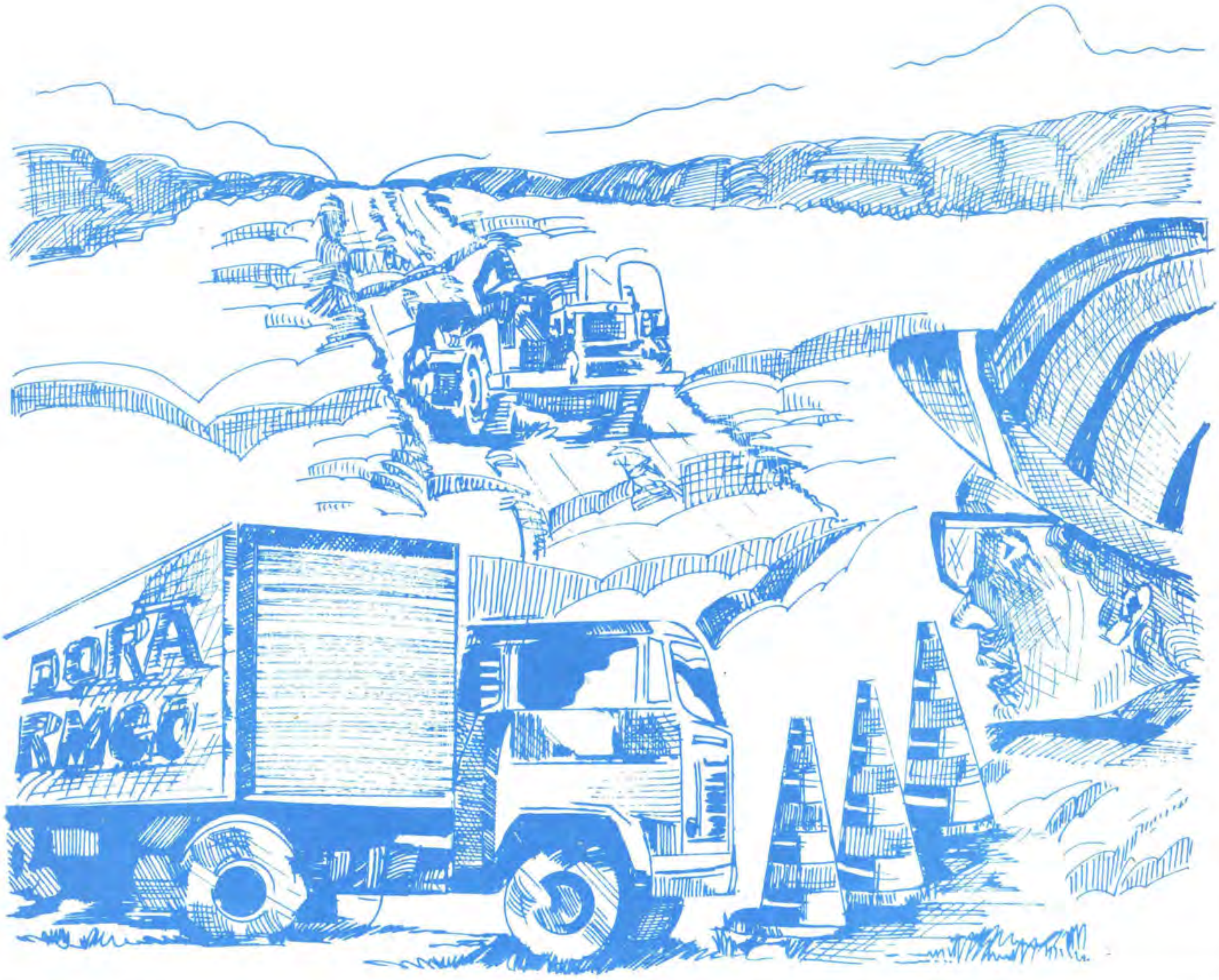
REPÚBLICA FEDERATIVA DO BRASIL

MINISTÉRIO DOS TRANSPORTES

United Nations Development Programme (UNDP)

Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization

Final Report - 1981



VOLUME 10 – MODEL FOR SIMULATING TRAFFIC (MST)

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PREPARED BY:

MINISTÉRIO DOS TRANSPORTES
Empresa Brasileira de Planejamento de Transportes - GEIPOT
Departamento Nacional de Estradas de Rodagem - DNER
UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP)
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WITH THE PARTICIPATION OF:

Departamento de Estradas de Rodagem de Goiás - DER/GO
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VOLUME 10 – MODEL FOR SIMULATING TRAFFIC (MST)

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Conteúdo: v.1 Summary of the ICR Research v.2 Methods and organization v.3 Instrumentation v.4 Statistical guide v.5 Study of road user costs v.6 Study of vehicle behavior and performance v.7 Study of pavement maintenance and deterioration v.8 Highway cost model (MICR) v.9 Model of time and fuel consumption (MTC) v.10 Model for simulating traffic (MST) v.11 Fundamental equations v.12 Index to PICR documents.

1. Rodovias - custos - Brasil 2. Rodovias conservação - Brasil 3. Rodovias - utilização - Brasil - I. Título.

PREFACE

This research project was funded through an agreement signed in January, 1975 by the Brazilian Government and the United Nations Development Programme (UNDP). The Ministry of Transportation, acting through the Brazilian Transportation Planning Agency (GEIPOT), assumed the responsibility for the project on behalf of the Brazilian Government, and tne International Bank for Reconstruction and Development (IBRD) acted as the executing agency for UNDP.

The research was carried out by GEIPOT and the National Highway Department (DNER), acting through its Road Research Institute (IPR). Funding from the Brazilian Government was channeled through the Institute for Economic and Social Planning (IPEA) and the Secretariat for International Economic and Technical Cooperation (SUBIN), along with the Ministry of Transportation.

The World Bank contracted the Texas Research and Development Foundation (TRDF) to organize the international technical staff and to select and purchase the imported equipment needed for the research. The participation of the TRDF continued until December of 1979.

This report is comprised of twelve volumes (each edited in both English and Portuguese) which summarize the concepts, methods and results obtained by December, 1981 by the project entitled "Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization (PICR)". It includes a documentary index volume which will aid researchers in locating topics discussed in this report and in numerous other documents of the PICR. This report contains much detailed analysis which is being presented for the first time, and also incorporates relevant parts of earlier reports and documents produced under the 1975 Agreement, updating them through the inclusion of new results and findings.

A special mention is due the Highway Departments of the States of Minas Gerais and Goiás, the Universities of Aston, Birmingham, Juiz de Fora, Minas Gerais and Texas, and the Western Australia Main Roads Department, which placed some of their best and most experienced personnel at the service of this project to fill many key positions on the research staff.

Finally, thanks are due the Transport and Road Research Laboratory for its assistance during the initial stages of the project, along with specialists from various countries who periodically visited Brazil to discuss the work being done in the PICR and to assist the permanent research staff in conducting analyses.

JOSÉ MENEZES SENNA
President

*VOLUMES IN THIS REPORT**

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* Volume 1 contains a brief description of the contents of each volume, while Volume 12 provides a subject index to this report and all other PICR documents, including technical memoranda and working documents.

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SUMMARY

The Model for Simulating Traffic (MST) is one of the products of the Research on the Interrelationships Between Costs of Highway Construction, Maintenance and Utilization (PICR). The Model simulates traffic flow on two-lane highway sections of any vertical and horizontal alignment complexity. This makes it possible to evaluate the impact of transportation policies and strategies, such as construction of a third (climbing) lane, construction of a highway intersection, or the introduction of new transportation technologies, such as that represented by the multitrailer ("road train"). The MST also makes it possible to compute travel times, operating speeds, fuel consumption and other data that can be used by the transportation planner in analyzing the effects of transportation policies and strategies.

The major purpose of the Model is to specify the relationships between both operating speed and fuel consumption, on one hand, and highway geometry, type of surface and roughness, on the other. This relationship may also be used in the Highway Planning Model, now being prepared by GEIPOT for the Ministry of Transportation, which seeks to define the relationships between the three components of highway transportation cost: highway construction, maintenance and utilization.

This document presents the second version of the MST, which is both more efficient and more complete than the first one. A third version of the MST, describing input data in greater detail, is expected to be completed soon.

The MST User's Manual is also available. This manual presents complete instructions for the codification of the input data and Model parameters, together with four examples of applications (present situation of the highway, introduction of a third lane, introduction of a transversal highway with a STOP sign, and the effect on traffic of the application of new technologies or vehicles, such as the multitrailer).

Finally, a Programmer's Manual has also been prepared, with the complete MST flow chart and the listing of the computer program.

CHAPTER 1
INTRODUCTION

1.1 OBJECTIVES

The Research on the Interrelationships of Highway Costs (PICR) has the objective of determining functional relationships between the three components of the total cost of highway transportation (construction, maintenance and utilization), by gathering and analyzing empirical data on highway designs, pavement deterioration and maintenance, as well as on the costs of vehicle operation. One of the basic activities of the research was to measure vehicle speeds and their fuel consumption. These experiments are carried out to relate a vehicle speed and fuel consumption with highway geometry, type of surfacing and roughness of the road surface.

A very large and complex series of experiments would be necessary if reliable empirical relationships were to be developed among these variables under non-free flow conditions. In spite of the fact that the traffic flow can be controlled to a certain extent by means of selected samples, it is doubtful that the entire inference space could be covered, since it would not be possible to control the directional division and composition of traffic. In addition, there seems to be no cost-efficient manner of elaborating a speed profile for every vehicle, under conditions of traffic congestion, for estimating fuel consumption. This is due to the fact that vehicle speeds are influenced in various ways by interactions with other vehicles in the traffic flow.

The enhanced speed and capacity of modern digital computers have made it possible to employ simulation techniques that describe the behavior of each of the vehicles as they are driven along a highway section. Therefore, it would seem that a traffic flow simulation model, with variables, parameters and constants calibrated based on a limited number of field observations, would be the most cost-efficient way of determining relationships between operating speed and fuel consumption, on the one hand, and the physical variables of the highway, on the other, under non-free flow conditions.

This Report describes the development of a traffic-flow simulation model on two-lane highways. By estimating operating speed and fuel consumption, the Model makes it possible to determine the aforementioned relationships.

The MST (Model for Simulating Traffic) is a traffic simulation model for two-lane highways. The simulation process consists of: (1) determining the moment of arrival of the vehicle at the beginning of the highway section under study; (2) generating the vehicle class, as car, bus, truck, etc.; (3) generating the speed performance of the binomial vehicle-driver within the class; (4) predicting this performance along the highway section, on the basis of preestablished rules; and (5) sampling the desired traffic-flow data, analyzing them and reporting the results (Bilich, 1981).

1.2 PREVIOUS STUDIES

This section presents a critical review of previous studies of the phenomenon of non-free traffic flow. It has the threefold purpose of identifying the factors which affect traffic and how they act, describing the various attempts to model the phenomenon of non-free traffic flow, and presenting some of the applications of these models to the analysis of alternative traffic policies.

1.2.1 *Factors Influencing Traffic*

The first to investigate the problem of overtaking on two-lane highways were Farben *et alii* (1967). They elaborated a research program with the purpose of developing one or more systems (radar, for example) that would make it possible to reduce problems related to a driver's imprecise perception of speed and distance of the vehicle approaching in the opposite lane, a phenomenon which normally leads to dangerous and even fatal consequences.

To determine the headways (time intervals between vehicles in a traffic flow) that would permit a pedestrian to cross a street, or a driver to safely cross a transversal street, Miller (1971) made a comparative study of nine of the various available methods.

McGee *et alii* (1978) carried out a study with respect to visibility distance or, in other words, the distance at which drivers are able to detect a potential danger or threat, in a disordered highway environment, come to a decision as to how to resolve the problem and put this decision into effect, safely and efficiently. This research sought to relate the concept of visibility distance to specific types of highways, speed limits, traffic levels, geometric characteristics and driver skills.

St. John and Kobett (1978) emphasized the modelling, simulation and interpretation of the traffic flows on a two-lane highway, where there was a large variety of vehicles duly represented. Among other factors, the method adopted included a representation of the acceleration capacity of the vehicles, the utilization of this capacity by drivers, driver behavior and estimates of the frequency of each type of vehicle in the traffic flow. They also sought to obtain information on how larger vehicles influenced the level of service and the safety enjoyed by other highway users.

Brach *et alii* (1978) describe a research project, conducted by *Planning Environment International*, to develop a model that would make it possible to determine fuel consumption and pollutant emissions as a function of vehicle speed and highway geometry.

Kadiyali *et alii* (1981) describe the preliminary results of a user cost study obtained in India. The study has the objective of determining the factors which cause both rolling and air resistance for the vehicles used in that country. These factors are needed as input data for the Swedish Model VTI, now being adapted to the conditions in India.

1.2.2 Traffic Simulation

Gerlough (1956) suggests two methods of simulating traffic flow. The first is a physical representation in which each vehicle is represented by a binary, and the highway by a group of memory cells. Some rules are set down to regulate vehicle movement. The second method is that of memorandum, whereby each simulated vehicle carries a file containing all of the physical information regarding itself, such as location coordinates, speed, spacing between vehicles and travel time. These files are periodically updated. The second method is generally the most widely employed since it requires less computer time than the first.

Janoff and Cassel (1970), of the Franklin Institute Research Laboratories, developed a traffic-flow model which simulates the movement of vehicles on a two-lane highway. Highway configuration includes zones in which overtaking is prohibited, restrictions as to visibility distance, and grades of each traffic lane, at any point along the simulated highway. Vehicle speeds and headways are generated according to the volume-speed and volume-headway relations in the *Highway Capacity Manual* (Highway Research Board, 1965). Using as inputs the traffic and highway data, the model simulates the traffic movement according to the conditions involving a particular vehicle. The output data of the model can be summarized in any time interval of the period of time simulated.

Heimbach *et alii* (1974) modified the simulation model of the Franklin Institute. They present the NCSU model, which is used to investigate the configuration of the non-overtaking zone with respect to the volumes of traffic on two-lane highways. This model incorporates two subroutines, designated "Truck-On-Grade" and "Car Exit", and a main routine called "Speed-Headway".

Boal (1974) formulates a traffic-simulation model for two-lane highways in which the highway is considered as straight and level. The model has the capacity to simulate overtaking moves.

Marwah (1976) developed stochastic models of daily and monthly traffic, based on five highways in Kampur (India), which were used for traffic predictions.

Gynnerstedt *et alii* (1977) describe a traffic simulation model for two- lane highways with traffic in both directions. The model assumes that, though limited by road geometry, speed limits or the presence of other vehicles, each vehicle travels at the basic speed desired by the driver. They also describe the effect of these factors and how they are combined.

Gravem (1979) presents a traffic simulation model based on a two-way highway network. The model considers such elements as horizontal and vertical road profile, auxiliary lanes, visibility, vehicle performance and driver characteristics. The model is applicable to the evaluation of proposed or already existing highway network projects, as well as to the evaluation of the influence of changes in geometry, regulations, flow conditions and vehicle/driver characteristics on traffic operations, safety and fuel consumption.

Gipps (1981) describes a simulation model designed to predict the response of a vehicle, within the traffic flow, to the behavior of the vehicle immediately ahead. The parameters used correspond to the obvious characteristics of driver behavior.

1.2.3 *Applications of Traffic Simulation*

Traffic simulation models have a wide variety of potential applications. Some of the applications effected with existent models are described below.

Cassel *et alii* (1970) carried out studies with the aim of making it possible to develop systems (radar, for example) that would aid drivers in perceiving more accurately the distance and speed of the vehicle in the opposite lane.

Both *et alii* (1980) describe a two year research project which investigated alternative projects involving the construction of a third lane on positive grades, on two-way highways. This study also included the development of a minimodel of simulation with the purpose of evaluating the effect of this additional lane.

Gynnerstedt and Troutbeck (1981) describe the process of data gathering and the changes that should be introduced into the traffic simulation model of the Swedish Institute of Highway Research (VTI) by the Central Road Research Institute (CRRI) in India, so that the model could be used to predict travel time and the number of overtakings.

CHAPTER 2
CONCEPTS INHERENT TO TRAFFIC SIMULATION

2.1 INTRODUCTION

The major concepts inherent to traffic flow simulation and, consequently, needed by the MST, are described in this Chapter.

2.2 DEFINITION OF HEADWAY

Headway is the time interval in seconds separating two successive vehicles, measured from the front of one vehicle to the front of the following vehicle (Figure 2.1).

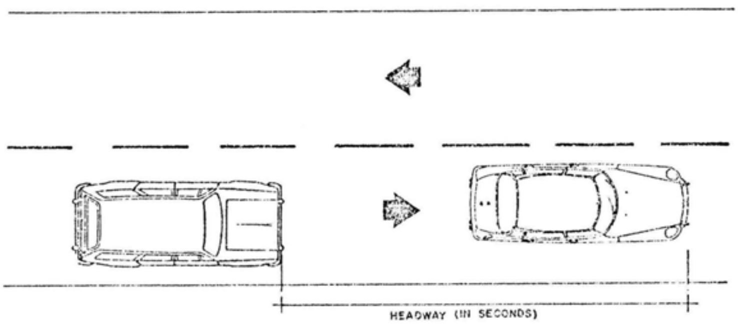


FIGURE 2.1 - REPRESENTATION OF THE HEADWAY CONCEPT.

There exist other more specific concepts of headway, such as minimum headway, average headway of constrained group, and free headway, correlated to this concept of headway.

- *Minimum headway* is the minimum time interval in seconds that is possible between two successive vehicles.
- *Constrained group* is the group of vehicles in a queue, each vehicle awaiting the opportunity to overtake the preceding vehicles.
- *Average headway of constrained group* is an average headway of all vehicles in one constrained group.
- *Free headway* is the average headway of a group of vehicles travelling at free speed, i.e., when not constrained.

By definition, the vehicles in the constrained group will be travelling at a speed lower than that desired, and their drivers will be awaiting the opportunity to overtake. On the other hand, the vehicles in the unconstrained group will be travelling either at the desired speed or at a lower speed, also in a platoon, but their drivers will not be trying to leave the platoon.

2.3 *HEADWAY DISTRIBUTION*

Adams (1936) was probably the first to observe the apparently random distribution of vehicle arrivals at a given point of a highway. He compared these observations of vehicle arrivals with values obtained from the Poisson distribution and obtained a good degree of adjustment at relatively low volumes of traffic. A number of authors have proposed modifications in the Poisson distribution, since this type of distribution accepts the hypothesis of zero headway, which is impossible. Schuhl (1955) showed that a traffic flow can be composed of a combination of vehicles in free flow and vehicles in constrained flow, and that both flows fit the Poissonian behavior.

On the basis of data gathered from a two-lane highway with traffic volumes per lane ranging between 50 and 950 vehicles/hour, Grecco and Sword (1968) developed predictions of parameters for Schuhl's headway distribution, and found that these parameters varied according to the traffic volume. The Schuhl's equation utilized by Grecco and Sword was the following:

$$P(h \geq t) = \sigma e^{-(t-MH)/t_1} + (1-\sigma) e^{-t/t_2}$$

where:

- $P(h \geq t)$ = probability that the headway be equal to or greater than the time t;
- σ = percentage (decimal) of the vehicles in the constrained group;
- MH = minimum headway of the vehicles of the constrained group, in seconds;
- t_1 = parameter based on the average headway of the constrained group, in seconds;
- t_2 = parameter based on the average headway of the free-speed group, in seconds;
- t = time, in seconds;
- e = base of Napierian logarithms

Grecco and Sword affirmed that one second was a reasonable value for the minimum headway (MH). However, on at least two sections of highway BR-381, which joins São Paulo and Belo Horizonte, minimum headways as short as half second were observed. The equations developed by Grecco and Sword for t_1, t_2 are as follows:

t_1 = 2.5s (constant value for any volume, on any lane);

t_2 = 24-1.22 (lane volume/100);

σ = 0.115 (lane volume/100).

It can be noted that σ is greater than 1 when the volume of traffic per hour and per lane is greater than 870..

Khasnabis and Heimbach (1977) tested three models of headway distribution: (1) negative exponential; (2) Schuhl; and (3) Pearson type III. The Schuhl model provided the highest degree of adjustment for the field data of North Carolina (USA).

In light of this result, it was decided to utilize the Schuhl model in the development of the MST, while analyzing the application of other headway distributions to data already gathered. With the exception of minimum headway - set at a half second in the MST on the basis of field observations carried out for this specific purpose - the parameters of Grecco and Sword were accepted.

2.4 *VEHICLE CLASSIFICATION*

In addition to determining the headway, each vehicle must be classified within one of the six classes used in the model: (1) automobiles; (2) utilities; (3) light gasoline-powered trucks; (4) medium trucks; (5) bus; or (6) heavy trucks. The MST user may adopt a different classification, provided that a free-speed model be constituted (to be used as input data), and that the functions of acceleration, deceleration, steady-state speed and the corresponding levels of fuel consumption of the vehicle classes adopted be introduced into the program.

The user specifies the percentage of vehicles in each class, for each traffic lane. The Model assembles an array for the accumulated distribution of the vehicle classes and designates a class for each vehicle, based on a random number generated according to the array of percentage distribution of the vehicle classes.

2.5 *ADDITIONAL LENGTH*

A basic concept in most traffic simulation models is the existence of a minimum headway that is independent of vehicle length. As previously stated, this minimum intervehicle time interval is approximately one half second. An intervehicle time interval equal to a half second, in the case of heavy trucks at low speed on steep positive grades would mean that the physical space corresponding to this headway between the fronts of consecutive vehicles would be less than the length of the vehicle. To resolve this problem and to test the effects of very long vehicles, such as the multitrailer rig (road train), on traffic flow, an additional-length table is included with the vehicle classification. This makes it possible for the user to specify an "additional length" in relation to vehicle class 1, for the vehicle classes from 2 to 6. At any point of the highway, therefore, the minimum headway is increased by the time spent in overtaking the "additional length" at the speed of the follower vehicle.

2.6 *VEHICLE PERFORMANCE*

In the MST, it is assumed that all drivers attempt to drive at the desired speed, defined here for a particular class of vehicles as the average of the free speeds, plus the variance of the speed of one vehicle. The average speed, however, varies along the highway due to such factors as type of surface, roughness, vertical and horizontal geometry and speed limits, all of which affect the speed of the vehicle in different degrees. The data gathered shows that the speed variance within each class of vehicles also differs from one point of the highway to another. In general, the higher the speed, the higher the variance.

Leong (1968) concluded that the normal distribution adjusted well (at a level of significance of 5%) to practically all speed distributions measured in 31 straight sections of New South Wales, Australia. In McLean's study (1976), only one of the 248 speed distributions obtained from speed measurements both on curves and straight sections showed a statistically significant deviation from normality ($p < 0.05$). Leong (1968) concluded that the standard deviation from the standardized distribution (coefficient of variation expressed in decimals) was practically the same for automobiles in all places, except in the case of grades of $>+7\%$ and $<-7\%$. Considering that the coefficient of variation is known for each vehicle class at all points of a highway section, the performance of each vehicle can be expressed as:

$$DV = 1 + VAR \times CV$$

where:

DV = vehicle performance;
VAR= deviation from the mean, in standard deviations;
CV = coefficient of variation.

To determine VAR, the scientific subroutine GAUSS, of IBM, is utilized. This subroutine generates random numbers normally distributed with zero mean and variance one. The desired speed (free speed) of the vehicle at any section of the highway is, therefore:

$$VL = VM \times DV$$

where:

VL = free speed of the vehicle;
VM = average of the free speeds of the vehicle class.

2.7 *MAXIMUM NUMBER OF VEHICLES OVERTAKEN AT A SINGLE TIME*

This is an input variable of the Model, for which a maximum value of six is accepted. Up to the present, the Model has spotted only a few events of six vehicles in a queue being overtaken at a single time. After a more complete analysis of field observations of overtaking operations this rule could be altered.

2.8 OVERTAKING-SPEED DIFFERENTIAL

For overtaking to be possible, there must be a minimum speed differential between vehicles. Boal (1974) used the Critical Overtaking Speed (COS), a value that is higher than the free speed of the vehicle by a fixed percentage. According to that author, one vehicle will not overtake another if its COS is not higher than the free speed of the preceding vehicle. However, the author does not mention the value of the COS utilized. No data seems to be available suggesting the values that should be used for all cases. However, field surveys (Miller and Pretty, 1968) suggest that some vehicles will never overtake a preceding vehicle if acceleration is required. It would therefore seem that some type of speed-differential relation should be incorporated into the Model. It is known that the number of overtakings increases as the overtaking-speed differential declines. The sensitivity of the Model output is being tested as to changes in this parameter, so as to determine the most realistic values of the speed differential.

2.9 SAFETY MARGIN

Safety Margin is a concept applicable principally to overtaking operations on two-lane roads. For safe overtakings, the vehicle should complete the overtaking operation, that is, should return to its lane several seconds before a vehicle coming in the opposite direction reaches the point at which the overtaking operation was completed (See Figure 2.2). It should be emphasized that such a safety margin depends on the interaction of the vehicles, and does not take visibility into account. However, the MST will not simulate an overtaking operation if visibility is not adequate.

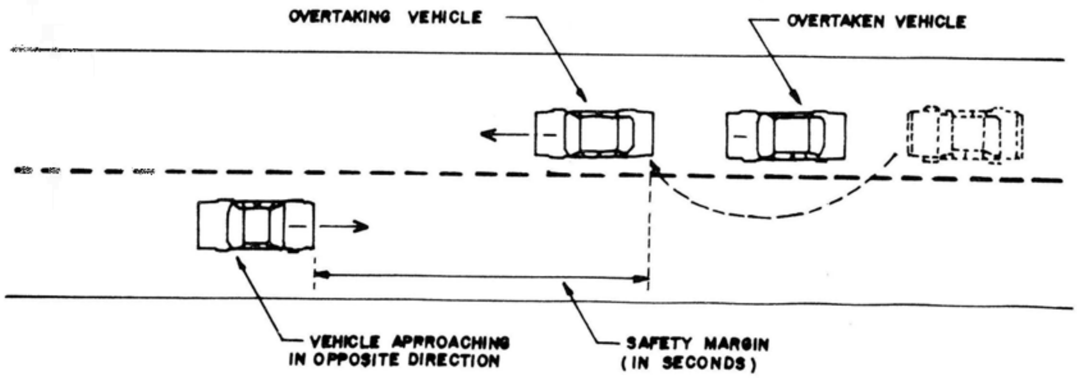


FIGURE 2.2 - PICTORIAL REPRESENTATION OF THE SAFETY MARGIN.

In future studies, a simple adaptation of the technique used to determine headway will make it possible to determine safety margins, particularly on positive grades, in the following manner: photographs are taken at a point from where perfect sight of the entire grade is possible. The camera is synchronized to a chronometer and activated at approximately equal time intervals. Along the entire course of the grade, equally spaced and numbered posts are set out (the smaller the space, the greater the precision of measurement). By examining the resulting photographs, one is able to obtain not only the beginning and end of overtaking operations, but also the safety margins. These observations would make it possible to elaborate a distribution of safety margins.

2.10 TIME INCREMENT

The time increment (time interval established by the MST user) is the time interval in which the vehicles in the primary lane and in the opposite lane are alternatively processed. In other words, after all of the vehicles in one lane have been processed within a given time increment, the MST program moves to the other lane and repeats the process. The MST user can establish a time increment of one up to nine seconds.

2.11 SUMMARY

This chapter defined and explained the basic concepts used in traffic simulations. The following chapter will describe how the free-speed profile is generated for the simulation model.

CHAPTER 3
GENERATION OF THE FREE-SPEED PROFILE

3.1 *INTRODUCTION*

The free-speed profile is one of the input data of the MST and can be generated either by the Model of Time and Fuel Consumption (MTC) (Zaniewski and Swait, 1979), developed by the GEIPOT Research on the Interrelationships of Highway Costs, or by the SPEEDS computer program, elaborated by the Main Roads Department of Western Australia (1977). The profile thus generated consists of a description of the behavior of the various vehicle classes (in terms of speed), as if each vehicle were covering the simulated section without interference from other vehicles. It is one of the basic inputs and the foundation upon which the effect of congestion will be introduced in the simulation. Currently, the MTC and the SPEEDS program are distinct from the MST, but they may well be incorporated into it as subroutines.

3.2 *MODEL OF TIME AND FUEL CONSUMPTION (MTC)*

For the MST to compute the time and fuel outlays of a vehicle, when its performance is conditioned by the presence of other vehicles on a given highway section it is necessary to establish a table of the speeds at which the vehicle would run were it alone. This table should be generated by a free-flow traffic model. In the case of Brazilian conditions, the Model of Time and Fuel Consumption (MTC) is used, since this model incorporates the speed and consumption equations obtained from experiments with vehicles representative of the national fleet, on sections of the country's highway network including the most varied characteristics.

In the operation of the MTC, the segments with homogeneous characteristics in terms of grade, alignment, surface type and condition are delimited, and the influences of the above factors on vehicle performance, as described in the basic flow chart of the MTC (Figure 3.1), are successively computed.

3.2.1 *Input Data*

The geometric elements (grade and alignment), as well as the

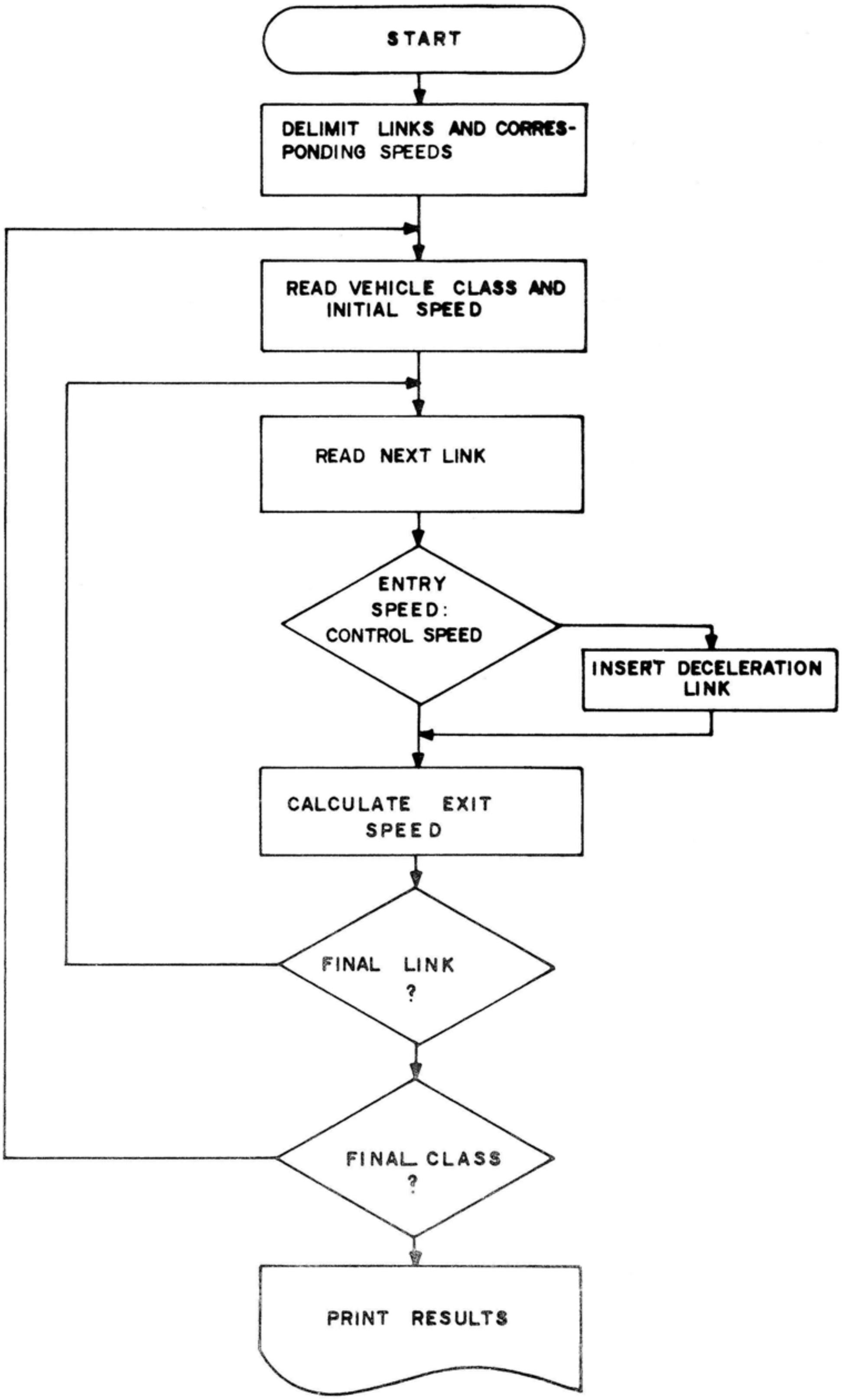


FIGURE 3.1 - BASIC FLOWCHART OF THE MTC.

surface type of the section analyzed, are normally included in designs or updated inventories of highway authorities. The surface condition is a measurable characteristic of each section and will have a numerical value representative of its roughness, designated Roughness Quotient (QI).

The Model can analyze six vehicle classes: automobiles, buses, empty utilities, loaded utilities, empty trucks and loaded trucks. Both classes of trucks can be further broken down into the following types: light gasoline-powered and light, medium and heavy diesel-powered trucks. Up to four power/weight ratios are permitted for each class and type. An entry speed should be ascribed to the first link analyzed, for each vehicle class.

3.2.2 *Simulation Process*

Given the input elements from the inventory or highway design, the MTC links together a succession of segments that are uniform as to grade, curved or straight alignment, and surfacing type and roughness. Other data are also inserted, such as speed limits (existent or established by the user). Based on equations developed through actual observations of traffic on the Brazilian highways, the Model ascribes an average speed on curves to each class of vehicles. In the same way, the Model establishes a steady-state speed for each grade. By steady-state speed is meant the speed at which vehicles, according to their class and load, tend to reach stability on roads of any grade. Consequently, a speed limit and a steady-state speed are implicitly ascribed to each link.

A vehicle can enter a restricted speed section at any velocity. Depending on the grade, type of surfacing, roughness and geometry, the vehicle tends to its own steady-state speed. If the vehicle attains this steady-state speed before reaching the end of the link, it will maintain it from that point onward. Therefore, travel time, fuel consumption and distance traveled are computed both for the stage of steady-state speed and for the previous stage. The rate of fuel consumption for each class of vehicles (in ml/km) is the average of the consumption rates of each subclass (power/weight) weighted by the percentage of vehicles in each subclass. This rate is then multiplied by the time spent on each stage of the course, to give the consumption on the link.

Following this, the vehicle enters the next link with the same speed it left the previous link, and the same process is repeated.

However, if the next link is subject to a lower speed limit, the program goes back to a previous stage, substitutes the previously computed speed mode with another whose deceleration rate matches the speed required on the link in question, and recalculates fuel consumption for the new situation.

This procedure goes on till the final link, when it is repeated for another class of vehicles. At conclusion, data involving speed, distance covered, travel time and fuel consumption for each vehicle class on the link in question are printed. The process is repeated in the same manner on the return trip.

3.2.3 *Example of Application*

In Table 3.1, the input data for a typical link of the Fernão Dias highway are presented, while Table 3.2 includes the results of the first class of vehicles calculated (automobiles). Both speed and fuel-consumption functions shown therein correspond to formulas derived from actual observations and tests performed on typical sections in different regions of the country. These and other aspects of the MTC are described in detail in Volume 9 of this report.

3.3 *THE SPEEDS MODEL*

The SPEEDS Program reads a highway survey file and generates the following results:

(a) A control-speed file of the link (data on speed limit, horizontal curvature and surface type). The control speeds (maximum speeds imposed by road conditions or by legal limits) are derived from the functional relations developed from traffic experiments or pertinent traffic legislation.

TABLE 3.1 - MTC INPUT DATA.

GEIPOT - EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES

PESQUISA ICR SISTEMA DE TRAFEGO

PROGRAMA MTC - MODELO DE TEMPO E COMBUSTIVEL - VERSAO 2.1 (JULHO 1980)

LISTAGEM DOS CARTOES DE ENTRADA

```
NUMERO          1         2         3         4         5         6         7         8
CARTAO 12345678901234567890123456789012345678901234567890123456789012345678901234567890

  1    XXXX   VERIFICACAO DO  SOFOT VERSAO 01  -  TRECHO-TESTE 568
  2    11100
  3       8   1   0   1  13   6   6
  4    123456
  5          0.0      +1.4       0.3      +2.5       0.4      +3.5       0.5      +5.1       1.5      +5.0
  6          1.6      +2.0       1.7      -1.0       1.9      -2.5       2.0
  7         80.3      65.3      72.8      69.6      59.6      50.2
  8         63.7      54.9      60.1      57.3      51.4      54.3
  9          1.3       1.6     680.0
 10          0.01      2.0
 11          0.0      36.0       0.1      37.0       0.2      38.0       0.6      39.0       0.7      40.0
 12          0.8      39.0       0.9      38.0       1.0      27.0       1.1      36.0       1.2      37.0
 13          1.3      38.0       1.4      39.0       1.8      40.0       2.0
 14    111   100.0       1.0     100.0
 15    211   100.0      10.0     100.0
 16    311   100.0       1.5     100.0
 17    411   100.0       2.5     100.0
 18    531   100.0      73.0     100.0
 19    631   100.0      73.0     100.0
```

TABLE 3.1 - MTC INPUT DATA (Cont'd).

GEIPOT - EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES

PESQUISA ICR SISTEMA DE TRAFEGO
PROGRAMA MTC - MODELO DE TEMPO E COMBUSTIVEL - VERSAO 2.1 (JULHO 1980)

VERIFICACAO DO SOFOT VERSAO 01 - TRECHO-TESTE 568

DADOS FORNECIDOS AO PROGRAMA

6 CLASSES DE VEICULOS
6 COMBINACOES DE CLASSES E TIPOS
8 GREIDES
1 CURVAS
0 SECOES DE CONTROLE DE VELOCIDADE
1 SECOES DE PAVIMENTO
13 SECOES DE IRREGULARIDADE

MATRIZ DE VELOCIDADES INICIAIS

CLASSE	SENTIDO PRIMARIO	SENTIDO SECUNDARIO
1	80.300	63.700
2	65.300	54.900
3	72.800	60.100
4	69.600	57.300
5	59.600	51.400
6	50.200	54.300

CLASSE	TIPO	PERCENTAGEM	PESO BRUTO	PERCENTAGEM	PESO BRUTO	PERCENTAGEM	PESO BRUTO	PERCENTAGEM	PESO BRUTO	PERCENTAGEM
1	1	100.0	1.000	100.0						
2	1	100.0	10.000	100.0						
3	1	100.0	1.500	100.0						
4	1	100.0	2.500	100.0						
5	3	100.0	73.000	100.0						
6	3	100.0	73.000	100.0						

TABLE 3.1 - MTC INPUT DATA (Cont'd).

GEIPOT - EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES

PESQUISA ICR SISTEMA DE TRAFEGO
PROGRAMA MTC - MODELO DE TEMPO E COMBUSTIVEL - VERSAO 2.1 (JULHO 1980)

VERIFICACAO DO SOFOT VERSAO 01 - TRECHO-TESTE 568

GEOMETRIA VERTICAL

DISTANCIA	GREIDE	DISTANCIA	GREIDE	DISTANCIA	GREIDE
0.0	1.400	0.300	2.500	0.400	3.500
0.500	5.100	1.500	5.000	1.600	2.000
1.700	-1.000	1.900	-2.500		
2.000	(FIM DO TRECHO)				

GEOMETRIA HORIZONTAL

INICIO (KM)	RAIO DA CURVA (M)	SUPER-ELEVACAO	FINAL (KM)	INICIO (KM)	RAIO DA CURVA (M)	SUPER-ELEVACAO	FINAL (KM)
1.300	680.	0.0	1.600				

TIPOS DE SUPERFICIE

DISTANCIA	PAVTO.	DISTANCIA	PAVTO.	DISTANCIA	PAVTO.
0.0	1				
2.000	(FIM DO TRECHO)				

SECOES DE IRREGULARIDADE

DISTANCIA	IRREG.	DISTANCIA	IRREG.	DISTANCIA	IRREG.
0.0	36.0	0.100	37.0	0.200	38.0
0.600	39.0	0.700	40.0	0.800	39.0
0.900	38.0	1.000	27.0	1.100	36.0
1.200	37.0	1.300	38.0	1.400	39.0
1.800	40.0				
2.000	(FIM DO TRECHO)				

TABLE 3.2 - MTC ANALYSIS RESULTS.

GEIPOT - EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES

PESQUISA ICR SISTEMA DE TRAFEGO

PROGRAMA MTC - MODELO DE TEMPO E COMBUSTIVEL - VERSAO 2.1 (JULHO 1980)

VERIFICACAO DO SOFOT VERSAO 01 - TRECHO-TESTE 568

SENTIDO 1 CLASSE 1

NOS	XL (KM)	GRD (%)	SUPF	IRREG. (QI)	SPS (KPH)	VEL (KPH)	TEMPO (SEG)	COMBUSTIVEL GASOLINA (ML)	COMBUSTIVEL DIESEL (ML)	FUNCAO DE VEL	FUNCAO DE COMB
1	0.0	1.4	1	36.	150.	80.3	4.48	13.27	0.0	LACC	FCS4P
2	0.100	1.4	1	37.	150.	80.5	4.46	13.24	0.0	LACC	FCS4P
3	0.200	1.4	1	38.	150.	80.7	4.45	13.20	0.0	LACC	FCS4P
4	0.300	2.5	1	38.	150.	80.9	4.45	11.88	0.0	PGSE	FC2P
5	0.400	3.5	1	38.	150.	80.9	4.46	11.92	0.0	PGSE	FC2P
6	0.500	5.1	1	38.	150.	80.5	4.52	12.08	0.0	PGSE	FC2P
7	0.600	5.1	1	39.	150.	78.7	4.63	12.36	0.0	PGSE	FC2P
8	0.700	5.1	1	40.	150.	76.9	4.74	12.65	0.0	PGSE	FC2P
9	0.800	5.1	1	39.	150.	75.1	4.85	12.96	0.0	PGSE	FC2P
10	0.900	5.1	1	38.	150.	73.3	2.39	6.39	0.0	PGSE	FC2P
11	0.948	5.1	1	38.	150.	72.4	2.56	7.15	0.0	CONS	FC1P
12	1.000	5.1	1	27.	150.	72.4	4.96	14.72	0.0	LACC	FCS4P
13	1.100	5.1	1	36.	150.	72.6	2.48	7.34	0.0	LACC	FCS4P
14	1.150	5.1	1	35.	150.	72.7	2.47	6.94	0.0	CONS	FC1P
15	1.200	5.1	1	37.	150.	72.7	4.95	13.90	0.0	CONS	FC1P
16	1.300	5.1	1	38.	150.	72.7	0.83	2.22	0.0	PGSE	FC2P
17	1.317	5.1	1	38.	150.	72.4	4.14	11.54	0.0	CONS	FC1P
18	1.400	5.1	1	39.	150.	72.4	4.97	13.90	0.0	CONS	FC1P
19	1.500	5.0	1	39.	150.	72.4	2.48	7.36	0.0	LACC	FCS4P
20	1.550	5.0	1	39.	150.	72.6	2.48	6.89	0.0	CONS	FC1P
21	1.600	2.0	1	39.	150.	72.6	4.93	14.63	0.0	LACC	FCS4P
22	1.700	-1.0	1	39.	150.	73.4	4.80	10.05	0.0	NGAE	FCS4N
23	1.800	-1.0	1	40.	150.	76.7	4.60	9.82	0.0	NGAE	FCS4N
24	1.900	-2.5	1	40.	150.	79.8	4.35	7.62	0.0	NGAE	FCS4N
25	2.000				150.	85.7					

SENTIDO 1 CLASSE 1

VELOCIDADE FUNCAO	VELOCIDADE % TEMPO	VELOCIDADE % COMPRIMENTO	COMBUSTIVEL FUNCAO	COMBUSTIVEL % TEMPO	COMBUSTIVEL % COMPRIMENTO	COMBUSTIVEL % GASOLINA	COMBUSTIVEL % DIESEL
NGSE	0.0	0.0	FC1N	0.0	0.0	0.0	0.0
NGAE	14.6	15.0	FC1P	22.8	21.7	23.7	0.0
NGDB	0.0	0.0	FC2P	32.7	33.3	32.5	0.0
PGSE	32.7	33.3	FCS4N	14.6	15.0	10.8	0.0
LACC	29.9	30.0	FCS4P	29.9	30.0	33.0	0.0
PGDB	0.0	0.0	FCDN	0.0	0.0	0.0	0.0
CONS	22.8	21.7	FCDP	0.0	0.0	0.0	0.0

(b) A distance/grade array. As presently structured, the program considers that a vertical curve with a radius equal to or less than 100m can be represented by the continuation of the adjacent grades up to the point of intersection, and that the vertical curves of more than 100m can be represented by an average grade, as depicted in the following figure.

(c) An inventory of road visibility and roughness for each tenth of a kilometer along the section.

In order to calculate successive free-speed averages along a section, a functional relation of the acceleration with the speed, grade, surface type and roughness was chosen (vide Figure 3.2). This relation has the advantage of including the acceleration and deceleration modes in a single equation.

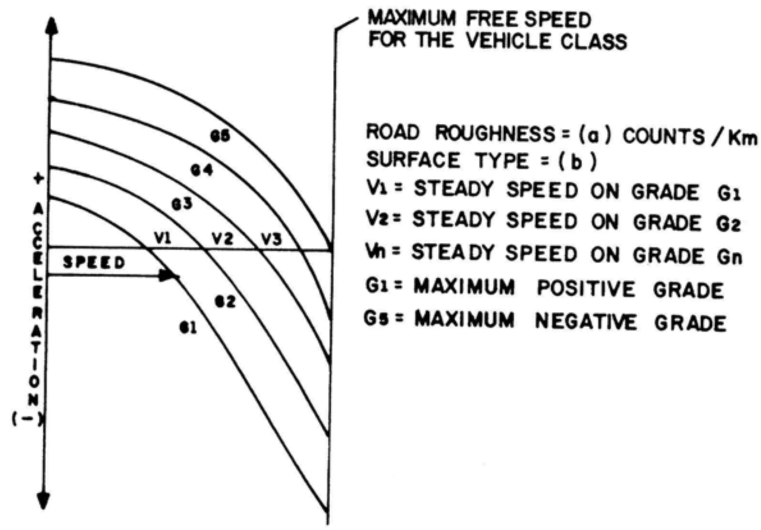


FIGURE 3.2 - ACCELERATION-SPEED RELATIONSHIP.

Aside from this, there is no necessity of knowing the position of the vehicle on the grade, as in the speed/distance relation (see *Highway Capacity Manual*, Highway Research Board, 1965, pp. 299-318). Utilizing the relations found in Figure 3.2 and the distance/grade array, the program calculates the mean spot speed, the coefficient of variation and the accumulated time at each tenth of a kilometer. At each point the speed is compared to the control speed and, should it be greater, the spot speed is made equal to the control speed, while the coefficient of variation and the accumulated time are adjusted accordingly.

In the subsequent control section, if the spot speed is greater than the next control speed, the program uses a deceleration rate that is equal to light braking conditions, until the deceleration curve intercepts the speed profile previously developed. Should the interception not occur within the previous control section, an increased rate of deceleration is utilized so as to diminish the speed at the beginning of the previous link to the control speed of the next link. This requires a more intense braking.

It has been argued that it is not realistic to return beyond the previous control section. The fact of the matter is that light or intense deceleration comes about on the link immediately prior to that which requires speed reduction. Earlier deceleration would only occur if some sort of restriction were already present, due to a warning sign or as a result of some other event.

In any case, the aspect of visibility takes precedence over driver attention, since the driver will only act on the brakes when the condition of restriction is perceived by him. In both cases, visibility will be a restrictive factor; therefore, the driver will be forced to utilize heavy braking.

3.4 THE FREE-SPEED PROFILE

An example of the free-speed profile is shown in Tables 3.3 and 3.4. These free speeds were obtained through the use of the MTC, and represent the free speeds by vehicle class obtained for test sec-

TABLE 3.3 - FREE SPEED ON PRIMARY LANE OF THE BR-381 HIGHWAY, SÃO PAULO-BELO HORIZONTE, TEST SECTION No.568, LENGTH: 2 km

DISTANCE OF FREE SPEED (KM)	AVERAGE SPEED OF EACH VEHICLE CLASS - 6 CLASSES* (km/h) x10^{-1}						COEFFICIENT OF VARIATION OF EACH VEHICLE CLASS x10^{-2}						ACCUMULATED TRAVEL TIME AT AVERAGE SPEED FOR EACH VEHICLE CLASS (IN SECONDS)						GRADE %	TYPE OF SURFACE: 1-PAVED 2-UN-PAVED	ROUGHNESS OF HIGHWAY (COUNTS/KM)	VISIBILITY (KM)
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				
0.0	745	690	625	493	653	480	13	12	12	18	23	17	00	00	00	00	00	00	1.4	1	36	1.5
0.1	753	697	636	508	653	484	13	12	12	18	23	17	48	52	57	72	55	75	1.4	1	37	1.4
0.2	760	703	646	521	652	487	13	12	12	18	23	17	96	103	113	142	110	149	1.4	1	38	1.3
0.3	767	708	655	532	652	490	13	12	12	18	23	17	143	155	169	210	166	223	2.0	1	38	1.2
0.4	770	710	659	539	651	480	13	12	12	18	23	17	190	205	223	278	221	297	3.0	1	38	1.1
0.5	767	705	656	541	642	465	13	12	12	18	23	17	237	258	278	344	277	373	4.5	1	38	1.0
0.6	750	688	638	519	604	432	13	12	12	18	23	17	284	308	334	412	334	453	5.1	1	39	0.9
0.7	732	670	620	499	567	399	13	12	12	18	23	17	333	361	391	483	396	540	5.1	1	40	0.8
0.8	721	666	601	499	530	365	13	12	12	18	23	17	382	415	449	555	462	634	5.1	1	39	0.7
0.9	723	667	596	499	492	332	13	12	12	18	23	17	432	469	510	627	532	737	5.1	1	38	0.6
1.0	724	669	597	503	455	299	13	12	12	18	23	17	483	523	571	699	608	851	5.1	1	37	0.5
1.1	726	670	599	502	417	280	13	12	12	18	23	17	532	577	631	771	691	978	5.1	1	36	0.4
1.2	727	672	600	503	380	280	13	12	12	18	23	17	581	630	691	843	781	1107	5.1	1	37	0.3
1.3	727	672	600	503	361	280	13	12	12	18	23	17	631	684	751	914	879	1235	5.1	1	38	0.2
1.4	724	669	597	500	361	280	13	12	12	18	23	17	680	738	811	987	979	1363	5.1	1	39	0.2
1.5	724	669	597	500	361	280	13	12	12	18	23	17	730	791	871	1058	1079	1492	5.0	1	39	0.2
1.6	726	669	600	503	364	280	13	12	12	18	23	17	780	845	932	1130	1178	1621	3.5	1	39	0.2
1.7	734	676	611	514	384	296	13	12	12	18	23	17	829	899	991	1201	1274	1746	0.5	1	39	0.2
1.8	767	708	645	549	437	349	13	12	12	18	23	17	877	951	1048	1269	1362	1857	-1.0	1	40	0.4
1.9	798	736	677	581	484	397	13	12	12	18	23	17	923	1000	1103	1332	1440	1954	-2.0	1	40	0.3
2.0	857	781	734	640	550	465	13	12	12	18	23	17	966	1048	1154	1391	1510	2037	-2.5	1	40	0.2

* Classes of vehicles:

1 - Automobiles
2 - Utilities
3 - Light Trucks
4 - Medium Trucks
5 - Buses
6 - Heavy Trucks

SOURCE: PICR, Traffic Group, Experiment TB-8, Test Section no. 568.

TABLE 3.4 - FREE SPEED ON OPPOSITE LANE OF THE BR-381 HIGHWAY, SÃO PAULO-BELO HORIZONTE, TEST SECTION No. 568
LENGTH: 2 KM

DISTANCE OF FREE SPEED (KM)	AVERAGE SPEED OF EACH VEHICLE CLASS - 6 CLASSES* (km/h) x10^{-1}						COEFFICIENT OF VARIATION OF EACH VEHICLE CLASS x10^{-2}						ACCUMULATED TRAVEL TIME AT AVERAGE SPEED FOR EACH VEHICLE CLASS (IN SECONDS)						GRADE %	TYPE OF SURFACE 1-PAVED 2-UNPAVED	ROUGHNESS OF HIGHWAY (COUNTS/KM)	VISIBILITY (KM)
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				
0.0	596	550	539	489	538	568	15	18	25	18	25	19	00	00	00	00	00	00	2.5	1	40	0.3
0.1	616	568	554	499	537	559	15	18	25	18	25	19	59	64	66	73	67	64	2.0	1	40	0.2
0.2	637	587	573	514	551	561	15	18	25	18	25	19	117	127	130	144	133	128	1.0	1	39	0.2
0.3	657	604	591	528	564	563	15	18	25	18	25	19	173	187	192	213	198	192	-0.5	1	39	0.2
0.4	719	663	645	581	616	610	15	18	25	18	25	19	225	244	250	278	259	254	-3.5	1	39	0.2
0.5	871	795	758	690	718	710	15	18	25	18	25	19	270	294	301	334	313	308	-5.0	1	39	0.2
0.6	871	795	796	797	821	809	15	18	25	18	25	19	311	339	317	383	360	355	-5.1	1	38	0.5
0.7	871	795	796	853	821	840	15	18	25	18	25	19	353	384	392	426	403	399	-5.1	1	37	1.9
0.8	871	795	796	853	821	840	15	18	25	18	25	19	394	429	437	468	447	441	-5.1	1	36	1.8
0.9	871	795	796	853	821	840	15	18	25	18	25	19	435	475	483	510	491	484	-5.1	1	37	1.7
1.0	871	795	796	853	821	857	15	18	25	18	25	19	477	520	528	552	535	526	-5.1	1	38	1.6
1.1	871	795	796	853	821	857	15	18	25	18	25	19	518	565	573	595	579	568	-5.1	1	39	1.5
1.2	871	795	796	853	821	857	15	18	25	18	25	19	559	611	618	637	622	610	-5.1	1	40	1.4
1.3	871	795	796	853	821	857	15	18	25	18	25	19	601	656	663	679	666	652	-5.1	1	39	1.3
1.4	871	795	796	853	821	857	15	18	25	18	25	19	642	701	709	721	710	694	-5.1	1	38	1.2
1.5	871	795	796	853	821	857	15	18	25	18	25	19	683	747	754	763	754	736	-4.5	1	38	1.1
1.6	871	795	796	853	821	857	15	18	25	18	25	19	724	792	799	806	798	778	-3.0	1	38	1.0
1.7	871	795	796	853	821	857	15	18	25	18	25	19	766	837	844	848	841	820	-2.0	1	38	0.9
1.8	871	795	796	853	821	857	15	18	25	18	25	19	807	882	889	890	885	862	-1.4	1	37	0.8
1.9	871	795	796	853	821	857	15	18	25	18	25	19	848	928	935	932	929	904	-1.4	1	36	0.7
2.0	871	795	796	853	821	857	15	18	25	18	25	19	890	973	980	974	973	946	-1.4	1	36	0.6

* Classes of Vehicles:

1 - Automobiles
2 - Utilities
3 - Light Trucks
4 - Medium Trucks
5 - Buses
6 - Heavy Trucks

SOURCE: PICR, TRAFFIC GROUP, Experiment TB-8, Test Section no. 568.

tion no. 568, located on the Fernão Dias highway.

Table 3.3 presents the free-speed profile of the vehicle classes trafficking on the lane conventionalized as the primary lane, while Table 3.4 presents the free-speed profile of the vehicle classes on the opposite lane. The following explanation with respect to columns is valid for both tables: the first column indicates that the section described is 2 km in length and is subdivided at intervals of 100m each. The six subsequent columns present the speeds at intervals of 100m, measured in (km/h) x 10^{-1}, for each of the 6 vehicle classes. The six vehicle classes are as follows:

1 - Automobiles
2 - Utilities
3 - Light trucks
4 - Medium trucks
5 - Buses
6 - Heavy trucks

The second grouping of six columns presents the coefficients of variation at each 100m, measured in 10^{-2}, for each one of the six vehicle classes. The third grouping of six columns presents the accumulated travel times in average speed, measured in seconds, at each 100m, for each one of the six vehicle classes. The next column indicates the grade at each 100m, measured in percentages. The antepenultimate column indicates the type of road surface: 1=paved, 2=unpaved. The penultimate column indicates the roughness of the highway at 100m intervals, measured in counts/km. The final column indicates visibility at each 100m, measured in km.

3.5 *SUMMARY*

This chapter described how the free-speed profile is generated. This profile will be utilized in the next chapter for the simulation of the behavior of the vehicles on the sections under study.

CHAPTER 4
VEHICLE-TRAVEL SIMULATION

4.1 INTRODUCTION

The modeling of vehicle behavior along the highway implies the simulation of two main interactions: (a) vehicle-highway interaction, and (b) vehicle-vehicle interaction. This chapter explains how these phenomena are brought into model form.

4.2 VEHICLE-HIGHWAY INTERACTION

The results of the traffic experiments designed by the ICR Research made it possible to develop correlations on the basis of observed data between free speed and the physical characteristics of highways. These functional forms are used to develop distributions of free-speed means for each vehicle class, on each traffic lane. The distributions of free-speed means, together with such highway survey data as grade, type of surface, surface roughness and visibility will then become input data for the simulation model. A more detailed description of the interaction between a vehicle at free speed and the physical characteristics of the highways can be found in Swait (1976).

4.3 VEHICLE-VEHICLE INTERACTION

In most cases, the speed of a vehicle is limited by changes in the speed of various other vehicles. This limitation of free speed leads to queues of vehicles whenever overtaking is impossible or whenever visibility distance or the intervals between vehicles in the opposite lane are inadequate. Since the simulation process is nothing more than a simplified representation of the real world, certain assumptions with respect to interaction must be made, and certain rules developed. In the case of the MST, these assumptions are as follows:

1) There exists a minimum free headway, termed unrestrained headway (UNH), beyond which the presence of a vehicle does not alter the free speed of the vehicle coming behind. This headway is an input variable for the Model.

2) After having been generated, classified and the performance index established, the vehicle is introduced at the start of the section, at free speed. However, if, at the moment in which it advances to the first time increment, the vehicle's headway is below free headway and its speed greater than that of the immediately preceding vehicle, then a test is carried out to determine the possibility of performing an overtaking operation. Should it be impossible to overtake and should the vehicle's headway already be at the minimum level, the speed of the vehicle is made equal to that of the immediately preceding vehicle. If the headway is greater than the minimum but below free headway, the vehicle is decelerated and its initial speed is adjusted in such a way that, upon advancing, the vehicle in the process of deceleration cannot come nearer the preceding vehicle than the minimum headway interval. After having reached minimum headway, speed must be made equal to that of the preceding vehicle.

3) In the first version of the MST, a vehicle could not overtake another if its free speed were not at least 10 km/h greater than that of the vehicle to be overtaken, at the point in which overtaking was initiated. In the second version of the MST, this speed differential is given as an input parameter.

4) The vehicle may never exceed its free speed, even during an overtaking operation.

5) The vehicle may initiate an overtaking operation from any position in the queue, but the maximum number of vehicles that may be overtaken at a single time is only six.

6) Adequate visibility and sufficient space in the opposite traffic flow are necessary for the execution of an overtaking operation. At the same time, there must exist a headway that is equivalent to double the minimum headway between the vehicle to be overtaken and that immediately in front of it (Figure 4.1). Having begun the overtaking operation, this headway is maintained by the overtaking vehicle.

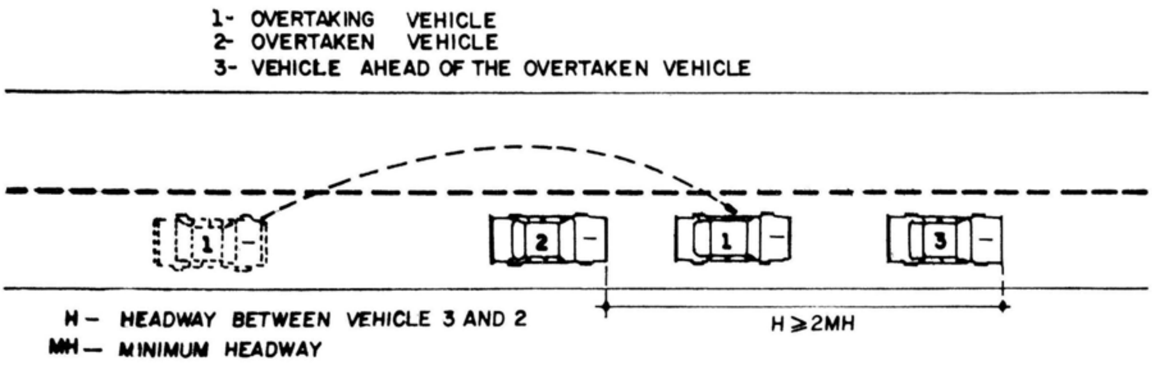


FIGURE 4.1 - REQUIRED HEADWAY BETWEEN VEHICLES FOR OVERTAKING TO BE POSSIBLE.

7) Overtaking is not permitted unless it can be completed within 30 seconds. The operation is considered completed when the overtaking vehicle is at a minimum headway in front of the vehicle overtaken. At this point in time, a vehicle on the opposite lane may be at the same distance, i.e., a zero safety margin is acceptable.

8) While being overtaken, a vehicle may only initiate its own overtaking operation after the overtaking vehicle has concluded its operation and attained a position in front of the last overtaken vehicle with a time interval equivalent to double the minimum headway.

Seven operating modes are utilized to describe the behavior of each vehicle:

- Mode 1: free-speed mode - the vehicle travels at a speed determined in the free-speed matrix;
- Mode 2: acceleration mode - the vehicle is accelerated from a speed lower than free speed (this can occur when an overtaking is completed);
- Mode 3: overtaking at free speed - the vehicle is capable of overtaking at free speed;
- Mode 4: overtaking with deceleration phase - the vehicle is initially hindered from overtaking by inadequate visibility or insufficient spacing in the opposite traffic flow, which requires deceleration before overtaking;

- Mode 5: deceleration mode - due to a insufficient speed differential, the vehicle is incapable of overtaking the vehicle in front and must decelerate;
- Mode 6: mode of follower-vehicle - the vehicle is incapable of overtaking and is forced to travel in a queue;
- Mode 7 to 12: vehicles in queue - these are equivalent to modes 1 to 6, the only difference being that they are applicable to vehicles while in a queue.

The assumption that a follower vehicle is forced to travel at the speed of the slower vehicle is valid only while the vehicle in front is at steady-state speed. For example, if the vehicle in front is in a acceleration phase on a negative grade, its speed will become greater than that of the vehicle coming behind it, at that given instant. Consequently, to maintain the headway at a constant value, the distance between the vehicles must be increased as the speed of both vehicles increases. The opposite occurs in the deceleration mode: the intervehicle space is reduced in order to compensate for the loss of speed and maintain the headway at a constant value.

4.4 PROCESSING OF VEHICLES THROUGH THE SYSTEM

To process the vehicles through the system, two computer files were assembled, one for the vehicles in the primary lane, and one for the vehicles in the opposite lane. In each file, each vehicle is identified by a single number. Its position relative to the vehicles in the same lane is easily identified, since each vehicle entry contains the number of the vehicle that is immediately in front, as well as that of the vehicle immediately behind.

The vehicles of each lane (primary and opposite) are processed alternatively at each time increment, which can be from one to nine seconds, at the discretion of the Model user.

With this description, the explanation of how the vehicles are simulated by the MST is concluded. The following chapter will show how to operate the MST.

CHAPTER 5
OPERATION OF THE MODEL

5.1 *INTRODUCTION*

The MST was programmed in FORTRAN IV, a language which permits its use in the IBM 370 and Cyber 127 computers. The Model consists of a main program (MST) and 17 subroutines, requiring a total of 76,000 octal words of memory. The files of results and data can be expanded to eliminate the present limitations of the Model. However, to make better use of computer time-sharing facilities while achieving a more rapid processing, the following limitations were temporarily established for the program:

(a) the maximum number of vehicles that can be processed at each time increment, in each lane, is 300;

(b) the maximum length of the section is 10 km;

(c) the maximum volume of traffic in each lane is 870 vehicles per hour. This is not a program limitation, but rather the Schuhl's headway distribution between vehicles. It may be possible to eliminate this limitation after the headway distribution obtained in the field is analyzed.

5.2 *MODEL INPUTS*

For the operation of the Model, two input files are necessary: the first - read on cards - consists of the following variables:

5.2.1 *Section Description*

LS = Length of section (km);

STN1 = Station at which output is requested - primary lane (km);

STNØ = Station at which output is requested - opposite lane (km);

SH = Shift between free-speed tables for the primary lane and opposite lane (km);

5.2.2 *Sample Description*

NIS = Sample size (total of both lanes);
VOL1 = Volume of traffic in primary lane (in vehicles/hour);
VOLØ = Volume of traffic in opposite lane (in vehicles/hour);
ARRAY1 = Percentage of each class of vehicles in primary lane;
ARRAY2 = Percentage of each class of vehicles in opposite lane;
ARRAY4 = Additional length of the vehicles of each class (meters).

5.2.3 *Headway Parameters*

IT = Time increment (seconds);
MH = Minimum headway (seconds);
AHR = Average headway of vehicles in queue (seconds);
UNH = Minimum free headway of the vehicles not in queue (seconds).

5.2.4 *Overtaking Parameters*

MN = Maximum number that can be overtaken in a queue;
MOT = Maximum overtaking time;
SPC = Speed differential to overtake automobiles, by vehicle class;
SPT = Speed differential to overtake heavy trucks, by vehicle class.

5.2.5 *Representation Options*

IPLOT = Graphic representation option IPLOT = 1 YES;
IPLOT = Ø NO;

DBUG = Option of representing numerically the position of the vehicles DBUG = Ø NO; DBUG = 1 YES;

PACTS = Time to start graphic or numerical representation (seconds);

PACTE = Time to finish graphic or numerical representatio (seconds).

5.2.6 *Location of 3rd (Climbing) Lane and STOP Sign*

SCL1 = Start of 3rd (climbing) lane - primary lane (km);

ECL1 = End of 3rd lane - primary lane (km);

SCLØ = Start of 3rd lane - opposite lane (km);

ECLØ = End of 3rd lane - opposite lane (km);

SSD1 = Distance of STOP sign in primary lane (km);

SSDØ = Distance of STOP sign in opposite lane (km);

VOL3 = Traffic volume in transversal highway (primary lane);

VOL4 = Traffic volume in transversal highway (opposite lane).

The second file consists of free-speed matrixes (see Tables 3.3 and 3.4) which are read from a disk file created by the MTC or by the SPEEDS Program. The data generated by the MST are stored outside the program in sequential files and are read when requested. The printer is used as output file.

5.3 *MODEL OUTPUT*

The output format was designed according to the types of data needed both for calibrating the Model, and for the applications it may have. In the Appendix, the output (for the primary and opposite lanes) of the simulation carried out on a 2-km section is presented, in which the free speeds in Tables 3.2 and 3.4 were utilized. The rate of traffic flow is 200 vehicles/hour in the primary lane, and 245 vehicles/hour in the opposite lane. The size of the sample is 100 vehicles (total of both lanes) and the sampling station is 0.5 km from the start of the section. The MST simulation and operation times were 939 and 128 seconds, respectively, on an IBM 370/45, resulting in a ratio of 7.34:1 (actual time against simulation time). Ratios of up to 14:1 are obtained in highway sections that are shorter and characterized by a lesser degree of geometric complexity.

For each vehicle class, the Model calculates the statistics of travel time and fuel consumption (see Appendix). Fuel consumption is calculated at each time increment on the basis of vehicle speed, grade, surfacing type, and highway roughness.

5.4 *TRAFFIC-FLOW SAMPLING*

The traffic-flow sampling, at any point of the route, is only initiated after the first vehicles in each direction have covered the entire section. If initiated before, the simulation of overtaking operations would take place in an empty section, which would not reflect an actual traffic situation.

5.5 *SUMMARY*

The operation of the MST was described in this chapter. The following chapter will discuss the calibration and validation of the Model.

CHAPTER 6
CALIBRATION AND VALIDATION OF THE MODEL

6.1 PURPOSE OF CALIBRATION AND VALIDATION OF THE MODEL

In order to verify if a model is satisfactory, it is essential to compare its simulation results with actual known responses. Validation is the process of examining if a simulation model produces satisfactory predictions (of traffic behavior, in the case of the MST). For any segment of a highway, the basic elements for the validation of the MST will be simply the average speed observed on the course, variance in traffic flow, composition of traffic and directional division. However, due to the nature of the assumptions of the Model, it is improbable that the results will, in first instance, agree with field observations. Therefore, the Model requires calibration, which can be defined as the process of adjusting the parameters, the assumptions and the logic of the Model, in such a way that the simulation results agree satisfactorily with field observations.

6.2 CALIBRATION OF FREE-SPEED MODEL

Since the behavior of the vehicle in the MST is, to a great extent, controlled by the free-speed matrices, it is essential that these free speeds, derived from the SPEEDS program or from the MTC, be compared with field observations. The free-speed experiment was carried out both on straight and curved sections, all of which were homogeneous segments with uniform grades. Aside from this - as already stated - certain assumptions were made with respect to the representation of vertical curves in terms of equivalent grades.

Observations of average speed were made on relatively short highway segments (4 - 5 km) on undulated terrain. Observers were positioned along each of these segments so that, through the utilization of intermediate time records, they could ensure that traffic conditions were truly free. After that, the mean of the average speeds of each vehicle class was compared with the estimates generated by the Model.

The differences between observed speed and estimated speed thus identified required additional efforts in data gathering and analysis. Two procedures were then adopted so that the Model would produce more satisfactory results:

(a) the data of specific equations were analyzed again with the inclusion of more recent data and, in some cases, other equations were adopted;

(b) the logic of the program was altered so as to include some speed-change equations representing specific situations.

As can be noted in Table 6.1, at the conclusion of this calibration process the analysis of variance did not reveal significant differences between the speeds computed by the MTC and those effectively observed on the test segments.

6.3 *CALIBRATION OF SIMULATION MODEL*

In the calibration of the MST under non-free flow conditions, the effects of interaction among vehicles (the headway distribution among them at any point along the highway section) were considered. Aside from this, the MST specifies number, size and distribution of queues, as well as overtaking operations, all of which are factors based on various suppositions and on the logic of the Model. These traffic flow characteristics, provided by the MST as output, were statistically compared with field observations and adjusted accordingly, as done in Australia, in September 1980, by Kaesehagen and others, and described by Moser (1980).

What is important to the operation of the Model is to number each one of the vehicles as they are introduced into the highway segment. As already indicated, use is made of a compound exponential distribution of the Schuhl type, together with prediction equations with parameters similar to those developed by Grecco and Sword (1968) for use in probability equations. However, Grecco and Sword (1968) made no mention of the occurrence of overtaking operations at the observation points, nor of the fact that these vehicles were included in the headway distribution. Since overtaking operations may occur at most points along the highway, it is necessary to record

TABLE 6.1 - MEAN SPEEDS GENERATED BY THE MTC VERSUS FIELD OBSERVATIONS

	SPEED (km/h
FIELD	64.2
MTC	64.2

	GRADE (%)	SPEED (km/h)
FIELD	0	68.6
MTC	0	69.7
FIELD	6	62.0
MTC	6	61.5

	TYPE OF SURFACING	SPEED (km/h)
FIELD	PAVED	72.8
MTC		71.0
FIELD	UNPAVED	59.9
MTC		60.8

	VEHICLE CLASS	SPEED (km/h)
FIELD	CAR	73.8
MTC		74.2
FIELD	BUS	64.3
MTC		61.2
FIELD	EMPTY UTILITY	68.9
MTC		68.6
FIELD	LOADED UTILITY	62.4
MTC		63.9
FIELD	EMPTY TRUCK	60.2
MTC		62.3
FIELD	LOADED TRUCK	55.4
MTC		55.0

	GRADE SIGN	SPEED (km/h)
FIELD	+	57.2
MTC	+	57.5
FIELD	-	71.2
MTC	-	71.0

Source: MOSER, Barry. Recalibration of the TAFA Speed Prediction (TB6), May 2, 1980, ICR/BM/073/80.

the vehicle in the overtaking mode, whenever this occurs at the observation points. In the same way, these vehicles should be considered as Model outputs, so that parameters can be developed for a headway distribution that takes this specific situation into consideration.

The order, classification and headway between vehicles at kilometer zero (start of segment), and at the sampling station at km 0.5, are presented in the Appendix. The headways are represented by the number of time increments, the latter being designated by (-). This type of presentation clearly shows the number, size, composition and distribution of queues for direct comparison with field observations. It also shows the headway distribution for various classes of vehicles in the overtaking mode at the start of the section and at the sampling station. At the present time, the MST routine for the generation of vehicles does not permit vehicles to enter the segment with a headway below the minimum. The vehicles in the overtaking mode at the start of the section are included in the headway distribution. However, at the sampling station, the vehicles listed in the overtaking mode are excluded from the distribution, since they could have no headway at all or even be slightly ahead the overtaken vehicle.

As the vehicles are introduced into the highway segment, a listing including the descriptive variables (class, additional length, etc.) and the operational variables (performance, speed, etc.) of the vehicles in both lanes is also given as output. The program also provides the option of generating a listing of the vehicle files for each time increment. This file contains the number of the lane, number of the vehicle, number of the previous vehicle, number of the posterior vehicle, class of the vehicle, operation mode, performance, speed, headway, distance covered, accumulated time, travel time and accumulated fuel consumption. Though this is a rather voluminous output, it does allow the user to describe the behavior of each vehicle along the entire segment.

Considering the fact that a satisfactory headway distribution can be developed for the vehicles at the moment they enter the segment, the headway distribution and the average simulated speeds for a given highway segment should agree with the field observations obtained at the sampling stations.

The differences between the average simulated speeds and those observed are a direct result of the Model's overtaking rules. To verify the correspondence between the simulated and the actual, it was also necessary to record the number of overtakings observed in the field, in each segment, comparing these to those simulated. The number of simple and multiple overtakings made between the start of the segment and the sampling station is presented and explained in the Appendix. The item "multiple overtaking" indicates the number of vehicles overtaken at a single time, in a queue.

Should the Model underestimate or overestimate the number of overtakings or the safety margin, or both, it will become necessary to adjust the overtaking speed differential or the maximum number of vehicles that can be overtaken in a queue, or both.

Once the procedure described above was established, the traffic flow times and speeds observed in seven segments with different characteristics and traffic of between 200 and 1,000 vehicles per hour (sum of both directions) were timed with a chronometer. Table 6.2 presents the most important characteristics of each test section between the three observation stations.

The calibration consisted in adjusting the parameters that constitute the Model's input data, in such a way that the MST would reproduce traffic flows that were comparable to those actually observed on the test sections. After successive processing operations, the parameters which resulted in the best approximations were the speed differences between the cars which overtake, and those that are overtaken, as well as the time the former spend in the opposite lane.

Input parameters	1st version	2nd version
Speed difference between automobiles	10 km/h	13 km/h
Speed difference between automobiles and other vehicles	10 km/h	15 km/h
Time spent in opposite lane	60 sec	30 sec

At the conclusion of the statistical analyses, approximations were obtained with deviations of less than 5%, a level considered fully acceptable for a simulation model.

TABLE 6.2 - GRADES OF TEST SECTIONS USED IN TRAFFIC-FLOW OBSERVATIONS - EXPERIMENTS TB-8 AND TB-9

TEST SECTION		PREDOMINANT GRADE BETWEEN STATIONS					% COURSE			ADT
		1 → 2		1 → 2		1 → 3	IN CURVES	VISIBILITY OF 500m		
		Gr.	Ext.	Gr.	Ext.			1 → 3	1 → 3	
TB - 8	568	5%	500m	5%	500m	1000m		~50%	~90%	12000
	571	5%	500m	5%	500m	1000m	~90%[1]	0%	0%	15000
	572	0%	540m	0%	500m	1040m		100%	100%	6600
	573	1.1	557m	1.1	464m	1021m	~40%[2]	~60%	~30%	7800
TB - 9	574	~5%	1100m	-4~	1500m	2.6km		~70%	~70%	4400
	575	-2.5~	1500m	~1.5	2600m	4.1km	~25%[3]	~80%	~80%	4600
	576	-5.8~	1400m	~6%	1300m	2.7km	~50%[4]	<10%	<10%	4000

[1] Approximately 90% of course with curves of R < 250m

[2] Approximately 40% of course with curve of R = 1500m

[3] Approximately 25% of course with curve of R ≃ 1200m

[4] Approximately 50% of course with curves of R < 400m

	Average Speeds	Headways	Overtakings
Actual data	66.9 km/h	2.382 seconds	430
Simulated data	65.8 km/h	2.345 seconds	413

6.4 VALIDATION OF SIMULATION MODEL

The process of validation of the MST consisted of the three following steps:

1) The travel times of a sample of vehicles between stations 4 and 5 (primary lane) and between stations 3 and 2 (opposite lane) on test section no. 568 (Figure 6.1) were recorded. (These data, as well as the mean, standard deviation and variance by vehicle class are found in Tables 6.3 and 6.4, respectively).

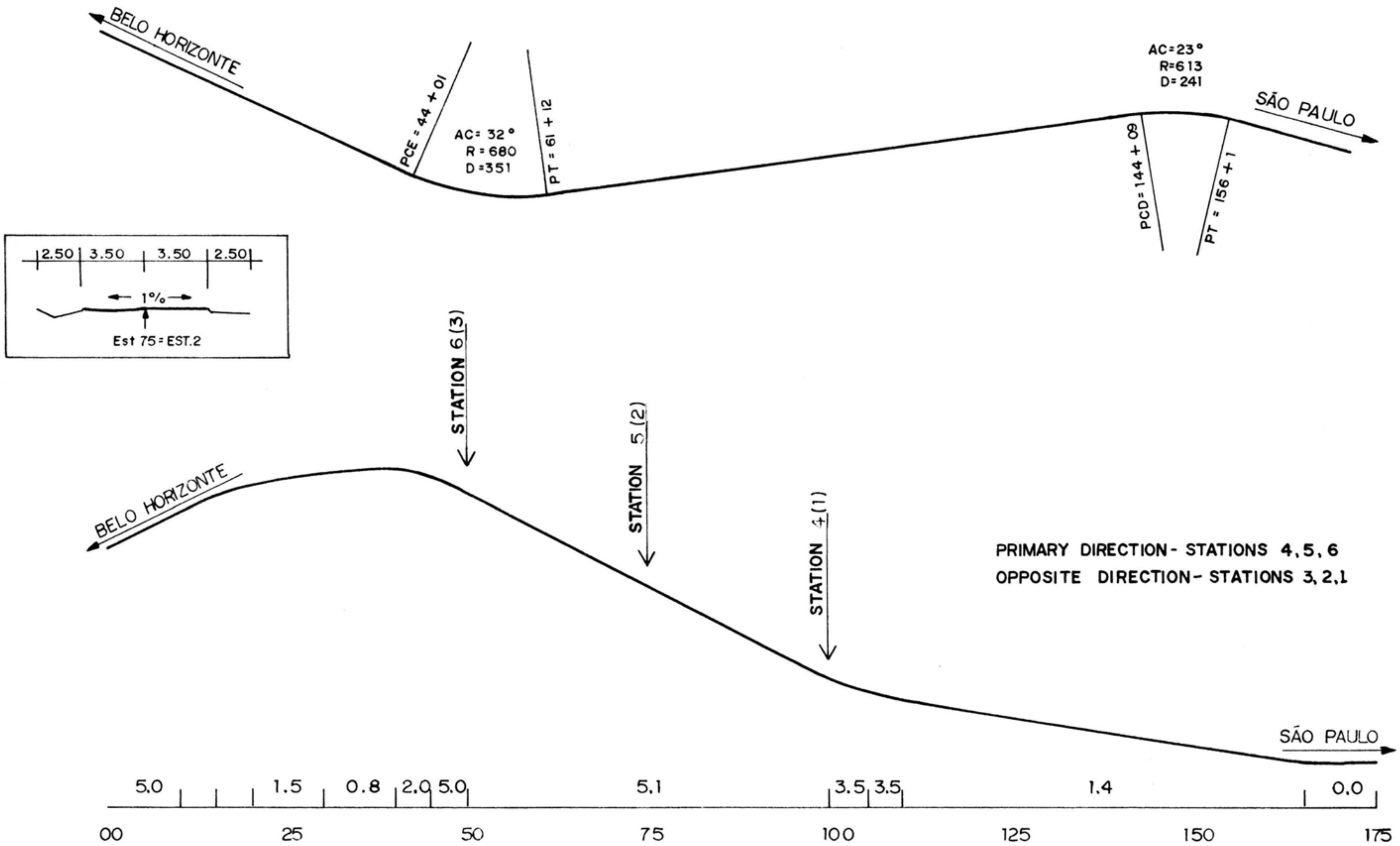
2) The MST was also used to simulate the behavior of the vehicles between the same stations 4 and 5 and between stations 3 and 2. (The results obtained are presented in Tables 6.5 and 6.6).

3) The hypothesis of equality of variances between the travel times observed and those simulated - utilizing the Bartlett test (Ostle, 1972) - and the hypothesis of equality of the means between the travel times observed and simulated, by vehicle class, were tested. These tests and their results are described below.

6.4.1 *Bartlett Test*

There are a number of possible procedures for testing the equality of variances of two samples. The Bartlett test of two samples was used in this analysis. (It is the standard parametric test in such cases).

In order to develop the Bartlett test of two samples it is necessary to define the following variables:



HIGHWAY: BR - 381	
LOCALITY: AT 23 km FROM MG - SP BORDERLINE	
HORIZONTAL SCALE	1:10000
VERTICAL SCALE	1:1000

FIGURE 6.1 - PROFILE OF TEST SECTION Nº 568.

TABLE 6.3 - TRAVEL TIMES (IN SECONDS) OF THE VEHICLES OBSERVED BETWEEN STATIONS 4 AND 5 OF TEST SECTION No.568 (PRIMARY LANE)

CLASSES					
1 (CARS)	2 (UTILITIES)	3 (LIGHT TRUCKS)	4 (MEDIUM TRUCKS)	5 (BUSES)	6 (HEAVY TRUCKS)
24.07	27.26	43.07	64.00	40.96	
32.02	36.66	25.24	74.17	39.37	
31.40	42.58	48.22	69.56	33.70	
25.24	47.81	30.28	68.02	33.51	
23.47	24.89	40.97	33.50	26.45	
29.02	27.45	27.83	40.80	29.65	
22.43	31.37	26.70	42.58	37.20	
25.64	31.77	38.59	59.23	25.29	
20.62	31.90	29.10	68.15	26.25	
25.31	31.38	29.24	-	42.47	
$\bar{x}$ = 25.92	$\bar{x}$ = 33.31	$\bar{x}$ = 33.92	$\bar{x}$ = 57.78	$\bar{x}$ = 33.49	
S_1 = 3.73	S_2 = 7.16	S_3 = 8.05	S_4 = 14.87	S_5 = 6.40	
S_1^2 = 13.94	S_2^2 = 51.23	S_3^2 = 64.74	S_4^2 =221.18	S_5^2 = 40.98	

SOURCE: Speed Experiment in a Traffic Flow (TB-8) of the PICR.

TABLE 6.4 - TRAVEL TIMES (IN SECONDS) OF THE VEHICLES OBSERVED BETWEEN STATIONS 3 AND 2 OF TEST SECTION No. 568 (OPPOSITE LANE)

CLASSES					
1 (CARS)	2 (UTILITIES)	3 (LIGHT TRUCKS)	4 (MEDIUM TRUCKS)	5 (BUSES)	6 (HEAVY TRUCKS)
26.45	27.64	28.74	25.55	24.41	25.69
35.96	28.87	37.47	25.92	23.38	27.17
26.18	31.34	23.13	28.63	19.23	25.91
33.24	22.65	29.89	33.09	25.55	36.37
33.53	22.66	28.87	28.88	23.81	30.58
24.43	26.58	27.23	34.87	23.54	30.19
25.26	27.36	27.91	32.21	26.22	23.36
25.08	30.39	33.02	32.83	37.21	24.99
35.78	27.69	34.94	31.07	38.42	24.99
26.79	28.29	28.46	27.72	31.33	26.51
$\bar{x}$ = 29.27	$\bar{x}$ = 27.35	$\bar{x}$ = 29.96	$\bar{x}$ = 30.07	$\bar{x}$ = 27.31	$\bar{x}$ = 27.71
S_1 = 4.73	S_2 = 2.85	S_3 = 4.13	S_4 = 3.20	S_5 = 6.30	S_6 = 3.77
S_1^2 = 22.42	S_2^2 = 8.14	S_3^2 = 17.09	S_4^2 = 10.22	S_5^2 = 39.72	S_6^2 = 14.27

SOURCE: Speed Experiment in a Traffic Flow (TB-8) of the PICR.

TABLE 6.5 - TRAVEL TIMES SIMULATED BY THE MST (IN SECONDS) OF THE VEHICLES BETWEEN STATIONS 4 AND 5 OF TEST SECTION no. 568 (PRIMARY LANE)

VEHICLE CLASS	RANGE		MEAN	STANDARD DEVIATION	VARIANCE	COEFFICIENT OF VARIATION	No. OBSERVATIONS
	MINIMUM	MAXIMUM					
1	20.54	33.52	24.78	3.39	11.49	13.7	13
2	21.57	34.31	25.91	3.73	13.91	14.4	13
3	-	-	-	-	-	-	-
4	25.63	44.74	35.44	5.58	31.14	15.7	14
5	-	-	-	-	-	-	-
6	33.76	36.04	35.15	1.00	1.00	2.8	3

TABLE 6.6 - TRAVEL TIMES SIMULATED BY THE MST (IN SECONDS) OF THE VEHICLES BETWEEN STATIONS 3 AND 2 OF TEST SECTION No. 568 (OPPOSITE LANE)

VEHICLE CLASS	RANGE		MEAN	STANDARD DEVIATION	VARIANCE	COEFFICIENT OF VARIATION	No. OBSERVATIONS
	MINIMUM	MAXIMUM					
1	23.55	41.05	28.03	4.19	17.55	14.9	13
2	26.80	36.04	30.71	3.11	9.67	10.1	12
3	-	-	-	-	-	-	-
4	26.06	44.25	36.31	5.14	26.41	14.2	23
5	28.84	37.40	33.56	3.06	9.36	9.1	5
6	25.03	41.18	33.34	5.86	34.33	17.6	5

X_{1kj} = the travel times of the vehicles of class k in the first sample, that is, of the sample of observed values.

X_{2kj} = the travel times of the vehicles of class k in the second sample, that is, of the sample of simulated values.

$j = 1,2....,n_{ik}$; $i=1,2$

The vehicle classes are as follows:

k = 1 - cars
k = 2 - utilities
k = 3 - light trucks
k = 4 - medium trucks
k = 5 - buses
k = 6 - heavy trucks

Y_{1kj} and Y_{2kj} are respectively defined as being:

$$Y_{1kj} = X_{1kj} - \overline{X}_{1k}$$

and

$$Y_{2kj} = X_{2kj} - \overline{X}_{2k}$$

The Bartlett method, presented in Table 6.7, uses the following notations as definitions of the variances of each sample:

$$S^2_{1k} = \sum_{j=1}^{n_{1k}} Y^2_{1kj}/(n_{1k}-1)$$

and

$$S^2_{2k} = \sum_{j=1}^{n_{2k}} Y^2_{2kj}/(n_{2k}-1)$$

The results of the Bartlett test are presented in Table 6.8. Comparing the corrected statistic χ^2, which was calculated in Table 6.8 with the χ^2 from the table for the eight vehicle classes (3 in the primary lane and 5 in the opposite lane), the conclusion is drawn that the variances of the speeds observed and those obtained

TABLE 6.7 - BARTLETT TEST OF HOMOGENEITY OF VARIANCES OF TWO SAMPLES

SAMPLE i	$\Sigma\ Y^2_{ik}$	DEGREES OF FREEDOM (d.f.)	1/d.f.	S^2_{ik}	$\log S^2_{ik}$	(d.f.) $\log S^2_{ik}$
1	$\sum_{j=1}^{n_{ik}} Y^2_{1kj}$	$n_{1k} - 1$	$1/(n_{1k} - 1)$	S^2_{1k}	$\log S^2_{1k}$	$(n_{1k} - 1) \log S^2_{1k}$
2	$\sum_{j=1}^{n_{2k}} Y^2_{2kj}$	$n_{2k} - 1$	$1/(n_{2k} - 1)$	S^2_{2k}	$\log S^2_{2k}$	$(n_{2k} - 1) \log S^2_{2k}$
SUM	W_{YY}	$\sum_{i=1}^{2} (n_{ik} - 1)$	$\sum_{i=1}^{2} 1/(n_{ik}-1)$			$\sum_{i=1}^{2} (n_{ik} -1) \log S^2_{ik}$

Notes: (1) The estimate of combined variance is given by:

$$S^2_{ik} = W_{YY} / \sum_{k=1}^{2} (n_{ik} - 1)$$

(2) The test uses the statistic χ^2_1 described below:

$$\chi^2_1 = (\ln 10) \left[B - \sum_{i=1}^{2} (n_{ik} - 1) \log S^2_{ik}\right]$$

Where:

$$B = (\log S^2_{ik}) \sum_{i=1}^{2} (n_{ik} - 1)$$

(3) The following correction factor can be used:

$$C = 1 + [1/3\ (2-1)] \left\{ \sum_{i=1}^{2} [1/(n_{ik} - 1)] - 1 \right\} / \sum_{i=1}^{2} (n_{ik} - 1)$$

(4) Finally, χ^2_1 corrected $= (1/C)\ \chi^2_1$

If $\chi^2_1 \geq \chi^2_{1\ (1-k)2}$, i.e. , χ^2 from the table, the hypothesis

$H_o : \sigma^2_1 = \sigma^2_2$ will be rejected.

through simulation are not statistically different, for the majority of the classes.

6.4.2 *Test of Equality of Two Means*

In the test of equality of two means (Hamburg, 1974), there are two hypotheses:

$H_o \quad : \mu_{1k} - \mu_{2k} = 0$

$H_1 \quad : \mu_{1k} - \mu_{2k} \neq 0$

where:

μ_{1k} = mean of the travel times of the vehicle population of class k;

μ_{2k} = mean of the simulated travel times of the vehicles of class k.

To test the null hypothesis, the statistic t_k is used:

$$t_k = \frac{(\bar{x}_{1k}-\bar{x}_{2k})-0}{S_{(\bar{x}_{1k}-\bar{x}_{2k})}} = \frac{\bar{x}_{1k}-\bar{x}_{2k}}{S_{(\bar{x}_{1k}-\bar{x}_{2k})}}$$

where:

$S_{(\bar{x}_{1k}-\bar{x}_{2k})}$ is the standard deviation of the difference between the two means.

Contrary to what occurs in the case of large samples, in this case it is necessary to admit the equality of the variances of the two populations. The hypothesis of this equality was submitted to the Bartlett test and could not be rejected.

An aggregate estimate of the variance is obtained by combining the variances of the two samples in a weighted mean, using as weights the numbers of degrees of freedom $n_{1k}-1$ and $n_{2k}-1$. This aggregate estimate of variance, designated by S_k^2, is given by:

TABLE 6.8 - APPLICATION OF THE BARTLETT TEST OF EQUALITY OF TWO VARIANCES - TEST SECTION No. 568

(continued)

VEHICLE CLASS	COMPARED SAMPLES O=OBSERVED S=SIMULATED	ΣY^2_{ik}	DEGREE OF FREEDOM (d.f.)	1/(d.f.)	S^2_{ik}	log S^2_{ik}	d.f. (log S^2_{ik})
PRIMARY LANE							
1	O	125.48	9	0.111	13.942	1.144	10.299
	S	137.88	12	0.083	11.49	1.060	12.720
SUM		263.36	21	0.194			23.019
2	O	461.07	9	0.111	51.23	1.710	15.385
	S	166.92	12	0.083	13.91	1.143	10.287
SUM		627.99	21	0.194			25.672
3	O	582.66	9	0.111	64.74	1.811	16.300
	S	-	-	-	-	-	-
SUM		582.66	9	0.111			16.300
4	O	1769.44	8	0.125	221.18	2.345	18.758
	S	404.82	13	0.076	31.14	1.493	19.409
SUM		2174.26	21	0.201			38.167
5	O	368.78	9	0.111	40.976	1.613	14.513
	S	-	-	-	-	-	-
SUM		368.78	9	0.111	40.976	1.613	14.513
6	O	-	-	-	-	-	-
	S	2.00	2	0.50	1.00	0.00	0.00
SUM		2.00	2	0.50			
OPPOSITE LANE							
1	O	201.75	9	0.111	22.417	1.351	12.155
	S	210.60	12	0.083	17.55	1.244	14.928
SUM		412.35	21	0.194			27.083
2	O	73.23	9	0.111	8.137	0.910	8.194
	S	106.37	11	0.090	9.67	0.985	10.835
SUM		179.60	20	0.201			19.029
3	O	153.79	9	0.111	17.088	1.233	11.094
	S	-	-	-	-	-	-
SUM		153.79	9	0.111	17.088	1.233	11.094
4	O	92.02	9	0.111	10.224	1.010	9.087
	S	581.02	22	0.045	26.41	1.421	31.262
SUM		673.04	31	0.156			40.349
5	O	357.49	9	0.111	39.721	1.599	14.389
	S	37.44	4	0.25	9.36	0.971	3.884
SUM		394.93	13	0.361			18.273
6	O	128.45	9	0.111	14.272	1.154	10.390
	S	137.32	4	0.25	34.33	1.535	6.14
SUM		265.77	13	0.361			16.530

TABLE 6.8 - APPLICATION OF THE BARTLETT TEST OF EQUALITY OF TWO VARIANCES - TEST SECTION No. 568

(Conclusion)

VEHICLE CLASS	ESTIMATE OF COMBINED VARIANCE (S_k^2)	$B=(\log S_k^2)\sum_{i=1}^{2}(n_{ik}-1)$	$\chi^2_{(i-1)}=\log_e 10\left[B-\sum_{i=1}^{2}(n_{ik}-1)\log S_{ik}^2\right]$	$C=1+\{1/3(2-1)\left[\sum_{i=1}^{2}1/(n_{ik}-1)-1/\sum_{i=1}^{2}(n_{ik}-1)\right]\}$	χ^2 CORRECTED
PRIMARY LANE					
1	12.54	23.06	0.094	0.987	0.095
2	29.90	30.99	12.246	0.987	12.407
3	-	-	-	-	-
4	103.54	42.32	9.563	0.987	9.689
5	-	-	-	-	-
OPPOSITE LANE					
1	19.636	27.153	0.161	0.987	0.163
2	8.98	19.066	0.085	0.987	0.086
3	-	-	-	-	-
4	21.711	41.437	2.505	0.991	2,528
5	30.379	19.273	2.303	0,984	2.340
6	20.444	17.373	1.941	0,984	1.973

$$S_k^2 = \frac{(n_{1k}-1)\ S_{1k}^2 + (n_{2k}-1)\ S_{2k}^2}{n_{1k} + n_{2k} - 2}$$

The estimate of the standard deviation of the difference between the two means is therefore:

$$S_{\bar{x}_{1k}-\bar{x}_{2k}} = \sqrt{\frac{S_k^2}{n_{1k}} + \frac{S_k^2}{n_{2k}}} = S_k \sqrt{\frac{1}{n_{1k}} + \frac{1}{n_{2k}}}$$

The results of the application of this test are found in Table 6.9.

The test of equality of the means indicates that there are no significant differences between the mean travel times observed and those simulated.

On the basis of the tests carried out (equality of means and variances), the conclusion can be drawn that the MST adequately simulates the behavior of the vehicles and constitutes a valid model for all classes of vehicles.

TABLE 6.9 - TEST OF EQUALITY OF TWO MEANS - TEST SECTION No. 568

	CALCULATED DATA				TABLES	
CLASS (k)	No. OF OBSERVATIONS IN THE TWO SAMPLES		t_k CALCULATED BETWEEN TWO SAMPLES	DEGREES OF FREEDOM	t_k FROM THE TABLE	LEVEL OF SIGNIFICANCE
	n_{1k}	n_{2k}				
PRIMARY LANE						
1	10	13	+ 0.216	23	1.714	0.10
2	10	13	+ 0.588	23	1.714	0.10
3	10	-	-	-	-	-
4	9	14	+ 0.492	23	1.714	0.10
5	10	-	-	-	-	-
6	-	3	-	-	-	-
OPPOSITE LANE						
1	10	13	+ 0.150	23	1.714	0.10
2	10	12	- 0.874	22	1.717	0.10
3	10	-	-	-	-	-
4	10	23	- 0.753	33	1.693	0.10
5	10	5	- 0.376	15	1.753	0.10
6	10	5	- 0.503	15	1.753	0.10

CHAPTER 7
APPLICATIONS OF THE MODEL

7.1 *INTRODUCTION*

After discussing the calibration and validation of the MST, the potential applications of this Model can be now examined.

The MST can be used in the development of correlations between the operating speed and fuel consumption of the vehicles, on the one hand, and the geometry, surfacing type and roughness, on the other. These correlations can be used in models of highway planning such as the Model for the Interrelationships of Highway Costs-MICR (see Vol. 8), which, in turn, can define the interrelationships of the three components of highway transportation costs: construction, maintenance and utilization.

7.2 *STRATEGIC PLANNING*

The NIMPAC planning model, developed by the NAASRA *Data Bank System Study (DBSS)* and described by Linsten (1978), utilizes the speed-geometry relations of the MODMERRI model, developed by the former Commonwealth Bureau of Roads (CBRds).

In the case of free-flow speeds, the MODMERRI uses free-speed tables associated with width, horizontal and vertical geometry and roughness of the highway. These tables were developed on the basis of an analysis of free-speed data gathered in 30 rural locations in New South Wales (Both, Harris and O'Loughlin, 1972). The general expressions of grade and curvature were compared with the grade and curvature data from the Australian Road Survey file. Grade was described in terms of type of terrain (level, rolling, and mountainous), and the curvature in terms of average highway speed. Aside from this, the CBRds model was aggregated in its form, with the main objective of determining warranted expenditures in the highway systems. On the other hand, the NIMPAC model of the NAASRA was designed for an intermediate level, concentrating on individual highways or routes, and thereby demanding more detailed data. The form used for the NAASRA data bank contains details on grades and horizontal and vertical curvatures.

In terms of computation costs, the NIMPAC may become efficient if a free-speed model (SPEEDS or MTC) is incorporated into it, as a subroutine. Up to the moment, the NIMPAC has only been tested on a 5-km section, using an arbitrary acceleration-speed relation, with a computer run time for both lanes that is lower than one second in the Cyber-172 computer.

In conditions of non-free flow, the MODMERRI uses a speed-flow relation that relates the operating speed to the free speed, and to the ratio between the hourly traffic volume (in units of equivalent passenger cars) and capacity. This is shown in Figure 1 of the Both and Bayley article (reproduced herein as Figure 7.1). The Model uses two tables: one of these tables provides the absolute hourly capacity in units of cars for each one of the states of the highway, that is, point B in Figure 7.1; the other table gives the units equivalent to passenger cars for various grades and types of trucks.

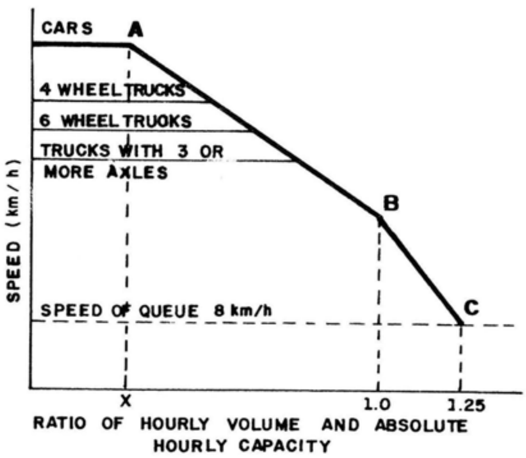


FIGURE 7.1 - SPEED-FLOW RELATIONSHIP.

The relatively high cost of running this simulation model makes its use difficult in aggregate or intermediate models, since various runs would be necessary in order to determine operating speed and fuel consumption at the various traffic levels which would occur during the period of analysis. However, the MODMERRI may be used to develop a functional relation between the average speed on the section for each vehicle class, and road geometry, traffic flow, traffic composition and direction.

A controlled experiment could be designed to use the average speed on the section and the fuel consumption calculated by the MST for several levels of the independent variables listed previously.

7.3 *HIGHWAY DESIGN*

Since the elaboration of highway designs is usually a short-term task, the MST, together with a free-speed model (MTC or SPEEDS), could be used directly to determine the most economical road design in terms of operating cost, under non-free flow conditions. Other applications can also be foreseen, such as the establishment of justification for a climbing lane (third lane) and for lane duplication. The user can analyze the effect of the introduction of a third lane on each traffic direction. This lane could have any length whatsoever, provided it is not longer than the section itself.

7.4 *TRAFFIC ANALYSIS*

The MST is very useful for traffic analyses. One can evaluate the impact of a number of alternative operating policies and of alternative technology on the traffic flow. This evaluation involves travel time, speed, fuel consumption, headway between vehicles, safety margin, etc. For example, one can evaluate the effect of introducing new vehicles or technologies (e.g., the multitrailer truck) or of operational changes, such as the temporal segregation of light and heavy vehicles.

CHAPTER 8
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY

The Model for Simulating Traffic (MST) was presented in this volume. This model simulates the traffic flow on two-lane highway sections of any complexity in terms of horizontal and vertical alignment.

Initially, existent literature on traffic simulation models was reviewed for identifying the major characteristics that a traffic simulation model should have, while also identifying the deficiencies of existent models. This procedure will make it possible to develop a more useful and efficient model than those already in use.

After the review of pertinent literature, the concepts inherent to traffic simulation were presented. The concepts of headway between vehicles, additional length, safety margin and, finally, the variable *time increment* were defined. Aside from this, a discussion was presented on the headway distribution, the maximum number of vehicles that can be overtaken at a single time, and the concept of overtaking-speed differential. Finally, the six classes of vehicles in the MST were established, together with a variable to characterize vehicle performance.

In Chapter 3, the Model of Time and Fuel Consumption (MTC) and the SPEEDS Model were presented. Either of these can be used to generate the free-speeds profile, which is an input data of the MST.

Chapter 4 explains the process of simulating vehicle travel in the MST. In this process, there are two fundamental types of interaction: the first between the vehicle and the road, and the second between vehicle and vehicle.

Chapter 5 shows how the MST is operated. Aside from describing the necessary inputs of the Model, together with its outputs, the possibility of effecting a sampling of the traffic flow at any transversal section of the highway being simulated is also presented.

The calibration and validation of the MST was discussed in Chapter 6. The calibration process is composed of two steps, the first of which associated with the Free Speed Model, and the second with the Simulation Model. The validation of the MST consists in comparing travel times observed with simulated travel times, on a given road section.

In Chapter 7, the potential and current applications of the MST are described. A discussion was presented on how the MST could be used in highway strategic planning and design, in traffic analysis and other applications.

The remaining sections of the present chapter contain the conclusions and recommendations regarding the MST.

8.2 CONCLUSIONS

Simulation is utilized when theoretical studies or field observations do not adequately describe the observed standard of behavior. A traffic flow simulation model can be a powerful tool in highway research, planning and design. However, like all tools, it must be calibrated for each application ascribed to it. The MST as described in this document was structured in such a way that the levels of the variables used can be rapidly altered, for purposes of calibration.

8.3 RECOMMENDATIONS

The utilization of the MST is recommended on highway sections that present the problem of traffic congestion or which may soon become congested. Apart from being the only calibrated and validated model in existence for Brazilian highways, it is highly efficient in terms of computation, principally when the vehicle sample utilized is not large. Although the MST can also be used for non-congested highway sections, this application is not recommended, since, being a simulation model, it will consume more computation time than the MTC and SPEEDS models. The MTC and SPEEDS models are used herein simply as subroutines for the calculation of travel time and fuel consumption at free speed by the MST. Therefore, in non-congested sections, the direct use of the MTC or SPEEDS is recommended.

In short, the current and potential applications of the MST warrant a recommendation to further improve and expand it, so as to make it capable of analyzing highway duplication, to determine units equivalent to passenger cars for all vehicle types, to determine overtaking-speed differentials, and to establish minimum distances for safe overtakings.

It is further recommended that the MST be adapted to urban traffic, so that Brazil will also have an urban traffic simulation model (MSTU). The MSTU could facilitate the study of the problem of traffic on urban streets, making possible the analysis of a number of alternative traffic policies, with the ultimate aim of reducing the problems of urban traffic, particularly congestion. To transform the MST into an urban traffic simulation model, the following steps should be taken: (1) to generate a traffic-sign subroutine for the MSTU, similar to the STOP-sign subroutine of the MST; (2) to eliminate MST limitations as to the existence of only one crossing and only one STOP-sign, so as to make it possible to analyze the effect of more than one crossing and STOP-sign, as commonly found in urban traffic; (3) to collect data (travel time, speed, fuel consumption, etc.), using the GEIPOT test vehicles or other vehicles, in congested urban traffic; (4) to calibrate the MSTU through the use of a part of the data collected in the previous item; (5) to validate the MSTU through the use of the other part of the data collected in item (3). After having been adapted, calibrated and validated, the MSTU could be used for analyzing the impact of a variety of alternative urban traffic policies, such as an exclusive lane for mass transit vehicles, priority traffic signs for mass transit vehicles, multiarticulated buses, unidirectional urban streets, economic feasibility of elevated and underground streets, and the reorganization of traffic directions in urban networks.

APPENDIX - MST COMPUTER OUTPUT

CONTROL CARDS FOR RUNNING THE
MSTØ2 PROGRAM

```
//NTR2568A JOB (3200221,'T=02,M=256,F=0'),
// 99999,CLASS=E,PRTY=12,TIME=02,MSGCLASS=X
LOG IEF403I NTR2568A STARTED TIME=18.02.15
LOG IEF233A M 280,FT0101,,NTR2568A,,SOFOT.D568
LOG IEC110D F 280,FT0101,NTR2568A,,SOFOT.D568
LOG R 60,U
LOG IEC209I NTR2568A FT0101 280 TR=000,TW=000,EG=000,CL=000,N=000,SIO=00038
LOG IEC202E K 280,FT0101,SL,NTR2568A,,SOFOT.D568
LOG IEF404I NTR2568A ENDED   TIME=18.09.14
//      EXEC PGM=MST02,TIME=02
//STEPLIB    DD  UNIT=3340,VOL=SER=PICR01,DSN=D.N.PTR06,DISP=SHR
//FT05F001  DD DDNAME=SYSIN
//FT06F001  DD UNIT=DISCO,DSN=&&TEMP4,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=28,BLKSIZE=2664)
//FT07F001  DD UNIT=DISCO,DSN=&&TEMP7,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=28,BLKSIZE=2664)
//FT01F001  DD  UNIT=TAPE,VOL=SER=FT0101,DSN=SOFOT.D568,LABEL=4,
//        DISP=(OLD,KEEP)
***T04F001 DD UNIT=3340,VOL=SER=PICR01,DSN=D.N.PTR01(DATA4),DISP=SHR
//FT02F001  DD SYSOUT=X,DCB=RECFM=UA,OUTLIM=1000
//FT08F001  DD UNIT=DISCO,DSN=&&TEMP8,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=20,BLKSIZE=2664)
//FT09F001  DD UNIT=DISCO,DSN=&&TEMP9,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=20,BLKSIZE=2664)
//FT10F001  DD UNIT=DISCO,DSN=&&TEMPO,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=20,BLKSIZE=2664)
//FT11F001  DD UNIT=DISCO,DSN=&&TEMP1,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=20,BLKSIZE=2664)
//FT12F001  DD UNIT=DISCO,DSN=&&TEMP2,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=16,BLKSIZE=2676)
//FT13F001  DD UNIT=DISCO,DSN=&&TEMP3,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=16,BLKSIZE=2676)
//FT15F001  DD UNIT=DISCO,DSN=&&TEMP6,DISP=(,DELETE),
//        SPACE=(TRK,(5,1),RLSE),DCB=(RECFM=VSB,LRECL=28,BLKSIZE=2664)
//FT03F001  DD *
//
IEF236I ALLOC. FOR NTR2568A
IEF237I 1C6    ALLOCATED TO STEPLIB
IEF237I 1C4    ALLOCATED TO FT06F001
IEF237I 1C3    ALLOCATED TO FT07F001
IEF237I 280    ALLOCATED TO FT01F001
IEF237I 1C4    ALLOCATED TO FT08F001
IEF237I 1C1    ALLOCATED TO FT09F001
IEF237I 1C4    ALLOCATED TO FT10F001
IEF237I 1C3    ALLOCATED TO FT11F001
IEF237I 1C4    ALLOCATED TO FT12F001
IEF237I 1C0    ALLOCATED TO FT13F001
IEF237I 1C4    ALLOCATED TO FT15F001
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   D.N.PTR06                                      KEPT
IEF285I   VOL SER NOS= PICR01.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP4          DELETED
IEF285I   VOL SER NOS= SYSR05.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP7          DELETED
IEF285I   VOL SER NOS= SYSR04.
IEF285I   SOFOT.D568                                     KEPT
IEF285I   VOL SER NOS= FT0101.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP8          DELETED
IEF285I   VOL SER NOS= SYSR05.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP9          DELETED
IEF285I   VOL SER NOS= SYSR02.
IEF2851   SYS82202.T180213.RF103.NTR2568A.TEMPO          DELETED
```

```
IEF285I   VOL SER NOS= SYSR05.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP1         DELETED
IEF285I   VOL SER NOS= SYSR04.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP2         DELETED
IEF285I   VOL SER NOS= SYSR05.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP3         DELETED
IEF285I   VOL SER NOS= SYSR01.
IEF285I   SYS82202.T180213.RF103.NTR2568A.TEMP6         DELETED
IEF285I   VOL SER NOS= SYSR05.
IEF373I STEP /        / START 82202.1802
IEF374I STEP /        / STOP  82202.1809 CPU   1MIN 51.02SEC STOR VIRT 222K
IEF298I  NTR2568A SYSOUT=X.
IEF375I  JOB /NTR2568A/ START 82202.1802
IEF376I  JOB /NTR2568A/ STOP  82202.1809 CPU   1MIN 51.02SEC
```

MST INPUT PARAMETERS

```
                                      EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT
                                                  SIMULATION   OF   FLOW   OF   TRAFFIC

     *** SOFOT RUN PARAMETERS ***

     SECTION DESCRIPTION
            LS =  1.80
            STN1 =  0.50
            STNO =  0.50
            SH =  1.00
     SAMPLE DESCRIPTION
            NIS =  100
            VOL1 =   200
            VOLO =   245
            ARRAY1 =  36 18  1 36  3  6
            ARRAY2 =  36 18  1 36  3  6
            ARRAY4 =   0.0  0.5  2.5  4.5  6.0 12.0
     HEADWAY PARAMETERS
            IT = 1.0
            MH =  0.5
            AHR =  2.0
            UNH =  4.5
     OVERTAKING PARAMETERS
            MN =  6
            MOT =   30
            SPC =  14. 14. 14. 14. 14. 14.
            SPT =  18. 18. 18. 18. 18. 18.
     PLOT AND DEBUG OPTIONS
            IPLOT =   0
            DBUG =   1
            PACTS =   180.
            PACTE =   185.
     CLIMBING LANE AND STOP SIGN LOCATIONS
            SCL1 =  0.0
            ECL1 =  0.0
            SCLO =  0.0
            ECLO =  0.0
            SSD1 =  0.0
            SSDO =  0.0
            VOL3 =      0
            VOL4 =      0
NO. IN SAMPLE LANE 1      44 VEHICLES
NO. IN SAMPLE LANE 0      56 VEHICLES
```

VEHICLE ORDERING, CLASSIFICATION, PERFORMANCE, HEADWAY, SPEED AND ACCUMULATED TIME AT THE BEGINNING OF PRIMARY AND OPPOSITE LANES OF THE HIGHWAY SECTION

LANE	VN	NVN	LVN	VC	MODE	VP	DIST	H	VS	ACT	TT	AFC	NIP	SP	EL	IN	DT	NNVN	FVH
1	1	0	2	4	1	1.14	0.0	100.00	56.40	0.0	0.0	0.0	1						
0	1	0	2	6	1	0.79	0.0	100.00	44.99	0.0	0.0	0.0	1						
0	2	1	3	2	1	0.91	0.0	2.86	50.12	4.00	0.0	0.0	1						
0	3	2	4	1	1	1.18	0.0	7.89	70.44	12.00	0.0	0.0	1						
0	4	3	5	1	1	0.90	0.0	1.75	53.72	14.00	0.0	0.0	1						
0	5	4	6	4	1	1.24	0.0	0.83	60.80	15.00	0.0	0.0	1						
1	2	1	3	4	1	0.88	0.0	14.10	43.31	15.00	0.0	0.0	1						
1	3	2	4	4	1	0.98	0.0	11.29	48.56	27.00	0.0	0.0	1						
0	6	5	7	4	1	0.86	0.0	15.06	41.92	31.00	0.0	0.0	1						
0	7	6	8	2	1	1.04	0.0	1.31	57.39	33.00	0.0	0.0	1						
0	8	7	9	4	1	1.13	0.0	12.87	55.06	46.00	0.0	0.0	1						
0	9	8	10	2	1	0.94	0.0	14.12	51.97	61.00	0.0	0.0	1						
1	4	3	5	2	1	0.95	0.0	36.20	65.86	64.00	0.0	0.0	1						
0	10	9	11	1	1	1.16	0.0	3.88	68.86	65.00	0.0	0.0	1						
1	5	4	6	4	1	1.46	0.0	19.80	71.97	84.00	0.0	0.0	1						
1	6	5	7	4	1	0.98	0.0	2.97	48.30	87.00	0.0	0.0	1						
1	7	6	8	4	1	0.90	0.0	1.21	44.39	89.00	0.0	0.0	1						
0	11	10	12	6	1	0.92	0.0	33.76	52.10	99.00	0.0	0.0	1						
0	12	11	13	1	1	0.99	0.0	2.68	59.07	102.00	0.0	0.0	1						
1	8	7	9	4	1	1.26	0.0	19.27	61.88	109.00	0.0	0.0	1						
0	13	12	14	2	1	0.89	0.0	31.80	49.09	134.00	0.0	0.0	1						
0	14	13	15	2	1	0.91	0.0	2.90	50.19	137.00	0.0	0.0	1						
0	15	14	16	2	1	1.10	0.0	22.89	60.23	160.00	0.0	0.0	1						
1	9	8	10	6	1	1.05	0.0	50.05	50.24	160.00	0.0	0.0	1						
0	16	15	17	5	1	0.93	0.0	0.83	49.85	161.00	0.0	0.0	1						
0	17	16	18	4	1	1.20	0.0	2.29	58.54	164.00	0.0	0.0	1						
0	18	17	19	5	1	1.40	0.0	3.08	75.25	168.00	0.0	0.0	1						
0	19	18	20	4	1	0.79	0.0	2.03	38.60	171.00	0.0	0.0	1						
0	11	0	12	6	1	0.92	1.513	38.87	78.61	180.00	81.00	999.00	1	1	12.0	0	0.022	0	10.11
0	12	11	13	1	6	0.99	1.485	1.28	78.61	180.00	78.00	999.00	1	1	12.0	0	0.022	0	38.87
0	13	12	14	2	1	0.89	0.758	36.87	70.95	180.00	46.00	999.00	1	1	0.0	0	0.020	11	38.87
0	14	13	15	2	5	0.91	0.722	2.82	72.41	180.00	43.00	999.00	1	1	0.5	0	0.020	12	36.87
0	15	14	16	2	1	1.10	0.355	16.85	69.69	180.00	20.00	0.04	1	1	0.5	0	0.019	13	36.87
0	16	15	17	5	1	0.93	0.266	5.98	51.85	180.00	19.00	0.07	1	1	0.5	0	0.014	14	36.87
0	17	16	18	4	6	1.20	0.248	1.26	51.68	180.00	16.00	0.17	1	1	6.0	0	0.014	15	5.98
0	18	17	19	5	6	1.40	0.231	1.16	51.51	180.00	12.00	0.07	2	1	4.5	0	0.014	16	5.98
0	19	18	20	4	1	0.79	0.097	12.01	39.36	180.00	9.00	0.06	1	1	6.0	0	0.011	17	5.98
1	6	0	7	4	1	0.98	1.296	43.98	49.28	180.00	93.00	999.03	1	1	4.5	0	0.014	0	5.98
1	7	6	8	4	1	0.90	1.168	10.20	45.26	180.00	91.00	999.03	1	1	4.5	0	0.013	0	5.98
1	8	7	9	4	6	1.26	1.152	1.26	45.25	180.00	71.00	999.03	1	1	4.5	0	0.013	6	10.20
1	9	8	10	6	1	1.05	0.282	77.79	51.23	180.00	20.00	0.26	1	1	4.5	0	0.014	7	10.20
0	11	0	12	6	1	0.92	1.535	38.87	78.61	181.00	82.00	999.00	1	1	12.0	0	0.022	0	10.20
0	12	11	13	1	6	0.99	1.507	1.28	78.61	181.00	79.00	999.00	1	1	12.0	0	0.022	0	38.87
0	13	12	14	2	1	0.89	0.778	36.98	70.95	181.00	47.00	999.00	1	1	0.0	0	0.020	11	38.87
0	14	13	15	2	5	0.91	0.742	2.80	72.41	181.00	44.00	999.00	1	1	0.5	0	0.020	12	36.98
0	15	14	16	2	1	1.10	0.374	16.74	70.93	181.00	21.00	0.04	1	1	0.5	0	0.020	13	36.98
0	16	15	17	5	1	0.93	0.281	6.26	52.02	181.00	20.00	0.07	1	1	0.5	0	0.014	14	36.98
0	17	16	18	4	6	1.20	0.262	1.26	51.85	181.00	17.00	0.17	1	1	6.0	0	0.014	15	6.26
0	18	17	19	5	6	1.40	0.246	1.16	51.68	181.00	13.00	0.07	2	1	4.5	0	0.014	16	6.26
0	19	18	20	4	1	0.79	0.108	12.27	39.48	181.00	10.00	0.06	1	1	6.0	0	0.011	17	6.26
1	6	0	7	4	1	0.98	1.310	43.98	49.26	181.00	94.00	999.03	1	1	4.5	0	0.014	0	6.26
1	7	6	8	4	1	0.90	1.181	10.29	45.28	181.00	92.00	999.03	1	1	4.5	0	0.013	0	6.26
1	8	7	9	4	6	1.26	1.165	1.26	45.26	181.00	72.00	999.03	1	1	4.5	0	0.013	6	10.29

0	15	14	16	2	1	1.10	0.394	16.62	72.20	182.00	22.00	0.04	1	1	0.5	0	0.020	13	37.09
0	16	15	17	5	1	0.93	0.295	6.55	52.20	182.00	21.00	0.07	1	1	0.5	0	0.014	14	37.09
0	17	16	18	4	6	1.20	0.277	1.26	52.02	182.00	18.00	0.17	1	1	6.0	0	0.014	15	6.55
0	18	17	19	5	6	1.40	0.260	1.16	51.85	182.00	14.00	0.07	2	1	4.5	0	0.014	16	6.55
0	19	18	20	4	1	0.79	0.119	12.53	39.62	182.00	11.00	0.07	1	1	6.0	0	0.011	17	6.55
0	20	19	21	6	1	0.75	0.0	10.38	42.52	182.00	0.0	0.0	1						
1	6	0	7	4	1	0.98	1.324	43.98	49.22	182.00	95.00	999.03	1	1	4.5	0	0.014	0	6.55
1	7	6	8	4	1	0.90	1.193	10.38	45.29	182.00	93.00	999.03	1	1	4.5	0	0.013	0	6.55
1	8	7	9	4	6	1.26	1.177	1.26	45.28	182.00	73.00	999.03	1	1	4.5	0	0.013	6	10.38
1	9	8	10	6	1	1.05	0.311	77.55	51.18	182.00	22.00	0.30	1	1	4.5	0	0.014	7	10.38
0	11	0	12	6	1	0.92	1.578	38.87	78.61	183.00	84.00	999.00	1	1	12.0	0	0.022	0	10.38
0	12	11	13	1	6	0.99	1.551	1.28	78.61	183.00	81.00	999.00	1	1	12.0	0	0.022	0	38.87
0	13	12	14	2	1	0.89	0.817	37.20	70.95	183.00	49.00	999.00	1	1	0.0	0	0.020	11	38.87
0	14	13	15	2	5	0.91	0.782	2.76	72.41	183.00	46.00	999.00	1	1	0.5	0	0.020	12	37.20
0	15	14	16	2	1	1.10	0.415	16.33	74.83	183.00	23.00	0.04	1	1	0.5	0	0.020	13	37.20
0	16	15	17	5	1	0.93	0.310	6.80	52.74	183.00	22.00	0.07	1	1	0.5	0	0.015	14	37.20
0	17	16	18	4	6	1.20	0.291	1.25	52.20	183.00	19.00	0.18	1	1	6.0	0	0.015	15	6.80
0	18	17	19	5	6	1.40	0.275	1.16	52.02	183.00	15.00	0.07	2	1	4.5	0	0.014	16	6.80
0	19	18	20	4	1	0.79	0.130	12.79	39.75	183.00	12.00	0.07	1	1	6.0	0	0.011	17	6.80
0	20	19	21	6	1	0.75	0.012	10.13	42.44	183.00	1.00	0.02	1	1	4.5	0	0.012	18	6.80
1	6	0	7	4	1	0.98	1.337	43.98	49.18	183.00	96.00	999.03	1	1	12.0	0	0.014	0	6.80
1	7	6	8	4	1	0.90	1.206	10.47	45.29	183.00	94.00	999.03	1	1	4.5	0	0.013	0	6.80
1	8	7	9	4	6	1.26	1.190	1.26	45.29	183.00	74.00	999.03	1	1	4.5	0	0.013	6	10.47
1	9	8	10	6	1	1.05	0.325	77.55	51.03	183.00	23.00	0.32	1	1	4.5	0	0.014	7	10.47
0	11	0	12	6	1	0.92	1.600	38.87	78.61	184.00	85.00	999.00	1	1	12.0	0	0.022	0	10.47
0	12	11	13	1	6	0.99	1.572	1.28	78.61	184.00	82.00	999.00	1	1	12.0	0	0.022	0	38.87
0	13	12	14	2	1	0.89	0.837	37.30	70.95	184.00	50.00	999.00	1	1	0.0	0	0.020	11	38.87
0	14	13	15	2	5	0.91	0.802	2.74	72.41	184.00	47.00	999.00	1	1	0.5	0	0.020	12	37.30
0	15	14	16	2	1	1.10	0.436	15.98	77.90	184.00	24.00	0.04	1	1	0.5	0	0.021	13	37.30
0	16	15	17	5	1	0.93	0.324	7.05	53.46	184.00	23.00	0.08	1	1	0.5	0	0.015	14	37.30
0	17	16	18	4	6	1.20	0.306	1.24	52.74	184.00	20.00	0.18	1	1	6.0	0	0.015	15	7.05
0	18	17	19	5	6	1.40	0.289	1.15	52.20	184.00	16.00	0.07	2	1	4.5	0	0.015	16	7.05
0	19	18	20	4	1	0.79	0.141	13.06	39.88	184.00	13.00	0.08	1	1	6.0	0	0.011	17	7.05
0	20	19	21	6	1	0.75	0.024	10.07	42.36	184.00	2.00	0.04	1	1	4.5	0	0.012	18	7.05
1	6	0	7	4	1	0.98	1.351	43.98	49.14	184.00	97.00	999.03	1	1	12.0	0	0.014	0	7.05
1	7	6	8	4	1	0.90	1.218	10.56	45.29	184.00	95.00	999.03	1	1	4.5	0	0.013	0	7.05
1	8	7	9	4	6	1.26	1.203	1.26	45.29	184.00	75.00	999.03	1	1	4.5	0	0.013	6	10.56
1	9	8	10	6	1	1.05	0.339	77.55	50.88	184.00	24.00	0.34	1	1	4.5	0	0.014	7	10.56
0	11	0	12	6	1	0.92	1.622	38.87	78.61	185.00	86.00	999.00	1	1	12.0	0	0.022	0	10.56
0	12	11	13	1	6	0.99	1.594	1.28	78.61	185.00	83.00	999.00	1	1	12.0	0	0.022	0	38.87
0	13	12	14	2	1	0.89	0.857	37.41	70.95	185.00	51.00	999.00	1	1	0.0	0	0.020	11	38.87
0	14	13	15	2	5	0.91	0.822	2.72	72.41	185.00	48.00	999.00	1	1	0.5	0	0.020	12	37.41
0	15	14	16	2	1	1.10	0.458	15.61	80.96	185.00	25.00	0.04	1	1	0.5	0	0.022	13	37.41
0	16	15	17	5	1	0.93	0.339	7.32	54.17	185.00	24.00	0.08	1	1	0.5	0	0.015	14	37.41
0	17	16	18	4	6	1.20	0.321	1.23	53.46	185.00	21.00	0.18	1	1	6.0	0	0.015	15	7.32
0	18	17	19	5	6	1.40	0.304	1.14	52.74	185.00	17.00	0.07	2	1	4.5	0	0.015	16	7.32
0	19	18	20	4	1	0.79	0.153	13.32	40.01	185.00	14.00	0.08	1	1	6.0	0	0.011	17	7.32
0	20	19	21	6	1	0.75	0.035	10.02	42.28	185.00	3.00	0.06	1	1	4.5	0	0.012	18	7.32
1	6	0	7	4	1	0.98	1.365	43.98	49.10	185.00	98.00	999.03	1	1	12.0	0	0.014	0	7.32
1	7	6	8	4	1	0.90	1.231	10.65	45.29	185.00	96.00	999.03	1	1	4.5	0	0.013	0	7.32
1	8	7	9	4	6	1.26	1.215	1.25	45.29	185.00	76.00	999.03	1	1	4.5	0	0.013	6	10.65
1	9	8	10	6	1	1.05	0.353	77.56	50.73	185.00	25.00	0.37	1	1	4.5	0	0.014	7	10.65
0	21	20	22	2	1	0.81	0.0	11.94	44.81	194.00	0.0	0.0	1						
0	22	21	23	1	1	0.99	0.0	33.94	59.20	228.00	0.0	0.0	1						
1	10	9	11	2	1	1.18	0.0	69.72	81.44	230.00	0.0	0.0	1						
0	23	22	24	6	1	0.88	0.0	3.80	49.94	232.00	0.0	0.0	1						
0	24	23	25	4	1	0.91	0.0	15.73	44.64	248.00	0.0	0.0	1						
0	25	24	26	4	1	0.83	0.0	2.26	40.37	251.00	0.0	0.0	1						
1	11	10	12	4	1	1.34	0.0	20.74	66.20	251.00	0.0	0.0	1						
1	12	11	13	4	1	1.15	0.0	3.01	56.91	255.00	0.0	0.0	1						
1	13	12	14	4	1	0.94	0.0	11.10	46.34	267.00	0.0	0.0	1						
1	14	13	15	1	1	1.10	0.0	6.24	81.70	274.00	0.0	0.0	1						
1	15	14	16	1	1	0.98	0.0	11.72	73.08	285.00	0.0	0.0	1						
0	26	25	27	4	1	1.26	0.0	36.35	61.81	288.00	0.0	0.0	1						
1	16	15	17	2	1	0.97	0.0	2.75	67.09	289.00	0.0	0.0	1						
0	27	26	28	4	1	0.61	0.0	1.05	39.42	290.00	0.0	0.0	1						

0	28	27	29	5	1	1.20	0.0	2.37	64.64	293.00	0.0	0.0	1
0	29	28	30	2	1	1.08	0.0	12.11	59.32	306.00	0.0	0.0	1
0	30	29	31	5	1	0.84	0.0	1.83	44.99	308.00	0.0	0.0	1
1	17	16	18	6	1	1.10	0.0	33.79	53.03	323.00	0.0	0.0	1
0	31	30	32	4	1	0.95	0.0	41.38	46.51	350.00	0.0	0.0	1
1	18	17	19	1	1	1.15	0.0	46.65	85.80	370.00	0.0	0.0	1
1	19	18	20	2	1	1.19	0.0	7.71	81.90	378.00	0.0	0.0	1
1	20	19	21	4	1	0.77	0.0	1.74	37.93	380.00	0.0	0.0	1
0	32	31	33	4	1	0.86	0.0	30.23	42.00	381.00	0.0	0.0	1
1	21	20	22	1	1	1.04	0.0	3.40	77.80	384.00	0.0	0.0	1
0	33	32	34	4	1	0.83	0.0	42.31	40.35	424.00	0.0	0.0	1
0	34	33	35	4	1	0.78	0.0	4.35	38.24	429.00	0.0	0.0	1
0	35	34	36	6	1	1.25	0.0	1.39	70.79	431.00	0.0	0.0	1
0	36	34	37	1	1	0.90	0.0	18.37	53.88	450.00	0.0	0.0	1
0	37	36	38	1	1	0.95	0.0	6.83	56.59	457.00	0.0	0.0	1
0	38	37	39	4	1	0.95	0.0	6.82	46.29	464.00	0.0	0.0	1
0	39	38	40	2	1	0.92	0.0	13.24	50.67	478.00	0.0	0.0	1
1	22	20	23	1	1	0.97	0.0	93.73	72.06	478.00	0.0	0.0	1
1	23	22	24	1	1	0.82	0.0	2.75	61.10	481.00	0.0	0.0	1
0	40	39	41	4	1	0.87	0.0	9.89	42.33	488.00	0.0	0.0	1
0	41	40	42	1	1	1.19	0.0	19.31	70.63	508.00	0.0	0.0	1
0	42	41	43	4	1	1.06	0.0	2.75	51.70	511.00	0.0	0.0	1
0	43	42	44	4	1	0.91	0.0	7.16	44.34	519.00	0.0	0.0	1
0	44	43	45	1	1	1.14	0.0	2.27	67.99	522.00	0.0	0.0	1
0	45	44	46	4	1	0.99	0.0	1.76	48.58	524.00	0.0	0.0	1
1	24	23	25	2	1	0.97	0.0	45.79	67.26	527.00	0.0	0.0	1
1	25	24	26	1	1	1.09	0.0	3.79	81.22	531.00	0.0	0.0	1
0	46	45	47	1	1	0.96	0.0	9.20	57.15	534.00	0.0	0.0	1
0	47	46	48	1	1	1.00	0.0	0.61	59.34	535.00	0.0	0.0	1
0	48	47	49	2	1	1.04	0.0	4.80	57.07	540.00	0.0	0.0	1
0	49	48	50	2	1	0.87	0.0	3.85	47.62	544.00	0.0	0.0	1
0	50	49	51	2	1	1.14	0.0	4.91	62.84	549.00	0.0	0.0	1
0	51	50	52	4	1	1.01	0.0	2.82	49.22	552.00	0.0	0.0	1
0	52	51	53	4	1	1.19	0.0	6.19	58.27	559.00	0.0	0.0	1
0	53	52	54	1	1	0.66	0.0	2.08	39.24	562.00	0.0	0.0	1
0	54	53	55	1	1	1.01	0.0	8.96	60.39	571.00	0.0	0.0	1
0	55	54	56	2	1	1.09	0.0	13.80	59.97	585.00	0.0	0.0	1
1	26	25	27	4	1	0.93	0.0	55.72	45.76	587.00	0.0	0.0	1
0	56	55	57	4	1	0.85	0.0	3.83	41.42	589.00	0.0	0.0	1
1	27	26	28	1	1	1.03	0.0	2.24	76.66	590.00	0.0	0.0	1
0	57	56	58	1	1	1.09	0.0	31.32	65.24	621.00	0.0	0.0	1
0	58	57	59	1	1	0.98	0.0	14.77	58.58	636.00	0.0	0.0	1
0	59	58	60	4	1	1.08	0.0	3.81	52.80	640.00	0.0	0.0	1
0	60	59	61	6	1	0.83	0.0	2.15	47.30	643.00	0.0	0.0	1
1	28	26	29	2	1	1.03	0.0	60.74	71.26	651.00	0.0	0.0	1
0	61	60	62	4	1	0.79	0.0	24.60	38.48	658.00	0.0	0.0	1
1	29	28	30	2	1	1.03	0.0	16.78	71.13	668.00	0.0	0.0	1
0	62	61	63	1	1	0.94	0.0	22.39	56.31	691.00	0.0	0.0	1
0	63	62	64	2	1	0.65	0.0	2.82	46.73	694.00	0.0	0.0	1
0	64	63	65	2	1	1.15	0.0	1.92	63.00	696.00	0.0	0.0	1
0	65	64	66	1	1	1.09	0.0	3.81	64.96	700.00	0.0	0.0	1
0	66	65	67	6	1	1.11	0.0	1.78	62.86	702.00	0.0	0.0	1
0	67	66	68	4	1	1.34	0.0	3.48	65.70	706.00	0.0	0.0	1
1	30	29	31	4	1	1.15	0.0	48.78	56.58	717.00	0.0	0.0	1
0	68	67	69	4	1	0.76	0.0	24.02	36.99	731.00	0.0	0.0	1
1	31	30	32	4	1	0.95	0.0	27.10	46.83	745.00	0.0	0.0	1
1	32	31	33	6	1	1.03	0.0	8.23	49.67	754.00	0.0	0.0	1
0	69	68	70	4	1	0.95	0.0	30.42	46.53	762.00	0.0	0.0	1
1	33	32	34	2	1	0.93	0.0	26.70	64.42	781.00	0.0	0.0	1
1	34	33	35	1	1	1.04	0.0	32.61	77.22	814.00	0.0	0.0	1
1	35	34	36	2	1	1.09	0.0	5.73	75.37	820.00	0.0	0.0	1
0	70	69	71	4	1	0.81	0.0	60.23	39.51	823.00	0.0	0.0	1
1	36	35	37	4	1	1.08	0.0	2.76	53.20	823.00	0.0	0.0	1
0	71	70	72	1	1	0.96	0.0	2.36	57.23	826.00	0.0	0.0	1
0	72	71	73	4	1	0.98	0.0	7.81	47.88	834.00	0.0	0.0	1
1	37	36	38	1	1	0.96	0.0	20.14	71.65	844.00	0.0	0.0	1

1	38	37	39	2	1	1.02	0.0	27.75	70.54	872.00	0.0	0.0	1
1	39	38	40	2	1	1.14	0.0	0.78	78.48	873.00	0.0	0.0	1
1	40	39	41	4	1	1.07	0.0	1.75	52.78	875.00	0.0	0.0	1
1	41	40	42	4	1	0.77	0.0	36.15	38.20	912.00	0.0	0.0	1
0	73	0	74	6	1	0.89	0.0	119.21	50.54	954.00	0.0	0.0	1
1	42	41	43	4	1	0.98	0.0	70.39	48.53	983.00	0.0	0.0	1
0	74	73	75	2	1	1.03	0.0	30.71	56.74	985.00	0.0	0.0	1
0	75	74	76	4	1	1.06	0.0	0.85	51.94	986.00	0.0	0.0	1
0	76	75	77	1	1	0.87	0.0	21.16	51.57	1008.00	0.0	0.0	1
0	77	76	78	2	1	1.36	0.0	2.85	75.02	1011.00	0.0	0.0	1
0	78	76	79	2	1	0.78	0.0	29.76	42.80	1041.00	0.0	0.0	1
1	43	42	44	1	1	1.09	0.0	58.20	81.25	1042.00	0.0	0.0	1
0	79	78	80	4	1	0.94	0.0	5.96	46.20	1047.00	0.0	0.0	1
0	80	79	81	4	1	1.08	0.0	6.24	52.83	1054.00	0.0	0.0	1
0	81	80	82	4	1	1.20	0.0	2.15	58.88	1057.00	0.0	0.0	1
1	44	43	45	4	1	0.91	0.0	25.72	44.86	1068.00	0.0	0.0	1
0	82	81	83	1	1	0.83	0.0	19.08	49.23	1077.00	0.0	0.0	1
0	83	82	84	4	1	1.14	0.0	2.86	55.75	1080.00	0.0	0.0	1
0	84	83	85	2	1	1.34	0.0	3.11	73.71	1084.00	0.0	0.0	1
0	85	84	86	2	1	0.89	0.0	2.77	48.97	1087.00	0.0	0.0	1
0	86	85	87	4	1	0.77	0.0	7.90	37.77	1095.00	0.0	0.0	1
0	87	86	88	4	1	0.80	0.0	2.40	39.27	1098.00	0.0	0.0	1
1	45	44	46	1	1	1.05	0.0	31.26	78.57	1100.00	0.0	0.0	1
1	46	45	47	4	1	1.09	0.0	9.73	53.91	1110.00	0.0	0.0	1
1	47	46	48	2	1	0.75	0.0	30.13	51.48	1141.00	0.0	0.0	1
1	48	47	49	1	1	0.91	0.0	0.88	67.54	1142.00	0.0	0.0	1
1	49	48	50	2	1	0.85	0.0	0.83	58.64	1143.00	0.0	0.0	1
1	50	49	51	2	1	1.12	0.0	6.84	76.94	1150.00	0.0	0.0	1
1	51	50	52	4	1	0.80	0.0	7.76	39.22	1158.00	0.0	0.0	1
0	88	87	89	1	1	0.95	0.0	71.37	56.81	1170.00	0.0	0.0	1
0	89	88	90	1	1	0.68	0.0	14.82	40.39	1185.00	0.0	0.0	1
0	90	89	91	2	1	1.36	0.0	1.94	74.83	1187.00	0.0	0.0	1

HEADWAY DISTRIBUTION AND VEHICLE ORDER AT THE BEGINNING OF THE PRIMARY LANE OF THE HIGHWAY SECTION

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT
SIMULATION OF FLOW OF TRAFFIC

PRIMARY LANE

TRAFFIC VOLUME 200 VEHICLES PER HOUR

VEHICLE CLASS	1	2	3	4	5	6
VEHICLE COMPOSITION	36.%	18.%	1.%	36.%	3.%	6.%
EXCESS LENGTH(METRES)	0.0	0.5	2.5	4.5	6.0	12.0

MINIMUM HEADWAY 0.5 SEC PLUS VEHICLE LENGTH COMPONENT
AVERAGE HEADWAY RESTRAINED GROUP 2.0 SEC
AVERAGE HEADWAY UNRESTRAINED GROUP 21.6 SEC
PERCENTAGE OF VEHICLES IN RESTRAINED GROUP 23.
TIME INCREMENT 1.0 SEC
NO. IN SAMPLE 43 VEHICLES

SECTION LENGTH 1.8 KMS
CLIMBING LANE START 0.0 KMS END 0.0 KMS
RELATIVE SHIFT OF FREE SPEED TABLES 1.0 KMS
NO STOP SIGN IN LANE

HEADWAY DISTRIBUTION AT 0.0 KMS

```
6-----------------------------------------------2---------------4----4--------4------1----------
1---2--------------------------5--------------------------1--------2--4---1---------------------
--------------------------------------------1---1---------------------------------2----1--------
-----------------------------------4---1------------------------------------2-------------------
2--------------------------------------4----------------4-------6-----------------2-------------
------------1-----2---4----------------1------------------2-2--4-----------------------4--------
--------------------------------------------4-----------------------------------------1---------
------------4----------------------1--------4------------------2-1-2------2-------4
```

VEHICLE ORDER ON GRID AT 0.0 KMS

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51																	

PRIMARY LANE

SUMMARY OF HEADWAY DISTRIBUTION

HEADWAY (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
0	0	0	0	0	0	1	1
1	1	2	0	0	0	0	3
2	0	0	0	2	0	0	2
3	2	1	0	1	0	0	4
4	2	0	0	1	0	0	3
6	0	1	0	0	0	0	1
7	1	1	0	0	0	0	2
8	0	1	0	1	0	0	2
9	0	0	0	0	0	1	1
10	0	0	0	1	0	0	1
12	1	0	0	1	0	0	2
17	0	1	0	0	0	0	1
21	1	0	0	1	0	0	2
26	0	0	0	1	0	0	1
27	0	1	0	0	0	0	1
28	0	1	0	1	0	0	2
31	0	1	0	0	0	0	1
32	1	0	0	0	0	0	1
33	1	0	0	0	0	0	1
34	0	0	0	0	0	1	1
37	0	0	0	1	0	0	1
46	0	1	0	0	0	0	1
47	1	0	0	0	0	0	1
49	0	0	0	1	0	0	1
56	0	0	0	1	0	0	1
59	1	0	0	0	0	0	1
61	0	1	0	0	0	0	1
70	0	1	0	0	0	0	1
71	0	0	0	1	0	0	1
94	1	0	0	0	0	0	1
TOTALS 998	13	13	0	14	0	3	43

AVERAGE HEADWAY TIME 23.76
STANDARD DEVIATION 23.53

VEHICLES IN PASSING MODE AT 0.00 KMS

21

STATISTICAL ANALYSIS OF TRAVEL TIME AND FUEL CONSUMPTION FOR THE VEHICLE CLASSES FROM THE BEGINNING OF THE SECTION TO THE SAMPLING STATION - km 0.5 OF THE PRIMARY LANE

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT

STATISTIGAL ANALYSIS

ANALYSIS FROM START OF SECTION TO 0.50 KMS
PRIMARY LANE

VEHICLE CLASS	-1-	-2-	-3-	-4-	-5-	-6-	ALL CLASSES
VEHICLES IN EACH CLASS	13	13	0	14	0	3	43
TRAVEL TIME (SECS)							
RANGE MIN.	20.54	21.57	0.0	25.63	0.0	33.76	0.0
MAX.	33.52	34.31	0.0	44.74	0.0	36.04	44.74
MEAN	24.78	25.91	0.0	35.44	0.0	35.15	29.31
STD DEVIATION	3.39	3.73	0.0	5.58	0.0	1.00	6.49
COEFF OF VARIATION	13.7	14.4	0.0	15.7	0.0	2.8	22.2
FUEL CONSUMPTION (LITRES)							
RANGE MIN.	0.034	0.055	0.0	0.282	0.0	0.876	0.0
MAX.	0.045	0.086	0.0	0.910	0.0	0.947	0.947
MEAN	0.039	0.071	0.0	0.450	0.0	0.905	0.243
STD DEVIATION	0.003	0.009	0.0	0.162	0.0	0.031	0.273
COEFF OF VARIATION	8.0	13.0	0.0	35.9	0.0	3.4	****

SIMULATION TIME FROM 111.0 SECS TO 1202.0 SECS

HEADWAY DISTRIBUTION AND VEHICLE ORDER IN THE PRIMARY LANE AT THE SAMPLING STATION - km 0.5 OF THE HIGHWAY SECTION

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT
SIMULATION OF FLOW OF TRAFFIC

PRIMARY LANE

```
TRAFFIC VOLUME   200 VEHICLES PER HOUR                                    SECTION LENGTH  1.8 KMS
VEHICLE CLASS           1       2       3       4       5       6         CLIMBING LANE   START  0.0 KMS   END  0.0 KMS
VEHICLE COMPOSITION  36.%    18.%     1.%    36.%     3.%     6.%         RELATIVE SHIFT OF FREE SPEED TABLES  1.0 KMS
EXCESS LENGTH(METRES) 0.0     0.5     2.5     4.5     6.0    12.0         NO STOP SIGN IN LANE
MINIMUM HEADWAY 0.5 SEC PLUS VEHICLE LENGTH COMPONENT
AVERAGE HEADWAY RESTRAINED GROUP 2.0 SEC
AVERAGE HEADWAY UNRESTRAINED GROUP 21.6 SEC
PERCENTAGE OF VEHICLES IN RESTRAINED GROUP 23.
TIME INCREMENT 1.0 SEC
NO. IN SAMPLE   42 VEHICLES
```

HEADWAY DISTRIBUTION AT 0.50 KMS

```
6---------------------------------------------------2-----------------------4-------4--------------1---4------1----2-----
---------------------------------6-------------------------------1--------2------1-----------------4---------------------
--------------------------------------------------1-------1---------------------------------------2-1--------------------
--------------------------------------------4-----------------------------------------------2----------------2-----------
---------------------------------------4------------------------------4--------6-----------------2-----------------------
---1------2----------4-------------1--------------------------2-2--------4---------------------------------------------4-
--------------------------------------------------------4------------------------------------------1---------------------
------------------4---------------1-----------------4--------------------------1---2--2-2----------------------4
```

VEHICLE ORDER ON GRID AT 0.50 KMS

9	10	11	12	14	13	15	16	17	18	19	21	20	22	23	24	25	26	28	29
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	48	50	47
49	51																		

PRIMARY LANE

SUMMARY OF HEADWAY DISTRIBUTION

HEADWAY (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
0	0	0	0	0	0	1	1
1	1	2	0	0	0	0	3
2	0	1	0	0	0	0	1
3	0	1	0	0	0	0	1
4	0	0	0	1	0	0	1
5	0	1	0	0	0	0	1
6	1	0	0	0	0	0	1
7	2	1	0	0	0	0	3
8	0	0	0	1	0	0	1
9	0	1	0	1	0	1	3
11	0	0	0	1	0	0	1
14	1	0	0	0	0	0	1
15	1	0	0	0	0	0	1
17	1	1	0	0	0	0	2
18	0	1	0	1	0	0	2
19	0	0	0	1	0	0	1
25	0	0	0	2	0	0	2
28	1	0	0	0	0	0	1
29	1	1	0	0	0	0	2
34	1	C	0	1	0	0	2
41	0	0	0	0	0	1	1
42	0	0	0	1	0	0	1
43	0	1	0	0	0	0	1
46	1	0	0	0	0	0	1
49	0	0	0	1	0	0	1
52	0	1	0	0	0	0	1
54	0	0	0	1	0	0	1
56	0	1	0	0	0	0	1
62	0	0	0	1	0	0	1
70	0	0	0	1	0	0	1
78	1	0	0	0	0	0	1
TOTALS 1005	12	13	0	14	0	3	42

AVERAGE HEADWAY TIME 24.51
STANDARD DEVIATION 20.90

VEHICLES IN PASSING MODE AT 0.50 KMS

27

NUMBER OF SINGLE AND MULTIPLE PASSES

-1-	-2-	-3-	-4-	-5-	-6-
3	1	0	0	0	0

SUMMARY DESCRIPTION OF THE SAFETY MARGINS IN OVERTAKING IN THE PRIMARY LANE OF THE HIGHWAY SECTION

PRIMARY LANE

SUMMARY OF SAFETY MARGIN IN OVERTAKING

SAFETY MARGIN (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
0	1	0	0	0	0	0	1
2	1	0	0	0	0	0	1
9	1	0	0	0	0	0	1
TOTALS 11	3	0	0	0	0	0	3

AVERAGE SAFETY MARGIN 3.67
STANDARD DEVIATION 4.73

HEADWAY DISTRIBUTION AND VEHICLE ORDER AT THE BEGINNING OF THE OPPOSITE LANE OF THE HIGHWAY SECTION

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT
SIMULATION OF FLOW OF TRAFFIC

OPPOSING LANE

```
TRAFFIC VOLUME   245 VEHICLES PER HOUR                                SECTION LENGTH  1.8 KMS
VEHICLE CLASS            1       2       3       4       5       6    CLIMBING LANE   START  0.0 KMS   END  0.0 KMS
VEHICLE COMPOSITION  36.%     18.%     1.%    36.%     3.%     6.%    RELATIVE SHIFT OF FREE SPEED TABLES  1.0 KMS
EXCESS LENGTH(METRES) 0.0      0.5     2.5     4.5     6.0    12.0    NO STOP SIGN IN LANE
MINIMUM HEADWAY 0.5 SEC PLUS VEHICLE LENGTH COMPONENT
AVERAGE HEADWAY RESTRAINED GROUP 2.0 SEC
AVERAGE HEADWAY UNRESTRAINED GROUP 21.0 SEC
PERCENTAGE OF VEHICLES IN RESTRAINED GROUP 28.
TIME INCREMENT 1.0 SEC
NO. IN SAMPLE   57 VEHICLES
```

HEADWAY DISTRIBUTION AT 0.0 KMS

```
2---2------------------------2-5---4----5---4----------6-----------2----------------------------1----6----------------4----4--
------------------------------------4--4---5-------------2--5-------------------------------------4------------------------------
--4--------------------------------------------4------4--6--------------------1-------1-------4-------------2-----------4--------------
------1---4---------4---1--4------------1-1------2-----2------2---4-------4---1---------1--------------2----4----------------------------
---1-----------------1----4---6-------------------------4----------------------1---2--2----1--6----4-----------------------4--------
------------------------4
```

VEHICLE ORDER ON GRID AT 0.0 KMS

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69			

OPPOSING LANE

SUMMARY OF HEADWAY DISTRIBUTION

HEADWAY (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
0	0	1	0	0	0	0	1
1	1	0	0	0	1	0	2
2	0	1	0	2	1	2	6
3	2	2	0	5	1	1	11
4	1	1	0	3	1	1	7
5	0	2	0	1	0	0	3
7	1	0	0	2	0	0	3
8	0	0	0	1	0	0	1
9	1	0	0	0	0	0	1
10	1	0	0	1	0	0	2
11	0	0	0	0	0	1	1
12	0	1	0	0	0	0	1
13	0	1	0	0	0	0	1
14	0	2	0	0	0	0	2
15	1	0	0	0	0	0	1
16	0	0	0	1	0	0	1
19	1	0	0	0	0	0	1
20	1	0	0	0	0	0	1
23	1	1	0	0	0	0	2
25	0	0	0	2	0	0	2
31	0	0	0	2	0	0	2
32	1	0	0	0	0	0	1
34	1	0	0	0	0	0	1
37	0	0	0	1	0	0	1
42	0	0	0	1	0	0	1
43	0	0	0	1	0	0	1
TOTALS 628	13	12	0	23	4	5	57

AVERAGE HEADWAY TIME 11.21
STANDARD DEVIATION 11.46

VEHICLES IN PASSING MODE AT 0.00 KMS

35

STATISTICAL ANALYSIS OF THE TRAVEL TIME AND FUEL CONSUMPTION FOR THE VEHICLE CLASSES, FROM THE BEGINNING OF THE SECTION TO THE SAMPLING STATION - km 0.5 F THE OPPOSITE LANE

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT

STATISTICAL ANALYSIS

ANALYSIS FROM START OF SECTION TO 0.50 KMS
OPPOSING LANE

VEHICLE CLASS	-1-	-2-	-3-	-4-	-5-	-6-	ALL CLASSES
VEHICLES IN EACH CLASS	13	12	0	23	4	5	57
TRAVEL TIME (SECS)							
RANGE MIN.	23.55	26.80	0.0	26.06	28.84	25.03	0.0
MAX.	41.05	36.04	0.0	44.25	37.40	41.18	44.25
MEAN	28.03	30.71	0.0	36.31	33.56	33.34	32.79
STD DEVIATION	4.19	3.11	0.0	5.14	3.06	5.86	5.61
COEFF OF VARIATION	14.9	10.1	0.0	14.2	9.1	17.6	17.1
FUEL CONSUMPTION (LITRES)							
RANGE MIN.	0.025	0.031	0.0	0.132	0.078	0.328	0.0
MAX.	0.030	0.047	0.0	0.246	0.087	0.426	0.426
MEAN	0.027	0.042	0.0	0.159	0.082	0.372	0.117
STD DEVIATION	0.001	0.004	0.0	0.031	0.004	0.041	0.100
COEFF OF VARIATION	4.8	9.3	0.0	19.7	4.6	11.0	85.5

SIMULATION TIME FROM 112.0 SECS TO 1202.0 SECS

HEADWAY DISTRIBUTION AND VEHICLE ORDER IN THE OPPOSITE LANE AT THE SAMPLING STATION - km 0.5 OF THE HIGHWAY SECTION

EMPRESA BRASILEIRA DE PLANEJAMENTO DE TRANSPORTES - GEIPOT
SIMULATION OF FLOW OF TRAFFIC

OPPOSING LANE

TRAFFIC VOLUME 245 VEHICLES PER HOUR
VEHICLE CLASS 1 2 3 4 5 6
VEHICLE COMPOSITION 36.% 18.% 1.% 36.% 3.% 6.%
EXCESS LENGTH(METRES) 0.0 0.5 2.5 4.5 6.0 12.0
MINIMUM HEADWAY 0.5 SEC PLUS VEHICLE LENGTH COMPONENT
AVERAGE HEADWAY RESTRAINED GROUP 2.0 SEC
AVERAGE HEADWAY UNRESTRAINED GROUP 21.0 SEC
PERCENTAGE OF VEHICLES IN RESTRAINED GROUP 28.
TIME INCREMENT 1.0 SEC
NO. IN SAMPLE 76 VEHICLES

SECTION LENGTH 1.8 KMS
CLIMBING LANE START 0.0 KMS END 0.0 KMS
RELATIVE SHIFT OF FREE SPEED TABLES 1.0 KMS
NO STOP SIGN IN LANE

HEADWAY DISTRIBUTION AT 0.50 KMS

```
2--2------------------2---------5-4-5----------------4-----------6-------2---------------------------1-----------6-----------------4-
-----4------------------4-----------------5----4---2-----------5------------------------------------------4------------------------
---------4------------------------------------6-----------4-----------4----------1------1---------------4-----------2---------------4-----
1-----------4-----1----------4---4----1-1-----2-----------2-2---------4----4----------1-----1-----------2------------------4-----------------
1--------------------1---------4----------6-----------------------------------4-----------1---2--1---2--6--4---------------------------------
---------4-----------------------4-------------------------------------------------------------------1-----------4----4-------------------------
------------------------------------------------------------------------------------------------------6---------------------------2----4-----
----------2--------1-----------------------------------------2----4----4-4--------------------------1-4-2----------2-------------------4---4--
-------------------------------------------------------------1
```

VEHICLE ORDER ON GRID AT 0.50 KMS

13	14	15	16	17	18	19	20	21	22	23	24	25	26	28	27	29	30	31	32
35	33	34	36	37	38	39	40	41	42	44	43	45	46	47	48	49	50	51	52
54	53	55	56	57	58	59	60	61	62	64	65	63	66	67	68	69	71	70	72
73	74	75	77	76	78	79	80	81	82	83	84	85	86	87	88				

SUMMARY OF HEADWAY DISTRIBUTION

OPPOSING LANE

HEADWAY (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
0	0	1	0	0	0	0	1
1	1	2	0	3	1	0	7
2	1	1	0	2	0	1	5
3	0	3	0	3	0	0	6
4	2	0	0	4	0	0	6
5	2	1	0	0	0	0	3
6	1	0	0	0	0	0	1
7	1	1	0	3	0	0	5
8	1	0	0	1	1	0	3
9	1	2	0	2	0	1	6
10	1	1	0	1	0	1	4
11	0	1	0	1	1	0	3
12	0	0	0	0	0	1	1
13	0	0	0	0	1	0	1
14	0	0	0	1	0	0	1
15	0	1	0	0	0	0	1
17	1	0	0	3	0	0	4
18	1	1	0	2	0	0	4
22	0	0	0	1	0	0	1
23	1	0	0	1	0	0	2
25	1	1	0	0	0	0	2
31	0	0	0	1	0	0	1
35	0	0	0	1	0	0	1
36	0	0	0	0	0	1	1
39	0	1	0	0	0	0	1
40	0	0	0	1	0	0	1
43	0	0	0	1	0	0	1
57	1	0	0	0	0	0	1
58	1	0	0	0	0	0	1
120	0	0	0	0	0	1	1
TOTALS 1037	17	17	0	32	4	6	76

AVERAGE HEADWAY TIME 13.83
STANDARD DEVIATION 17.66

VEHICLES IN PASSING MODE AT 0.50 KMS

0

NUMBER OF SINGLE AND MULTIPLE PASSES

-1-	-2-	-3-	-4-	-5-	-6-
10	0	0	0	0	0

SUMMARY DESCRIPTION OF THE SAFETY MARGINS IN OVERTAKING IN THE OPPOSITE LANE OF THE HIGHWAY SECTION

OPPOSING LANE

SUMMARY OF SAFETY MARGIN IN OVERTAKING

SAFETY MARGIN (SECONDS)	NUMBER OF VEHICLES CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	ALL VEHICLES
-21	0	0	0	0	0	1	1
0	0	1	0	0	0	0	1
3	1	0	0	0	0	0	1
5	0	0	0	0	0	1	1
10	1	1	0	0	0	0	2
11	0	0	0	0	1	0	1
17	1	0	0	0	0	0	1
22	1	0	0	0	0	0	1
TOTALS 57	4	2	0	0	1	2	9

AVERAGE SAFETY MARGIN 6.33
STANDARD DEVIATION 12.29

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