CHAPTER 4 - ROAD USER COSTS AND TRAFFIC EXPERIMENTS

INTRODUCTION

Time and fuel savings are two of the more important benefits that accrue to users through road improvements. Time savings result when road improvements reduce travel distance and speed changes.

Many factors affect the speed adopted by a driver when traveling on the road. The more obvious and important ones are 1) the capacities of the vehicle and driver; 2) the geometric characteristics of the roadway; 3) surface type and roughness; 4) traffic and 5) climatic conditions.

These factors alone, or in combination, cause vehicles to accelerate or decelerate to or from a desired cruising speed causing in turn variations in the rate of fuel consumption.

The objective of the road user costs and traffic experiments is to develop parameters to be used in a computer based user costs simulation model for estimating the speed (time) and fuel consumption and hence costs for each vehicle class traversing any section of the road network.

THE SPEED/FUEL CONSUMPTION MODEL

It is assumed that details of the vertical and horizontal alignment will be available as input to the model. With this information it is proposed to develop time and fuel consumption profiles by use of the model for each vehicle type by working through matrices of the form shown in Table 9.

For each vehicle type four matrices consisting of acceleration and deceleration on positive and negative grades would be used for each road segment for each of wet and dry conditions. A road segment would be defined as being homogeneous if there was no significant variation in surface type, grade, width, roughness, etc., within its length. Because of the

TABLE 9 - TYPICAL SPEED/FUEL CONSUMPTION FOR DECELERATION ON POSITIVE GRADES

GRADE % / LENGTH	2			3			4			------- N GRADE		
KM	SPEED *	TIME SECS *	FUEL *									
00	75	-	-	75	00		75	00		75	00	
0.1	72	4.9	.016	71			70			68		
0.2	69	10.0	.022									
0.3	66	15.4	.037									
0.4	63	21.0	.051									
0.5	60	26.9	.065									
0.6	56	33.1	.079									
0.7	53	39.8	.092									
0.8	50	47.0	.105									
0.9	48	54.5	.118									
1.0	46	62.3	.131									
1.1	45	70.3	.144									
1.2	44	78.5	.156									
Distance at which steady state speed occurs	34											

* SPEED = the spot speed at the distance shown (km/hour)
TIME = the time taken to travel the distance shown (secs.)
FUEL = the fuel consumption over the distance shown (litres)

sporadic distribution and variation in the design (or safe) speed of horizontal curves, it is proposed to isolate this factor from the speed/fuel matrices. A separate highway speed profile will be developed for the horizontal alignment and this in turn will be used by the model to constrain speeds in the speed matrices for each road section.

To construct these matrices, curves of the forms shown in Figure 15 will need to be developed empirically.

It is proposed to develop the speed/length curves for free speed conditions for each vehicle type operating on any type section of the road network under both wet and dry conditions. To ensure that the speeds measured represent the free speed desired by the driver under the particular set of road conditions and climate only the speeds of isolated vehicles or those leading a platoon of vehicles will be measured.

The hourly traffic volume on any road segment may vary considerably for the 8,760 hours in a year and in general, as the volume varies so does the actual operating speed of the vehicles so that free flow conditions may not exist throughout all hours of the year.

It will therefore be necessary to establish the volume of traffic at which free flow conditions no longer exist and to incorporate a sub-routine within the model which will estimate the reduction in speed of each vehicle class for traffic volumes where free flow conditions do not exist.

In the model the hourly distribution will be specified by a histogram in terms of the number of hours during which traffic volume is, say, in the range of 0-5 per cent of Annual Average Daily Traffic (AADT) 5-10 per cent AADT, 10-15 per cent etc. as shown in a smoothed form in Figure 16. Vehicle speeds, time and fuel consumption and their corresponding costs can then be calculated for each bar of the histogram. The annual costs would thus be obtained by summing over all bars of the complete histogram. Provision would need to be made for different histograms to be specified where different seasonal variations of traffic flow occur.

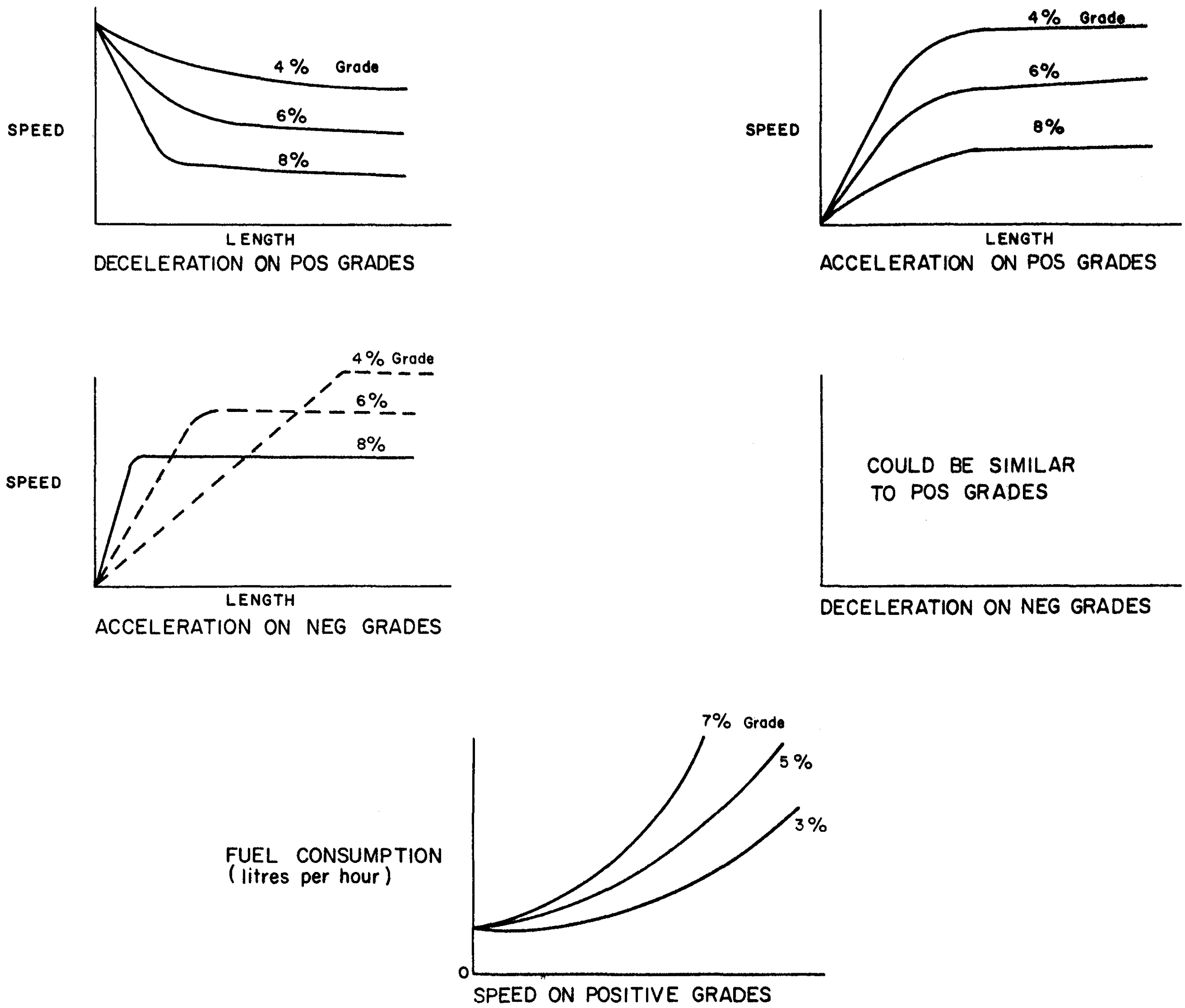

Figure 15 - Speed/length and fuel/speed curves

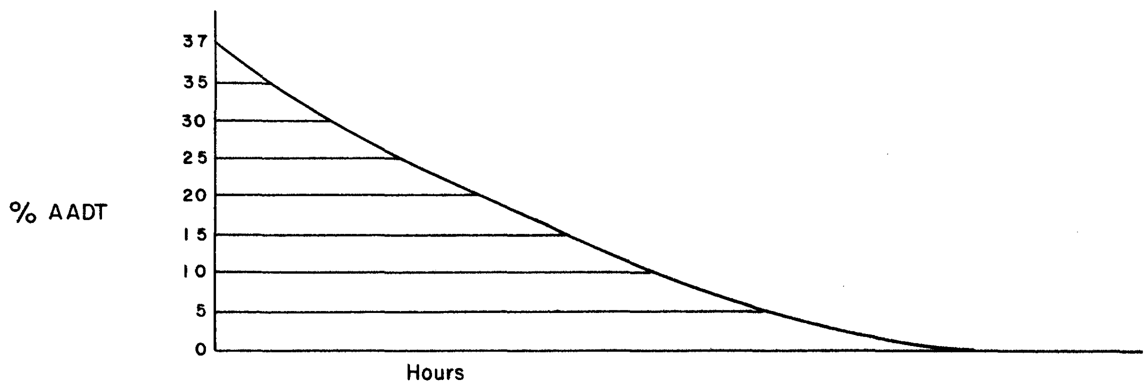

Figure 16 - Traffic Histogram

THE EXPERIMENTAL DESIGN

As matrices and hence curves of the type shown in Figure 15 will be required for all road geometric and climatic conditions for each vehicle type, the experimental design should include all possible road and climatic parameters.

The following parameters have been identified for possible inclusion in the experiment:

a) Road Geometry
   - horizontal curvature (average highway speed)
   - vertical alignment (grades)
   - roadway width
b) Surface Type
   - asphaltic concrete (AC)
   - double surface treatment (DST)
   - gravel surface
   - earth surface
c) Surface Condition
   - roughness
   - rut depth
   - looseness (gravel and earth only)
   - moisture content (gravel and earth only)
d) Rainfall
e) Altitude

The results of work in Kenya (Ref. 19) show that speeds are significantly reduced on roads narrower than 5.0 meters. Extensive enquiries with officers of DNER and DER in a number of states indicate that all constructed rural roads in Brazil have a minimum pavement width of about 6.0 meters and a formation or crown width of about 10 meters for unpaved roads. The width parameter has therefore been omitted from the experimental design.

The physical properties of the materials forming the surface of earth roads vary considerably within each kilometer and preclude them from use in the experimental design. However, three different types of gravel roads will be included to investigate significant variations in speed caused by the properties of the surface material.

Ideally each of the remaining factors should be considered at three levels in the experimental design as set out below in Table 10. This would require a minimum of 243 test sections without any repeat sections. Observation would be required at three different times on the gravel sections to cover the range of roughness and three times on all sections to obtain measurements at the three-levels of climatic environment.

Preliminary investigations in Brazil make it apparent that test sections conforming to all these conditions can not be located. Technical resources also dictate that the scale of this portion of the study needs to be reduced to a more manageable proportion.

Project Location

In order to achieve this objective it is planned to conduct the major portion of the study in the geographical area around Brasília and extending into the States of Goiás and Minas Gerais. However, to include all of Brazil within the inference space, satellite studies will be undertaken in other geographical areas of Brazil.

The sampling frame selected for the main study is shown in Figure 17.

The number of test sections required for this frame is as follows:

27 Double Surface Treated
27 Asphalt Concrete
9 Gravel (Laterite)*
10 Repeat Sections
73 Total

A search of the plans and profiles of federal and state roads in D.F. and portion of Goiás indicates that most or all

* The same laterite gravel sections will be tested at three different levels of roughness.

HORZ. CURV.	VERT. PROFILE	SURFACE TYPE: DOUBLE SURF. TREATMENT			ASPHALT CONCRETE			GRAVEL (LATERITIC)		
	ROUGHNESS	1	2	3	1	2	3	1	2	3
50-70	0-2									
	3-4									
	5-9									
80-90	0-2									
	3-4									
	5-9									
100+	0-2									
	3-4									
	5-9									

Figure 17 - The Sampling Frame for Main Study

TABLE 10 FACTORS AND LEVELS FOR THE IDEAL EXPERIMENTAL DESIGN

FACTORS		LEVELS	
Horizontal curvature (average highway speed)	40-70 km/hr	80-90 km/hr	>100 km/hr
Vertical Alignment (percent grade)	0-2%	3-5%	6% - 10%
Surface Type	Asphaltic Concrete	Double Surface Treatment	Gravel 1 Gravel 2 Gravel 3
Surface Condition	Smooth	Inter.	Rough.
Climatic Condition	Dry	Light Rain	Heavy Rain
Altitude	0-200m	300-500m	700m

Note: The actual sampling frame proposed is shown in Figure 17 of this sampling frame can be filled. However, the low volumes of traffic on the gravel roads may necessitate locating further gravel sections in the more populated areas in the south of Brazil for observation of existing vehicle speeds.

Wet vs. Dry Conditions

The sporadic distribution and relatively short duration of rain storms in Brazil will also preclude observations of speed being made on all test sections under wet conditions. However, it is intended to study dry versus wet conditions on at least a small number of sections.

Two experimental approaches will be considered. The first is a controlled design where the factor levels are narrowly specified. This is the ideal approach but may be too restrictive because of the difficulty of estimating when it will be raining on the sections. The second approach is less restrictive since the selection of sections is not controlled. Instead data will be collected for wet conditions on as many sections as possible.

A reduced experiment to test wet vs. dry conditions using the first approach would use the following factors and levels.

Factors	Levels		
Surface Type	AC	DST	Gravel (Lat.)
Roughness	Smooth		Rough
Vert. Profile (Grade)	0-2		5-9
Horiz. Curv. (AHS)	<70		>100

To obtain two roughness levels for gravel the same sections will be tested at different times. Therefore, the total number of wet test sections needed is 20.

The sampling frame for this experiment is shown in Figure 18.

The sampling frame proposed for the second approach where the sections are not controlled is shown in Figure 19.

SURF. TYPE		GRAVEL			A.C		D.S.T	
ROUGHNESS		1		2	1	2	1	2
HORZ. CURV.	VERT. PROFILE	WET	DRY					
>100	5+							
	0-2							
<70	5+							
	0-2							

Figure 18 - Sampling Frame for Testing Wet vs Dry Specified Sections

	WET			DRY		
SECTIONS	LENGTH			LENGTH		
	2	3	4	2	3	4
1						
2						
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n *						

Figure 19 - Sampling Frame for Testing Wet vs Dry Conditions Unspecified Sections

Satellite Study for Gravel Roads

In the main experiment the free speed measurements have been restricted to study only one type of gravel, laterite . This has been done since the areas of District Federal and Goias have gravel roads predominantly constructed with late - ritic materials. However, there is a possibility that other gravel types with the same roughness as lateritic will have different effects on free speed. Therefore, the following ex periments are proposed for dry conditions only.

The sampling frame proposed is as shown in Figure 20.

DEVELOPMENT OF FREE SPEED PREDICTION CURVES

Steady State Speeds on Positive Grades

Test sections approximately one kilometer long with a transition section of 500 meters at each end of similar cha - racteristics to the test section itself are proposed for use in the development of those portions of the speed/length curves (Figure 15)within the range of speeds recorded for each vehicle type as illustrated in Figure 21.

It is considered that for positive grades most vehicle types will reach a steady state or crawl speed within the latter portion of the test sections for all grades. Speed observations will be made at three stations, entry, exit and mid-point of the test sections by use of radar speed detection meters, (spot speed). In addition space mean speeds will be calculated from the differences in times recorded at each of the three observation points.

In the event that steady state speed has not reached at the exit of the test section, i.e., the difference in speed at the mid-point is say 5 km greater than the exit speed , then the test section for the positive grade will be moved 500 meters uphill by incorporating the departure transition in the test section.

		REGIONS		
		BRASÍLIA	PARANÁ	MINAS
ROUGHNESS	3	FROM		
	2	MAIN		
	1	STUDY		

3 REPEATED SECTIONS

Figure 20 - Sampling Frame for Satellite Study for Gravel Roads

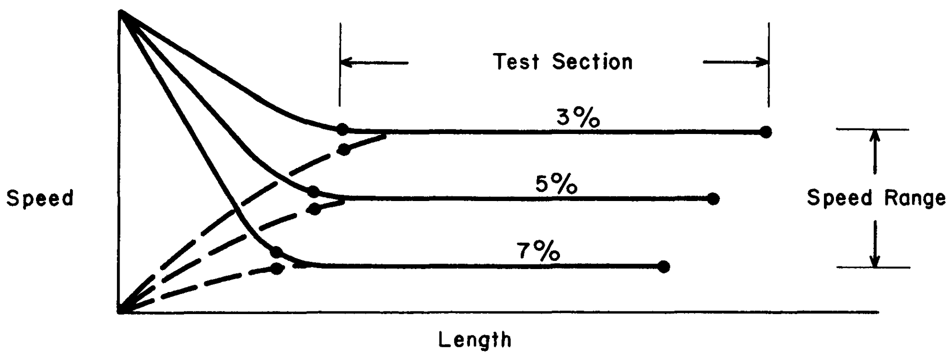

Figure 21 - Typical Speed Length Curves for Positive Grades

Development of the Steady State Speed Prediction Curves

Depending on the magnitude and sign of the grade preceeding the transition zone of the test section vehicles may be in a deceleration or acceleration phase at entry to the test section. Limited spot speed observations to date verify that some vehicle classes are still in a deceleration phase 500 meters above the base of certain grades.

The factorial matrix (Figure 17) will be used for the analysis of steady state speeds. The dependent variables to be investigated in this experiment are 1) spot speeds at each of three stations, 2) space mean speeds between the stations, and 3) the overall space mean speed.

In order to predict the steady state speeds for any vehicle class for the various road characteristics analysis of variance procedures will be used. The dependent variable, spot speed, which is measured at three stations on the test section, start, midpoint and exit will be analyzed by methods described in Appendix 4.1. It will be possible through this analysis to not only predict steady state speeds but also to verify if each of the vehicle classes is on a deceleration of acceleration phase or at its steady state speed.

The factor 'station' has to be analyzed very carefully. Two possible situations can occur. First if 'station' is a non-significant effect then the mean spot speeds are equal at the three stations, that is, the vehicle has maintained steady state speed throughout the test section. The overall mean spot for each vehicle class at these three stations will then be used as the dependent variable in regression analysis. Secondly, if 'station' is a significant effect then the mean spot speeds at each station are not all equal. If this is the case then the mean spot speeds at each station will be analyzed.

The difference will have to occur between the first station and the other two stations since the method of measuring requires steady state speed be maintained over the last subsection. Therefore the average spot speed of the last two stations will be used for the prediction equations. Also, if the first spot speed is less than the second two then the vehicle is on an acceleration phase, and if greater then the vehicle is on a deceleration phase. The estimate for steady state speed developed here can then be checked against the estimates obtained from space mean speeds. If the vehicle is on a deceleration phase the first space mean speed estimate will be greater than the second estimate and if the vehicle is on an acceleration phase the opposite will be true.

Deceleration on Positive Grades

For the development of the remainder of the speed/length curves for deceleration it is proposed to measure spot speeds at 150-200 meter intervals commencing at the start of the transition zone and extending within the test section to the point where steady state speed is reached for all vehicle classes. However, limited observations have shown that it may not be possible to locate all test sections of a length of two kilometers that will permit vehicles to attain maximum free speed at the entry to the transition zone, as some sections are preceeded by positive grades of a different magnitude or have restricted horizontal geometry.

It will, therefore, be necessary to locate for these experiments additional sections of shorter length which are preceded by negative grades and by horizontal geometry permitting high speeds.

The analysis procedure for the development of the speed/length prediction equations for the deceleration phase on positive grades will be as set out in Appendix 4.1. The analysis of variance table there depicts the factors involved, the only difference being that the levels of the factor 'station' will be actual length measurements.

The dependent variable will be spot speed while the analysis of variance procedures will identify the significant independent variables. Various covariates, the levels of which cannot be controlled will also be included in the analysis of variance. Regression analysis will then be used to develop the prediction equations for speed. Since the steady state speed is known from the previous experiment for any road condition it will be possible to identify the actual distance the vehicle travels on the grade before reaching steady state speed. From these two experiments it will then be possible to develop the entire speed curve for deceleration on positive grades.

Free Speeds in Other Geographical Areas

In addition to the above experiments it is proposed to measure free speeds on level smooth paved roads throughout Brazil to determine whether trip length or purpose affects speed. If there is a significant variation in free speeds at different locations, adjustment will need to be made to the maximum speeds at zero length on the deceleration curves for the various geographical areas. The sampling frame for this experimental design is shown in Figure 22 and the analysis is similar to the one presented in Appendix 1. Since all the vehicle classes are measured at each location this design is also called a split plot design (Ref. 20). The location within each geographical region form the whole plot treatments. The vehicle classes then form the split plot. Since locations within geographical regions are considered chosen at random from an infinite population of locations, the variance estimate for locations will test differences across geographical regions. The interaction of locations by vehicle class will test vehicle classes in the analysis of variance.

Acceleration on Positive Grades

For the development of the remainder of the curves for the acceleration phase two courses of action are open;

a) Stop a sample of vehicles of all classes at the start of the transition zone on all test sections and measure spot speeds in a manner similar to the deceleration measurements, or

GEOGRAPHIC AREA	1			2			3			4		
LOCATIONS	1	2	3	4	5	6	7	8	9	10	11	12
VEH CLASS												
1												
2												

Figure 22 - Sampling Frame for Free Speeds in Different Geographical Areas

VEHICLE TYPES	1				2				3		4		5		6		7	
VEIHICLES WITHIN TYPES	1		2		3		4		5		6		7		8		9	
LOAD	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
ROAD CHARACTERISTICS 1																		
2																		
3																		
4																		
27																		

Figure 23 - Design Matrix for Acceleration on Positive Grades

b) Use the Project test vehicles from a dead stop at the beginning of the transition.

Ideally, the first approach should be used because the prediction equations developed from the analysis will be used to simulate actual road vehicles. However, the logistic problems associated with stopping a large number of vehicles on some of the test sections may preclude this approach. Therefore, the test vehicles will be used for the development of these curves. The procedure to be used for the field measurements is described on page 102. Also as a check a few private vehicles will also be stopped for comparison.

For the main acceleration experimental design the following factors will be investigated:

Vehicle Characteristics	Vehicle Types Vehicles within Types Loads
Road Characteristics	Surface Types Roughness Vertical Profile Horizontal Curvature Stations

The levels of the factors are the same as those presented in Appendix 4.2 except that the stations will be identified by the actual distance along the test section. The analysis of variance matrix is shown in Figure 23.

The dependent variable to be analyzed is the space mean speed for each vehicle at the several stations along the grade. The actual analysis of variance procedure follows the methodology set out in Appendix 4.2 except that some of the factors are eliminated. Once the analysis of variance procedure has identified the significant independent variables, regression analysis will be run to develop the prediction equations. It should be noted that although only a small fleet of vehicles is used, vehicles within types is considered a random effect so that the inferences can be taken across all vehicles of the types tested (refer to Appendix 4.2 for more complete explanation).

Development of the Speed/Length Prediction Curves for Negative Grades

A preliminary study has been conducted to test the hypothesis that the speed selected by drivers on negative grades depends on the length of the grade, its magnitude and the exit conditions e.g. when a negative grade is followed by a positive grade, drivers may take advantage of the later portion of the negative grade to develop maximum momentum, consistent with the prevailing road conditions, to assist in ascending the following positive grade.

At three sites situated at the base of grades ranging in magnitude from 4 to 7% and followed by level or positive grades, continuous observations were made of the speeds of vehicles descending the grade by using a radar speed meter operated in the manual mode. In the manual mode spot speeds are not locked in as in the automatic mode but instead speed changes are instantaneously shown on the readout display.

The observations clearly demonstrated that certain vehicles, particularly loaded trucks, do pass through an acceleration phase near the base of some negative grades. In some cases loaded trucks and semitrailers reached speeds in excess of 100 km/hr from speeds of approximately 70 km/hr in the last 700 meters of the negative grade.

Research carried out in Colombia (Ref. 21) showed that vehicles, particularly loaded trucks, adopt a steady state speed in descending long steep grades, of the same order as adopted for ascending a similar grade. It is therefore important that the simulation model be able to predict when to apply the acceleration phase on negative grades.

It is proposed to conduct a pilot study with the objective of determining the speed patterns on grades up to two kilometers in length. Spot speeds and space mean speeds will be taken at 500 meter intervals along the section. Only paved sections that provide encouraging conditions for acceleration will be used in the pilot study.

The sampling frame proposed for this experiment is shown in Figure 24.

The analysis proposed for this experiment is set out in Appendix 4.3. Based on the results of the pilot the main study design for acceleration and deceleration on negative grades will be developed.

CALIBRATION OF THE SIMULATION MODEL FOR PREDICTION OF FREE SPEEDS

It is essential that the results of simulation be compared with known real responses to the same inputs in order to verify that the modelling has been satisfactory. Validation is the process of evaluating the simulation model to determinate whether it satisfactorily predicts traffic behaviour.

It is proposed that calibration of the model will be carried out in two ways:

1) Speed observations will be made on relatively short (4-5 km) sections of roads in rolling terrain which can be monitored by observers along the route to record intermediate times and insure that free flow conditions exist throughout the section. The averages of space-mean speeds of each vehicle class will then be compared with the estimates derived from the model. It will be possible to get confidence on the free speed estimates for the whole section if the estimates for the short homogeneous subsections are added and the variances are assumed additive. If the observed average speeds for any of the vehicle classes over the whole route are outside the confidence band of the predicted equations of the model then the intermediate estimates must be investigated in detail and compared with the intermediate observed speeds. The homogeneous subsections, where the estimates are not in agreement with the observed data will then have to be retested so that the prediction equation can be developed more accurately.

		GRADE														
		1					2					3				
REPLICATES	1	STATION					STATION					STATION				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	2	STATION					STATION					STATION				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Figure 24 - Sampling Frame for Free Speeds on Negative Grades

2) Speed profiles will be obtained from tachographs fitted to users vehicles operating on fixed routes of say 50 km in length. The speed profiles from the tachographs will be compared with profiles developed by the model for the particular vehicle class at the extreme values of the confidence band established for each homogeneous subsection.

SPEED/CAPACITY RELATIONSHIPS

Reduction in speed below free speed is in most cases caused by either;

a) delays at junctions where a certain area of carriageway must be used alternatively by two crossing streams of vehicles; this can lead to queues of waiting vehicles. Variations between speeds of individual vehicles are of secondary importance.

or b) delays on rural roads where the variation in free speeds of various vehicle classes cause queues of vehicles to develop if overtaking is not always possible, either because of lack of overtaking sight distance or inadequate gaps in the opposing traffic stream in the case of single carriage roads.

As this Project is concerned primarily with rural roads the latter condition only will be investigated.

<u>Operating Speed Simulation Model</u>

Free speed profiles will be available for each homogeneous road section from the simulation process previously described. The problem then is to predict;

a) how will vehicles enter each homogeneous road section, that is, e.g. in what order and headway for each level of traffic flow, and

b) given this order, what vehicles will be restricted from travelling at free speed over what portion of the section and to what degree.

In order to obtain an intuitive feeling for how the traffic system is operating a simulation model will be constructed using as input;

a) the free speed profiles of each vehicle class
b) the visibility profile of the road section
c) flow rate and composition of traffic
d) the directional split of the traffic.

The simulated vehicles will be initially placed in a random array on both carriageways. The vehicles will then be processed through the section using the periodic-scan method while allowing other vehicles to enter the section randomly with headways exponentially distributed.

The model will be run until a sufficiently large sample of all vehicle classes has passed through the section. The average time (speed) of each vehicle class will then be calculated. A comparison of these average speeds with the free flow speeds will indicate the traffic flow at which free speeds no longer exist for the particular road characteristics of that section.

CALIBRATION OF THE OPERATING SPEED MODEL

Field Experiment

Since capacity conditions are seldom found on unsurfaced roads, test sections will be restricted to surfaced roads. One kilometer sections will be located with the following factors and levels:

FACTOR	LEVELS		
Grades	Flat	Inter	Steep
Overtaking sight distance	None		Full
* Traffic Flow	Free flow	Medium	Heavy

* If possible the same test sections can be used by sampling in off-peak through to peak conditions.

The total number of sections required is thus six. However, because of the necessity to provide an estimate of the error terms as outlined in Appendix 4.4 all sections will be duplicated.

Measurement will be taken of spot speeds at entry, midpoint and exit to the sections and space mean speeds will be determined from the differences in travel times recorded at the three observation points. In addition the traffic flow will be measured in the opposing lane using a recording counter.

Data Analysis

The following information will be obtained from these observations:

vehicle speed (spot and space mean)
headway
vehicle classification
estimate of load
traffic flow by unit time in both directions
number of overtaking manoeuvres within each subsection

These data will be analyzed using the procedures set out in Appendices 4.4 and 4.5 and the results compared with the estimates produced by the simulation model.

DEVELOPMENT OF FUEL CONSUMPTION MODELS

Selection of the Test Vehicles

Unlike free speeds where the vehicle population can, for the most part, be sampled to derive free speed prediction curves, fuel consumption curves have to be developed from measurements taken of fuel consumed by test vehicles operating over the test sections used for speed measurements. It is therefore important to select vehicles that are truly representative of the vehicle population.

To be representative the test vehicles selected should fulfill the following objectives:

1) The range of test vehicles must cover the full range of the vehicle population from the smallest car to the largest truck.
2) As both diesel and gasoline trucks are operating on the road system, the fuel consumption characteristics of these two types should be tested.
3) There should be a sufficient number of vehicles between the smallest and largest vehicle to permit reasonable interpolation between test vehicles to cover all vehicles.
4) The vehicles selected should be representative of the rural vehicle fleet for each particular class.
5) Because of the relatively large number of buses operating on the rural roads, a bus should be included in the test vehicle fleet.
6) At least one of the vehicles should be replicated to allow a random error component to be estimated.

The following vehicles have been selected to satisfy these objectives:

1) Small Car - In order to cover a full range of vehicles it has been proposed to select a small car. There have been trends in other countries towards smaller vehicles because of the economical benefits gained, due to the increasing price of fuel. According to the production figures for Brazil 1957/1973 (Ref. 22) the Volkswagen 1300 is the most produced passenger vehicle on the road. It also has the smallest engine of the popular models.

   In August 1975 40% of all passenger vehicles produced in Brazil were VW 1300's. This compares with a figure of 25% in the previous August (Ref. 23). These figures strengthen the feeling that the trend in passenger vehicles is toward the smaller car and that the VW 1300 leads the trend.

   The origin - destination survey conducted on 99 road sections in Goiás in 1972-1973 only covered cargo vehicles. Therefore, no figures are available for this class of vehicle. It should also be noted that the origin-destination sample taken simply counted vehicles, their age and their present km readings on the odometer. The survey did not produce actual vehicle miles of travel on rural roads. Since the VW 1300 comprises such a large percentage of the population and is operating on the rural road system it has been selected as representative of the small vehicle class.

2) Pickup or Utility Vehicle (2000 kg gross weight) - In order to fill the weight range between passenger vehicles and commercial trucks, a utility vehicle has been selected. This vehicle is used in rural areas mainly for farm-to-market transport by small producers.

The VW Kombi comprises 45% of the vehicles produced in this class from 1957-1973. This trend in production is continuing since the Kombi also represents 41% of the production in August 1974 and 45% in August 1975.

Of the actual users, there are fleets of Kombies operated by small companies in rural areas. It will be possible to collect data from these companies in the road user survey and hence correlate these data with the data collected from the test vehicle.

The origin-destination survey carried out in Minas Gerais and Goiâs did not count the Kombies on the road since they are not classified as open-bed cargo vehicles. The Chevrolet was the most representative vehicle of the light cargo class in this survey. However, as the weight range of vehicles in this class was very wide, it did include much heavier cargo vehicles than the VW Kombi. Therefore, when choosing a representative vehicle of this class the origin-destination figures are not directly applicable.

The VW Kombi has been selected as the utility vehicle for this class.

3) Light Truck (Gasoline vs. Diesel), (6,000 kg gross weight) - This is the smallest class of vehicles where both gasoline and diesel trucks are produced. If there is a significant economical saving in the use of diesel fuel vs. gasoline in this class, then a more substantial saving can be realized in the heavy class since their fuel consumption rate is higher. However, if gasoline vs. diesel were tested in a heavier weight class and one fuel type showed economic savings over the other, the results could not be generalized to a lighter vehicle class since the fuel consumption rate is less in the smaller class. For this reason, the light truck class is chosen for testing gasoline vs. diesel.

It is essential that the two vehicles be as identical as possible in all aspects other than the type of fuel used. The Ford F-350 (gas) leads production with 45% of all vehicles of this class (based on 1957-1973 production figures). The two other most popular models in this class are the F-400 (gas) and the F-4000 (diesel). These two vehicles have just been introduced to the market recently, so that comparative production figures are not available. However based on all specifications the F-400 and the F-4000 are most similar, differing only in fuel type and engine type and weight.

Based on these similarities and a probable increased popularity of the F-400 and F-4000 these two vehicles have been selected for the light truck class.

4) Medium Truck (11,000 kg gross weight) (Replicate Vehicles) - The production figures for 1957/75 show that the medium truck class Mercedes Benz comprises 85% of the vehicle fleet. The origin-destination survey shows that for 99 sites checked in Minas Gerais and Goiás the Mercedes Benz accounted for over

50% of the vehicles counted in the 11,000 kg average gross weight class. The medium class truck will allow the gap in weight class to be filled between the light truck (gross vehicle 6000 kg) and the heavy truck class (gross weight 40,000 kg). With the addition of a third axle the MBL-1113 will cover a weight range up to 18,500 kg when fully loaded. This vehicle, therefore offers a great deal of versatility to represent a large range of weights.

By replicating the medium class truck it will be possible to estimate the variation between two vehicles of the same type, for both speed and fuel consumption. This variation (called within error) will be estimated over all the road sections tested. The differences calculated will be due to the differences in the two vehicles themselves and will not be related to the road characteristics. This variation between vehicles of the same type will then be used to test the differences due to the various road characteristics. Dr. Anderson, the statistical consultant to the project agrees that the replication of at least one vehicle is necessary for these experiments. Since the variation between the two vehicles of the same type will be used to test all other effects, it is essential that the estimate be accurate. However, this estimate variation could be different if another vehicle, say the VW 1300, were replicated.

It is important, therefore, to have some check which insures that our estimate of the within error is the same for all vehicle classes. One way in which this could be done is to repeat another vehicle type across a few road sections. Preferably this extra vehicle should be one from a lighter class since any differences in the within error should be most significant between the widest range of vehicle weights. Then, two estimates of within error will be available for comparison. If the two are not significantly different then the confidence in the first estimate will be that much stronger. If there is a significant difference between the two estimates, then a transformation of the data is necessary to make the two variances more homogeneous.

If this extra replication is not carried out, it is possible that the estimated "within error" will not be correct. In the case where the estimate is smaller than the true within error, more of the road characteristics will become significant. In the case where the estimate is larger than the true "within error", it is possible that some road characteristics that are truly significant will be called insignificant.

It has been decided to purchase two MBL-1113 trucks to represent the medium truck class and to provide replication in this class. A project Kombi for use for the speed observation crew can be used for replicating in the light commercial class on a limited number of sections.

5) Heavy Truck (Semi Trailer, 40,000 kgs Gross Vehicle Weight) - In order to cover the full range of vehicle weights it is necessary to include a heavy truck. Production figures from 1957/1975 indicate that the FNM has produced 56% of the vehicles in this class while Scania has 25%. However, between January and October 1975 FNM sales were 55% while Scania sales were 45%. The origin-destination study reported that 68% of the vehicles in this heavy weight class (average sampled had gross weight of 40,000 kg) were Scania semi trailers. FNM recorded only 14% of the total. The difference in these figures is possibly due to the fact that the sample was taken on specific road sections in Minas Gerais and Goiás for one week on each road. The seasonal variation in kilometers of travel and the location of the road sections could

have biassed the results.

Based on the gross vehicle weights of the FNM CM-200 and the Scania L-11038 and other characteristics there is little difference between these vehicles.

It was decided to select the Scania equipped with a triple axle trailer.

6) Bus - The Mercedes Benz represents about 85% of all buses produced in Brazil from 1957-1975. Scania, the next most popular bus is only 5% of production during that period, and current monthly production figures confirm this pattern.

The Mercedes Benz "monobloco" represents 42% of bus sales from January to October 1975 and is used almost exclusively on inter-urban travel. It has been decided to select the 0-362 "monobloco" model to represent the bus population operating on rural roads. Table 11 shows the vehicles purchased and their characteristics.

Vehicle Instrumentation

The test vehicles will be used in three forms of controlled experiments:

a) for the development of speed/length acceleration prediction curves on positive grades and, subject to the result of the pilot study, acceleration on negative grades.

b) for the development of fuel consumption/speed prediction equations for short homogeneous road sections.

c) calibration of fuel consumption with users over reasonably long routes of 50 km in length.

For experiments a) and b) all test vehicles will be equipped with:

1) a distance measuring instrument (DMI) with an accuracy of 1 meter per kilometer.

2) two stop watches.

TABLE 11 TEST VEHICLE DESCRIPTIONS

VEHICLE TYPE	VEHICLE MAKE	TARE WEIGHT (KG)	GROSS WEIGHT (KG)	BRAKE HORSE POWER	FUEL
Passenger Car	Volkswagen 1300	780	1160	46	Gasoline
Pickup	Volkswagen Kombi	1195	2155	58	Gasoline
Light Truck	Ford 400	2277	6000	163	Gasoline
Light Truck	Ford 4000	2444	6000	98	Diesel
Medium Truck	Mercedes Benz L-1113/42	3685	18500	147	Diesel
Heavy Truck	Scania 110/38 Articulated	13470	40000	285	Diesel
Bus	Mercedes Benz 0-362 Mono-bloco	7500	11500	147	Diesel

3) a fuel gauge of the type used in the Kenya road transport cost study (Ref. 9). This gauge consists of a 250 millilitre glass measuring cylinder fitted with a float and needle valve which allows the cylinder to be filled with a constant quantity of fuel at all times using an electric fuel pump. The outlet from the cylinder is connected to a two-way fuel tap which is, in turn connected to the vehicle fuel tank and the feed lines feeding the engine. The system is modified for operating on the diesel engines in order to accommodate the spill-over from the diesel engine. In the case of the heavy vehicles two 500 millilitre cylinders will be used in tandem.

4) a lapse time camera (one only to be used on all vehicles) for photographing the DMI and stop watch.

For experiment (c), calibration with the road users, those test vehicles that match the particular user will be equipped with tachographs and fuel gauges of the types to be installed in the users' vehicles.

FIELD MEASUREMENTS

Acceleration on Positive Grades - On all the test sections used for the fuel consumption experiments the test vehicles will be accelerated from a stopped start at the beginning of the section to the steady state speed recorded for each vehicle class for the particular section. The lapse time camera will be used to photograph the distance measuring device and a stop watch at approximately one-second intervals. The space mean speeds thus obtained will be used in the analysis outlined previously on page 88.

Fuel Consumption - In order to include many of the factors that affect fuel consumption in the controlled experiment, in particular driver characteristics and condition of the engine, it is proposed to rotate the drivers on all the test vehicles and to run the vehicles in both a tuned and untuned condition.

As fuel consumption will need to be measured at three different speeds in a loaded and unloaded condition, the number of test sections has been reduced to 24 with 3 repeat sections and containning the following factors and levels:

Factors	Levels		
Surface type	Asphaltic conc.	DST	gravel
Roughness	Smooth		Rough
Grade	0-2%		5%+
Average highway speed	$<$70 km/hr		$>$100 km/hr

Each test vehicle will be driven over the one-kilometer sections at three nominated speeds to cover the range of speeds possible under the particular road and load condition. As the vehicles must travel at constant speed, two trial runs will be made at each speed to enable the driver to establish the correct gear to maintain constant speed.

At the start of the transition the distance measuring device will be started. At a reading of 500 meter (the start of the test section) the observer in the vehicle will turn on the two-way fuel tap and start the two stop watches. At a reading of 1000 meters one of the watches will be stopped and at 1500 meters the two-way tap will be turned off and the other watch stopped. The space mean speeds for the two 500-meter subsections will be compared to ensure that constant speed has been maintained throughout the section.

Data Analysis

The analysis outlined in Appendix 4.2 will be used for developing prediction equations for fuel consumption using the factors set out above.

Calibration with Road Users

Fuel consumption calibrations will be carried out in a manner similar to the speed calibration by fitting fuel meters in addition to tachographs in user vehicles operating on known routes. In addition, test vehicles which are of the same class as the users' will be run over the routes at similar speeds as recorded on the user tachograph. A comparison can then be made between the users', test vehicles and the simulation model.

WORK PLAN AND SCHEDULE

Figure 25 shows the ordering of the activities necessary to complete the speed/fuel consumption experiments.

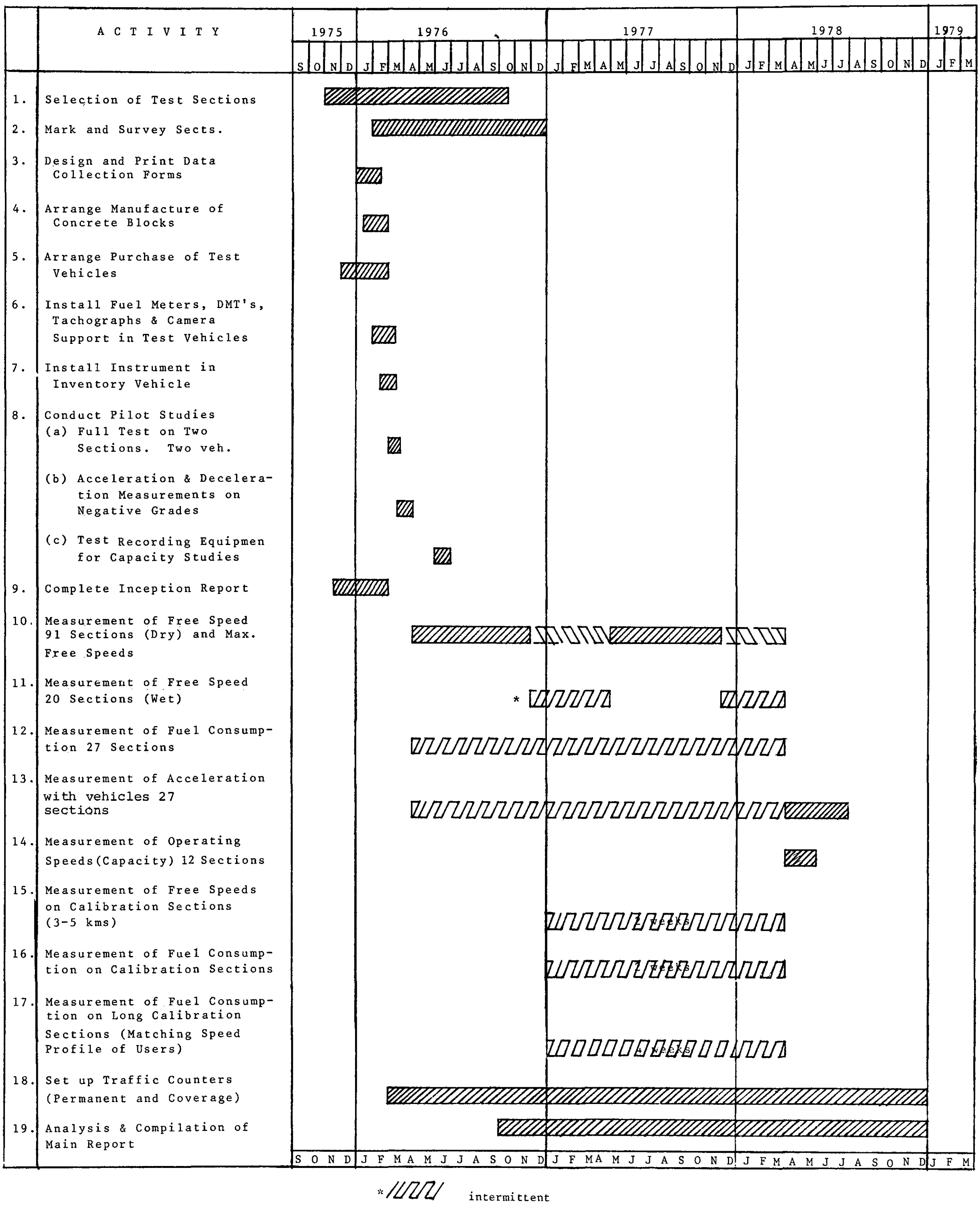

Figure 25 - User Cost and Traffic Work Plan and Schedule