CHAPTER 2
LOGIC AND BASIC CONCEPTIONS
OF THE MTC

2.1 CALCULATION OF FREE SPEED

The MTC version presented here uses a series of equations which make it possible to calculate the free speed of six different classes of vehicles for an entire range of situations which may be encountered while traveling on a given road.

These series of equations was obtained from the experiments described in Volume 6. The choice of one or the other equation for the calculation of free speed will be discussed after the following terminology is explained:

- Road Connection - the road (or part of it) that one intends to analyse;
- Section - any subdivision of the road connection; and

- Nodes - points along each section at which the program calculates speeds. At the start of the analysis, these points correspond to the beginning of each grade variation, to the beginning of each curve or straight line, to the start of each change in the type or level of surface roughness and to the beginning and end of each speed-control section. Later, during the process of analysis, the program defines additional nodes for each change in vehicle speed mode(constant/acceleration/deceleration);
- Speed-Control Sections - locations along the road where, for legal or safety reasons, traffic speed is limited to a value independent of the capacity of the vehicles;
- Link - the connection between two consecutive nodes. Therefore, on a given link, the value of the grade, the alignment, the speed control, the type of road surface, the roughness, and the vehicle speed mode are all constant.

For the user to understand the process of calculating free speed, it is necessary to begin with the definition adopted for *steady-state speed.*

Suppose that a link (homogeneous characteristics as to roughness, alignment, profile, etc.) is sufficiently long to permit a vehicle to reach a certain speed at a given point of the segment, and that from this point on it will maintain the same speed till the end of the segment. For example, if the link is a positive grade, it can be ex-

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pected that the speed of the vehicle will gradually diminish until
achieving stability at a certain point. It is just as if, for each
class of vehicles on the segment, there existed a speed that would be
reached and maintained, should the segment be of sufficient length.
Thus, on a given segment, each class of vehicle tends to reach and
maintain a certain speed, defined as its *steady-state-speed.*

Therefore, it is possible to associate to a given road
segment a single steady-state speed for each class of vehicles.

The calculation of the free speed through the use of the
MTC is based on the supposition that, on each link, the vehicles will
accelerate, decelerate or maintain their present speed, depending on
whether the speed of entry into the segment is below, above or equal
to its respective steady-state speed. Thus, the choice of the speed
equation will be subordinated to the conception of the model, which
attempts to take the vehicle from entry speed to the steady-state
speed of the segment. To do this, the MTC has six speed functions.

The general forms of these speed functions are presented in
Figure 2.1. The mnemonics of the functions used in the program are
composed of four letters. The first two letters indicate that its
use is for positive grades (PG) or negative grades (NG). The third
letter indicates either acceleration (A), deceleration (D) or steady-
state speed (S). When the fourth letter is B, it indicates that the
function is used for forced deceleration, which occurs when the vehi-
cle tries to enter a speed-control link at a speed higher than that
permitted. The letter (E) is used only to complete the fourth posi-
tion, and has no meaning in itself. The single exception to the
composition of these mnemonics is the function LACC, used to acceler-
ate vehicles on positive grades.

Summarizing, the functions are as follows:

- PGSE - steady-state speed on positive grades;
- LACC - acceleration on positive grades;
- PGDB - forced deceleration on positive grades;
- NGSE - steady-state speed on negative grades;
- NGAE - acceleration on negative grades; and
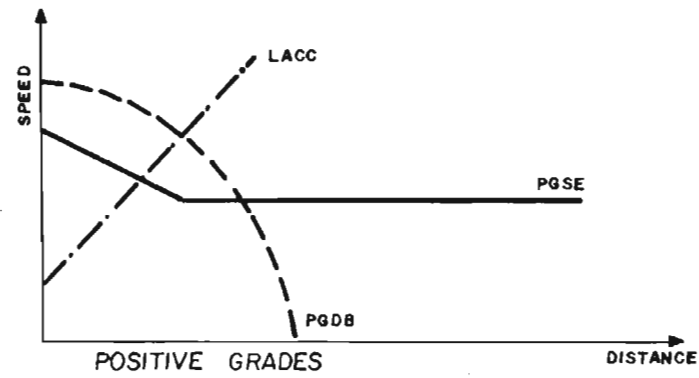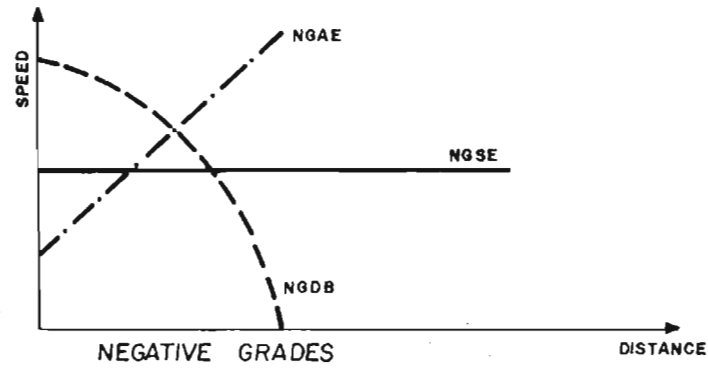- NGDB - forced deceleration on negative grades.

Figure 2.1 – GENERAL FORM OF SPEED FUNCTIONS.

A final observation should be made with relation to function PGSE (steady-state speed on positive grades). Figure 2.1 shows that this function can be utilized to decelerate vehicles. This occurs when the vehicle enters a positive grade at a speed higher than the steady-state speed of the grade. It is as if the vehicle loses speed until reaching the level of steady-state speed. This situation thus differs from that of forced deceleration. In the latter situation, the vehicle is below its capacity. In the former, it loses speed not due to speed controls because it is running at a speed higher than the steady-state speed of the positive grade.

2.2   CALCULATION OF FUEL CONSUMPTION

Six functions are used to calculate the rate of fuel consumption (volume per time unit). To obtain the volume of fuel consumed on each link, the rate of consumption is multiplied by the time spent to cover it. Time is calculated as the distance divided by the average speed on the link, the latter being obtained on the basis of speed at the start and at the end of the link. The consumption function chosen for each link depends on the speed function utilized in the description of vehicle behavior. As independent variables, the consumption functions use grade, roughness, surface type, vehicle class, type and gross weight, though not all the functions utilize all these factors.

The final letter of the mnemonics of the fuel-consumption functions indicates whether the function should be used for positive (P) or negative (N) grades. With the exception of functions FCDP (consumption during forced deceleration on positive grades) and FCDN (consumption during forced deceleration on negative grades), the letters and the preceding numbers show which experiment was performed to produce the respective equation (vide Volume 6). For the two exceptions specified above, the average rates of fuel consumption were estimated on the basis of the data gathered during Experiment TBS-6 (forced deceleration).

Fuel consumption is calculated according to vehicle class and type. In the case of gasoline-powered automobiles, utilities and light

trucks (empty and loaded), the rate is given in units of milliliters per second of the gasoline mixture with 20% alcohol (as explained in Volume 6), whereas for the remaining classes and types of vehicles units of milliliters of diesel fuel per second are used.

Summarizing, the functions are as follows:
- FC1P - consumption at steady-state speed on positive grades;
- FCS4P- consumption during acceleration on positive grades;
- FCDP - consumption during forced deceleration on positive grades;
- FC2P - consumption during deceleration by gravity on positive grades;
- FC1N - consumption at steady-state speed on negative grades;
- FCS4N- consumption during acceleration on negative grades; and
- FCDN - consumption during forced deceleration on negative grades.

2.3   SELECTION OF SPEED AND FUEL-CONSUMPTION EQUATIONS

The process of selecting equations for the calculation of speed (or travel time) and fuel consumption will be shown under this item.

The choice of the fuel-consumption equation is based on the speed equation chosen to describe a vehicle's behavior on a specific link or, in other words, a consumption equation will be associated to each speed equation. Consequently, once the speed equation is determined, the consumption equation will be automatically determined.

Speed is calculated at each node (already defined) of a section of the road. Therefore, before calculating speed it is necessary that the section be divided into links, composed of the stretches between two consecutive nodes. As already stated, the physical characteristics of a given link (grade, alignment, roughness, etc.) are constant. Consequently, it is possible to determine the constant speed for each vehicle class on the segment in question. The result of the comparison between the speed of the vehicle at the entry node of the segment (or, simply, entry speed) and the steady-state speed on the

segment will determine the choice of the speed equation. This occurs
since the MTC is designed in such a way that the vehicle always tends
to steady-state speed. If the speed is lower than the steady-state
speed, the vehicle should be accelerated, if higher, it should be de-
celerated; if speed is equal to steady-state speed, it should be main-
tained. It is with this in mind that one utilizes the acceleration,
deceleration or steady-state speed equation, respectively. Before
choosing one of these equations, however, the program will determine
if the grade of the link is positive or negative[1], since the equations
and vehicle behavior will be different in each situation.

The following terminology is now considered:
- V1 - vehicle speed at the entry node of the link or, sim-
    ply, entry speed;
- V2 - vehicle speed at the exit node of the link or, sim-
    ply, exit speed; and
- SSS - steady-state speed.

Suppose that a vehicle is on a positive-grade link. Figure
2.2 shows the possible behaviors of the vehicle on this link. For
those cases in which the vehicle reaches the steady-state speed on the
link, should the vehicle be above (or below) the steady-state speed,
it will be accelerated (or decelerated) and, once steady-state speed
has been reached, the MTC program creates an additional node at this
point and maintains speed until the end of the link (cases 2 and 4 of
Figure 2.2). The user should observe that the original segment was
divided into two smaller segments, both of which possess the same
physical characteristics. However, the new segment is created due to
change in vehicle behavior (from deceleration to steady-state speed,
in case 2, and from acceleration to steady-state speed, in case 4 of
Figure 2.2).

Figure 2.3 shows possible vehicle behaviors on negative-grade
links. The speed equations will be chosen through a comparison between
entry speed (V1) and steady-state speed (SSS), just as was done pre-
viously, the only difference being that, when entry speed is higher
than steady-state speed, the vehicle should be decelerated on negative

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[1] If the grade is neutral, the results will be the same, independently
of whether one uses the positive or negative grade equations. However,
the program deals with neutral grades as if they were negative grades.

grades, maintaining the same speed over the entire segment (case 1 of Figure 2.3).

The equations of forced deceleration on positive (PGDB) and negative (NGDB) grades will only be utilized in those cases in which the vehicle attempts to enter a speed-control link at a speed higher than permitted (Figures 2.4 and 2.5).

Figure 2.4 shows the original speed profile on two consecutive links, assuming a random situation for the first (for example, steady-state speed) and a speed-control situation for the second. Clearly, the entry speed (V1) of a link should be the same as the exit speed (V2) of the previous link, or the speed profile will experience a lack of continuity.

To avoid discontinuity, the MTC utilizes the maximum speed permitted on the second segment as the exit speed (V2) of the first link (Figure 2.5). Consequently, the speeds should be calculated backwards along the road until reaching the point where the vehicle should begin deceleration to reach the required exit speed. This is shown in Figure 2.5.

The additional node created in the first segment is the point at which the vehicle begins deceleration. In this way, the first segment is divided into two smaller segments, both possessing the same physical characteristics. The new segment, however, is created as a result of a change in vehicle behavior (from steady-state speed to deceleration). Figure 2.6 shows the new links with the final speed profile.

If the grade of the second link of Figure 2.6 is positive, the equation to use will be PGDB - forced deceleration on positive grades. If negative, the equation will be NGDB - forced deceleration on negative grades. Once the two final possible situations for vehicle behavior have been discussed, the description of the process of choosing the speed equations and, consequently, the fuel-consumption equations, is completed.

2.4   COMPUTATIONAL LOGIC

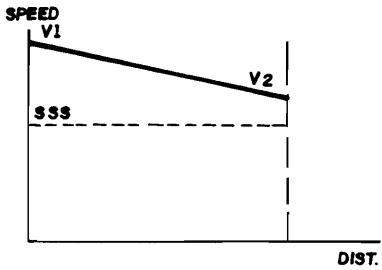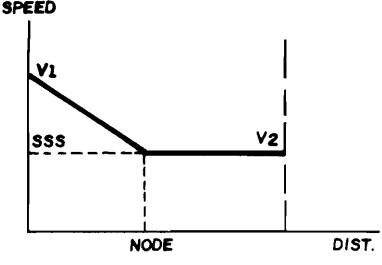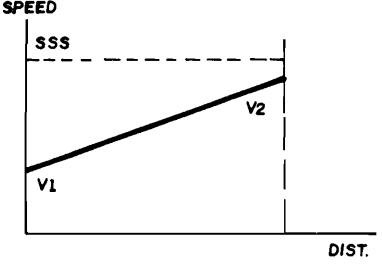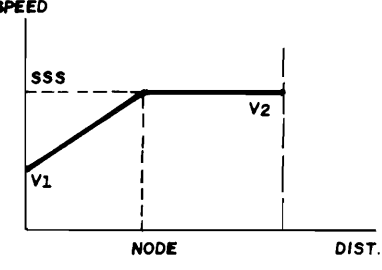This item presents an explanation of the logic of the MTC
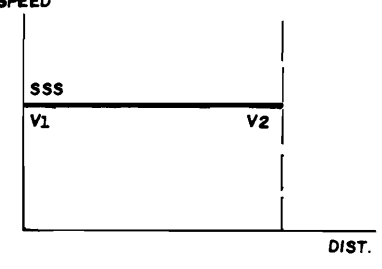
CASE	SPEED PROFILE	SPEED FUNCTION(s) USED
1	SPEED, V1, V2, SSS, DIST.	PGSE – DECELERATION BY GRAVITY
2	SPEED, V1, SSS, V2, NODE, DIST.	1st LINK : DECELERATION BY GRAVITY 2nd LINK : STEADY - STATE SPEED
3	SPEED, SSS, V2, V1, DIST.	LACC – ACCELERATION
4	SPEED, SSS, V2, V1, NODE, DIST.	1st LINK : LACC – ACCELERATION 2nd LINK : STEADY - STATE SPEED
5	SPEED, SSS, V1, V2, DIST.	PGSE – STEADY - STATE SPEED

Figure 2.2 – POSSIBLE PERFORMANCES OF VEHICHES ON POSITIVE GRADES.
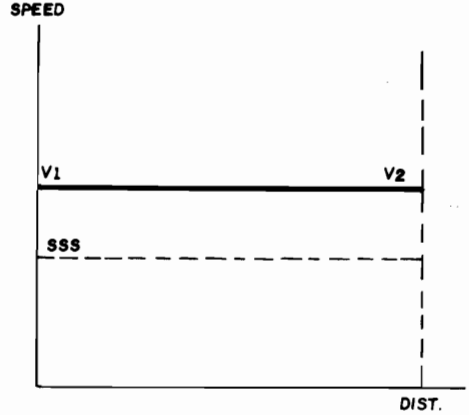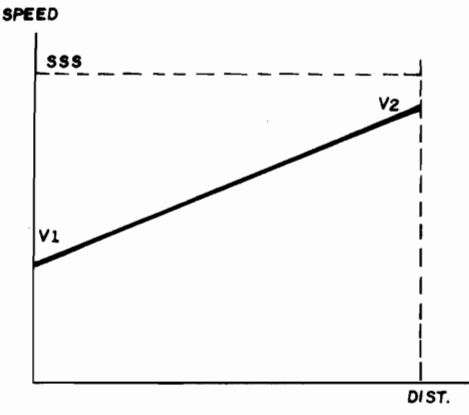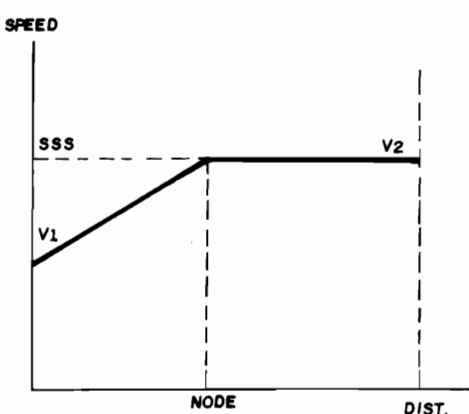
CASE	SPEED PROFILE	SPEED FUNCTION(s) USED
1	SPEED — V1 ———— V2 — SSS —————— DIST.	NGSE – STEADY-STATE SPEED
2	SPEED — SSS ———— V2 — V1 ——— DIST.	NGAE – ACCELERATION
3	SPEED — SSS —— V2 — V1 — NODE DIST.	1st LINK : ACCELERATION 2nd LINK : STEADY-STATE SPEED

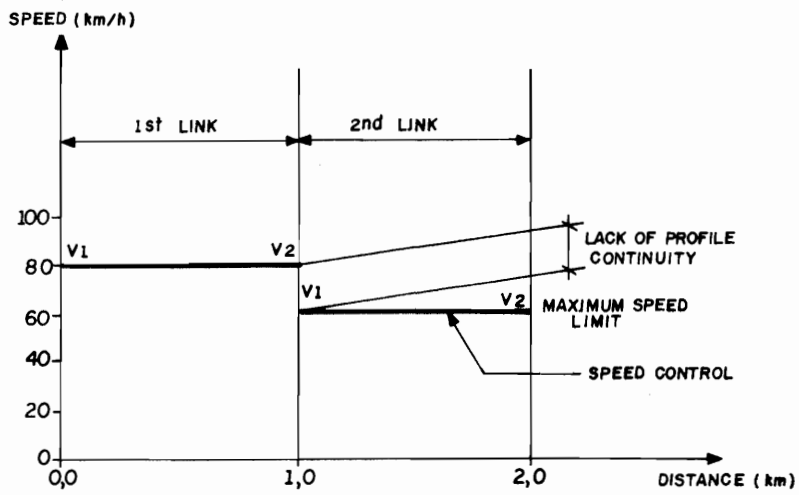Figure 2.3 – POSSIBLE PERFORMANCES OF VEHICLES ON NEGATIVE GRADES.
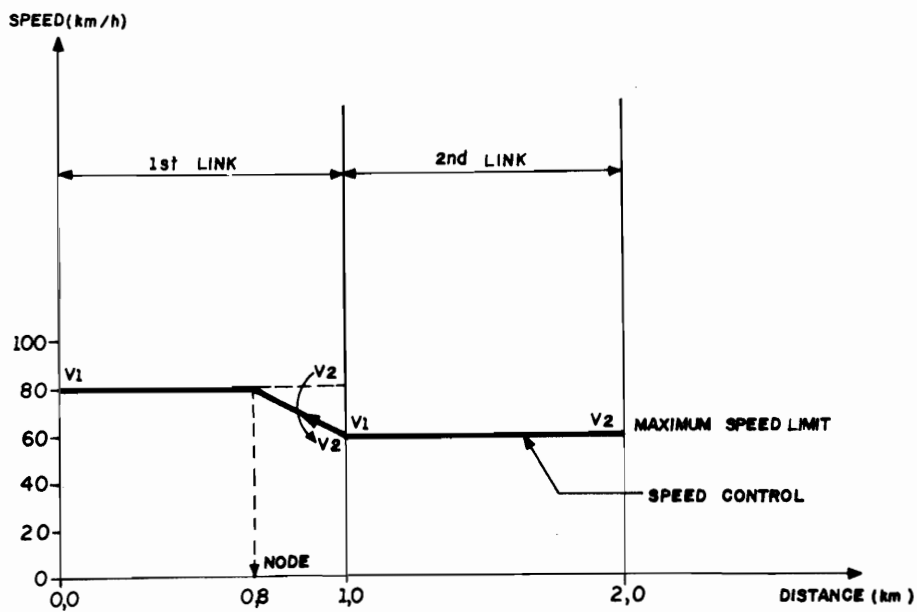
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Figure 2.4 - ORIGINAL SPEED PROFILE.
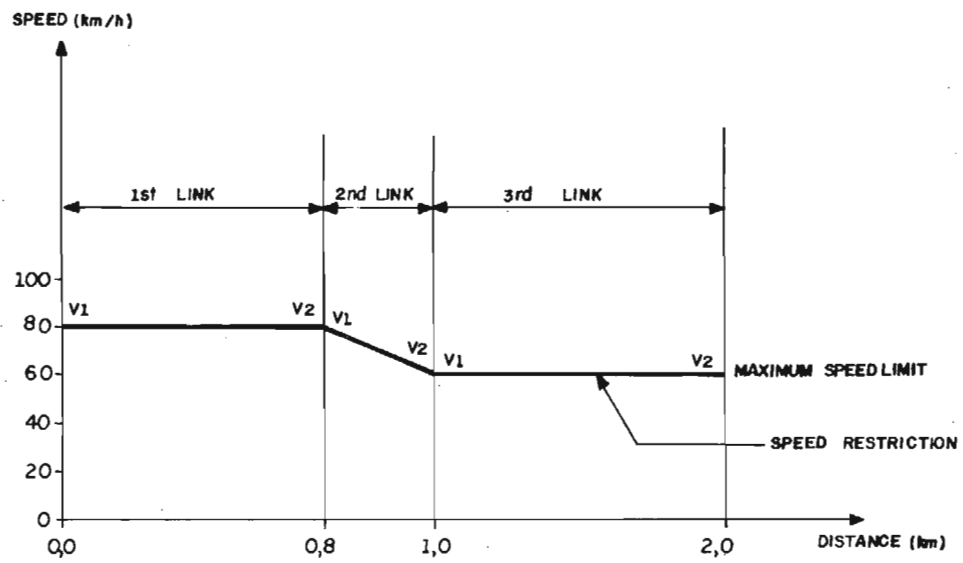

Figure 2.5 - FINAL SPEED PROFILE.

Figure 2.6 - CREATION OF NEW LINK.

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computer program, coded in FORTRAN IV. In the MTC, the physical char-
acteristics of the road are analysed consecutively, as nodes are es-
tablished at the transitions between sections with different character-
istics. The flowchart of the major aspects of the model is presented
in Figure 2.7.

As shown in Figure 2.7, the MTC executes interactions at three
levels: direction, vehicle class and link. The direction loop makes
it possible to analyse the road in both traffic directions. The vehi-
cle-class loop repeats the logic of the program for each of the vehicle
classes specified by the user. Finally, speed, time and fuel consump-
tion are calculated in each link.

There are three major execution phases in the MTC: establish-
ment of analysis arrays, calculation of forward speed and calculation
of backward speed. The establishment of analysis arrays consists of
converting the input data to the form required by speed calculations:
the program creates the links where the physical characteristics (grade,
alignment, roughness, etc.) are constant, thus permitting the
speed calculations. The forward-speed calculation gives the speed that
the vehicle reaches at the end of the link (exit speed). The backward
speed must be calculated when the entry speed on a speed-control link
is greater than the maximum speed permitted. It should be recalled
that, when this occurs, speeds must be calculated backwards along the
road, until one finds the point at which the vehicle should begin de-
celerating to reach the entry speed required on the speed-control link.

Figures 2.9, 2.10 and 2.11 provide greater details as to the
three functional parts of the MTC. The small graphs shown in Figures
2.10 and 2.11 represent speed profiles on a link. The only symbol still
not defined that appears in the figures is ESPM. It appears when it is
necessary to calculate backward speed (Figure 2.11).

ESPM is the greatest speed at which the vehicle can enter
the segment previous to the speed-control link and still manage to de-
celerate to the required speed. If the original entry speed is greater
than ESPM, this means that the vehicle cannot decelerate to the required
speed on this link. In this case, it will be necessary to move back-
wards one or more links until reaching a point at which ESPM is greater
than the original entry speed, as shown in Figure 2.8.

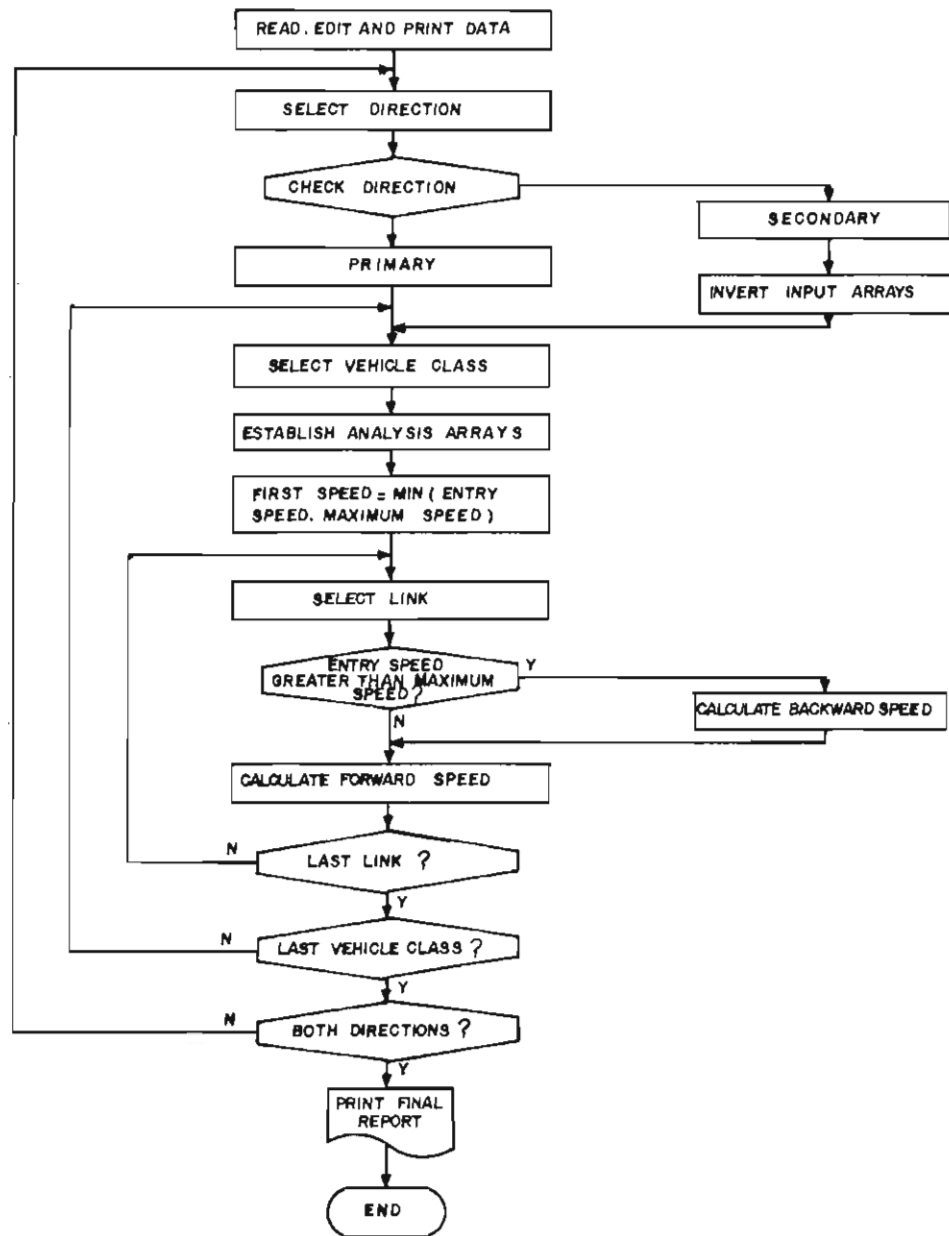In Figure 2.8, the original entry speed in the second segment
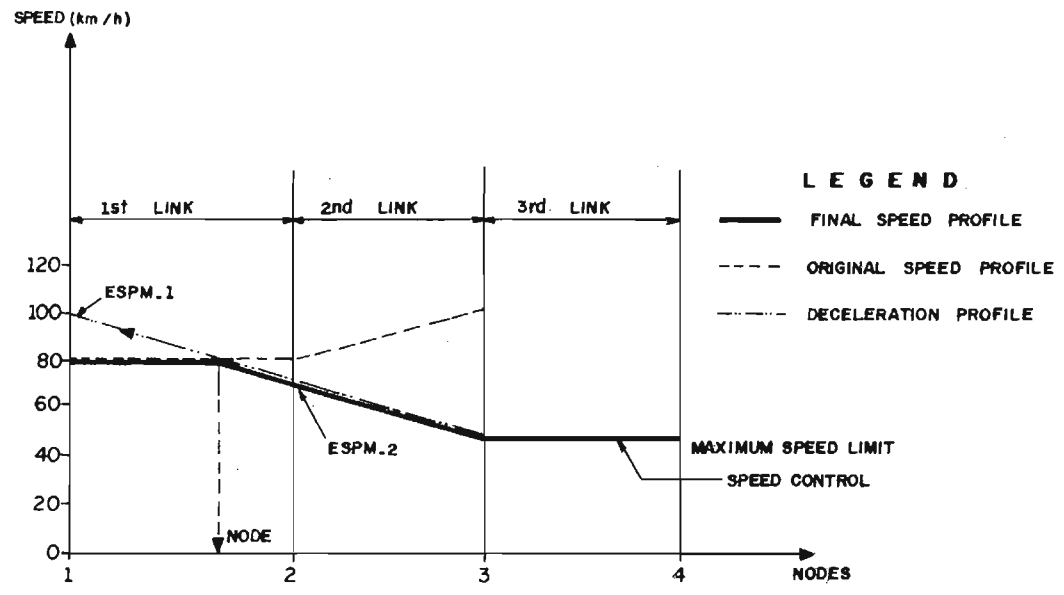
Figure 2.7 - BASIC LOGIC OF THE MTC.

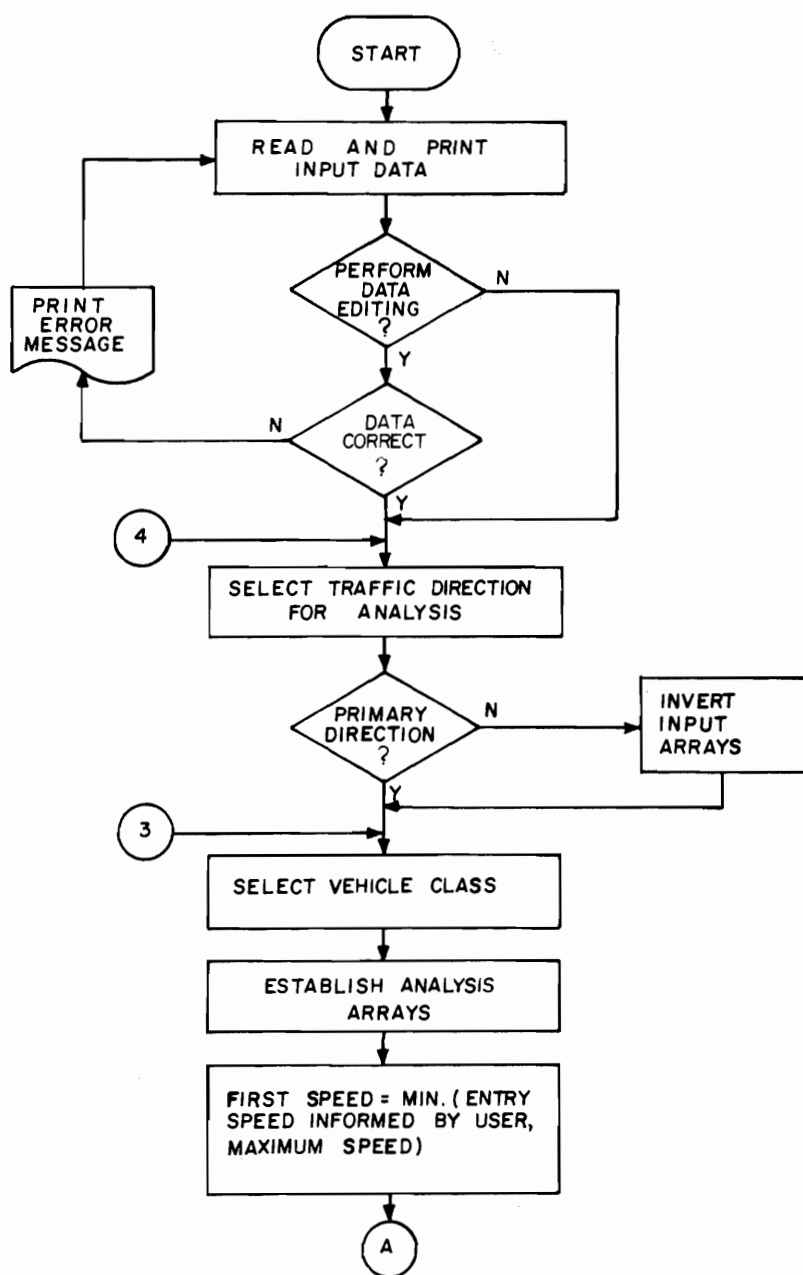Figure 2.8 - CALCULATION OF BACKWARD SPEED.

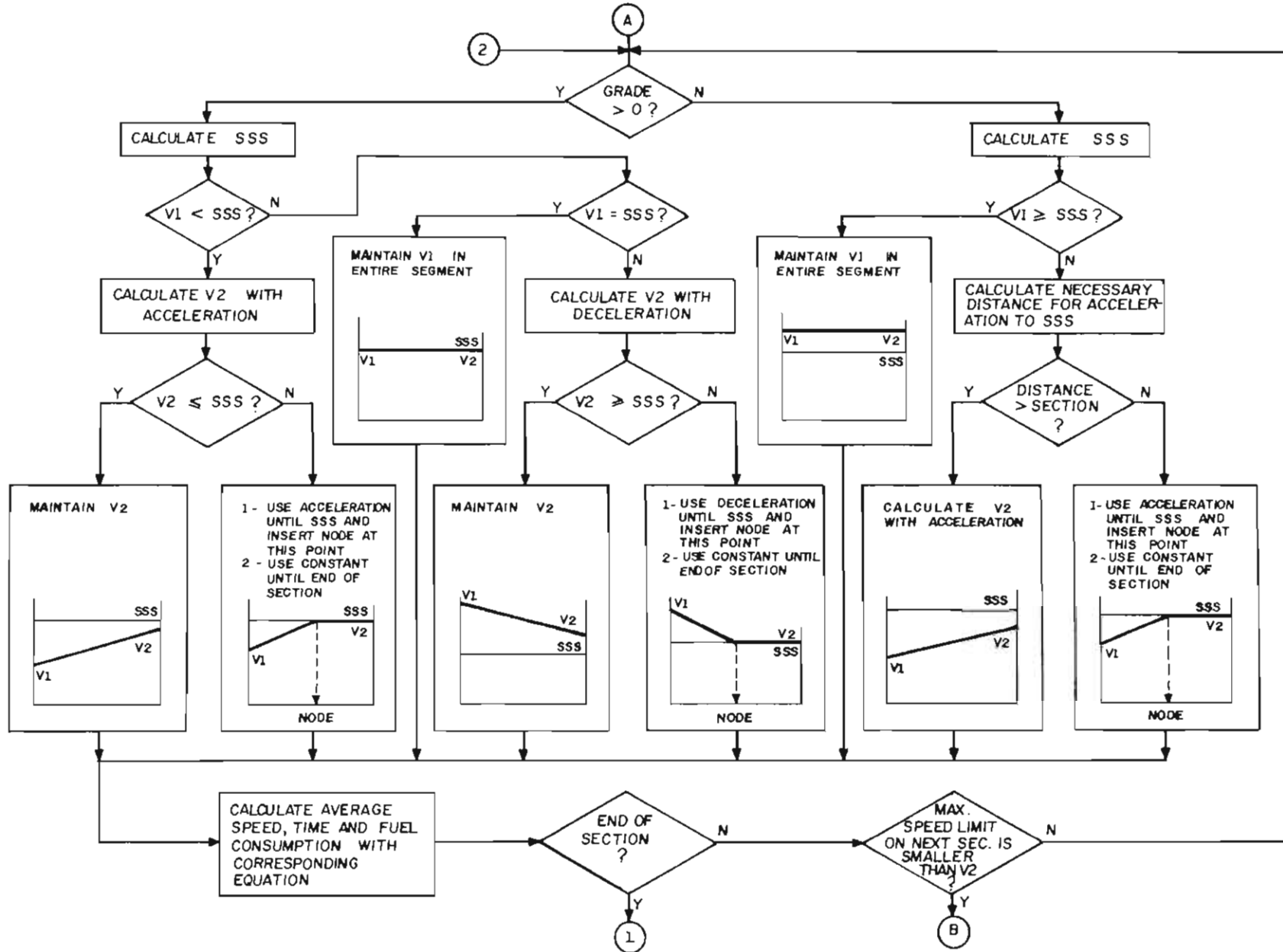Figure 2.9 - LOGIC OF THE MTC – ESTABLISHMENT OF ANALYSIS ARRAYS.

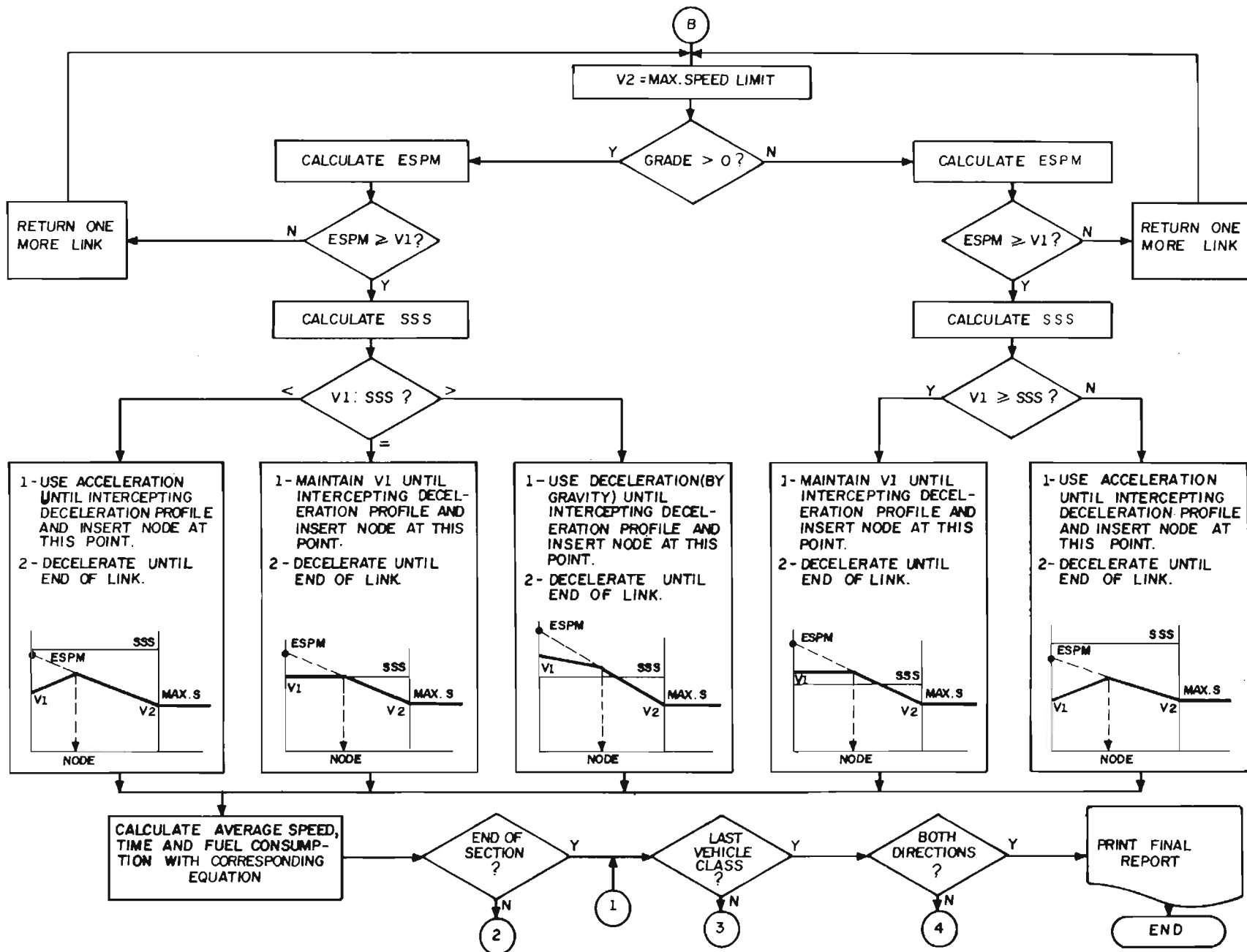Figure 2.10 – LOGIC OF THE MTC – CALCULATION OF FORWARD SPEED.

Figure 2.11- LOGIC OF THE MTC - CALCULATION OF BACKWARD SPEED.

is greater than ESPM-2. Since the vehicle cannot, therefore, deceler-
ate on this link, it is necessary to move backwards one or more links
to the point at which ESPM is greater than the original entry speed.
In Figure 2.8, this occurs in the first link, where ESPM-1 is greater
than the original entry speed. This, makes it possible for
the vehicle to decelerate to the speed required on the third link.

Finally, in Figure 2.9, the user will note that, should
there be a speed control on the first link of a section, vehicle speed
at the first node will be either the entry speed supplied by the user
himself or the maximum speed permitted. The program will choose that
which is the lowest.