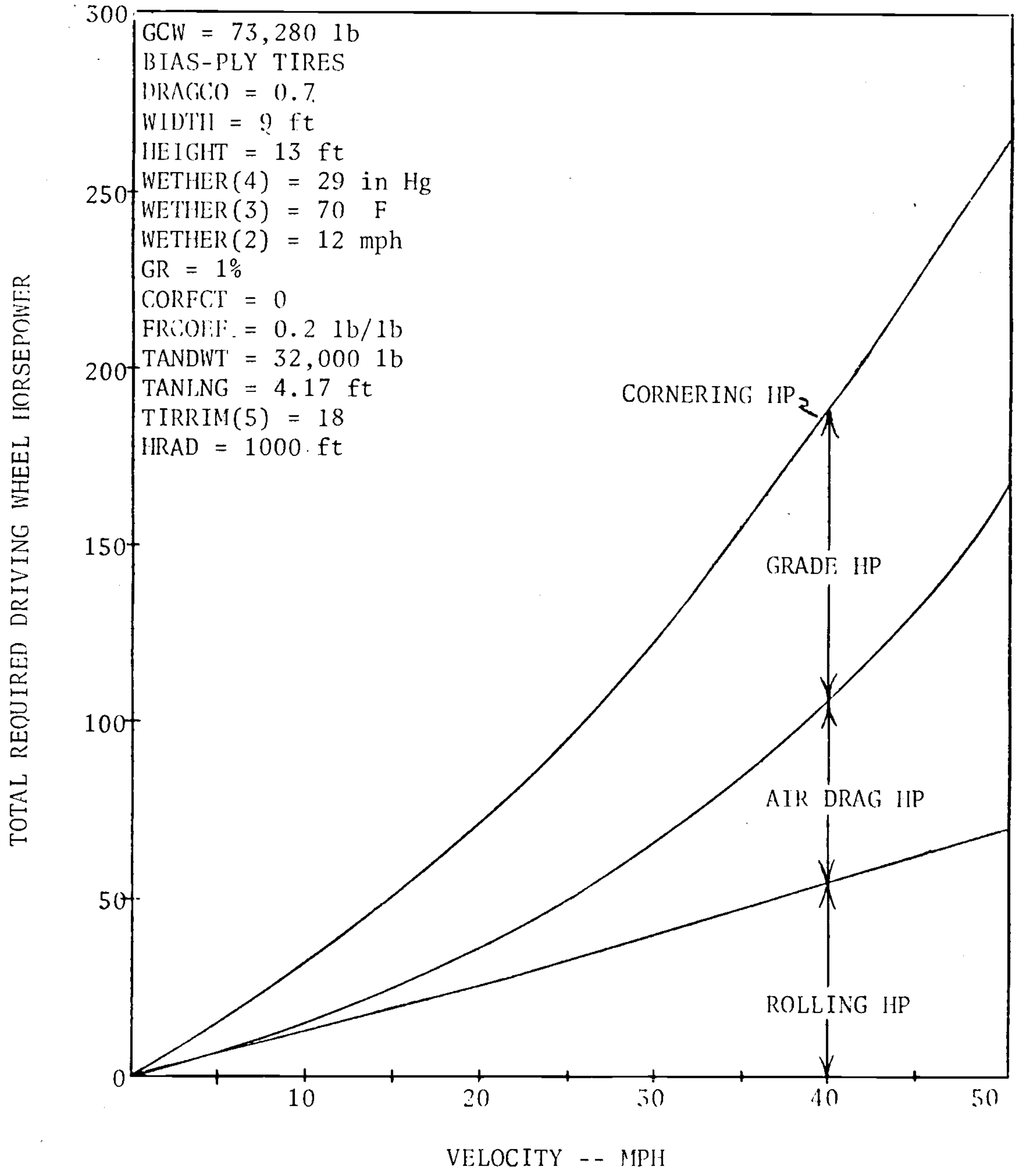

Figure 9. Comparison of Truck Resistances

force is relatively small in a freeway situation, it has not been included in the calculation of required rear wheel horsepower in Subroutine WHLBHP. However, it should be included if the program is extended to predict truck performance on other types of roads.

The rolling, air and grade forces are calculated and summed in Subroutine WALBHP. The total road resistance (TOTRES) is then converted from force to horsepower using the relationship (18)

$$TWHLHP = \frac{(TOTRES)(VORVEL)}{375.0} \qquad [10]$$

The total wheel horsepower required to overcome these vehicle forces (TWHLHP) is then returned to subroutine TRKOPS.

3. Finding the Horsepower Available

At this point in the Truck Performance Program, it is necessary to know the range of horsepower available from the engine at the present engine speed. This will be used to find the present throttle setting in Subroutine THRTTL. Subroutine VMAXHP is called to find the maximum gross horsepower and friction horsepower. A general flowchart for this subroutine is shown in Figure 10.

a. Gross Horsepower

Engine manufacturers often supply maximum horsepower (wide-open-throttle) curves in their sales literature. These are usually given in terms of gross horsepower (AVLBHP), or the brake horsepower of the

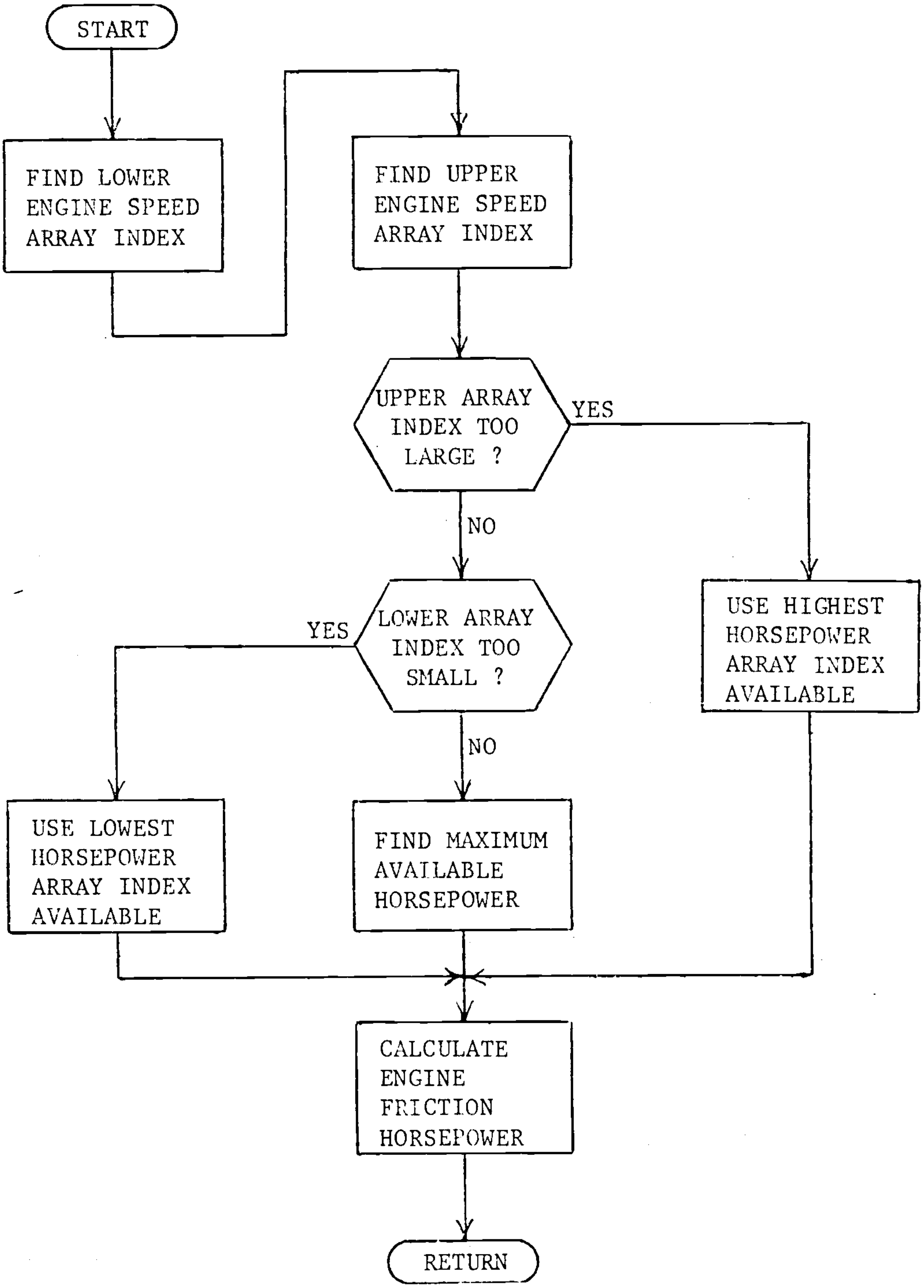

Figure 10. General Flowchart for Subroutine VMAXHP

engine before power losses to any engine accessories are accounted for. A typical horsepower curve is shown in **Figure 11. Data for** the engine to be used in the program are taken from such a curve in one hundred rpm increments starting from the lowest allowable speed (ENGINE(6)) to the maximum engine speed (ENGINE(7)). This information is stored in a one dimensional array (BHPMAX). Linear interpolation is used between the data points to obtain a gross horsepower value for the present engine speed (ENGRPM).

The horsepower curves supplied by the manufacturer are for standard conditions (85 F, 29.4 C; 29.38 in Hg, 99 kPa) is prescribed by the "Engine Rating Code -Diesel- SAE J270" (19). In order to correct these data to the ambient conditions, they are multiplied by a correction factor (ENGINE(9)) calculated by

$$\text{ENGINE}(9) = \left[\frac{29.00}{\text{WETHER}(4) - \text{WETHER}(5)}\right]\left[\frac{460 + \text{WETHER}(3)}{545.0}\right]^{0.7} \qquad [11]$$

where WETHER(3) = ambient air temperature, in F,

WETHER(4) = barometric pressure, in in. Hg,

and WETHER(5) = water vapor pressure, in in. Hg.

This correction is valid for dry barometric pressures between 28 and 30 inches of mercury (95 and 101 kPa) and between 60 and 110 F (289 and 317 K) (20). The horsepower correction factor is calculated during the initialization of TRKOPS.

b. Friction Horsepower

When the throttle is closed, "engine braking" occurs. This

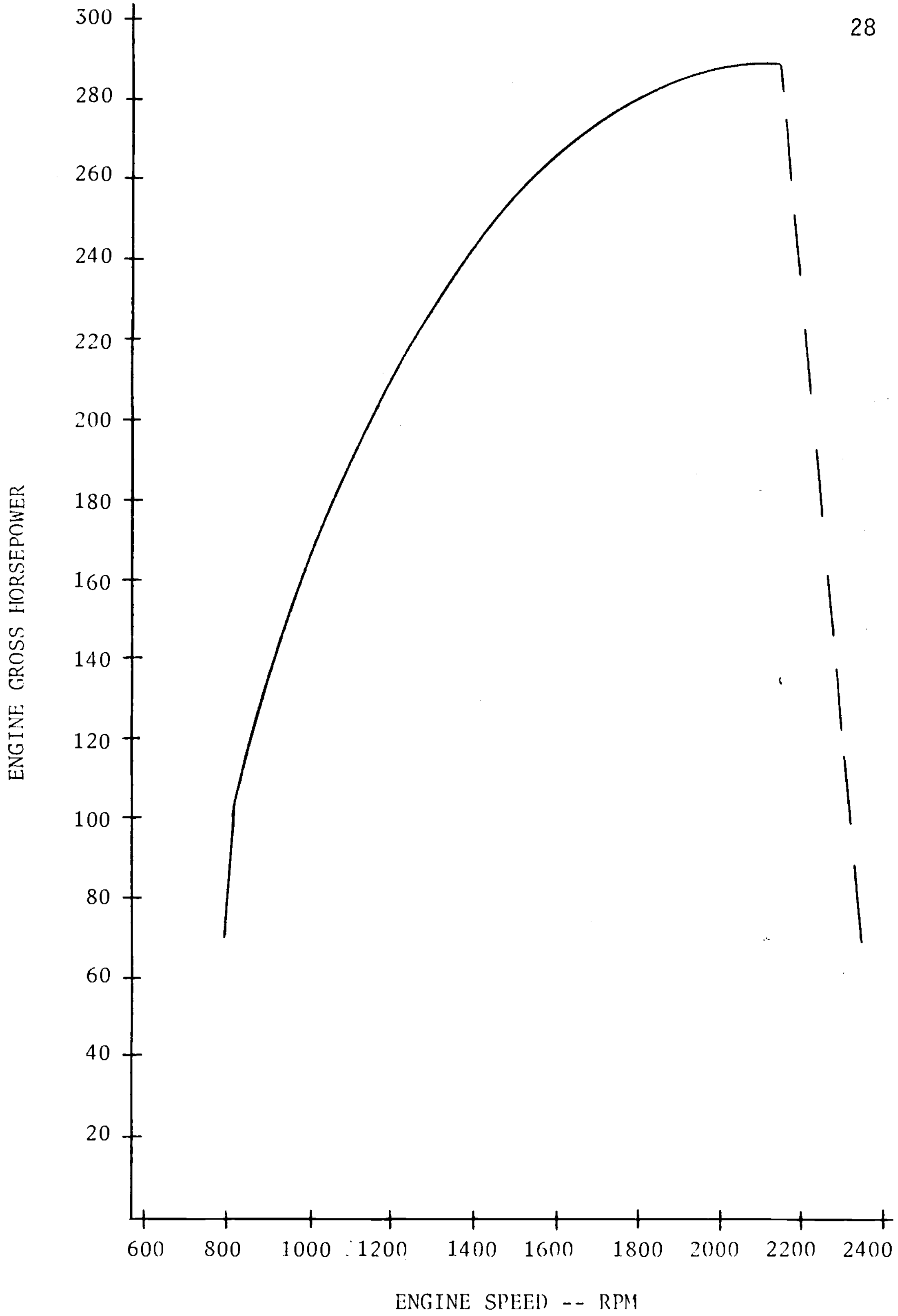

Figure 11. Engine Horsepower Curve

phenomenon is due to engine friction work which is dependent upon such factors as oil viscosity and shearing area, oil film thickness and engine displacement, compression ratio and speed (21). Ideally, data for closed-throttle tests could be used to calculate engine friction work. Since this information was not available for the Performance Model, the engine friction work is estimated from hot motored work calculations. It should be noted that this is an approximation and its accuracy has not been verified (22).

Relationships for hot motor work are given in the "Engine Rating Code -Diesel- SAE J270" (23). The mechanical efficiency (MECHEF) for a hot motored engine is

$$MECHEF = \frac{1}{1 + \left(\frac{COEFFT}{BMEPEN}\right)} \qquad [12]$$

where

$$COEFFT = 20.1893 - 3.75948\left(\frac{ENGRPM}{1000}\right) + 3.33129\left(\frac{ENGRPM}{1000}\right)^2 \qquad [13]$$

$$BMEPEN = \frac{(AVLBHP)(792{,}000)}{[ENGINE(1)]\ (ENGRPM)} \qquad [14]$$

and ENGINE(1) = engine displacement, in cubic inches. The available friction horsepower can then be estimated by the relationship

$$AVLFHP = (1.0 - MECHEF)(AVLBHP) \qquad [15]$$

4. Finding the Present Throttle Setting

In a vehicle, the driver constantly varies the throttle position. The driver compares the actual vehicle speed to the desired vehicle speed, is aware of the vehicle acceleration rate and can see the immediate conditions and changes in road terrain. All of these factors influence the drivers input to the vehicle by means of the throttle.

The driver's throttle response is simulated by subroutine THRTTL which is supported by inputs from other subroutines. A flowchart for this subroutine is shown in Figure 12. Part of the throttle logic used is that described by Klokkenga (24).

In subroutine THRTTL, an attempt is made to maintain the truck velocity (VORVEL) to within two miles per hour of the allowed velocity. If the truck velocity is less than the allowed speed, the throttle setting (RAKSET) is increased; if the velocity is greater, the throttle setting is decreased. As the length of the time intervals increases, the amount the throttle is moved during each time interval is decreased (e.g., road conditions are not changing). Also, as the truck velocity approaches the allowed velocity, the throttle movement allowed during each time interval is decreased.

Other conditions may also influence the throttle setting. If the acceleration rate (VACCEL) exceeds one-tenth the acceleration of gravity (2.1973 mph/sec; 7.1975 kmh/sec), the setting is reduced. This rate is considered a "comfortable" maximum for trucks (25). The throttle setting is held constant while a gear change is being made. If the throttle is closed on a steep downgrade and the truck is accelerating when it should be slowing, Subroutine VELDST is signaled

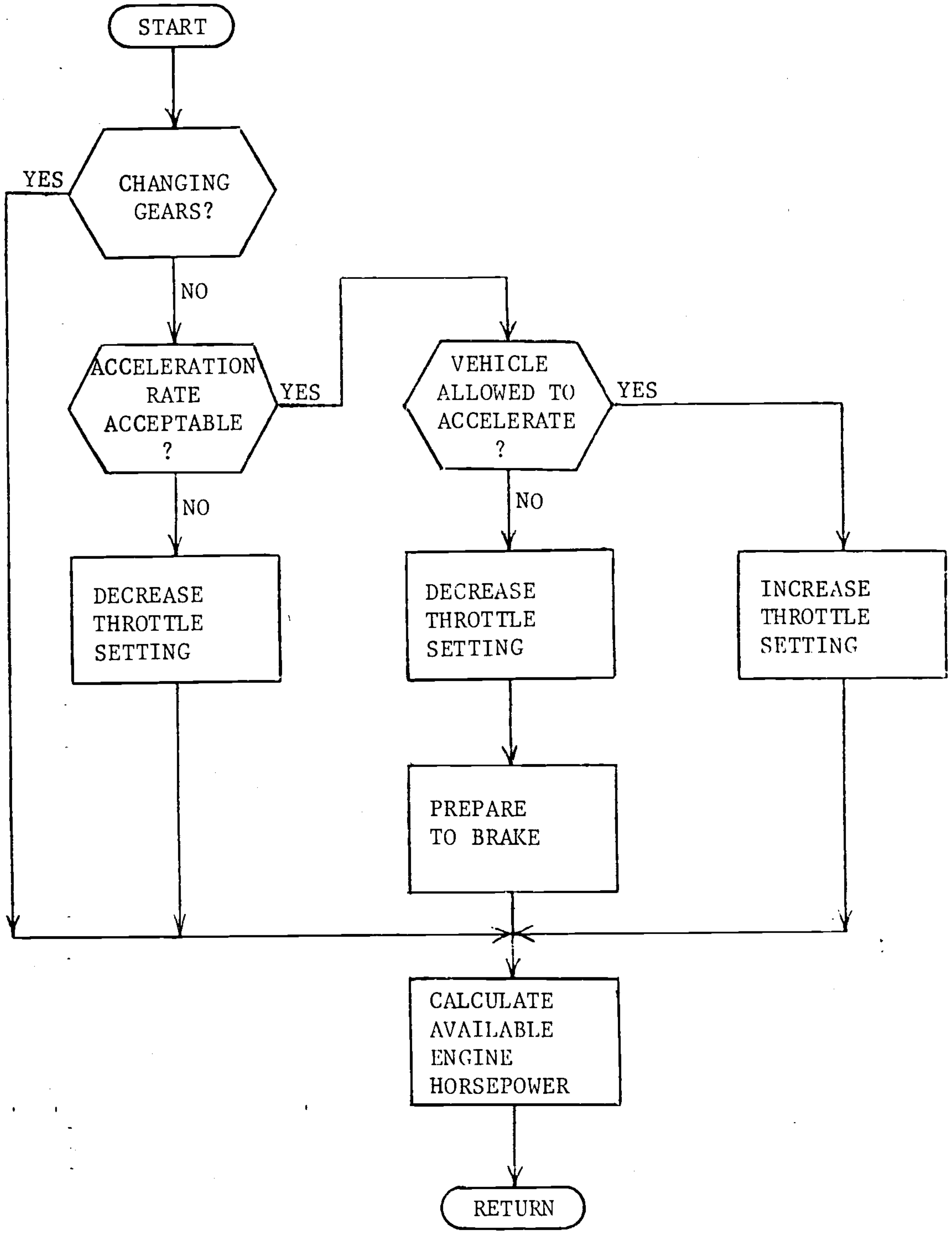

Figure 12. General Flowchart for Subroutine THRTTL

to apply the brakes (KBRAKE = 1).

After the throttle setting (RAKSET) has been determined, the gross horsepower available (ENGBHP) can be found. This is done by interpolating between the maximum available gross horsepower (AVLBHP) and the engine friction horsepower with respect to the throttle position

$$ENGBHP = [(RAKSET)(AVLBHP - AVLFHP)] - AVLFHP \qquad [16]$$

5. Calculating the Fuel Used and Exhaust Gaseous Emissions

After the engine speed (ENGRPM) and the available engine horsepower (ENGBHP) have been found, the fuel consumed and the particulates emitted can be determined. Fuel consumption can be estimated from fuel performance maps which can be obtained from the engine manufacturers. These maps include lines of constant horsepower or brake mean effective pressure, engine speed and fuel rate. These data are obtained from engine dynamometer tests performed upon the specific engine of interest. A typical fuel performance map is shown in Figure 13. The fuel performance map, like the maximum horsepower curve, is given for standard conditions.

The Truck Performance Model stores data from a fuel performance map in a two-dimensional array (BSFC) in 100 rpm and 10 horsepower increments. The data required by the program are in terms of brake specific fuel consumption which has units of pounds-mass of fuel per brake horsepower hour. These data are read by Subroutine DIESEL. A general flowchart for this subroutine is shown in Figure 14.

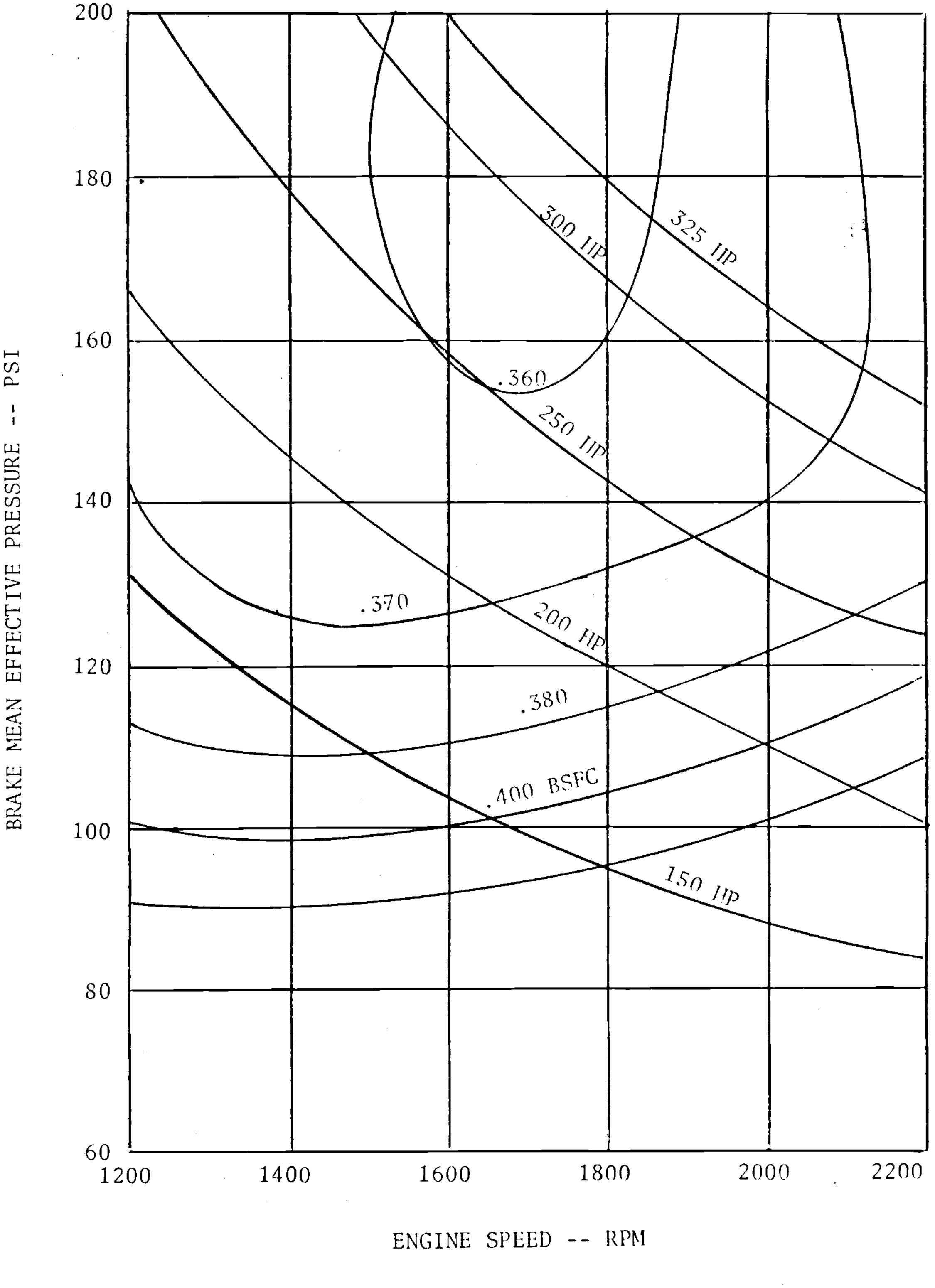

Figure 13. Fuel Performance Map

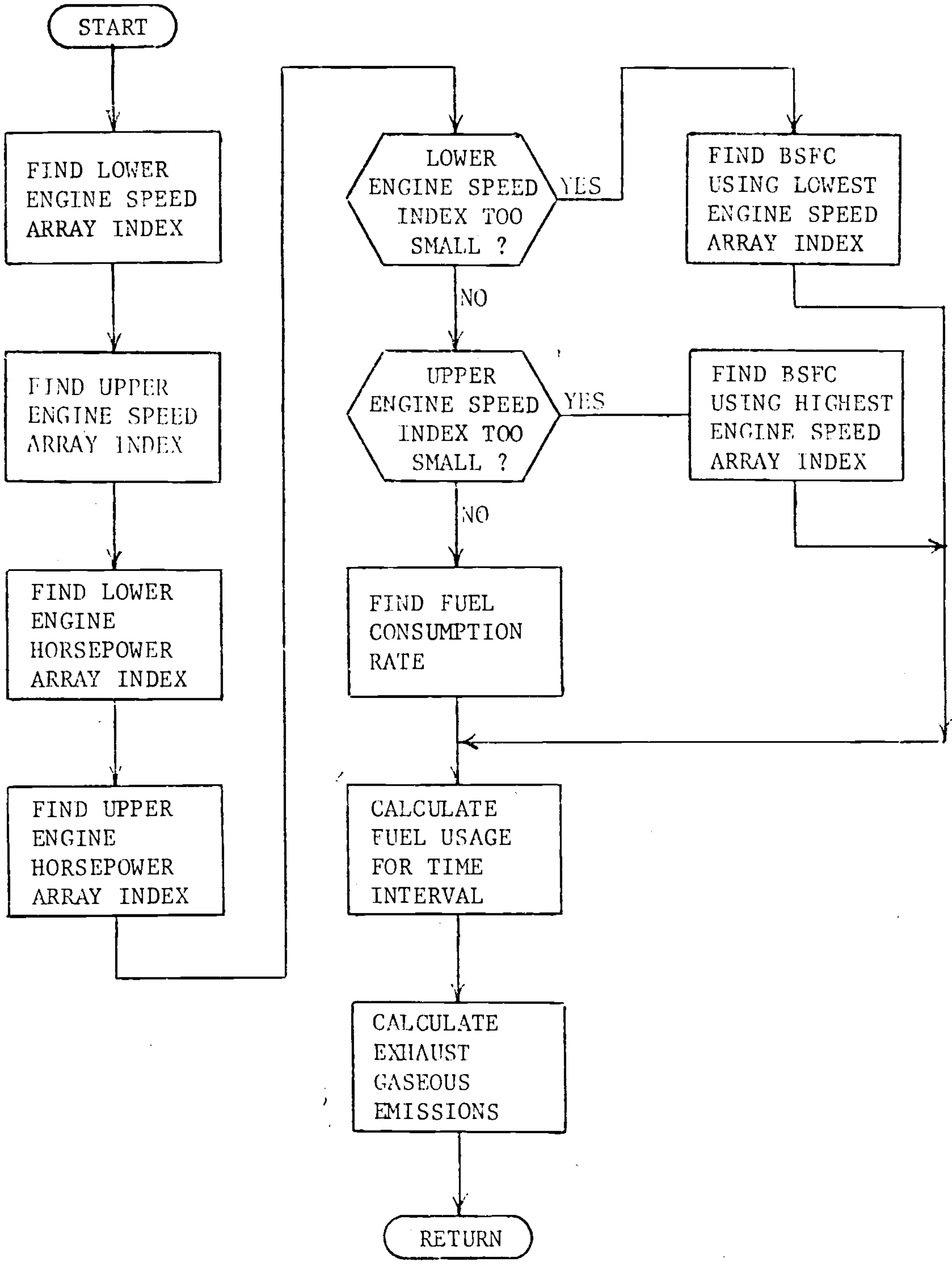

Figure 14. General Flowchart for Subroutine DIESEL

Subroutine DIESEL finds the absolute value of the available engine horsepower (TRKBHP) and then corrects it to standard conditions (CORBHP). Then the data points in array BSFC which bound the desired value are found. These data points are then used to perform linear interpolation: first, for the present engine speed and, secondly, for the available engine horsepower. Once the brake specific fuel consumption (TOTBSC) has been found, the amount of fuel consumed (TRKSFC), in gallons, for the time interval can be calculated since

$$TRKSFC = \frac{(TOTBSC)(CORBHP)(TIMINT)(7.12)}{25632.0} \qquad [17]$$

The density of the diesel fuel is assumed to be 7.12 pounds per gallon (853 kg / m^3).

Ideally, an emissions map similar to a fuel performance map could be used to find exhaust gaseous emissions. However, this source of data was not available for the Truck Performance Model. Therefore, an estimate of the brake specific emission rate, in grams per brake horsepower hour, is made using the maximum limits set by the United States Environmental Protection Agency for hydrocarbons (BSER(1)), carbon monoxide (BSER(2)) and oxides of nitrogen (BSER(3)). The limits now in effect and those proposed for the future are shwon in Table 4 (26).

The total amount of exhaust gaseous emissions (TKEMMS) are calculated using the relationship

TABLE 4. PAST, PRESENT AND FUTURE STANDARDS FOR BRAKE SPECIFIC EMISSION RATES (gm/bhp-hr) (From(26))

<table>
<tr><th></th><th colspan="2">1975</th><th colspan="2">1977</th><th colspan="2">1978</th><th colspan="2">1979</th></tr>
<tr><th>POLLUTANT</th><th>C</th><th>F</th><th>C</th><th>F</th><th>C</th><th>F</th><th>C</th><th>F[b]</th></tr>
<tr><td>Hydrocarbons</td><td rowspan="2">10</td><td rowspan="2">16</td><td rowspan="2">5</td><td rowspan="2">16</td><td rowspan="2">5[a]</td><td rowspan="2">16</td><td rowspan="2">5[a]</td><td>1.5</td></tr>
<tr><td>Oxides of Nitrogen</td><td>10</td></tr>
<tr><td>Carbon Monoxide</td><td>30</td><td>40</td><td>25</td><td>40</td><td>25</td><td>40</td><td>25</td><td>25</td></tr>
</table>

* C - California
F - Federal

[a]Alternative standards of HC - 1.0 gm/bhp-hr and NO_x = 7.5 gm/bhp-hr are provided for the manufactor's option

[b]Planned

$$TKEMMS = (SUMPRT)(CORBHP)(TIMINT) \quad [18]$$

where

$$SUMPRT = \sum_{i=1}^{3} BSER(i) \quad [19]$$

The value of SUMPRT remains constant for a given set of emissions data and is calculated during the initialization of TRKOPS. Present emission standards combine hydrocarbons and oxides of nitrogen. This can be done in the Truck Performance Model by entering the total amount in either BSER(1) or BSER(3) while setting the other variable equal to zero. It should be noted that the exhaust gaseous emissions calculated in this manner are the maximum that could be emitted by the truck. The actual amount of emissions will be equal to, or less than, the amount predicted by the simulation model.

6. Calculating Tractive Effort and Related Factors

Subroutine VELDST is now called by the Performance Model to calculate tractive effort, distance traveled, truck velocity and average acceleration for the present time interval. A general flowchart for this subroutine is shown in Figure 15.

a. Driveline Efficiency

The percentage of the available engine horsepower that reaches the driven wheels or the tractive effort horsepower, depends upon the efficiency of the driveline components (e.g., the transmission, differential and other related components). The overall driveline efficiency approach suggested by Smith (27) isused in the program. The following

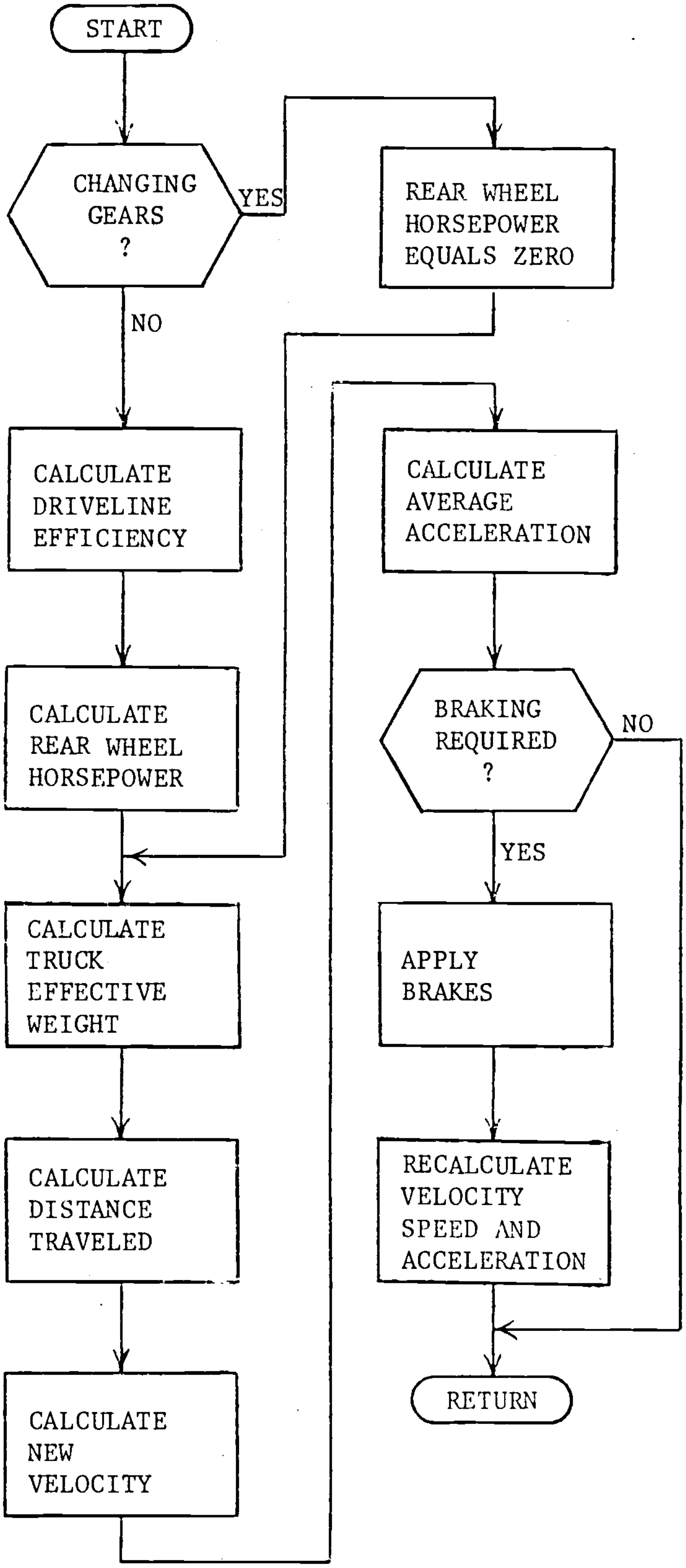

Figure 15. General Flowchart for Subroutine VELDST

empirical relationship can be used to predict driveline efficiency (PTHEFF),

$$PTHEFF = [DRLOSS(1)] \left(1.0 - \left\{[DRLOSS(2)]\left(\frac{1}{RAKSET}\right)\right\}\right) \qquad [20]$$

where DRLOSS(1) = driveline efficiency at full throttle,

and DRLOSS(2) = viscous loss factor.

The values for the driveline factors depend upon the type of truck tractor being modeled. Recommended values for use in Equation 20 are listed in Table 5 (28). The driveline equation becomes undefined as the throttle setting approaches zero (i.e., the throttle is closed). Therefore, the driveline efficiency is assumed to reach a minimum of fifty percent in the Performance Simulation Model.

b. Tractive Effort

It is now possible to determine the tractive effort of the truck. The total power required to run the engine accessories (ENGINE(3)) (such as the fan, air compressor, turbocharger and power steering) is subtracted from the available engine horsepower (ENGBHP). The resulting term is multiplied by the part throttle efficiency term (PTHEFF) to obtain the horsepower presently available at the driven wheels. When a gear change is occurring, the engine is disengaged from the driveline, and the available wheel horsepower is assumed to be zero.

TABLE 5. SUGGESTED DRIVELINE FACTORS FOR CALCULATING EFFICIENCY

Type of Tractor	Full Throttle Efficiency, (DRLOSS(1))	Viscous Loss Factor. (DRLOSS(2))
4 x 2	0.90	0.042
4 x 2 w/aux.	0.86	0.066
4 x 4	0.86	0.066
6 x 4	0.86	0.066
6 x 4 w/aux.	0.82	0.092
6 x 6	0.82	0.041

c. Net Accelerating Force

The net accelerating force (ACCFRC) can now be calculated by subtracting the available wheel horsepower (AVLWHP) by the total wheel horsepower (TWHLHP) required to overcome the road resistances. This value is then converted to pounds-force. If the accelerating force is positive, the truck will accelerate; if it is negative, the truck will decelerate.

d. Effective Weight

The moving masses of the engine and driveline components have rotational, as well as translational, motion during acceleration. The inertial effects caused by this rotational motion can be approximated by using an effective weight for the truck. This effective weight (EFFWGT) will be larger than the actual vehicle weight (GCW) during acceleration.

The engine, clutch, brake drums, wheels, and tires are the major contributers to the total inertial effect. If the relatively small effects of the propeller shaft, axle shafts and transmission and differential gears, wheels and brake drums are neglected, the effective weight of the truck can be estimated using the relationship (29)

$$EFFWGT = GCW + \left(\frac{32.174}{[TIRRIM(7)]^2} \{[(EINRTA)(TOTRED)^2] + TINRTA\} \right) \quad [21]$$

where TIRRIM(7) = tire rolling radius, in feet,

EINRTA = engine and clutch inertia, in ft-lb-sec^2,

TOTRED = overall gear reduction,

and TINRTA = inertia of the tires, in fg-lb-sec^2.

The tire rolling radius is calculated during the initialization of subroutine TRKOPS using the relationship (30)

$$\text{TIRRIM(7)} = \frac{5280}{(2)(\pi)[\text{TIRRIM(4)}]} \qquad [22]$$

where TIRRIM(4) = speed of the driven tires, in revolutions per mile. The engine and clutch inertia for a four-cycle diesel engine is approximated by (31)

$$\text{EINRTA} = \frac{1}{32.174}\left(4 + \left[(1.6)\left\{\frac{\text{ENGINE(1)}}{100}\right\}^2\right]\right) \qquad [23]$$

where ENGINE(1) = engine displacement, in cubic inches. The inertia of the tires (TINRTA) is calculated by using the equation given by Davisson (30)

$$\text{TINRTA} = \left[\left(\left\{(0.2882)\left[\frac{\text{TIRRIM(1)} + \text{TIRRIM(6)}}{12}\right]\right\} - 0.0990\right)^2 \left([\text{TIRRIM(2)}]\ [\text{TIRRIM(5)}]\right)\right] \qquad [24]$$

where TIRRIM(1) = tire outside diameter, in inches,

TIRRIM(2) = tire weight, in lbs,

TIRRIM(5) = total number of tires

and TIRRIM(6) - nominal rim diameter, in inches.

e. Distance and Velocity

The distance traveled and truck velocity for the current time interval are now calculated by Subroutine VELDST. The method used to calculate velocity and distance is based upon the work of Firey and Peterson (33). If variable grade sections are modeled as circles of large radius, Newtons second law states that

$$\frac{\text{EFFWGT}}{\text{G}}\left[\frac{d^2(\text{VHDIST})}{d(\text{TIMINT})^2}\right] = \text{ACCFRC} - \frac{(\text{EFFWGT})(\text{VHDIST})}{\text{VCRAD}} \qquad [25]$$

where EFFWGT = vehicle effective weight, in lbs,

G = acceleration due to gravity, in ft / sec^2,

VHDIST = distance traveled, in ft,

TIMINT = the length of the time interval, in seconds,

ACCFRC = vehicle accelerating force, in lb,

and VCRAD = radius of the vertical curve, in ft.

Rearranging and simplifying

$$\frac{d^2(\text{VHDIST})}{d(\text{TIMINT})^2} + (\text{CONSTB})^2(\text{VHDIST}) = \text{CONSTA} \qquad [26]$$

where $\text{CONSTA} = \dfrac{(\text{ACCFRC})(\text{VCRAD})}{\text{EFFWGT}}$

and $\text{CONSTB} = \left(\dfrac{\text{G}}{\text{VCRAD}}\right)^{0.5}$ Now, a general solution to this nonhomogeneous, second-order differential equation is

$$VHDIST = K1 \cos (CONSTB)(TIMINT) + K2 \sin (CONSTB)(TIMINT) + CONSTA \qquad [27]$$

where K1 and K2 are constants of integration. Setting the initial distance equal to zero and setting the initial velocity equal to the truck velocity (TRKVEL), in feet per second, at the beginning of the time interval

$$K1 = - CONSTA \qquad [28]$$

$$K2 = \frac{TRKVEL}{CONSTB} \qquad [29]$$

Therefore,

$$VHDIST = CONSTA - (CONSTA)(CONSTB) + \left(\frac{TRKVEL}{CONSTB}\right)(CONSTE) \qquad [30]$$

and $VELNEW = [(TRKVEL)(CONSTD) + (CONSTA)(CONSTB)(CONSTE)](BCONST)$ [31]

where VELNEW = truck velocity at the end of the time interval, in mph,

CONSTC = (CONSTB)(TIMINT)

CONSTD = cos(CONSTC)

CONSTE = sin(CONSTC)

and $BCONST = \frac{3600}{5280} \frac{\text{mi-sec}}{\text{ft-hr}}$

For grades with a vertical radius greater than 20,000 feet, the grade is assumed to be constant. Then the following differential equation applies

$$\frac{EFFWGT}{G}\left[\frac{d^2(VHDIST)}{d(TIMINT)^2}\right] = ACCFRC \qquad [32]$$

Integrating and solving for the constants

$$VHDIST = TRKVEL + \left(\frac{FACTOR}{2}\right)(TIMINT) \qquad [33]$$

$$VELNEW = (TRKVEL + FACTOR)(BCONST) \qquad [34]$$

and

$$FACTOR = \frac{(ACCFRC)(32.174)(TIMINT)}{EFFWGT} \qquad [35]$$

This modeling technique has been shown to be accurate for grades of less than ten percent (34).

f. Average Acceleration

The average acceleration (VACCEL), in miles per hour per second, can be calculated using the relationship (35)

$$VACCEL = \left[\frac{(VELNEW)^2 - (VELOLD)^2}{(2)(VHDIST)}\right](ACONST) \qquad [36]$$

where VELOLD = velocity at the beginning of the time interval, in mph,

and $ACONST = \frac{5280}{3600}\frac{ft\text{-}hr}{mi\text{-}sec}$

Subroutine VELDST also checks to see if the truck should be slowing (KBRAKE has been set to one by Subroutine THROTTLE). If the truck is accelerating, the truck is braked at a rate not exceeding three miles per hour per second (4.40 ft / sec^2, 0.81 kph / s)(36). This requires the recalculation of velocity, in miles per hour, and distance, in feet, for the time interval using the following relationships which are valid for constant deceleration rates (37)

$$VHDIST = \{[VELOLD + (0.5)(VACCEL)(TIMINT)](TIMINT)\}(ACONST) \quad [37]$$

$$VELNEW = VELOLD + [(VACCEL)(TIMINT)] \quad [38]$$

where VACCEL = rate of deceleration, in mph / sec.

7. Recording Vehicle Data

Subroutine DTAKPR records the data for each time interval when the truck is not approaching a downgrade or horizontal curve. A general flowchart for this subroutine is shown in Figure 16. The length of the time interval (TIM), in seconds, the average truck velocity (TSPD), in miles per hour, and the total number of time intervals (NUMTIM) for the present vertical road section (NOVSEC) are stored in the labeled COMMON area TROPS. A cummulative total of the fuel consumed (DTAINI(3)), in gallons, the exhaust gaseous emissions (DTAINI(4)), in grams, and the distance traveled (VODIST), in feet, for the present section are also kept by Subroutine DTAKPR.

When the truck drives beyound the end of the vertical road section (the variable ENDSEC becomes negative), the truck data for the current time interval is corrected to the end of the road section using the relationship

$$TKDATA = [TKDATA(i)]\left[\frac{TKDATA(2) + ENDSEC}{TKDATA(2)}\right] \quad [39]$$

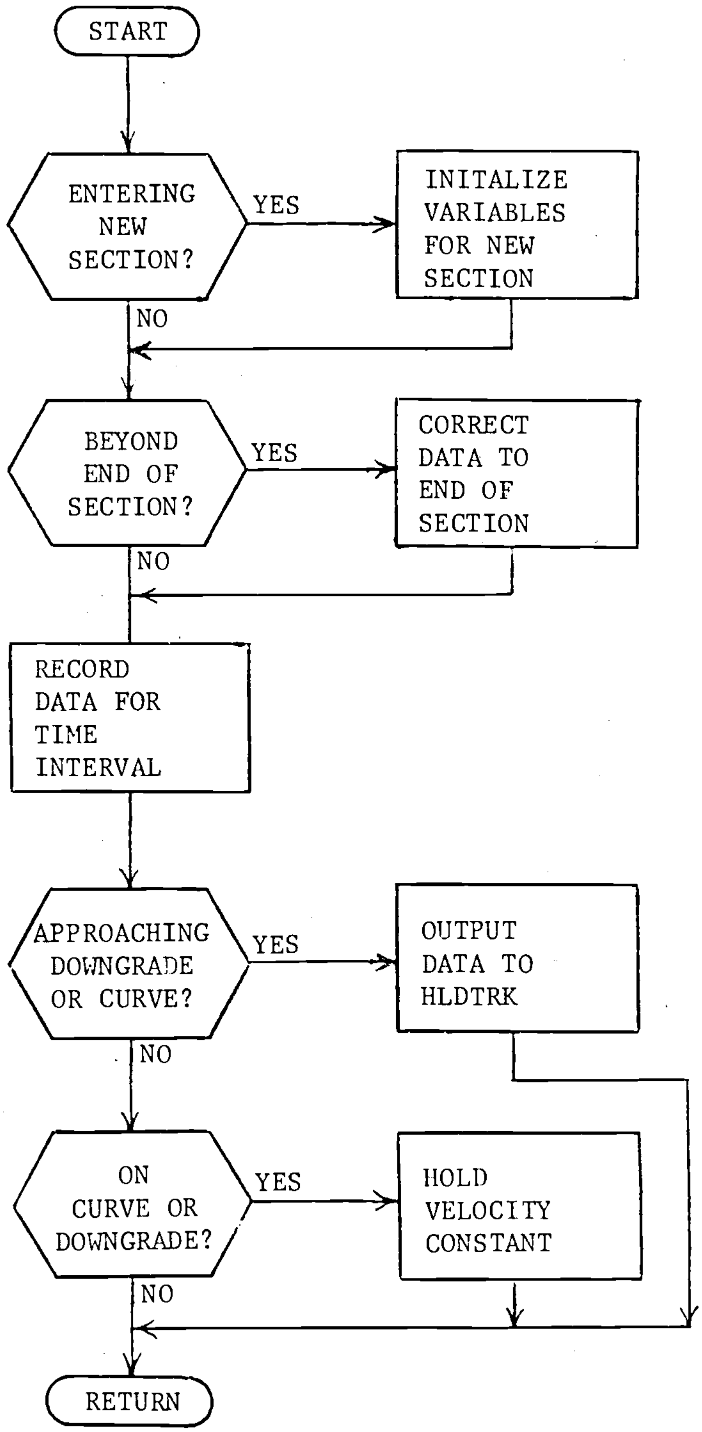

Figure 16. General Flowchart for Subroutine DTAKPR

where TKDATA(i) = time, distance, fuel consumed or emissions for the current time interval,

TKDATA(2) = uncorrected distance traveled during the current time interval,

and ENDSEC = the distance the truck has driven beyond the end of the road section, in ft (a negative quantity).

The Performance Model is signaled that a new vertical section is about to be entered (variable NEWSEC is set equal to one). Also, the section data are sent to Subroutine TRKOPS for processing.

Subroutine TRKOPS is supplied by the traffic operations subsystem in the USDOT decision model. It has been replaced by a supportive subroutine in the present Performance Model. The function of the supportive Subroutine TRKOPS will be described in a later section.

If the truck is approaching a downgrade or curve (variable IFLGTR equals one), the data for the time interval is transferred to Subroutine HLDTRK using array DTAINI. When the truck is on a downgrade or curve (variable KNSTSP equals one) a record of the distance remaining for the grade or curve (HLDDST) is kept. The maximum allowed truck velocity (VELLMT) is set equal to the maximum speed allowed for the current road geometrics (VELMAX). At the end of the grade or curve, the maximum speed allowed is reset to the speed set by Subroutine (ALLVEL).

8. Changing Gears

In order to provide the required tactive force at the driven wheels, the engine must be maintained within a narrow range of speeds.

This speed range is usually bounded by the maximum torque engine speed (ENGINE(4)) and the maximum horsepower engine speed (ENGINE(5)). Subroutine GRSLCT keeps the engine speed within this range by selecting the proper transmission gear for the prevailing road conditions. A general flowchart for this subroutine is shown in Figure 17.

Subroutine GERCHG is used by Subroutine GRSLCT to find the overall gear reduction (TOTRED) and engine speed (ENGRPM) for the current truck velocity (VORVEL), in miles per hour, and transmission gear being used (NUMGER). A flowchart for this subroutine is shown in Figure 18. The overall gear reduction (TOTRED) is found by multiplying the rear axle ratio (AXLRTO) by the gear ratio of the transmission gear currently in use (GEARNO). The engine speed, in revolutions per minute, is then found using the relationship (38)

$$\text{ENGRPM} = \frac{(\text{VORVEL})\ \text{TIRRIM}(4)\ (\text{TOTRED})}{60} \qquad [40]$$

where TIRRIM(4) = driven tire revolutions per mile.

Subroutine GRSLCT upshifts (reduces the overall gear ratio) if the current engine speed is greater than the upper shift point (ENGINE(5). The engine speed is never allowed to go above the maximum engine, or "red-line" speed (ENGINE(7)). Subroutine GRSLCT downshifts whenever the current engine speed is less than the lower shift rpm (ENGINE(4)). On curves and downgrades, the truck remains in the lowest gear possible for the maximum velocity allowed. This is done to provide greater engine braking.

When a gear change does occur, other parts of the Performance

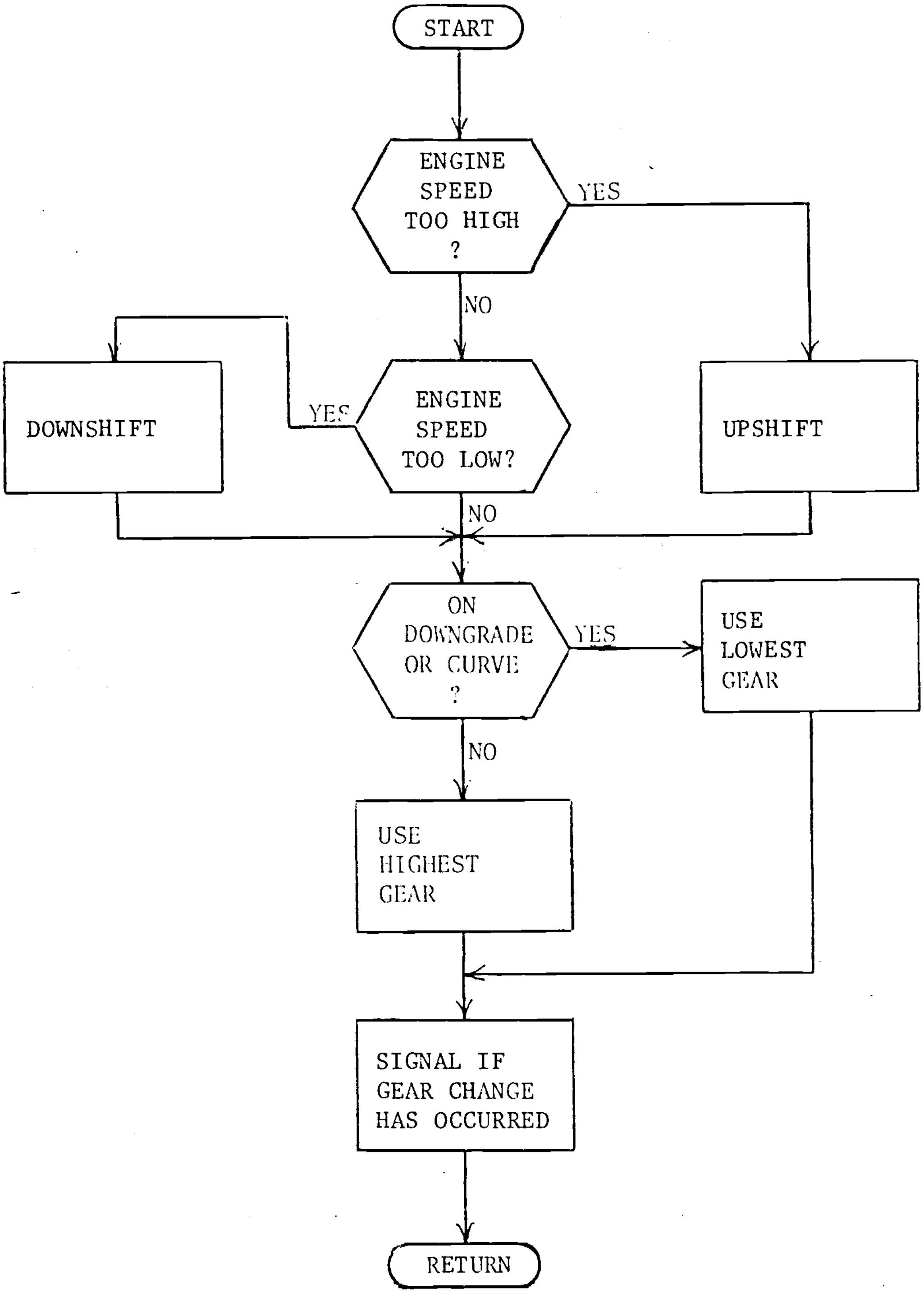

Figure 17. General Flowchart for Subroutine GRSLCT

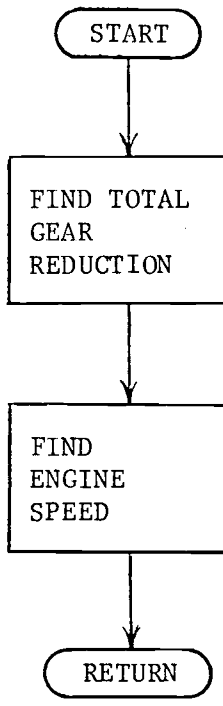

Figure 18. General Flowchart for Subroutine GERCHG

Model affected by the change are signaled by Subroutine GRSLCT (variable IFSHFT is set equal to one). The subroutine also supplies the engine speed and the number of the gear being used (INGEAR) for each time interval.

9. Truck Behavior on Downgrades

On a long downgrade, a truck must rely upon its wheel brakes and upon engine braking to maintain a safe speed. The truck driver usually knows from experience what gear to select and at what speed to begin the downgrade in order not to overheat his brakes and to insure a safe speed around any corners that will be encountered. This driver behavior is simulated in the Truck Performance Model using a technique described by Hykes (39).

The minimum brake rating horsepower (TRKBHP) recommended by "Brake Rating Horsepower Requirements - Commercial Vehicle - SAE J257" (40) is defined by the relationship

$$TKBRHP = 12 + \left[\frac{(1.4)(GCW)}{1000}\right] \qquad [41]$$

where GCW = the total weight of the truck, in lbs.

The brake rating horsepower of the truck is estimated using this relationship. This calculation is made during the initialization of Subroutine TRKOPS.

The available braking horsepower for the truck can now be calculated using the relationship

$$TKBRHP = 12 + \left[\frac{(1.4)(GCW)}{1000}\right] \qquad [41]$$

where GCW = the total weight of the truck, in lbs.

The brake rating horsepower of the truck is estimated using this relationship. This calculation is made during the initialization of Subroutine TRKOPS.

The available braking horsepower for the truck can now be calculated using the relationship

$$AVBRHP = TKBRHP + AVLFHP - TWHLHP \qquad [42]$$

where AVLFHP = engine friction horsepower,

and TWHLHP = total road resistances, in hp.

Due to the velocity dependence of the road resistance term, a velocity can be reached on a downgrade where the truck brake rating plus the truck friction horsepower will be exceeded by the road resistance horsepower (the available braking horsepower will become less than zero). At this and larger velocities the truck can no longer brake safely on the downgrade.

A constant check is made of the vertical road sections ahead of the truck by Subroutine DWNHIL. A flowchart for this subroutine is shown in Figure 19. The look-ahead distance (EYEDST) has been set to 1500 feet (PREDST) plus the distance traveled in the present time interval (VHDIST). If a downgrade begins in this distance, all the vertical road sections in the downgrade section are examined and the maximum grade (LSTGRD) is found. The maximum velocity allowed by the

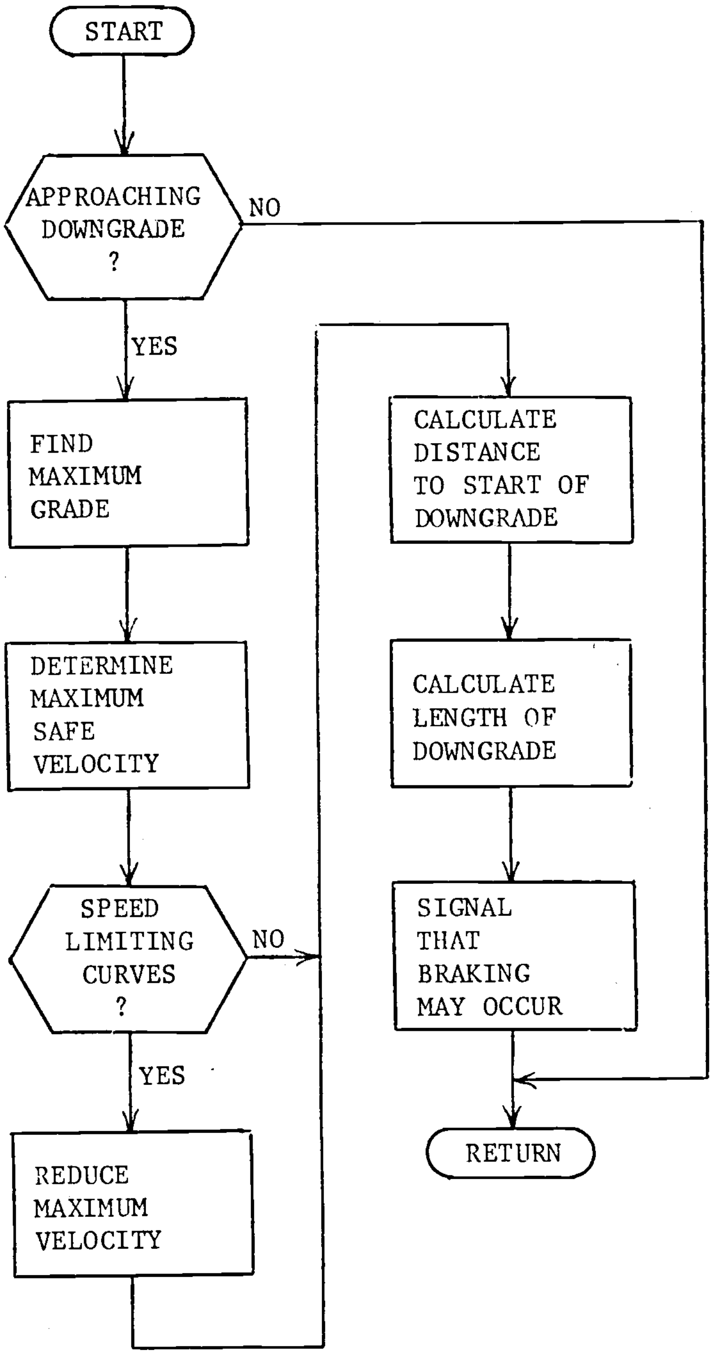

Figure 19. General Flowchart for Subroutine DWNHIL

downgrade (VELMAX) is then found by using Equation [42] at the point of maximum grade.

Subroutine DWNHIL also checks the downgrade for horizontal curves. If the maximum curve velocity (HASPD) is less than the allowed grade velocity, it becomes the maximum velocity allowed on the downgrade. Subroutine DWNHIL also calculates the total length of the downgrade section (HLDDST) and the distance from the truck to beginning of the downgrade at the end of the present time interval (SLWDST). The Truck Performance Model is then signaled that the truck is approaching a downgrade (variable IFLGTR is set equal to one).

10. Truck Behavior for Curves

For road sections without downhill sections, Subroutine HRZCRV is called to check for horizontal curves. A general flowchart for this subroutine is shown in Figure 20. The horizontal road data includes a signal (MPLA) 1500 feet before each horizontal curve. When the truck approaches the curve signal point, Subroutine HRZCRV finds the length of the curve (HLDDST) and the maximum curve velocity (VELMAX). It then calculates the present distance from the truck to the curve (SLWDST). The performance Model is then signaled that the truck is approaching a curve (variable IFLGTR is set equal to one).

11. Truck Braking

When the truck approaches a downhill road section or curve, it is allowed to travel to the beginning of the downgrade or curve and its velocity is checked. If the truck velocity (VORVEL) exceeds the

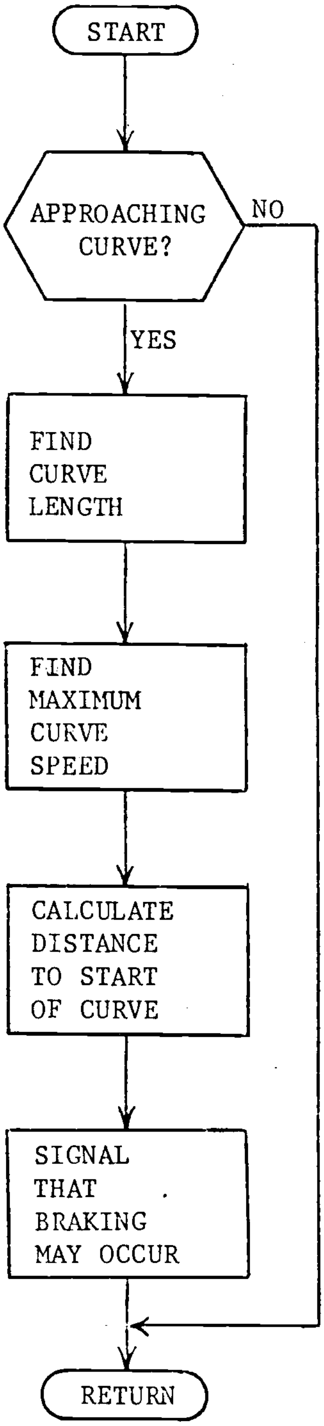

Figure 20. General Flowchart for Subroutine HRZCRV

maximum allowed velocity (VELMAX), the truck is then backed up to the point where the truck can safely brake to enter the downgrade or curve at the velocity allowed.

The truck braking sequence is controlled by Subroutine HLDTRK. A general flowchart for this subroutine is shown in Figure 21. When a downgrade or curve is approached (variable IFLGTR has been set equal to one), Subroutine HLDTRK is called and its variables receive their initial values. The time elapse (DTAINI(1)), distance traveled (DTAINI(2)), fuel consumed (DTAINI(3)), amount of pollutants (DTAINI(4)), total truck distance traveled in the present road section (DTAINI(5)), and the available engine horsepower (DTAINI(6)), for each subsequent time interval in the slowing distance (SLWDST) are stored in an array (DTALOG). The transmission gear used in each time interval is also stored in an array (LOGDTA).

If the number of time intervals in the slowing distance reaches forty, the data for the first twenty intervals are processed in the same manner as done by Subroutine DTAKPR. The data for the last twenty intervals is then numerically resequenced and the program is allowed to continue.

When the truck reaches the beginning of the downgrade or curve, if the truck velocity is less than or equal to the maximum grade or curve velocity allowed, no braking is necessary to reach the allowed velocity (VELLNIT). Then the data is processed by Subroutine DTADMP. A general flowchart for this subroutine is shown in Figure 22. Subroutine DTADMP qrocesses the data in a manner similar to Subroutine DTAKPR. The time and speed for each time interval in a vehicle road

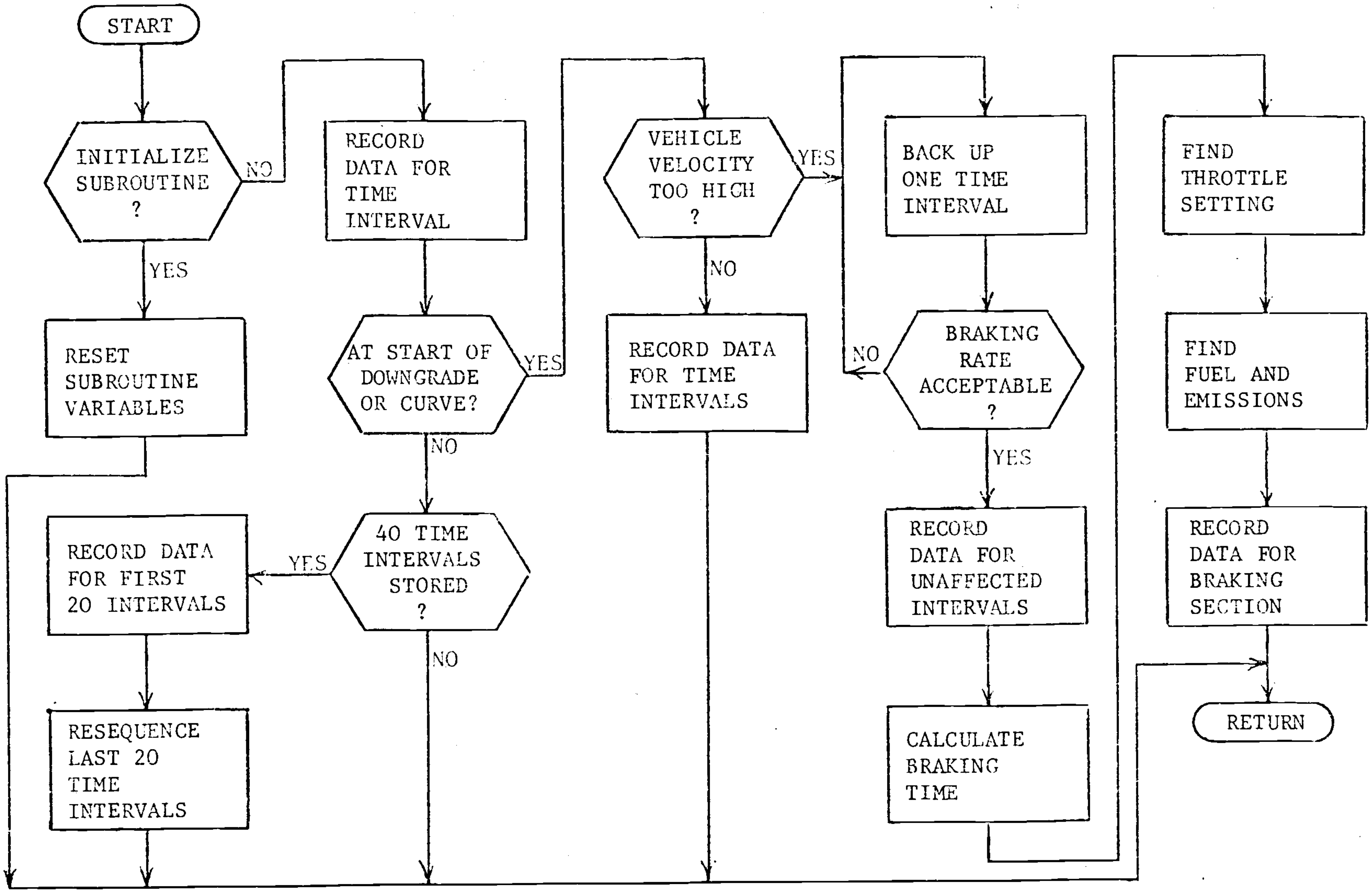

Figure 21. General Flowchart for Subroutine HLDTRK

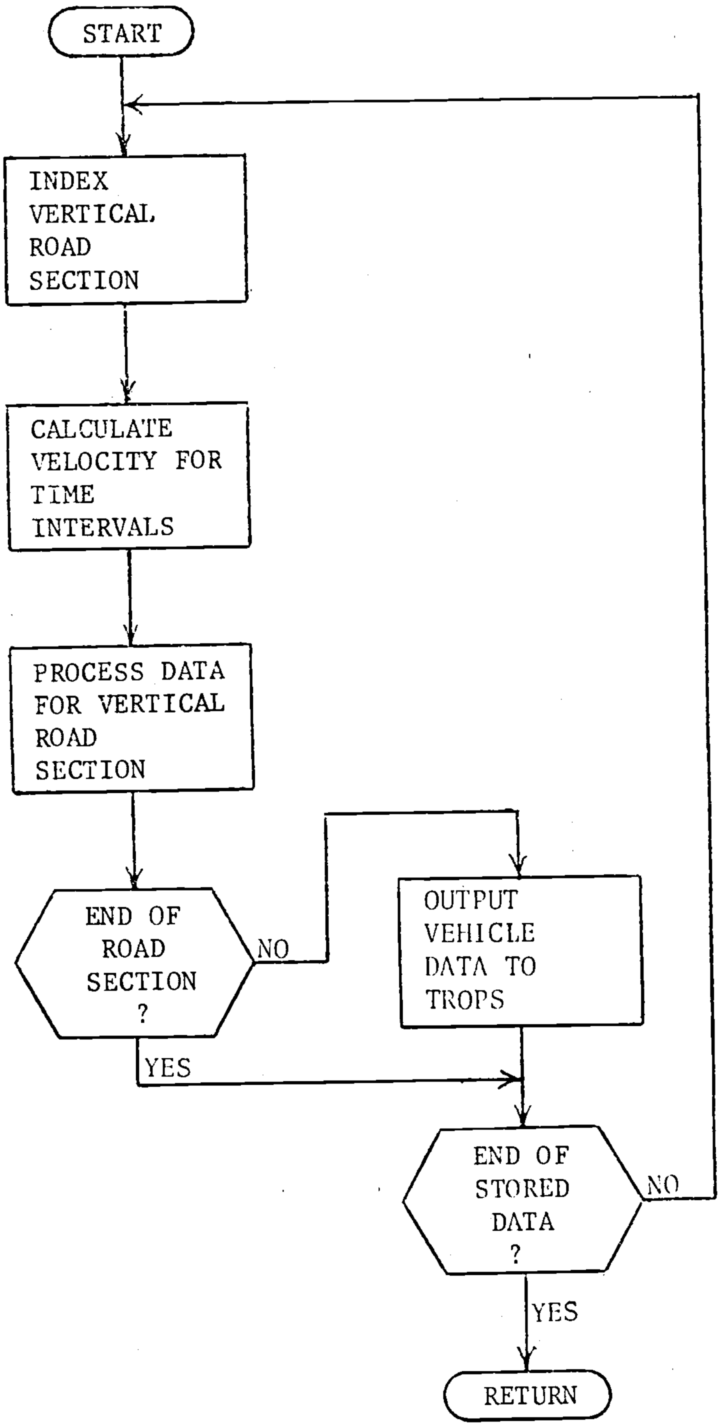

Figure 22. General Flowchart for Subroutine DTADMP

section are stored in labeled COMMON area TROPS. Subroutine TRKOUT is called at the end of each vertical section to process these and other vehicle data.

If the truck velocity exceeds the maximum allowed velocity at the beginning of a downhill section or curve, Subroutine HLDTRK reviews the present vertical road section until a safe braking rate can be found. The deceleration rate (DECCEL), in miles per hour per second is calculated using the relationship (41)

$$\text{DECCEL} = \left[\frac{(\text{VELMAX})^2 - (\text{ENDVEL})^2}{2(\text{SLWDST} - \text{DSTLOG})}\right] (\text{ACONST}) \qquad [43]$$

where ENDVEL = velocity at the end of the time interval being checked, in mph,

and DSTLOG = distance remaining to the beginning of the curve or downgrade, in ft.

When a deceleration rate is found which is less than three miles per hour per second (0.81 kph / s), the truck is braked from the end of the time interval involved to the beginning of the grade or curve. The data in the time intervals not affected by braking are processed by Subroutine DTADMP.

The total time for braking (BRKTIM), in seconds, can now be calculated using the equation (42)

$$\text{BRKTIM} = \left[\frac{\text{VELMAX} - \text{ENDVEL}}{\text{DECCEL}}\right] (\text{ACONST}) \qquad [44]$$

After the braking sequence has been completed: Subroutine GRSLCT is used to find the proper transmission gear (INGEAR); the time interval (TIMINT) is reset to one second in Subroutine VOTIME, Subroutine WHLBHP is used to find the tractive power required (TWHLHP); and Subroutine VMAXHP is used to find the available engine horsepower (AVLBHP) and friction horsepower (AVLFHP).

When approaching a curve or downgrade, the driver may be able to slow down the truck sufficiently by "letting up" on, or closing the throttle. This action is simulated in the Truck Performance Model by approximating the desired throttle position by the relationship

$$SETLST = \frac{AVLBHP - TWHLHP}{AVLBHP - AVLFHP} \qquad [45]$$

This throttle setting (which neglects driveline efficiency) is used to reset Subroutine THRTTL. This approximation is used when the truck is approaching from an upgrade section. However, when the truck is approaching on a level or downgrade section, the throttle position is set to zero (the driver's foot is assumed to be on the brake).

The engine horsepower (AVGBHP) during the braking process is estimated by averaging the engine horsepower for the last unaffected time interval and the presently available horsepower. This average horsepower and the engine speed at the end of braking are used in Subroutine DIESEL to find estimates of the fuel consumed and the amount of exhaust gaseous emissions produced during the braking sequence. These quantity estimates are divided among the road sections traveled during the braking period in proportion to the section length to the total braking distance (BRKDST). If the vehicle is not at the end of a vertical road section after the slowdown sequence, the data for the current section are recorded in Subroutine DTAKPR. Finally, the Performance Model is signaled that the truck is at the beginning of the downgrade or curve (variable IFLGTR is reset to zero).

12. Ending the Simulation Loop

At the end of each vertical road section, the truck data is collected and stored by Subroutine TRKOUT. When the Truck Simulation Program reaches the end of the roadway data, Subroutine TRKOPS returns control to Program TSTTRK. Subroutine OUTPUT is then called to print the truck data accumulated during the program run. This completes the simulation run.

D. Supporting Subroutines

Subroutine TRKOUT and Subroutine OUTPUT have not yet been described. They replace subroutines supplied in the USDOT decision model and allow the Truck Performance Program to be run independently.

1. Recording Vertical Road Section Data

Subroutine TRKOUT is called at the end of each vertical road section (NOVSEC). It records the length (TIM) and speed (TSPD) of each time interval (NUMINT) from the COMMON area named DATA. This subroutine also calculates the total time for the road section in seconds. The total time (TOTIME), number of time intervals (TOTINT), the amount of fuel used (TKFUEL), in gallons, and the total amount of exhaust gaseous emissions (TKEMNS) are also stored in COMMON area DATA by Subroutine TRKOUT.

2. Printing Final Results

Subroutine OUTPUT has two basic functions. If an error occurs in the Truck Performance Model, the variable IEXIT is set equal to an integer unique to the subroutine where the problem occurs. Subroutine OUTPUT is then called to print an error message and data generated up to the time when the error occurred. If no error occurs, then, when the road data ends, the subroutine is called to print data generated for the vertical road sections traveled by the truck. Subroutine OUTPUT prints the number of gallons of fuel used and the number of grams of exhaust gaseous emissions produced by the truck for each vertical road section. A summary of the length of each time interval and the truck velocity at the end of the time interval are also printed.

III. INITIAL PROGRAM TEST RESULTS

The road section shown in Figure 2 was used while testing the Truck Performance Simulation Program. The extreme road geometrics of this test section are not typical for interstate highways. However, the road section provided a means of evaluating all the subroutines with the exception of Subroutine HRZCRV.

The truck configuration used while testing the Program was a three axle tractor semi trailer combination. A 350 horsepower engine and a ten-speed transmission were used. A total vehicle weight of 80,000 pounds was used. The truck and road data used and performance data acquired are given in Appendix 3.

A plot of truck velocity versus distance is shown in Figure 23. The truck velocity was not restricted on the 1.4 percent downgrade in Section 1. However, the velocity was restricted in Section 17 and in Section 13 due to the steepness of the downgrades encountered.

A summary of fuel consumption and exhaust gaseous emissions are given in Table 6. The fuel consumption data have been converted to miles per gallon and gallons per payload ton-mile. The gaseous exhaust emissions have been converted to grams per payload ton-mile. A payload weight of 60,000 pounds was assumed for these calculations.

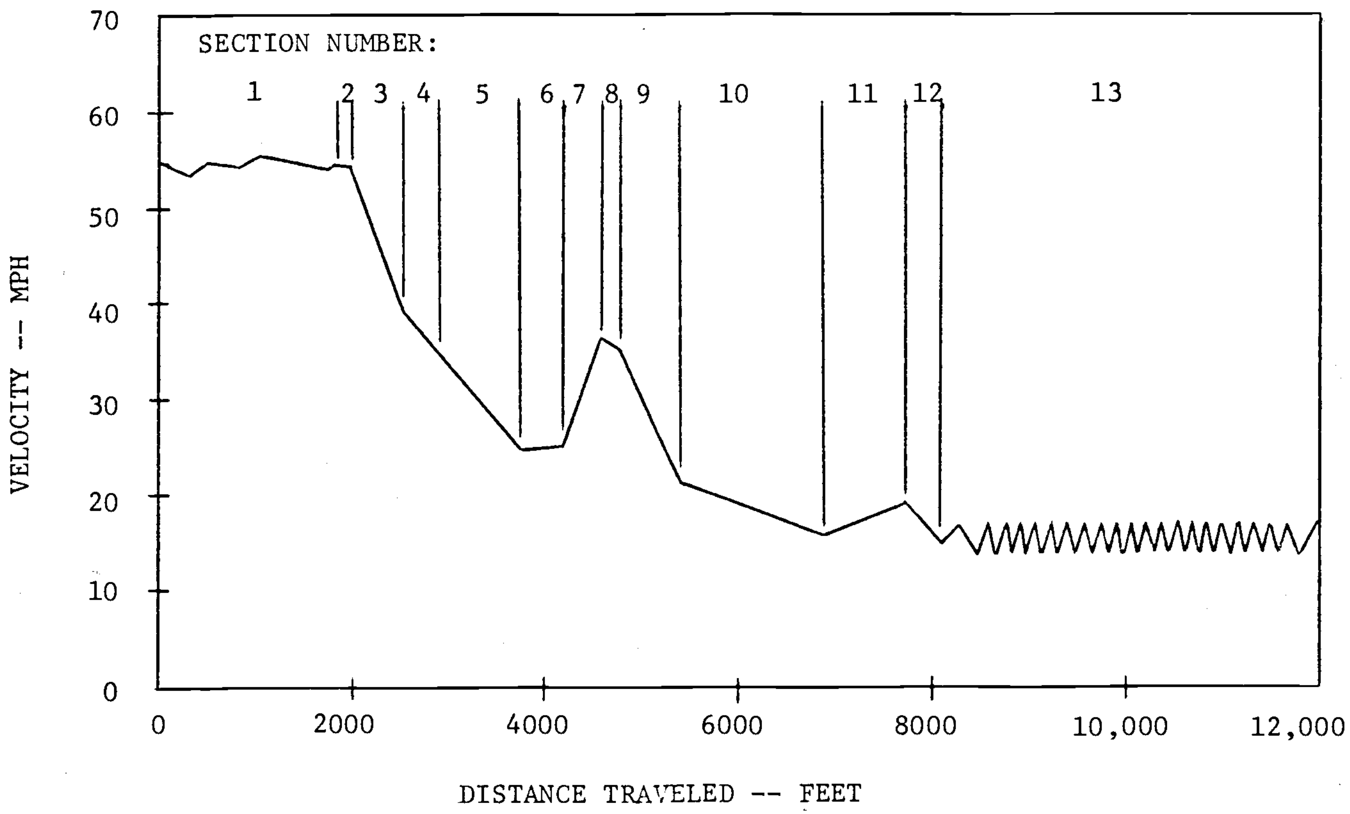

Figure 23. Truck Velocity Profile for Initial Test Data

TABLE 6. DATA FOR INITIAL TEST SECTION

VERTICAL ROAD SECTION	FUEL CONSUMED			EXHAUST GASEOUS EMISSIONS	
	GALLONS	MILES / GALLON	GALLONS / PAYLOAD TON - MILE	GRAMS	GRAMS / PAYLOAD TON - MILE
1	0.085	4.08	0.004	87.4	4.18
2	0.010	3.07	0.005	10.3	5.78
3	0.038	1.71	0.006	40.0	6.25
4	0.028	2.32	0.007	29.3	7.59
5	0.096	1.70	0.010	101.4	10.41
6	0.043	1.50	0.011	45.9	11.78
7	0.053	1.78	0.009	56.4	9.92
8	0.019	2.01	0.008	20.0	8.80
9	0.065	1.76	0.009	68.4	10.03
10	0.273	1.04	0.016	289.6	16.99
11	0.144	0.94	0.018	153.0	18.70
12	0.029	3.14	0.005	21.7	3.98
13	0.440	1.68	0.010	401.2	9.05

IV. CONCLUSION AND RECOMMENDATIONS

The initial test of the Truck Performance Simulation Model suggests that it will provide the data required for the USDOT decision model. Simulation programs developed by former researchers suggest that this program should have an accuracy of at least 95% (43). However, the accuracy of this program has not been verified at this time. Program testing and validation will be included in phase two of the USDOT project (44).

A. Further Testing of Program

Further testing should be done using road sections with varying terrain in the program. A variety of truck configurations should also be tried. This will ensure that all programing errors have been removed from the model.

B. Possible Future Program Modification

An interesting anomaly can be seen in the truck test data. The velocity of the truck tends to oscillate about the desired velocity. This is probably due to the equations presently being used in Subroutine THRTTLE. The throttle setting is governed by the equations

$$DLTRAK = \{1.0 - \cos[(\pi)(DIFVEL)(.25)]\} \quad (DLTTIM) \qquad [46]$$

and

$$DLTTIM = \frac{(31.0 - TIMINT)}{31.0} \qquad [47]$$

where DLTRAK = change in throttle setting, and DIFVEL = variation of the truck velocity from the allowed velocity. Equation [46] provides greater throttle movement as the velocity of the truck (VORVEL) deviates more from the velocity allowed (VELALL). The throttle is either opened or closed completely when the variation in velocity (variable DIFVEL) exceeds two miles per hour. Equation [46] limits the change in throttle setting allowed for longer time intervals. The present throttle setting (RAKSET) is calculated by

$$RAKSET = SETLST + DLTRAK \qquad [48]$$

where SETLST is the throttle setting for the previous time interval. The above equations could be changed or modified to prevent the present velocity variation. By reducing or eliminating the above anomaly, the number of time intervals required will decrease. This will occur since the time interval is a function of engine speed variation. (Engine speed is, in turn, related to the road velocity by the overall gear reduction). A saving in computer time and possibly, an increase in program accuracy will also result.

C. Suggested Methods for Validating the Program

There are two possible methods that can be used to validate the computer program. One method is to run tractive effort tests on various trucks and compare these results with the data obtained from the program. The other method is to compare the program data for this Simulation Model with a program whose accuracy has already been verified (Such as the Cummins Vehicle Mission Simulation). The second method would probably be the most economical of the two.

It is strongly recommended that this program be validated before it is used to simulate truck performance. Only then can this analytical model be used with confidence.

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43. Smith, Commercial Vehicle Performance, p. 19.

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APPENDICES

Appendix 1. Copy of the Computer Program

```
      PROGRAM TSTTRK (INPUT,OUTPUT)
      REAL MPLA, LENG
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
      COMMON /TIREIN/ TIRRIM(7)
      COMMON /WEIGHT/ GCW
      COMMON /ATMCND/ WETHER(5)
      COMMON /CONFIG/ WIDTH, HEIGHT, DRAGCO
      COMMON /TRANSM/ NOGEAR, AXLRTO, GEARNO(15)
      COMMON /PAVT/ CS, CV, CP
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VCRAD(300), R(300), NVERT
      COMMON /HORIZ/ HMP(300), HRAD(300), HCURL(300),
     *  HASPD(300), MPLA(300), NCURVE
      COMMON /TRAFC/ SPDLMT
      COMMON /FUELIN/ BSFC (20,70)
      COMMON /TREMMS/ BSER(3)
      COMMON /TROPS/ TIM(200), TSPD(200), NUMINT
      COMMON /DATA/ TIME(20,200), SPEED(20,200), DIESEL(20),
     *  EXHAST(20), TOTIME(20), TOTINT(20)
C
C     READ IN DATA
      READ 10, NCURVE, NVERT, SPDLMT
   10 FORMAT(5X,I3,7X,I3,7X,F2.0)
      READ 20, (VMP(I), GR(I), VCRAD(I), R(I), LENG(I),
     *  I=1,NVERT)
   20 FORMAT(5F12.6)
      READ 20, (HMP(J), HRAD(J), HCURL(J), HASPD(J),
     *  MPLA(J), J=1,NCURVE)
      READ 30, CS, CV, CP
   30 FORMAT(2F8.6, F8.2)
      READ 40, (WETHER(K), K=1,5)
   40 FORMAT(5F5.1)
      READ 50, GCW, WIDTH, HEIGHT, DRAGCO
   50 FORMAT(F8.1, 2F5.2, F5.3)
      READ 60, (ENGINE(M), M=1,9), (BHPMAX(N), N=1,20),
     *  (DRLOSS(I), I=1,2)
   60 FORMAT(9F6.0/10F6.0/10F6.0/2F6.3)
      READ 70, (TIRRIM(J), J=1,6)
   70 FORMAT(6F10.2)
      READ 80, NOGEAR, AXLRTO, (GEARNO(K), K=1,NOGEAR)
   80 FORMAT(I2,3X,11F5.2)
      DO 90 M=1,20
   90 READ 100, (BSFC(M,N), N=1,70)
  100 FORMAT(12F5.3)
      READ 110, (BSER(I), I=1,3)
  110 FORMAT(3F10.1)
```

```
C
C     START TRUCK SIMULATION
      CALL TRKOPS
C
C     PRINT DATA
      IEXIT = 0
      CALL OUTPUT (NVERT, IEXIT)
      STOP
      END
```

```
      SUBROUTINE TRKOPS
      DIMENSION DTAINI(6)
      REAL LENG, MPLA
      INTEGER OLDGER, OLDHSC
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
      COMMON /TIREIN/ TIRRIM(7)
      COMMON /TREMMS/ BSER (3)
      COMMON /WEIGHT/ GCW
      COMMON /ATMCND/ WETHER(5)
      COMMON /CONFIG/ WIDTH, HEIGHT, DRAGCO
      COMMON /TRANSM/ NOGEAR, AXLRTO, GEARNO(15)
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VCRAD(300), R(300), NVERT
      COMMON /HORIZ/ HMP(300), HRAD(300), HCURL(300),
     *  HASPD(300), MPLA(300), NCURVE
C
C
C     PROGRAM INITIALIZATION
      DATA IFLGTR, INTLIZ, KFRSTM, KNSTSP, KBRAKE, LWRGER,
     *  NEWSEC, NOHSEC, NOVSEC, HLDDST, TRKDST, VODIST,
     *  PREDST, VACCEL /6*0, 3*1, 3*0.0, 1500.0, 2.1937/
C
C     UNIT CONVERSION CONSTANTS
      ACONST = 5280.0 / 3600.0
      BCONST = 1.0 / ACONST
C
C     CONSTANT FOR AIR RESISTANCE CALCULATION
      AREKTR = 0.0042558 * DRAGCO * WIDTH * HEIGHT
C     FOR EMISSION CALCULATION
      SUMPRT = (BSER(1) + BSER(2) + BSER(3)) / 3600.0
C
C     TRUCK MAXIMUM VELOCITY
      TRKMAX = (ENGINE(7) * 60.0) / (AXLRTO * GEARNO(NOGEAR)
     *  * TIRRIM(4))
C
C     LIMITS FOR BSFC MATRIX
C     LOWER RPM
      LTLRPM = IFIX(ENGINE(6) / 100.0) - 1
C     UPPER RPM
      LTURPM = IFIX((ENGINE(7) - ENGINE(6) + 100.0) / 100.0)
C
C     HORSEPOWER CORRECTION FACTOR
      BAROFK = 29.0 / (WETHER(4) - WETHER(5))
      TEMPFK = ((460.0 + WETHER(3)) / 545.0) ** 0.7
      ENGINE(9) = BAROFK * TEMPFK
C     ENGINE INERTIA, FT-LB-SEC-SEC
      EINRTA = (4.0 + (0.00012 * ENGINE(1) * ENGINE(1))) /
     *  32.174
```

```
C
C     CALCULATE PI
      PI = 4.0 * ATAN(1.0)
      PI2 = PI * 2.0
C
C     TIRE ROLLING RADIUS, FT.
      TIRRIM(7) = 5280.0 / (PI2 * TIRRIM(4))
C
C     CONSTANT FOR CALCULATING VEHICLE EFFECTIVE WEIGHT

      CEFFWT = 32.174 / (TIRRIM(7) * TIRRIM(7))
C
C     TIRE MOMENT OF INERTIA, LB-FT-FT
      TCNSNT = (0.2822 * ((TIRRIM(1) + TIRRIM(6)) / 12.0))
     *  - 0.3996
      TINRTA = (TCNSNT * TCNSNT * TIRRIM(2) * TIRRIM(5)) /
     *  32.174
C
C     TRUCK MINIMUM BRAKING HORSEPOWER
      TKBRHP = 12.0 + (1.4 * GCW * 0.001)
C
C
C     FIND INITIAL VELOCITY OF TRUCK (VELALL)
      VELMAX = TRKMAX
C
C     FIND INITIAL VELOCITY ALLOWED
      CALL ALLVEL (NOVSEC, TRKMAX, VELALL)
C
C     SELECT INITIAL GEAR (INGEAR), CALCULATE OVERALL GEAR
C       REDUCTION (TOTRED) AND ENGINE SPEED (ENGRPM)
      CALL GRSLCT (LWRGER, NOVSEC, VELALL, NOGEAR, IFSHFT,
     *  INGEAR, TOTRED, ENGRPM)
      IFSHFT = 0
      RPMLST = ENGRPM
      VORVEL = VELALL
      VELLMT = VELALL
      GO TO 200
C
C     BEGINNING OF TRUCK OPERATION LOOP
C
  100 IF (NEWSEC .NE. 1) GO TO 200
C
C     IF A NEW VERTICAL ROAD SECTION (NOVSEC) IS ENTERED
C       (NEWSEC = 1), FIND VELOCITY ALLOWED (VELALL)
      NOVSEC = NOVSEC + 1
      IF (NOVSEC .GT. NVERT) GO TO 500
      CALL ALLVEL (NOVSEC, TRKMAX, VELALL)
```

```
      VODIST = 0.0
C
C     FIND LENGTH OF TIME INTERVAL (TIMINT)
  200 CALL VOTIME (ACONST, INTLIZ, RPMLST, NOVSEC, IFSHFT,
     *   VORVEL, VELALL, ENGRPM, VODIST, VHDIST, TIMINT)
C
C     FIND REQUIRED WHEEL HP TO MAINTAIN CONSTANT SPEED
C       (TWHLHP)
      CALL WHLBHP (ARFKTR, VODIST, NOVSEC, VORVEL, EFFGRD,
     *   TWHLHP)
C
C     FIND MAXIMUM ENGINE HP (AVLBHP) AND ENGINE FRICTION HP
C     (AVLFHP)
      CALL VMAXHP (LTLRPM, LTURPM, ENGRPM, AVLBHP, AVLFHP)
      IF (INTLIZ .EQ. 1) GO TO 300
C
C     ESTIMATE INITIAL THROTTLE SETTING DURING THE FIRST
C       PROGRAM LOOP
      SETLST = (AVLFHP - TWHLHP) / (AVLBHP + AVLFHP)
      IF (SETLST .LT. 0.0) SETLST = 0.0
C
C     FIND MAXIMUM VELOCITY ALLOWED FOR THE PRESENT CONDI-
C       TIONS (VELLMT)
  300 VELLMT = AMIN1(VELALL, VELLMT)
C
C     FIND PRESENT THROTTLE SETTING (RAKSET) AND PRESENT
C       ENGINE GROSS HORSEPOWER (ENGBHP)
      CALL THRTTL (PI, IFSHFT, VACCEL, SETLST, AVLBHP,
     *   AVLFHP, VELLMT, VORVEL, TIMINT, RAKSET, KBRAKE,
     *   ENGBHP)
C
C     CALCULATE FUEL CONSUMPTION (TRKSFC) AND TRUCK
C       EMISSIONS (TKEMMS)
C
      CALL DIESEL (LTLRPM, LTURPM, SUMPRT, ENGRPM, ENGBHP,
     *   TIMINT, TRKSFC, TKEMMS)
C
C     FIND PRESENT ACCELERATION RATE (VACCEL), TRUCK
C       VELOCITY (VORVEL) AND DISTANCE TRAVELED (VHDIST)
      VELOLD = VORVEL
      CALL VELDST (ACONST, BCONST, IFSHFT, KBRAKE, ENGBHP,
     *   RAKSET, VELOLD, CEFFWT, EINRTA, TOTRFD, TINRTA,
     *   NOVSEC, TIMINT, TWHLHP, VACCEL, VELNEW, VHDIST)
```

```
C
C     RECORD TRUCK DATA AND CHECK FOR THE END OF THE SECTIC
      TRKDST = VODIST
      CALL DTAKPR (BCONST, NOVSEC, IFLGTR , KNSTSP, LWPGER,
     *  VELALL, VELMAX, HLDDST, TRKDST, NEWSEC, VELOLD,
     *  VELNEW, VELLMT, VACCEL, TIMINT, VHDIST, TRKSFC,
     *  TKEMMS, DTAINI, VODIST, VORVEL)
C
C     CHECK PRESENT ENGINE SPEED AND CHANGE GEARS IF
C       REQUIRED
      OLDGER = INGEAR
      CALL GRSLCT(LWPGER, NOVSEC, VORVEL, OLDGER, IFSHFT,
     *  INGEAR, TOTRED, ENGRPM)
      IF (IFLGTR .EQ. 1) GO TO 400
      OLDHSC = NOHSEC
C
C     CHECK FOR POSSIBLE DOWNGRADE AHEAD
      CALL DWNHIL (AREKTR, TKBRHP, LTLRPM, LTURPM, PREDST,
     *  INGEAR, NOVSEC, OLDHSC, VHDIST, VODIST, VORVEL,
     *  INTLIZ, SLWDST, VELMAX, HLDDST, NOHSEC, KNSTSP,
     *  IFLGTR)
      IF (IFLGTR .EQ. 1) GO TO 400
      IF (INTLIZ .NE. 1 .AND. KNSTSP .EQ. 1) GO TO 460
C
C     CHECK FOR HORIZONTAL CURVE
      CALL HRZCRV (NOVSEC, OLDHSC, VODIST, VHDIST, SLWDST,
     *  VELMAX, HLDDST, NOHSEC, IFLGTR)
      IF (IFLGTR .EQ. 0) GO TO 450
C
C     PREPARE TO SLOW DOWN IF A DOWNGRADE OR HORIZONTAL
C       CURVE IS APPROACHING
  400 CALL HLDTRK (KFRST1, ACONST, BCONST, LTLRPM, LTURPM,
     *  AREKTR, SUMPRT, SLWDST, VODIST, NOVSEC, NEWSEC,
     *  VELMAX, INGEAR, DTAINI, AVLBHP, RAKSET, ENGRPM,
     *  TOTRED, IFSHFT, VORVEL, VACCEL, KNSTSP, KBRAKE,
     *  IFLGTR)
  450 IF (INTLIZ .EQ. 1) GO TO 100
  460 INTLIZ = 1
      GO TO 100
  500 RETURN
      END
```

```
      SUBROUTINE ALLVEL (NOVSEC, TRKMAX, VELALL)
      REAL LENG
      COMMON /TRAFC/ SPDLMT
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VCRAD(300), R(300), NVERT
C
C     FIND SPEED OF THE TRAFFIC STREAM (SPD)
      CALL STRMSPD (NOVSEC, SPD)
C
C     COMPARE TO THE TRUCK MAXIMUM SPEED DUE TO GEARING
C       (TRKMAX) AND THE POSTED SPEED (SPDLMT) AND OUTPUT
C       THE LEAST OF THESE AS THE ALLOWED VELOCITY (VELALL)
      VELALL = AMIN1 (TRKMAX, SPD, SPDLMT)
      RETURN
      END
```

```
C
C     OUTPUT CONSTANT STREAM SPEED
      SUBROUTINE STRMSPD (NOVSEC, SPD)
      SPD = 60.0
      RETURN
      END
```

```
      SUBROUTINE VOTIME (ACONST, INTLIZ, RPMLST, NOVSEC,
     *  IFSHFT, VORVEL, VELALL, ENGRPM, VODIST, VHDIST,
     *  TIMINT)
      REAL LENG
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VGRAD(300), R(300), NVERT
      IF (INTLIZ .EQ. 0) GO TO 5
      IF (IFSHFT .NE. 1) GO TO 10
C
C     IF A GEAR CHANGE IS OCCURING SET TIME INTERVAL EQUAL
C       TO ONE SECOND
    5 TIMINT = 1.0
      GO TO 60
C
C     DECREASE TIME INTERVAL IF TRUCK IS GOING TOO FAST
   10 IF (VORVEL .GT. VELALL + 2.0) GO TO 40
C
C     REDUCE VELOCITY IF APPROACHING END OF VERTICAL SECTION
      IF ((TIMINT * VORVEL * ACONST) .GE. (LENG(NOVSEC) -
     *  (VODIST + VHDIST))) GO TO 40
      IF (RPMLST .GT. ENGRPM) GO TO 20
      CNGRPM = (ENGRPM - RPMLST) / RPMLST
      GO TO 30
   20 CNGRPM = (RPMLST - ENGRPM) / ENGRPM
C
C     IF CHANGE IN ENGINE SPEED IS GREATER THAN FIVE
C       PERCENT, REDUCE TIME INTERVAL
   30 IF (CNGRPM .GT. 0.05) GO TO 40
C
C     IF CHANGE IN ENGINE SPEED IS LESS THAN TWO PERCENT,
C       INCREASE TIME INTERVAL
      IF (CNGRPM .LT. 0.02) GO TO 50
      GO TO 60
   40 TIMINT = TIMINT * 0.5
      IF (TIMINT .LT. 1.0) TIMINT = 1.0
      GO TO 60
   50 TIMINT = TIMINT * 1.5
      IF (TIMINT .GT. 30.0) TIMINT = 30.0
   60 RPMLST = ENGRPM
      RETURN
      END
```

```
      SUBROUTINE WHLEHP (ARFKTR, VODIST, NOVSEC, VORVEL,
     *  EFFGRD, TWHLHP)
      REAL LENG
      COMMON /ENGPAR/ ENGINE(8), BHPMAX(20), DRLOSS(2)
      COMMON /CONFIG/ WIDTH, HEIGHT, DRAGCO
      COMMON /ATMCND/ WETHER(5)
      COMMON /PAVT/ CS, CV, CP
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VCRAD(300), R(300), NVERT
      COMMON /WEIGHT/ GCW
C
C     CALCULATE ROLLING RESISTANCE
      ROLRES = GCW * (CS + (CV * VORVEL)) * CP
C
C     CALCULATE AIR RESISTANCE
      EFFVEL = VORVEL + WETHER(2)
      AIRRES = ARFKTR * (WETHER(4) / (459.67 + WETHER(3))) *
     *  EFFVEL * EFFVEL
C
C     CALCULATE PRESENT GRADE
      EFFGRD = (VODIST * R(NOVSEC)) + GR(NOVSEC)
C
C     CALCULAGE GRADE RESISTANCE
      GRDRES = GCW * EFFGRD
C
C     FIND TOTAL RESISTANCE, LBS
      TOTRES = - (ROLRES + AIRRES + GRDRES)
C
C     FIND TOTAL WHEEL HORSEPOWER REQUIRED
C
      TWHLHP = (TOTRES * VORVEL) / 375.0
      RETURN
      END
```

```
      SUBROUTINE VMAXHP (LTLRPM, LTURPM, ENGRPM, AVLBHP,
     *   AVLFHP)
      REAL MECHEF
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
C
C     FIND LOWER ENGINE SPEED DATUM POINT
      LOWRPM = IFIX (((ENGRPM - ENGINE(6)) / 100.0) + 1.0)
C
C     FIND UPPER ENGINE SPEED DATUM POINT
      JUPRPM = LOWRPM + 1
C
C
      IF (JUPRPM .GT. LTURPM) GO TO 10
      IF (LOWRPM .LE. 1) GO TO 20
      RPMLOW = FLOAT((LOWRPM + LTLRPM) * 100)
      AVLBHP = (BHPMAX(LOWRPM) + (((BHPMAX(JUPRPM) -
     *   BHPMAX(LOWRPM)) * (ENGRPM - RPMLOW)) / 100.0)) *
     *   ENGINE(9)
      GO TO 30
   10 AVLBHP = 0.0
      AVLFHP = 0.0
      GO TO 40
   20 AVLBHP = BHPMAX(1) * ENGINE(9)
C
C     CALCULATE ENGINE FRICTION HP
   30 COEFFT = 20.1893 - (3.75948E-03 + (3.33129E-06 *
     *   ENGRPM) * ENGRPM)
      BMEPEN = (AVLBHP * 792000.0) / (ENGINE(1) * ENGRPM)
      MECHEF = 1.0 / (1.0 + (COEFFT / BMEPEN))
      AVLFHP = (1.0 - MECHEF) * AVLBHP
   40 RETURN
      END
```

```
      SUBROUTINE THRTTL (PT, IFSHFT, VACCEL, SETLST, AVLBHP,
     *  AVLFHP, VELALL, VORVEL, TIMINT, RAKSET, KBRAKE,
     *  ENGBHP)
C
C     THROTTLE SETTING IS NOT CHANGED DURING GEAR CHANGE
      IF (IFSHFT .EQ. 1) GO TO 70
C
C     REDUCE THROTTLE SETTING IF ACCELERATION IS TOO GREAT
      IF (VACCEL .LT. 2.1937) GO TO 10
      RAKSET = SETLST * (2.1973 / VACCEL)
      IF (RAKSET .LT. 0.0) RAKSET = 0.0
      GO TO 70
C
C     THROTTLE SETTING IS AFFECTED BY LENGTH OF TIME
C       INTERVAL
   10 DLTTIM = (31.0 - TIMINT) / 31.0
      DIFVEL = VELALL - VORVEL
      IF (DIFVEL .GE. 2.0) GO TO 20
C
C     THROTTLE SETTING IS AFFECTED BY THE DIFFERENCE BETWEEN
C       TRUCK VELOCITY AND ALLOWED VELOCITY
      IF (DIFVEL .LE. -2.0) GO TO 50
      DLTRAK = (1.0 - COS(PI * DIFVEL * 0.25)) * DLTTIM
      IF  (DIFVEL .LT. 0.0) GO TO 40
      RAKSET = SETLST + DLTRAK
      IF (RAKSET .LE. 1.0) GO TO 30
   20 RAKSET = 1.0
   30 KBRAKE = 0
      GO TO 70
   40 RAKSET = SETLST - DLTRAK
      IF (RAKSET .GE. 0.0) GO TO 60
   50 RAKSET = 0.0
C
C     SIGNAL POSSIBILITY OF BRAKING
   60 KBRAKE = 1
   70 SETLST = RAKSET
C
C     CALCULATE THE PRESENTLY AVAILABLE ENGINE GROSS HP
      ENGBHP = (RAKSET * (AVLBHP + AVLFHP)) - AVLFHP
      RETURN
      END
```

```
      SUBROUTINE DIESEL (LTLRPM, LTURPM, SUMPRT, ENGRPM,
     *  ENGBHP, TIMINT, TRKSFC, TKEMMS)
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
      COMMON /FUELIN/ BSFC(20,70)
      IF (ENGBHP .GT. 0.0) GO TO 10
      TRKBHP = -ENGBHP
      GO TO 20
   10 TRKBHP = ENGBHP
C
C     CORRECT ENGINE GROSS HORSEPOWER TO STANDARD CONDITIONS
   20 CORBHP = TRKBHP / ENGINE(9)
C
C     FIND LOWER ENGINE SPEED DATUM POINT
      LOWRPM = IFIX(((ENGRPM - ENGINE(6)) / 100.0) + 1.0)
C
C     FIND UPPER ENGINE SPEED DATUM POINT
      JUPRPM = LOWRPM + 1
C
C     FIND LOWER ENGINE HP DATUM POINT
      LOWBHP = IFIX ((CORBHP / 10.0) + 1.0)
C
C     FIND UPPER ENGINE HP DATUM POINT
      IUPBHP = LOWBHP + 1
C
C     INTERPOLATE TO FIND BSFC WITH RESPECT TO ENGINE SPEED
      RPMLOW = FLOAT((LOWRPM + LTLRPM) * 100)
      BHPLOW = FLOAT((LOWBHP - 1) * 10)
C
C     INTERPOLATE TO FIND BSFC WITH RESPECT TO ENGINE HP
      IF (LOWRPM .LE. 1) GO TO 30
      IF (JUPRPM .GE. LTURPM) GO TO 40
      CONSNT = (ENGRPM - RPMLOW) * 0.01
      BSFCLW = (CONSNT * (BSFC(JUPRPM,LOWBHP) - BSFC(LOWRPM,
     *  LOWBHP))) + BSFC(LOWRPM,LOWBHP)
      BSFCHI = (CONSNT * (BSFC(JUPRPM,IUPBHP) - BSFC(LOWRPM,
     *  IUPBHP))) + BSFC(LOWRPM,IUPBHP)
      GO TO 50
   30 BSFCLW = BSFC(1, LOWBHP)
      BSFCHI = BSFC(1, IUPBHP)
      GO TO 50
   40 BSFCLW = BSFC(LTURPM,LOWBHP)
      BSFCHI = BSFC(LTURPM,IUPBHP)
   50 TOTBSC = ((CORBHP - BHPLOW) * 0.1 * (BSFCHI - BSFCLW))
     *  + BSFCLW
C
C     CALCULATE AMOUNT OF FUEL CONSUMMED IN GALLONS
      TRKSFC = (TOTBSC * CORBHP * TIMINT) / 25632.0
C
C     CALCULATE GASEOUS EMISSIONS IN GRAMS
      TKEMMS = SUMPRT * CORBHP * TIMINT
      RETURN
      END
```

```
      SUBROUTINE VELDST (ACONST, BCONST, IFSHFT, KBRAKE,
     *   ENGBHP, RAKSET, VELOLD, CEFFWT, EINRTA, TOTRED,
     *   TINRTA, NOVSEC, TIMINT, TWHLHP, VACCEL, VELNEW,
     *   VHDIST)
      REAL LENG
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
      COMMON /WEIGHT/ GCW
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *   VCRAD(300), R(300), NVERT
      IF (IFSHFT .EQ. 0) GO TO 10
C
C     AVAILABLE WHEEL HP IS ZERO DURING A GEAR CHANGE
      AVLWHP = 0.0
      GO TO 40
C
C     FIND PART THROTTLE DRIVELINE EFFICIENCY
   10 IF (RAKSET .GT. 0.09) GO TO 20
      PTHEFF = 0.5
      GO TO 30
   20 PTHEFF = DRLOSS(1) * (1.0 - (DRLOSS(2) * ((1.0 /
     *   RAKSET) - 1.0)))
      IF (PTHEFF .LT. 0.5) PTHEFF = 0.5
C
C     CALCULATE THE HP AVAILABLE AT THE WHEELS
   30 AVLWHP = (ENGBHP - ENGINE(3)) * PTHEFF
C
C     CALCULATE THE ACCELERATING FORCE, LBS
   40 ACCFRC = (AVLWHP + TWHLHP) * (375.0 / VELOLD)
C
C     CONVERT TRUCK VELOCITY TO FT/SEC
      TRKVEL = VELOLD * ACONST
C
C     CALCULATE TRUCK EFFECTIVE WEIGHT DUE TO INERTIA, LBS
      EFFWGT = GCW + (CEFFWT * ((EINRTA * TOTRED * TOTRED)
     *   + TINRTA))
      IF (VCRAD(NOVSEC) .LT. 20000.0) GO TO 60
C
C     CALCULATE THE NEW VELOCITY IN MPH AND DISTANCE
C       TRAVELED ON A CONSTANT GRADE
      FACTOR = ((ACCFRC * 32.174) / EFFWGT) * TIMINT
      VELNEW = (TRKVEL + FACTOR) * BCONST
      VHDIST = (TRKVEL + (FACTOR * 0.5)) * TIMINT
      GO TO 70
```

```
C
C     CALCULATE NEW VELOCITY AND DISTANCE TRAVELED ON A
C        CHANGING GRADE
   60 CONSTA = (ACCFRC * VCRAD(NOVSEC)) / EFFWGT
      CONSTB = SQRT(32.174 / VCRAD(NOVSEC))
      CONSTC = CONSTB * TIMINT
      IF (CONSTC .LT. 1.57) GO TO 66
      PRINT 64, NOVSEC
   64 FORMAT (2X,≠ERROR IN TIME SPECIFICATION IN SECTION≠,
     *   2X,I3)
      GO TO 140
   66 CONSTD = COS(CONSTC)
      CONSTE = SIN(CONSTC)
      VELNEW = ((TRKVEL * CONSTD) + (CONSTA * CONSTE *
     *   CONSTB)) * BCONST
      VHOIST = CONSTA - (CONSTA * CONSTD) + ((TRKVEL /
     *   CONSTB) * CONSTE)
C
C     CALCULATE THE RATE OF ACCELERATION, MPH/SEC
   70 VACCEL = (((VELNEW * VELNEW) - (VELOLD * VELOLD)) /
     *   (2.0 * VHOIST)) * ACONST
C
C     CHECK THROTTLE STATUS AND BRAKE IF REQUIRED
      IF (KBRAKE .NE. 1) GO TO 90
      IF (VACCEL .LE. 0.0) GO TO 90
      VELNEW = VELOLD - 2.0
      VACCEL = (VELNEW - VELOLD) / TIMINT
      IF (VACCEL .GE. -3.30) GO TO 80
      VACCEL = -3.30
      VELNEW = VELOLD + (VACCEL * TIMINT)
   80 VHOIST = ((VELOLD + (0.5 * VACCEL * TIMINT)) * TIMINT)
     *   * ACONST
   90 IF (VELNEW .GT. 0.0) GO TO 110
      PRINT 100, NOVSEC
  100 FORMAT (10X, ≠THE TRUCK HAS STOPPED IN SECTION≠, 2X.
     *   I3)
      GO TO 140
  110 IF (VHOIST .GT. 0.0) GO TO 130
      PRINT 120, NOVSEC
  120 FORMAT(10X.≠NEGATIVE PROGRESS IN SECTION≠,2X,I3)
      GO TO 140
  130 RETURN
  140 IEXIT = 7
      CALL OUTPUT (NOVSEC, IEXIT)
      END
```

```
      SUBROUTINE DTAKPR (BCONST, NOVSEC, IFLGTR, KNSTSP,
     *   LWRGEP, VELALL, VELMAX, HLDDST, TRKDST, NEWSEC,
     *   VELOLD, VELNEW, VELLMT, VACCEL, TIMINT, VHDIST,
     *   TRKSEC, TKEMMS, DTAINI, VODIST, VORVEL)
      REAL LENG
      DIMENSION TKDATA(4), DTAINI(6)
      COMMON /TROFS/ TIM(200), TSPD(200), NUMTIM
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *   VCRAD(300), R(300), NVERT
      COMMON /TRAFC/ SPDLMT
      TKDATA(1) = TIMINT
      TKDATA(2) = VHDIST
      TKDATA(3) = TRKSEC
      TKDATA(4) = TKEMMS
C
C     INITIALIZE VARIABLES IF AT BEGINNING OF NEW SECTION
      IF (NEWSEC .NE. 1) GO TO 10
      DTAINI(3) = 0.0
      DTAINI(4) = 0.0
      IF (IFLGTR .EQ. 1) GO TO 5
      NUMTIM = 0
    5 NEWSEC = 0
      VODIST = 0.0
C
C     CALCULATE DISTANCE TRAVELED IN PRESENT SECTION
   10 VODIST = TRKDST + TKDATA(2)
C
C     CHECK FOR END OF SECTION
      ENDSEC = LENG(NOVSEC) - VODIST
      VORVEL = VELNEW
      IF (ENDSEC .GT. 0.0) GO TO 30
C
C     CORRECT DATA IF AT END OF SECTION
      NEWSEC = 1
      CORECT = (TKDATA(2) + ENDSEC)/ TKDATA(2)
      DO 20 I = 1, 4
      TKDATA(I) = TKDATA(I) * CORECT
   20 CONTINUE
      VORVEL = VELOLD + (VACCEL * TKDATA(1))
      VODIST = LENG(NOVSEC)
C
C     TRANSFER DATA TO ARRAY DTAINI FOR SUBROUTINE HLDTRK
   30 DTAINI(1) = TKDATA(1)
      DTAINI(2) = TKDATA(2)
      DTAINI(3) = DTAINI(3) + TKDATA(3)
      DTAINI(4) = DTAINI(4) + TKDATA(4)
      DTAINI (5) = VODIST
```

```
C
C     RETURN IF HLDTRK IN CONTROL (IFLGTR = 1)
      IF (IFLGTR .EQ. 1) GO TO 50
C
C     RECORD DATA
      NUMTIM = NUMTIM + 1
      TIM(NUMTIM) = TKDATA(1)
      TSPD(NUMTIM) = (TKDATA(2) / TKDATA(1)) * BCONST
      IF (NEWSEC .NE. 1) GO TO 40
C

C     OUTPUT DATA IF AT END OF ROAD SECTION
      CALL TRKOUT (NOVSEC, DTAINI(3), DTAINI(4))
   40 IF (KNSTSP .NE. 1) GO TO 50
C
C     KEEP TRACK OF HORIZONTAL CURVE AND DOWNGRADE  SECTION
C       LENGTHS
      VELLMT = VELMAX
      HLDDST = HLDDST - TKDATA(2)
      IF (VELMAX .LT. SPDLMT) LWRGER = 1
      IF (HLDDST .GE. 0.0) GO TO 50
      KNSTSP = 0
      VELLMT = VELALL
      LWRGER = 0
   50 RETURN
      END
```

```
      SUBROUTINE GRSLCT (LWRGER, NOVSEC, VORVEL, NUMGER,
     *  IFSHFT, INGEAR, TOTRED, ENGRPM)
      COMMON /ENGPAR/ ENGINE(9), BHPMAX(20), DRLOSS(2)
      COMMON /TRANSM/ NOGEAR, AXLRTO, GEARNO(15)
      IFSHFT = 0
      INITGR = NUMGER
C
C     CALCULATE PRESENT ENGINE SPEED
C
      CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
C
C     UPSHIFT IF REQUIRED
      IF (ENGRPM .GT. ENGINE(5)) GO TO 40
C
C     DOWNSHIFT IF REQUIRED
      IF (ENGRPM .GT. ENGINE(4)) GO TO 20
   10 NUMGER = NUMGER - 1
      IF (NUMGER .LT. 1) GO TO 30
      CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
      IF (ENGRPM .LT. ENGINE(4)) GO TO 10
   20 IF (LWRGER .EQ. 1) GO TO 60
      GO TO 100
   30 NUMGER = 1
      GO TO 90
   40 NUMGER = NUMGER + 1
      IF (NUMGER .GT. NOGEAR) GO TO 50
      CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
      IF (ENGRPM .GT. ENGINE(5)) GO TO 40
      GO TO 100
   50 NUMGER = NOGEAR
      CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
      IF (ENGRPM .GT. ENGINE(7)) GO TO 110
      GO TO 100
C
C     USE LOWEST GEAR IF ON DOWNGRADE OR CURVE
   60 NUMGER = NUMGER - 1
      IF (NUMGER .LT. 1) GO TO 30
      CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
      IF (ENGRPM .LT. ENGINE(5)) GO TO 60
      NUMGER = NUMGER + 1
   90 CALL GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
  100 INGEAR = NUMGER
C
C     SIGNAL IF A SHIFT HAS OCCURRED (IFSHIFT = 1)
      IF (INGEAR .NE. INITGR) IFSHFT = 1
      RETURN
  110 PRINT 120, NOVSEC
  120 FORMAT (2X,*ERROR IN GEAR SELECTION IN SECTION*,I5)
      IEXIT = 9
      CALL OUTPUT (NOVSEC, IEXIT)
      END
```

```
      SUBROUTINE GERCHG (VORVEL, NUMGER, TOTRED, ENGRPM)
      COMMON /TRANSM/ NOGEAR, AXLRTO, GEARNO(15)
      COMMON /TIREIN/ TIRRIM(7)
C
C     CALCULATE NEW GEAR REDUCTION
      TOTRED = AXLRTO * GEARNO(NUMGER)
C
C     CALCULATE NEW ENGINE SPEED
      ENGRPM = (VORVEL * TIRRIM(4) * TOTRED) / 60.0
      RETURN
      END
```

```
      SUBROUTINE DWNHIL (ARFKTR, TKBRHP, LTLRPM, LTURPM,
     *   PREDST, INGEAR, NOVSEC, OLDHSC, VHDIST, VODIST,
     *   VORVEL, INTLIZ, SLWDST, VELMAX, HLDDST, NEWHSC,
     *   KNSTSP, IFLGTR)
      REAL LENG, MPLA, LSTGRD
      INTEGER OLDHSC, STRTGR
      COMMON /ALIGN/ VMP(310), GR(300), LENG(300),
     *   VCRAD(300), R(300), NVERT
      COMMON /HORIZ/ HMP(300), HRAD(300), HCURL(300),
     *   HASPC(300), MPLA(300), NCURVE
      COMMON /TRAFC/ SPDLMT
      IF (INTLIZ .NE. 0) GO TO 5
C
C     SUBROUTINE INITIALIZATION
      TOTDST = 0.0
      KNTSEC = NOVSEC
      EYEDST = PREDST + VHDIST
      DSTKPR = 0.0
      GO TO 10
C
C     IF NO NEW ROAD SECTION IS IMMINENT, RETURN TO MAIN
C     PROGRAM
    5 DSTKPR = DSTKPR - VHDIST
      IF (DSTKPR .GT. 0.0) GO TO 140
      TOTDST = VODIST
      KNTSEC = NOVSEC + 1
      IF (KNTSEC .LE. LSTSEC) GO TO 140
      DSTKPR = 0.0
C
C     CALCULATE LOOK AHEAD DISTANCE
      EYEDST = PREDST + VHDIST
      IF (EYEDST .LE. LENG(NOVSEC)) GO TO 140
C
C     CHECK FOR DOWNGRADE WITHIN LOOK AHEAD DISTANCE
   10 IF (GR(KNTSEC) .LT. 0.0 .OR. R(KNTSEC) .LT. 0.0)
     *   GO TO 20
      TOTDST = TOTDST + LENG(KNTSEC)
      IF (TOTDST .GT. EYEDST) GO TO 140
      KNTSEC = KNTSEC + 1
      GO TO 10
C
C     FIND MAXIMUM GRADE SECTION ON DOWNGRADE
   20 LSTGRD = 0.0
```

```
      STRTGR = KNTSEC
   30 IF (R(KNTSEC) .LT. 0.0) GO TO 40
      GRDMAX = GR(KNTSEC)
      DSTGRD = 0.0
      GO TO 45
   40 GRDMAX = GR(KNTSEC) + (LENG(KNTSEC) * R(KNTSEC))
      DSTGRD = LENG(KNTSEC)
   45 IF (GRDMAX .GE. LSTGRD) GO TO 50
      LSTGRD = GRDMAX
      LSTPSC = KNTSEC
      DSTLST = DSTGRD

   50 KNTSEC = KNTSEC + 1
      IF (KNTSEC .GT. NVERT) GO TO 60
      IF (GR(KNTSEC) .LT. 0.0) GO TO 30
      IF (R(KNTSEC) .LT. 0.0) GO TO 40
C
C     FIND THE MAXIMUM ALLOWED VELOCITY ON THE DOWNGRADE
   60 VELMAX = VORVEL
      NOGVEL = 0
      LSTSEC = KNTSEC - 1
   70 CALL WHLBHP (AFFKTR, DSTLST, LSTPSC, VELMAX, LSTGRD,
     *   TWHLHP)
      CALL GRSLCT(1, LSTPSC, VELMAX, INGEAR, IFSHFT, NEEDGR,
     *   REQRED, REQRPM)
      CALL VMAXHP (LTLRPM, LTURPM, REQRPM, AVLBHP, AVLFHP)
      AVBRHP = TKEPHP + AVLFHP - TWHLHP
      IF (AVBRHP .GT. 0.0) GO TO 80
      NOGVEL = 1
      VELMAX = VELMAX - 5.0
      GO TO 70
   80 IF (NOGVEL .EQ. 1) GO TO 95
      IF (AVBRHP .LT. 0.0) GO TO 90
      VELMAX = VELMAX + 5.0
      IF (VELMAX .LE. SPDLMT) GO TO 70
      VELMAX = SPDLMT
      GO TO 100
   90 VELMAX = VELMAX - 5.0
   95 IF (NOVSEC .NE. 1) GO TO 100
C
C     CALCULATE THE DISTANCE TO THE DOWNGRADE (SLWDST) AND
C       THE LENGTH OF THE GRADE (HLDDST)
      SAMDST = VODIST
      GO TO 105
  100 SAMDST = VMP(NOVSEC - 1) + VODIST
  105 SLWDST = VMP(STRTGR) - SAMDST
      HLDDST = VMP(LSTSEC) - SAMDST
      DSTKPR = HLDDST - EYEDST
  110 IF (HMP(OLDHSC) .GT. (SAMDST + HLDDST)) GO TO 130
```

```
C
C     CHECK FOR SPEED LIMITING HORIZONTAL CURVES ON THE
C       DOWNGRADE
      IF (HASPD(OLDHSC) .GT. VELMAX) GO TO 120
      VELMAX = HASPD(OLDHSC)
  120 OLDHSC = OLDHSC + 1
      IF (OLDHSC .LT. NCURVE) GO TO 110
  130 NEWHSC = OLDHSC

      IF (INTLIZ .NE. 0) GO TO 135
      VELMAX = AMIN1(VELMAX, SPDLMT)
      KNSTSP = 1
      SLWDST = 0.0
      GO TO 140
  135 IFLGTR = 1
  140 RETURN
      END
```

```
      SUBROUTINE HRZCRV (NOVSEC, OLDHSC, VODIST, VHDIST,
     *   SLWDST, VELMAX, HLDDST, NEWHSC, IFLGTR)
      REAL LENG
      INTEGER OLDHSC
      COMMON /HORIZ/ HMP(300), HRAD(300), HCURL(300),
     *   HASPD(300), MPLA(300), NCURVE
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *   VCRAD(300), R(300), NVERT
C
C     CHECK FOR HORIZONTAL CURVES WITHIN LOOK AHEAD DISTANCE
      IF (NOVSEC .NE. 1) GO TO 10
      SAMDST = VODIST
      GO TO 20
   10 SAMDST = VMP(NOVSEC - 1) + VODIST
   20 IF (MPLA(OLDHSC) .GT. (SAMDST + VHDIST)) GO TO 40
C
C     FIND LENGTH OF CURVE
      HLDDST = HCURL(OLDHSC)
C
C     FIND MAXIMUM SPEED ALLOWED ON THE CURVE
      VELMAX = HASPD(OLDHSC)
      NEWHSC = OLDHSC + 1
      IF (NEWHSC .LE. NCURVE) GO TO 30
      NEWHSC = OLDHSC
C
C     FIND DISTANCE TO CURVE
   30 SLWDST = HMP(OLDHSC) - SAMDST
      IFLGTR = 1
   40 RETURN
      END
```

```
      SUBROUTINE HLDTRK (KFRSTM, ACONST, BCONST, LTLRPM,
     *  LTURPM, ARFKTR, SUMDST, SLWDST, VODIST, NOVSEC,
     *  NEWSEC, VELMAX, INGEAR, DTAINI, AVLBHP, RAKSET,
     *  ENGRPM, TOTRED, IFSHFT, VOFVEL, VACCEL, KNSTSP,
     *  KBRAKE, IFLGTR)
      REAL LENG
      INTEGER OKSTEN, OLDSEC
      DIMENSION INTRVL(20), DTALOG(20,41,6), SUMLOG(4),
     *  DTAINI(6), LOGDTA(20,41)
      COMMON /ALIGN/ VMP(300), GR(300), LENG(300),
     *  VCRAD(300), R(300), NVERT
      COMMON /TROPS/ TIM(200), TSPD(200), NUMINT
      IF (KFRSTM .EQ. 1) GO TO 30
C
C     INITIALIZE SUBROUTINE
      DSTLOG = 0.0
      NUMSEC = 1
      INTNUM = 0
      KFRSTM = 1
      INTDTA = 0
      IF (NEWSEC .NE. 1) GO TO 10
      KBGSEC = NOVSEC + 1
      OLDSEC = KBGSEC
      GO TO 20
   10 KBGSEC = NOVSEC
      OLDSEC = NOVSEC
   20 RETURN
C
C     RECORD DATA FOR TIME INTERVAL
   30 DTAINI(6) = AVLBHP
      IF (NOVSEC .EQ. OLDSEC) GO TO 40
      INTRVL(NUMSEC) = INTNUM
      OLDSEC = NOVSEC
      NUMSEC = NUMSEC + 1
      IF (NUMSEC .GT. 20) GO TO 200
      INTNUM = 0
   40 INTNUM = INTNUM + 1
      IF (INTNUM .GT. 40) GO TO 200
      DO 60 K = 1, 6
      DTALOG(NUMSEC, INTNUM, K) = DTAINI(K)
   60 CONTINUE
      LOGDTA(NUMSEC,INTNUM) = INGEAR
      DSTLOG = DSTLOG + DTAINI(2)
      IF (DSTLOG .GE. SLWDST) GO TO 80
      INTDTA = INTDTA + 1
      IF (INTDTA .LT. 40) RETURN
C
C     RECORD DATA FOR FIRST 20 TIME INTERVALS
      INTRVL(NUMSEC) = INTNUM
```

```
      KNTSEC = 1
      INTDTA = 0
      NUMTIM = NUMINT + INTRVL(1)
      KUMINT = 0
      GO TO 68
   64 KNTSEC = KNTSEC + 1
      IF (KNTSEC .GT. 20) GO TO 200
      KBGSEC = KBGSEC + 1
      KUMINT = 0
      NUMTIM = INTRVL(KNTSEC)
      NUMINT = 0
   68 INTDTA = INTDTA + 1
      IF (INTDTA .GT. 20) GO TO 72
      NUMINT = NUMINT + 1
      KUMINT = KUMINT + 1
      IF (NUMINT .GT. NUMTIM) GO TO 70
      TIM(NUMINT) = DTALOG(KNTSEC,KUMINT,1)
      TSPD(NUMINT ) = (DTALOG(KNTSEC,KUMINT,2) /
     *  DTALOG(KNTSEC,KUMINT, 1)) * BCONST
      GO TO 68
   70 NUMINT = NUMTIM
      CALL TRKOUT(KBGSEC, DTALOG(KNTSEC,NUMINT,3),
     *  DTALOG(KNTSEC,NUMINT,4))
      GO TO 64
   72 INTRSQ = 0
      NOMINT = KUMINT
C
C     RESEQUENCE REMAINING TIME INTERVALS
      INTRVL(KNTSEC) = INTRVL(KNTSEC) - KUMINT
   74 NUMTIM = INTRVL(KNTSEC)
      INTRSQ = INTRSQ + 1
      DO 77 I = 1, NUMTIM
      DO 76 J = 1, 6
      KOUNTR = NOMINT + I
      DTALOG(INTRSQ,I,J) = DTALOG(KNTSEC,KOUNTR,J)
   76 CONTINUE
      LOGDTA(INTRSQ,I) = LOGDTA(KNTSEC,KOUNTR)
   77 CONTINUE
      NOMINT = 0
      KNTSEC = KNTSEC + 1
      IF (KNTSEC .LE. NUMSEC) GO TO 74
      INTDTA = 20
      NUMSEC = INTRSQ
      INTNUM = NUMTIM
      RETURN
   80 INTRVL(NUMSEC) = INTNUM
      IF (VORVEL .GT. VELMAX) GO TO 90
C
C     RECORD DATA IF TRUCK VELOCITY DOES NOT EXCEED VELOCITY
C       ALLOWED
```

```
      KNSTSP = 0
      CALL DTADMP (BCONST, KBGSEC, KFSTSC, NUMSEC, INTRVL,
     *  DTALOG, NOWSEC)
      GO TO 170
C
C     BRAKE TRUCK IF VELOCITY EXCEEDS VELOCITY ALLOWED
   90 TOTDST = 0.0
  100 DSTLOG = DSTLOG - DTALOG(NUMSEC,INTRVL(NUMSEC),2)
      ENDVEL = (DTALOG(NUMSEC,INTRVL(NUMSEC),2) /
     *  DTALOG(NUMSEC,INTRVL(NUMSEC),1)) * BCONST
      BRKDST = SLWDST - DSTLOG
      IF (BRKDST .LT. 0.0) GO TO 180
      DECCEL = (((VELMAX * VELMAX) - (ENDVEL * ENDVEL)) /
     *  (2.0 * BRKDST)) * ACONST

      IF (DECCEL .GE. -3.00) GO TO 105
      INTRVL(NUMSEC) = INTRVL(NUMSEC) - 1
      IF (INTRVL(NUMSEC) .GE. 1) GO TO 100
      NUMSEC = NUMSEC - 1
      IF (NUMSEC .LT. 1) GO TO 180
      GO TO 100
  105 CALL DTADMP (BCONST, KBGSEC, KFSTSC, NUMSEC, INTRVL,
     *  DTALOG, NOWSEC)
      BRKTIM = (VELMAX - ENDVEL) / DECCEL
      IF (BRKTIM .LT. 0.0) BRKTIM = -BRKTIM
C
C     RESET SUBROUTINES AFTER BRAKING
      CALL GRSLCT (1, NOVSEC, VELMAX, LOGDTA(NUMSEC,INTRVL
     *  (NUMSEC)), IFSHFT, INGEAR, TOTRED, ENGRPM)
      CALL VOTIME (0.0, 1, ENGRPM, NOVSEC, 1, 0.0, 0.0,
     *  ENGRPM, 0.0, 0.0, TIMINT)
      CALL WHLBHP (ARFKTR, VODIST, NOVSEC, VELMAX, EFFGRD,
     *  TWHLHP)
      CALL VMAXHP (LTLRPM, LTURPM, ENGRPM, AVLBHP, AVLFHP)
C
C     FIND THROTTLE SETTING
      IF (GR(NOVSEC) .GT. 0.0) GO TO 110
      SETLST = 0.0
      GO TO 120
  110 SETLST = (AVLFHP - TWHLHP) / (AVLBHP + AVLFHP)
  120 CALL THRTTL (0.0, 0, 5.0, SETLST, AVLBHP, AVLFHP,
     *  0.0, 0.0, 0.0, RAKSET, 0, ENGBHP)
      KBRAKE = 0
C
C     ESTIMATE FUEL CONSUMED AND EMISSIONS
      AVGBHP = (DTALOG(NUMSEC,INTRVL(NUMSEC), 6) + ENGBHP)
     *  * 0.5
      CALL DIESEL (LTLRPM, LTURPM, SUMPFT, ENGRPM, AVGBHP,
     *  BRKTIM, FNLGAL, AVGEMS)
```

```
C
C     RECORD DATA FOR BRAKING SECTION
      CUMGAL = DTALOG(NUMSEC, INTRVL(NUMSEC),3)
      CUMGRM = DTALOG(NUMSEC, INTRVL(NUMSEC),4)
      IF (NOWSEC .NE. NOVSEC) GO TO 125
      SECPER = 1.0
      NUMINT = NUMINT + 1
      OKRTRN = 1
      GO TO 130
  125 OKRTRN = 0
      NUMINT = INTRVL(KFSTSC) + 1
      SECPER = (LENG(NOWSEC) - DTALOG(NUMSEC,INTRVL(NUMSEC),
     *   5)) / BRKDST
  130 SUMLOG(1) = BRKTIM * SECPER
      SUMLOG(2) = BRKDST * SECPER
      SUMLOG(3) = (FULGAL * SECPER) + CUMGAL
      SUMLOG(4) = (AVGEMS * SECPER) + CUMGRM
      TIM(NUMINT) = SUMLOG(1)
      TSPD(NUMINT) = (SUMLOG(2) / SUMLOG(1)) * BCONST
      IF (OKRTRN .EQ. 1) GO TO 150
      CALL TRKOUT (NOWSEC, SUMLOG(3), SUMLOG(4))
      TOTDST = TOTDST + SUMLOG(2)
      NOWSEC = NOWSEC + 1
      NUMSEC = NUMSEC + 1
      NUMINT = 1
      CUMGAL = 0
      CUMGRM = 0
      IF (NOWSEC .GE. NOVSEC) GO TO 140
      SECPER = LENG(NUMSEC) / BRKDST
      GO TO 130
  140 OKRTRN = 1
      KNSTSP = 1
      IFSHFT = 0
      VACCEL = DECCEL
      SECPER = (BRKDST - TOTDST) / BRKDST
      GO TO 130
  150 VORVEL = TSPD(NUMINT)
      IF (NENDSC .NE. 1) GO TO 160
      CALL TRKOUT (NOVSEC, SUMLOG(3), SUMLOG(4))
      GO TO 170
C
C     RESET SUBROUTINE DTAKER
  160 CALL DTAKER (BCONST, NOVSEC, IFLGTR, KNSTSP, 0,
     *   VELMAX, VELMAX, 0.0, DTALOG(NUMSEC,INTRVL(NUMSEC),5)
     *   , 1, VELMAX, VORVEL, VELMAX, 0.0, SUMLOG(1),
     *   SUMLOG(2), SUMLOG(3), SUMLOG(4), DTAINI, VODIST,
     *   VORVEL)
  170 IFLGTR = 0
      KFRSTM = 0
      IFSHFT = 0
      NUMINT = INTRVL(NUMSEC)
```

```
      RETURN
  180 PRINT 190, K3GSEC
  190 FORMAT (10X, ≠TRUCK CANNOT REDUCE SPEED TO A SAFE
     *  VELOCITY≠, 2X, I3)
      GO TO 210
  200 PRINT*, ≠ SECTION NUMBER OVERLOAD≠
  210 IEXIT = 12
      CALL OUTPUT (NOVSEC, IEXIT)
      RETURN
      END
```

```
      SUBROUTINE DTACMP (BCONST, KBGSEC, KFSTSC, NUMSEC,
     *   INTRVL, DTALOG, NOWSEC)
      DIMENSION INTRVL(20), DTALOG(20,41,6)
      COMMON /IROFS/ TIM(200), TSPD(200), NUMINT
C
C     RECORD TIME INTERVAL DATA
      KFSTSC = 1
   10 NOWINT = INTRVL(KFSTSC)
      DO 20 J = 1, NOWINT
      KCOUNT = J + NUMINT
      TIM(KCOUNT) = DTALOG(KFSTSC, J, 1)
      IF (TIM(KCOUNT) .LE. 0.0) GO TO 40
      TSPD(KCOUNT) = (DTALOG(KFSTSC,J,2) / DTALOG(KFSTSC,J,1
     *   )) * BCONST
      IF (TSPD(KCOUNT) .LE. 0.0) GO TO 60
   20 CONTINUE
      NUMINT = KCOUNT
      IF (NUMSEC .EQ. KFSTSC) GO TO 30
      CALL TRKOUT (KBGSEC, DTALOG(KFSTSC,NOWINT,3),
     *   DTALOG(KFSTSC,NOWINT,4))
      KFSTSC = KFSTSC + 1
      IF (KFSTSC .GT. 20) GO TO 75
      NUMINT = 0
      KBGSEC = KBGSEC + 1
      GO TO 10
   30 NOWSEC = KBGSEC
      RETURN
   40 PRINT 50, KBGSEC, NUMINT
   50 FORMAT (10X, ≠ERROR IN TIME SPECIFICATION IN SECTION≠,
     *   I4,≠WHEN NUMINT EQUALS≠,I4)
      GO TO 80
   60 PRINT 70, KBGSEC, KCOUNT
   70 FORMAT(10X,≠ERROR IN DISTANCE SPECIFICATION IN SECTION
     *   ≠,I4,≠WHEN NUMINT EQUALS≠,I4)
      GO TO 80
   75 PRINT*, ≠ SECTION NUMBER OVERLOAD≠
   80 IEXIT = 13
      CALL OUTPUT (KBGSEC, IEXIT)
      END
```

```
      SUBROUTINE TRKOUT (NOVSEC, TKFUEL, TKEMMS)
      COMMON /TROPS/ TIM(200), TSPD(200), NUMINT
      COMMON /DATA/ TIME(20,200), SPEED(20,200), DIESEL(20),
     *  EXHAST(20), TOTIME(20), TOTINT(20)
C
C     TRANSFER TIME AND SPEED TO COMMON DATA
      TOTIME(NOVSEC) = 0.0
      DO 10 I=1,NUMINT
      TIME(NOVSEC,I) = TIM(I)
      SPEED(NOVSEC,I) = TSPD(I)
C
C     CALCULATE TOTAL TIME IN SECTION
      TOTIME(NOVSEC) = TOTIME(NOVSEC) + TIM(I)
   10 CONTINUE
C
C     TRANSFER NUMBER OF TIME INTERVALS (TOTINT)
C              FUEL CONSUMED            (TKFUEL)
C              EMISSIONS                (TKEMMS)
C     TO COMMON DATA
      TOTINT(NOVSEC) = NUMINT
      DIESEL(NOVSEC) = TKFUEL
      EXHAST(NOVSEC) = TKEMMS
      RETURN
      END
```

```
      SUBROUTINE OUTPUT (NOVSEC, IEXIT)
      COMMON /TROFS/ TIM(200), TSPD(200), NUMINT
      COMMON /DATA/ TIME(20,200), SPEED(20,200), DIESEL(20),
     *  EXHAST(20), TOTIME(20), TOTINT(20)
      NUMSEC = 1
      IF(IEXIT .EQ. 0) GO TO 20
C
C     IF IEXIT IS NOT ZERO, A PROGRAM ERROR HAS OCCURRED.
C     SUBROUTINE TRKOUT IS CALLED TO PROCESS THE DATA FOR
C       THE LAST VERTICAL SECTION
C
      PRINT 10, NOVSEC, NUMINT, IEXIT
   10 FORMAT(≠ ERROR IN SECTION≠,I3,≠ AFTER INTERVAL≠,I3,
     *  ≠ WHEN IEXIT =≠I3)
      CALL TRKOUT(NOVSEC, 0.0, 0.0)
C
C     PRINT DATA FOR EACH VERTICAL SECTION
   20 PRINT 30, NUMSEC, DIESEL(NUMSEC), EXHAST(NUMSEC)
   30 FORMAT(≠0FOR SECTION NUMBER≠,I3,5X,≠FUEL USED = ≠,
     *  E11.4,≠ GALLONS≠,/,5X,≠EMISSIONS = ≠,E11.4,≠GRAMS≠,
     *  /,≠       INTERVAL    TIME   SPEED≠)
      INTRVL = TOTINT(NUMSEC)
      DO 50 I = 1, INTRVL
      PRINT 40, I, TIME(NUMSEC, I), SPEED(NUMSEC, I)
   40 FORMAT (8X, I3, 3X, 2(F7.2))
   50 CONTINUE
      NUMSEC = NUMSEC + 1
      IF(NUMSEC .LE. NOVSEC) GO TO 20
      IF (IEXIT .NE. 0) GO TO 60
      RETURN
   60 STOP
      END
```

APPENDIX 2. GLOSSARY OF IMPORTANT VARIABLE NAMES

PROGRAM NAME	DESCRIPTION
ACCFRC	Vehicle acceleration force, lb
ACONST	Unit conversion, (ft-hr)/(mi-sec)
AIRRES	Air resistance, lb
ARFKTR	Air resistance coefficient, (in.Hg.-mph^2)/($^\circ$F-ft^2)
AVBRHP	Available braking horsepower
AVLBHP	Engine gross horsepower
AXLRTO	Rear axle ratio
BCONST	Unit conversion, (mi-sec)/(ft-hr)
BRKDST	Braking distance, ft
CNGRPM	Change in engine speed, rpm
CNRFC	Cornering resistance, lb
DECCEL	Braking deceleration rate, mph/sec
DSTLOG	Distance traveled, ft
DTAINI(1)	Length of time interval, sec
DTAINI(2)	Distance traveled during time interval, ft
DTAINI(3)	Fuel consumed, gal
DTAINI(4)	Gaseous Exhaust Emissions, gm

PROGRAM	DESCRIPTION
DTAINI(5)	Distance traveled in vertical section, ft
DTAINI(6)	Engine gross horsepower
EFFWGT	Truck effective weight, lb
EINRTA	Engine and clutch inertia, ft-lb-sec^2
ENDVEL	Velocity before braking, mph
ENGBHP	Engine gross horsepower
ENGINE(9)	Engine horsepower correction factor
ENGRPM	Engine speed, rpm
EYEDST	Look-ahead distance, ft
GRDRES	Grade force, lb
HLDDST	Total length of downgrade or curve, ft
INGEAR	Present transmission gear
IFLGTR	Signal for approaching downgrade or curve
IFSHFT	Signal for gear change
KBRAKE	Signal that truck should be slowing
LOGDTA	Present transmission gear

PROGRAM	DESCRIPTION
LSTGRD	Maximum grade, percent/100
NOVSEC	Number of vertical sections
NUMGER	Number of transmission gear
NUMTIM	Number of time intervals
PREDST	Pre-set look ahead distance, ft
PTHEFF	Part throttle driveline efficiency
RAKSET	Throttle setting
ROLRES	Rolling resistance, lb
SETLST	Throttle setting for previous time interval
SLWDST	Braking distance, ft
SPD	Traffic stream speed, mph
SPDLMT	Posted speed limit
SUMPRT	Constant for calculating emissions, gm/bhp-hr
TIM	Length of time interval, sec
TIMINT	Length of time interval, sec
TINRTA	Tire inertia, ft-lb-sec^2
TIRRIM(7)	Tire rolling radius, ft
TKDATA(1)	Length of time interval, sec

PROGRAM	DESCRIPTION
TKDATA(2)	Distance traveled during time interval, ft
TKDATA(3)	Fuel consumed during time interval, gal
TKDATA(4)	Emissions during time interval, gm
TKEMMS	Exhaust gaseous emissions, gr
TOTBSC	Fuel consumed, gal
TOTRED	Overall gear reduction
TOTRES	Total road resistance, lb
TRBRHP	Truck braking horsepower
TRKBHP	Absolute horsepower value
TRKMAX	Maximum truck velocity
TRKSFC	Exhaust gaseous emissions, gm
TRKVEL	Truck velocity, ft/sec
TSPD	Truck velocity for time interval, mph
TWHLHP	Total road resistance, hp
VACCEL	Average acceleration rate, mph/sec
VELALL	Velocity allowed by Subroutine ALLVEL, mph
VELMAX	Velocity allowed by road geometrics, mph

PROGRAM	DESCRIPTION
VELLMT	Maximum velocity allowed, mph
VELNEW	Velocity at end of time interval, mph
VELOLD	Average velocity of previous time interval, mph
VHDIST	Distance traveled during time interval, ft
VODIST	Distance traveled in vertical section, ft
VORVEL	Present truck velocity, mph

APPENDIX 3. INITIAL TEST DATA

INPUT DATA

```
C
C
C      THESE DATA ARE IN ORDER FOR USE AS INPUT INTO THE
C        SIMULATION MODEL
C
C
C      NCURVE, NVERT, SPDLMT
C
    4          13          55
C
C      VERTICAL SECTION DATA
C      VMP(I), GR(I), VGRAD(I), R(I), LENG(I)
C
 1840.0        -0.014   99999.0          0.0        1840.0
 1997.5        -0.014     553.649        0.000089    157.5
 2560.0         0.000     553.649        0.000089    562.5
 2900.0         0.050   99999.0          0.0         340.0
 3757.143       0.050     915.751       -0.000058    857.143
 4100.0         0.0       915.751       -0.000058    342.857
 4600.0        -0.020   99999.0          0.0         500.0
 4800.0        -0.020     604.417        0.0001      200.0
 5400.0         0.0       604.417        0.0001      600.0
 6900.0         0.060   99999.0          0.0        1500.0
 7620.0         0.060     894.182       -0.000083    720.0
 8100.0         0.0       894.182       -0.000083    480.0
12000.0        -0.040   99999.0          0.0        3900.0
C
C      HORIZONTAL SECTION DATA
C      HMP(J), HRAD(J), HCURL(J), HASPD(J), MPLA(J)
C
 1600.0       1537.0       1000.0        70.0        100.0
 3050.0       2865.0       1250.0        70.0       1500.0
 5000.0        550.0        600.0        45.3       3500.0
 6500.0       2500.0       1000.0        70.0       5000.0
C
C      CS, CV, CP, RADIAL TIRES AND ROUGH ASPHALT
C
0.0043  0.000016    1.00
C
C      WETHER(K)
C
  0.0 10.0 70.0 30.0 0.0
C
C      GOW, WIDTH, HEIGHT, DRAGCO
C
 80000.011.00 8.000.070
```

```
C
C     ENGINE(M)
C
  855. 2200.   20. 1500. 2100.  300. 2400.  350.
C
C     BHPMAX(N), 350 HP
C
   89.  114.  144.  174.  204.  232.  253.  278.  295.  310.
  324.  332.  340.  348.  350.  255.     0.
C
C     DRLOSS(I). 6 X 4 TRACTOR
C
  0.86 0.066
C
C     TIRRIM(J), RADIAL TIRES
C


     41.8      130.0      19.2      519.       10.0      22.5
C
C     NOGEAR, AXLRTO, GEARNO(I)
C
10    4.11 8.05 6.30 4.99 3.95 3.20 2.51 1.97 1.56 1.24 1.00
C
C
C     BSFC(M,N), 350 HP ENGINE
C
0.6410.6410.5160.4630.4450.4340.4270.4270.4360.4510.4630.473
0.504
C     PLACE 4 BLANK CARDS HERE
0.7120.7120.5340.4750.4450.4200.4220.4170.4180.4190.4200.427
0.4390.4490.4650.4750.543
C     PLACE 4 BLANK CARDS HERE
0.7830.7830.5700.4960.4540.4340.4210.4070.4030.4110.4060.403
0.4090.4160.4270.4370.4540.4820.583
C     PLACE 4 BLANK CARDS HERE
0.8540.8540.6050.5100.4630.4410.4270.4120.4090.4070.3990.399
0.3990.4000.4020.4090.4180.4270.4350.4570.4510.492
C     PLACE 4 BLANK CARDS HERE
0.9260.9260.6140.5340.4910.4560.4330.4220.4100.4030.3990.395
0.3920.3920.3940.3960.3980.4040.4110.4670.4240.4340.4430.443
0.460
C     PLACE 3 BLANK CARDS HERE
0.9970.9970.6760.5460.5160.4530.4450.4270.4130.4110.3990.395
0.3920.3890.3920.3890.3920.3940.3960.4010.4020.4070.4050.409
0.4150.4090.411
C     PLACE 3 BLANK CARDS HERE
1.2101.2100.7390.5930.5340.4910.4690.4450.4360.4130.4130.395
0.3930.3890.3920.3840.3870.3810.3830.3850.3830.3900.3580.390
0.3890.3930.3920.3960.400
```

```
C       PLACE 3 BLANK CARDS HERE
1.2821.2820.7830.6650.5520.4380.4370.4780.4450.4270.4200.395
0.4030.3940.3970.3940.3870.3810.3840.3780.3840.3800.3820.378
0.3800.3840.3610.3620.3610.3780.387
C       PLACE 3 BLANK CARDS HERE
1.4241.4240.9900.7990.5870.5410.4980.4840.4540.4510.4510.421
0.4120.4000.3970.3690.3870.3810.3800.3730.3770.3760.3750.375
0.3770.3730.3750.3740.3760.3760.3790.3860.3830.383
C       PLACE 3 BLANK CARDS HERE
1.4951.4930.9260.7360.6140.5700.5340.5030.4720.4590.4410.440
0.4120.4110.4020.3990.3920.3850.3840.3780.3770.3760.3750.371
0.3710.3700.3700.3730.3710.3710.3730.3770.3730.383
C       PLACE 3 BLANK CARDS HERE
1.7031.7031.0320.7930.6760.5840.5560.5190.4880.4750.4560.447
0.4270.4220.4120.4030.4010.3940.3920.3850.3840.3800.3790.375
0.3710.3700.3700.3690.3690.3710.3730.3720.3740.3730.377
C       PLACE 3 BLANK CARDS HERE
1.9941.9941.1040.8780.7120.6410.5970.7490.5160.4900.4770.455
0.4440.4330.4220.4160.4090.4050.4000.3970.3920.3870.3850.381
0.3800.3730.3750.3720.3710.3710.3730.3720.3740.3730.3750.376
C       PLACE 3 BLANK CARDS HERE
2.1362.1361.2450.9460.7650.6340.5170.5800.5430.5140.4910.473
0.4530.4440.4420.4320.4230.4150.4110.4050.3990.3970.3920.390
0.3860.3840.3930.3800.3790.3780.3770.3770.3760.3750.3770.376
C       PLACE 3 BLANK CARDS HERE
2.4212.4211.2100.9260.7480.6840.6330.6100.5700.5450.5200.505
0.4630.4440.4420.4270.4250.4190.4070.4050.3930.4000.3920.390
0.3860.3640.3830.3820.3790.3780.3770.3770.3760.3780.3770.376
C       PLACE 3 BLANK CARDS HERE
2.7062.7061.4691.0920.8900.7590.7000.6410.6050.5620.5410.51
0.5040.4870.4730.4600.4540.4480.4390.4350.4310.4240.4210.415


0.4120.4070.4050.4010.4020.3950.3960.3930.3910.3890.3870.367
C       PLACE 3 BLANK CARDS HERE
2.9192.9191.6021.1870.9610.8400.7360.6920.6410.6090.5770.550
0.5340.5090.5030.4890.4510.4590.4570.4570.4430.4410.4370.433
0.4240.4240.4220.4170.412
C       PLACE 3 BLANK CARDS HERE
3.204
C       PLACE 23 BLANK CARDS HERE
C       BSER(I), 1978 STANDARDS
C
C
C       BSER(I), 1978 STANDARDS
      16.0          40.0          0.0
```

DATA OUTPUT

```
FOR SECTION NUMBER  1       FUEL USED =     .8545E-01 GALLONS
    EMISSIONS =     .3741E+02GRAMS
     INTERVAL      TIME   SPEED
           1       1.00   55.07
           2       1.50   54.14
           3       1.50   53.56
           4       2.25   54.72
           5       2.25   54.45
           6       2.25   54.18
           7       2.25   55.64
           8       2.25   55.36
           9       2.25   54.86
          10       3.38   54.35
          11       1.69   53.90
          12        .42   54.78
FOR SECTION NUMBER  2       FUEL USED =     .9709E-02 GALLONS
    EMISSIONS =     .1034E+02GRAMS
     INTERVAL      TIME   SPEED
           1       1.00   54.52
           2        .99   53.51
FOR SECTION NUMBER  3       FUEL USED =     .3769E-01 GALLONS
    EMISSIONS =     .3997E+02GRAMS
     INTERVAL      TIME   SPEED
           1       1.00   52.16
           2       1.00   50.70
           3       1.00   49.38
           4       1.00   47.96
           5       1.00   46.46
           6       1.00   44.86
           7       1.00   43.19
           8       1.00   41.20
           9        .19   39.21
FOR SECTION NUMBER  4       FUEL USED =     .2772E-01 GALLONS
    EMISSIONS =     .2933E+02GRAMS
     INTERVAL      TIME   SPEED
           1       1.50   39.11
           2       1.50   38.25
           3       1.50   37.39
           4       1.00   36.68
           5        .64   36.11
FOR SECTION NUMBER  5       FUEL USED =     .9576E-01 GALLONS
    EMISSIONS =     .1014E+03GRAMS
     INTERVAL      TIME   SPEED
           1       1.50   35.14
           2       1.00   33.04
           3       1.00   31.80
           4       1.00   31.01
           5       1.00   30.30
           6       1.00   29.66
           7       1.00   29.09
           8       1.50   28.38
           9       1.50   27.37
          10       1.00   26.28
          11       1.00   25.74
          12       1.50   25.65
          13       2.25   25.16
          14       2.25   24.26
          15       1.13   23.78
          16       1.00   24.10
          17        .43   24.48
```

FOR SECTION NUMBER 6 FUEL USED = .4336E-01 GALLONS
EMISSIONS = .4590E+02GRAMS

INTERVAL	TIME	SPEED
1	1.50	24.70
2	2.25	24.98
3	3.33	24.59
4	1.69	23.61
5	.73	24.30

FOR SECTION NUMBER 7 FUEL USED = .5310E-01 GALLONS
EMISSIONS = .5635E+02GRAMS

INTERVAL	TIME	SPEED
1	1.00	25.05
2	1.00	26.32
3	1.00	27.57
4	1.00	28.80
5	1.00	30.02
6	1.00	30.77
7	1.50	31.74
8	1.00	33.09
9	1.00	34.16
10	1.00	35.21
11	.61	36.26

FOR SECTION NUMBER 8 FUEL USED = .1888E-01 GALLONS
EMISSIONS = .2000E+02GRAMS

INTERVAL	TIME	SPEED
1	1.50	36.42
2	1.00	35.85
3	1.00	35.70
4	.29	35.45

FOR SECTION NUMBER 9 FUEL USED = .6456E-01 GALLONS
EMISSIONS = .6841E+02GRAMS

INTERVAL	TIME	SPEED
1	1.50	35.12
2	1.50	33.33
3	1.50	32.41
4	1.50	30.86
5	1.00	29.51
6	1.00	28.73
7	1.00	27.88
8	1.00	26.96
9	1.00	25.60
10	1.00	24.30
11	1.00	23.43
12	1.00	22.52
13	.09	21.56

FOR SECTION NUMBER 10 FUEL USED = .2734E+01 GALLONS
EMISSIONS = .2896E+03GRAMS

INTERVAL	TIME	SPEED
1	1.50	21.57
2	1.00	20.60
3	1.00	19.20
4	1.00	18.52
5	1.50	18.75
6	2.25	18.09
7	3.38	17.72
8	3.38	17.23
9	3.38	16.83
10	1.00	15.96
11	1.00	15.40
12	1.50	15.62
13	2.25	15.95
14	2.25	16.31
15	2.25	16.65
16	3.38	17.01
17	3.38	17.41
18	3.38	17.74
19	5.06	18.10
20	5.06	18.47
21	1.00	17.96
22	1.00	17.22
23	1.50	17.05
24	2.25	16.92
25	1.00	15.02
26	1.00	15.45
27	1.50	15.67
28	.56	15.89

FOR SECTION NUMBER 11 FUEL USED = .1444E+00 GALLONS
EMISSIONS = .1530E+03GRAMS

INTERVAL	TIME	SPEED
1	1.50	15.82
2	1.50	15.47
3	2.25	15.10
4	2.25	14.51
5	2.25	14.17
6	3.38	13.82
7	1.00	12.37
8	1.00	12.25
9	1.00	13.04
10	1.00	13.81
11	1.00	14.56
12	1.00	15.28
13	1.00	15.18
14	1.00	15.04
15	1.00	15.68
16	1.00	16.33
17	1.00	16.99
18	1.00	17.65
19	1.00	18.31
20	1.00	18.94
21	1.00	19.23
22	1.00	19.81
23	1.00	19.43
24	1.00	20.08
25	.41	19.18

FOR SECTION NUMBER 12 FUEL USED = .2898E-01 GALLONS
EMISSIONS = .2172E+02GRAMS

INTERVAL	TIME	SPEED
1	2.25	19.02
2	1.00	19.20
3	1.50	18.75
4	1.00	18.23
5	1.50	17.95
6	1.50	17.47
7	1.50	17.10
8	2.25	16.67
9	1.13	16.12
10	1.69	16.23
11	1.00	16.25
12	1.00	15.33
13	.41	13.33

FOR SECTION NUMBER 13 FUEL USED = .4395E+00 GALLONS
EMISSIONS = .4012E+03GRAMS

INTERVAL	TIME	SPEED
1	1.00	14.71
2	1.00	16.27
3	1.00	15.62
4	1.00	13.62
5	1.00	13.85
6	1.00	15.43
7	1.00	16.88
8	1.00	16.97
9	1.00	16.45
10	1.00	15.92
11	1.00	13.92
12	1.00	14.14
13	1.00	15.72
14	1.00	17.16
15	1.00	17.25
16	1.00	16.57
17	1.00	15.90
18	1.00	13.90
19	1.00	14.12
20	1.00	15.70
21	1.00	17.14
22	1.00	17.23
23	1.00	16.56
24	1.00	15.90
25	1.00	13.90
26	1.00	14.12
27	1.00	15.69
28	1.00	17.14
29	1.00	17.23
30	1.00	16.56
31	1.00	15.90
32	1.00	13.90
33	1.00	14.12
34	1.00	15.69
35	1.00	17.14
36	1.00	17.22
37	1.00	16.56
38	1.00	15.90
39	1.00	13.90

40	1.00	14.12
41	1.00	15.69
42	1.00	17.14
43	1.00	17.22
44	1.00	16.56
45	1.00	15.90
46	1.00	13.90
47	1.00	14.12
48	1.00	15.69
49	1.00	17.14
50	1.00	17.22
51	1.00	16.56
52	1.00	15.90
53	1.00	13.90
54	1.00	14.12
55	1.00	15.69
56	1.00	17.14
57	1.00	17.22
58	1.00	16.56
59	1.00	15.90
60	1.00	13.90
61	1.00	14.12
62	1.00	15.69
63	1.00	17.14
64	1.00	17.22
65	1.00	16.56
66	1.00	15.90
67	1.00	13.90
68	1.00	14.12
69	1.00	15.69
70	1.00	17.14
71	1.00	17.22
72	1.00	16.56
73	1.00	15.90
74	1.00	13.90
75	1.00	14.12
76	1.00	15.69
77	1.00	17.14
78	1.00	17.22
79	1.00	16.56
80	1.00	15.90
81	1.00	13.90
82	1.00	14.12
83	1.00	15.69
84	1.00	17.14
85	1.00	17.22
86	1.00	16.56
87	1.00	15.90
88	1.00	13.90
89	1.00	14.12
90	1.00	15.69
91	1.00	17.14
92	1.00	17.22
93	1.00	16.56
94	1.00	15.90
95	1.00	13.90
96	1.00	14.12
97	1.00	15.69
98	1.00	17.14
99	1.00	17.22
100	1.00	16.56
101	1.00	15.90
102	1.00	13.90
103	1.00	14.12
104	1.00	15.69
105	1.00	17.14
106	1.00	17.22
107	1.00	16.56

108	1.00	15.90
109	1.00	13.90
110	1.00	14.12
111	1.00	15.69
112	1.00	17.14
113	1.00	17.22
114	1.00	16.56
115	1.00	15.90
116	1.00	13.90
117	1.00	14.12
118	1.00	15.69
119	1.00	17.14
120	1.00	17.22
121	1.00	16.56
122	1.00	15.90
123	1.00	13.90
124	1.00	14.12
125	1.00	15.69
126	1.00	17.14
127	1.00	17.22
128	1.00	16.56
129	1.00	15.90
130	1.00	13.90
131	1.00	14.12
132	1.00	15.69
133	1.00	17.14
134	1.00	17.22
135	1.00	16.56
136	1.00	15.90
137	1.00	13.90
138	1.00	14.12
139	1.00	15.69
140	1.00	17.14
141	1.00	17.22
142	1.00	16.56
143	1.00	15.90
144	1.00	13.90
145	1.00	14.12
146	1.00	15.69
147	1.00	17.14
148	1.00	17.22
149	1.00	16.56
150	1.00	15.90
151	1.00	13.90
152	1.00	14.12
153	1.00	15.69
154	1.00	17.14
155	1.00	17.22
156	1.00	16.56
157	1.00	15.90
158	1.00	13.90
159	1.00	14.12
160	1.00	15.69
161	1.00	17.14
162	1.00	17.22
163	1.00	16.56
164	1.00	15.90
165	1.00	13.90
166	1.00	14.12
167	1.00	15.69
168	1.00	17.14
169	.63	17.22