CHAPTER 5-PAVEMENT PERFORMANCE AND MAINTENANCE STUDIES

INTRODUCTION

In this research project on the interrelationship between cost of highway construction, maintenance and utilization, pavement deterioration plays an integral and important role in the minimization of road transport costs. In fact, some measure of pavement performance is the common denominator linking the three study areas of the Project. That is, pavement performance as measured by roughness is the measure of pavement life and of the effectiveness of pavement maintenance procedures. Likewise roughness affects user costs, speed, and fuel consumption. Thus the condition of the pavement surface describes both figuratively and actually the interface of the project parts or submodels.

Pavements are complex structural systems involving many variables which include various combinations of load, environment, materials, geometric layout of the road, construction and maintenance. These variable influence pavement performance, and consequently overall transportation costs. Besides attempting to determine a pavement deterioration model, a pavement maintenance model and a variety of maintenance policies will be examined to create a capability within the overall model to predict costs for a range of maintenance policies.

The proposed experimental design, and work related to the pavement performance and maintenance study is discussed in this chapter. Indications are given of the pre-pilot and pilot study work which are being carried out before the design can be finalized. Some of the variables discussed could also have an effect on other portions of the study, e.g. road maintenance could also affect road safety, but in this chapter only the effects of the variables on pavement performance and deterioration will be discussed.

OBJECTIVES

The objectives of the pavement performance and maintenance studies are:

a. To determine a pavement performance relationship as a function of 1) structural variables, 2) materials, 3) age of road surface, 4) traffic, 5) climate, 6) rehabilitation and 7) maintenance. This relationship will be determined for roads which are as-constructed, and also for roads which have been overlayed, since the relationship may be different. The models obtained should be predictive in order that the total transport cost of different decisions can be tested. Such as when to upgrade an earth road to a gravel road, to a double surface treated road, or to asphaltic concrete surface, etc.

b. To determine a maintenance simulation model which will allow different maintenance policies to be examined. Maintenance management systems are being implemented in many areas of the world and the resulting model could be input into one of those systems.

SURFACED ROADS

The study has two main sub-parts involving asphalt surfaced roads and gravel or earth roads. Installation will be given first to the discussion of surfaced roads.

Approach

The approach proposal to the problem of determining a pavement deterioration relationship is to monitor a number of variables describing pavement behaviour, distress and performance on a number of selected test sections. Adjacent test sections will be treated with different maintenance levels. It is envisaged that each observation section will be 300 m in length, with a 100 m transition between the adjacent nil-maintenance and maintenance sections. This means that each experimental location will be 700 m in length. The 300 m length is sufficient to take measurements, and this relatively short length will also help reduce the random variability within the section.

Factors in the Experiment

Factors, which are defined as independent variables with specified controlled levels, are selected to cover the range of the variables which are to be studied. The factors have been selected based on 1) general observations of performance of different road sections in Brazil, 2) on the results of previous research in pavement performance and 3) also on the results obtained in the Kenya study (Ref. 10).

The factors shown in Table 12 will be considered at two levels, for which tentative limits have been set. Although ranges have been indicated for the selection of the sections, it should be understood that actual values will be measured and used in the analysis of the data.

Discussion of Factors

a) Surface type In Brazil only asphaltic concrete and double surface treatments have been used in the recent past for surfacing roads. In general federal roads have an asphaltic concrete surfacing and state roads have a double surface treatment. Single surface treatments are normally only used for paved shoulders. Tests will be carried out on the asphaltic material.

b) Base type In general three base types are found in Brazil, 1) natural granular material, 2) crushed stone and 3) cement treated bases. Since cement treated bases are generally found primarily in the north-east and the south of Brazil, this base type will be considered in a satellite study. Another fact which will have to be investigated further is that it appears as if crushed stone is only used with an asphaltic concrete surface, and if the surface is a double surface treatment then usually soil is added to the crushed stone. This will not, however, affect the analysis as indicated below.

c) Traffic The present ADT will be used to stratify the sections. The factor levels have been selected to cover the lowest and the highest ADT on both surface types. In addition

TABLE 12 - FACTORS AND LEVELS PLANNED FOR SURFACED

Factors	Levels	
	1	2
Surface type	Asphaltic concrete	Double surface treatment
Base type	Natural granular material	Crushed stone
Traffic (ADT)	Low (100-500)	High (1000 +)
Vertical Geometry	Flat (0-1,5%)	Steep (4 % +)
State of rehabilitation	As - constructed	Overlayed
Age (years since last new surface)		
As - constructed	New (0-4)	Old (12+)
Overlayed	New (0-2)	Old (6+)
Maintenance	Nil-Maintenance	Maintenance at a level higher than normal

equivalent 80 kN axles will be used as a covariate as discussed below.

d) Vertical geometry In order to investigate the effect of grades on pavement deterioration, two levels have been selected to cover the extremes of vertical geometry.

e) State of rehabilitation The pavement deterioration relationship may be different for roads which are as - construc ted and those which are subsequently overlayed. In order to investigate the relationship for these two road states, these factors were included.

f) Age of road surface Since total traffic or equivalent 80 kN axles alone do not describe the deterioration pattern of surfaced roads, the age since the last new surface will also be considered. Since overlays are generally not older than 6 years, different levels have to be used for the two states of rehabilitation.

g) Maintenance The lower level of maintenance will essentially be a nil-maintenance strategy, and this will only consist of filling potholes with gravel, cleaning the culverts and correcting any bad slope erosion which may occur.

The decision on which standard to use for the other level has caused some problems. Three maintenance residences of the DNER have conducted a study over the last 3 years to set up the methodology for determining maintenance costs. A visit to one of these pilot residences, at Ponta Grossa, indicated that there are problems about applying the information available directly to the Project. Besides budget problems the residence also suffers from a lack of maintenance staff, and this has resulted in minimal maintenance work being carried out especially on the pavement. Only about 25 per cent of the maintenance budget is spent on the pavement where as more than 50 per cent is spent on aspects related directly to road safety. For this reason it has been decided to set a maintenance standard for the level other than nil-maintenance at a level which is above what is generally used. If pavement deterioration is related to the maintenance applied, then a rapid difference in performance between the two maintenance levels will be obtained. The exact descripton of this standard will be developed during the pilot study phase.

The information required for the maintenance model will also be captured on the test sections by having the highway authority measure the work accomplished and costs by location and then this information will be verified during condition surveys on test sections. Work standards defining the procedures and productivity for maintenance activities can be established from time-and-motion observations. Pavement maintenance activities are confined to the roadway and lend themselves to photographic monitoring with time-lapse equipment. This will be further investigated during the pilot phase.

Covariates to be Measured or Determined

Besides the factors listed above, the following covariates will be measured or determined:

a. Cumulative equivalent 80 kN axles
b. Deflection and curvature
c. Pavement strength, as a structural number.

a. Cumulative equivalent 80 kN axles Weight classification of different vehicle types on different routes will be obtained from axle load surveys and classification counts and from these the cumulative equivalent 80 kN axles on each test section will be determined. In fact four levels of classification will be used:

1) Traffic counts
2) Vehicle classification counts
3) Sampling vehicle weights by loadometer surveys by the Project and by the DNER or DER
4) Sampling vehicle weights with the WIM-IA weigh-in-motion system.

The AASHTO axle load equivalency factors will then be used. There is a problem in that the AASHTO tables do not consider 3 rear axles, but some further work will be carried out to overcome this problem. A further problem is that the historical data is a weak link in the whole analysis of pavement deterioration and it will always be so, since very little traffic count data or vehicle weight data is available over the life to date of many of the surfaced roads.

b. Deflection and curvature Most of these measurements will be obtained with the Dynaflect and Benkelman beam but the initial work will be done by Benkelman beam since the Dynaflect will not be available until June 1976. Correlations will also be determined between these instruments to incorporate the local practice of using the Benkelman beam into the study. In addition the deflection will be determined with the Road Rater on a few sections to obtain a correlation. It is envisaged that 10 tests per section per direction will be carried out; the feasibility of this procedure will be tested in the pilot study. There will be at least two tests per year, but on a small sample of roads in the vicinity of Brasilia tests will be conducted at monthly intervals to try to obtain a seasonal weighting factor, since the climatic and geological conditions around Brasilia are representative of those in the central plateau of Brazil. Deflection will be used in this study as the first surrogate for strength, and it can also be used as a fall back for predicting performance.

c. Pavement strength From in-situ measurements of 1) CBR, 2) density, 3) moisture content and 4) layer thicknesses, pavement strength will be determined. This may be in the form of a structural number, or in some other form which will be determined during analysis.

Dependent Variables

As outlined in several references on the subject, particularly the work by Hudson and Finn (Ref. 24,25) we will monitor the following dependent variables which will be used in the analysis:

1) Serviceability - Performance
   Serviceability index by surface dynamics profilometer
   Roughness index.
2) Distress - distress surveys
   Cracking
   Patching
   Rutting

These recordings will continue beyond the 3-year duration of the UNDP sponsored project, and therefore results can be forthcoming over the entire life of many road sections.

Experimental Design

In order to develop pavement performance equations with statistical accuracy the experimentation will be carried out in accordance with controlled design procedures. This will allow more reliable estimates of the results to be made while at the same time increasing the efficiency of the data collection.

Two maintenance levels are carried out at each location and these can consequently be accommodated within a split-plot design and thus six factors with two levels each remain. Normally a complete factorial is used in analysing an experiment of this type, and for this case 64 locations would be required. However, since there are six factors with two levels each the full inference space can be covered with only half the effort by statistically selecting only half the blocks of the complete factorial design. This is termed a half replicate factorial design. The analysis of the half replicate factorial is discussed in Appendix 5. Additionally, replicate sections should be chosen so an error estimate can be calculated.

By having only two levels of each factor only linear relationships between the factors and variables can be investigated. Curvature relationships can be investigated by using star points, which are selected at a level in between the levels of the factors in the factorial design. The design for curvature is also discussed in Appendix 5.

Using the designs as described above would require the following number of locations:

From:	the half replicate factorial	32
	the 10 replicates of 32	10
	the 28 star points	28
	Total	70

If it is not possible to find the same two base types for the different surface types, then a pseudofactorial can be used to represent the four levels of surface and base type. The analysis remains the same as above, but eventually the results are interpreted in terms of the four levels. The pseudofactorial design is also discussed in Appendix 5.

UNPAVED ROADS

A second major experiment will be conducted for unpaved roads. The general approach for the unpaved roads is the same as for the surfaced road experiment in that two sections of 300 m each will be used for the two maintenance levels, and these will be separated by a 100m transition. The selection of the factors has been based on the results of previous research of pavement performance with major input from the Kenya study (Ref.10).

Factors in Experiment

The following factors will be considered, and tentative limits have been indicated. Although ranges have been indicated for the selection of the sections, actual values will be measured and used in the analysis of the data.

TABLE 13. FACTORS AND LEVELS PLANNED FOR UNPAVED ROADS

Factors	Levels	
Type of surface material		
Gravel	Laterite, Granite, Quartzite,	
Earth	Clay, Sand	
Traffic (ADT)	Low (100)	High (400+)
Vertical Geometry	Low (0-1,5%)	High (4%+)
Horizontal Geometry	Straight	Curved
Maintenance	No blading, blading at 3-month intervals	

Discussion of Factors

a) Type of surface material In Brazil the three gravel types indicated are primarily used for the wearing surface materials on roads which are designed. On undesigned roads the surfacing material frequently does not fall within the DNER specification for surfacing materials, and from observation these materials result in rapid pavement deterioration. From discussions it appears as if the quartzite and granite have a similar performance, but this will be investigated in the pilot studies.

b. Traffic Unpaved roads generally have an ADT less than 700 vehicles per day, and the levels selected should be able to cover the full range.

c. Vertical geometry In order to investigate the effect of grades on pavement deterioration, two levels have been selected to cover the extremes of vertical geometry. Extremes, i.e., grades up to nine percent will be included in the regression analysis.

d. Horizontal geometry Pavement deterioration on unpaved roads is generally worse on horizontal curves, as a result of shear forces at the surface generating loose material and the superelevation promoting erosion of the surface.

e. Maintenance Maintenance on unsurfaced roads generally only consists of blading when the surfacing layer is thicker than about 2 cm. Roughness is therefore dependent on the frequency of blading. On the one maintenance section the blading frequency will be about once every three months, and on the other section there will be no maintenance at all.

Covariates to be Measured or Determined

Since the deterioration relationship of unpaved roads is relatively unknown a number of associated covariates will be used. These covariates, listed below are all readily obtainable:

a. Average daily traffic (ADT)
b. Percentage heavy vehicles
c. Total weight passing over the section per day
d. Passenger-car units (PCU) - the heavy vehicles are expressed as equivalent passenger-car units to consider pavement deterioration
e. Number of vehicles that used the road since the last blading
f. Number of days since last blading
g. Identify which blading period we are in since time zero

h. Plasticity index (PI) and liquid limit (LL)
i. Moisture content - to identify wet or dry season
j. Deflection and curvature
k. In-situ CBR of subgrade
l. Wet abrasion test results to classify durability of the surfacing material

Dependent Variables

The following dependent variables will be monitored for use in the analysis:

a. Serviceability index by surface dynamics profilometer.
b. Gravel loss i.e. the rate at which the wearing course material is lost
c. Looseness of gravel. Before the surface material is lost, it is loosened, and this will particularly affect vehicles performance especially on steep grades.
d. Rut depth

Experimental design

Setting up the full factorial - In this case a full factorial will be used, i.e. all the cells in the experimental design will be filled. Although there may be 4 or 5 types of surface material this would not influence the experimental design and it would only change the number of locations from 32 to 40. Maintenance at two levels will be performed at each location and it will be considered a split plot.

Composite factorial, including star points - Since the full factorial will be used, the following locations will be required for the composite factorial analysis. It was suggested that granite and quartzite have the same performance, but until this statement has been verified the two options will be considered separate.

a. If 5 surface gravel materials are used then the following locations would be required:

    40 locations for the factorial part

    35 locations for star points

10 locations for replicates

85 locations total

b. If 4 surface gravel materials are used then the following locations would be required:

32 locations for the factorial part

28 locations for the star points

10 locations for replicates

70 locations total

Incomplete Factorial - If it proves impossible to fill all the cells within the experimental design, an incomplete factorial analysis will be carried out similar to that discussed for the surfaced experiment in Appendix 5.

SATELLITE STUDIES

There are variables such as climate which play an important rule in pavement performance. When these variables are included into the experimental design they increase the number of locations required by a product of the number of levels, and generally these variables are also located outside the main study area. In order to keep the experimental design to a manageable size, these factors which occur outside the main study area are investigated as satellite studies. These satellite studies are independent experiments whose results are ultimately compared with those of the main study.

Cement-Treated Bases: Surfaced Roads

Cement-treated bases are generally found near São Paulo and in the Northeast of Brazil. By eliminating this variable from the main experiment the number of factors remaining are of a form suitable for using a half replicate factorial design. The sections to be selected for this satellite study will be selected in the same rainfall area as the main experiment, i.e. the range of 1500 to 2000mm per annum. The following experiment is proposed, and it is imperative that all the cells be filled for an analysis to be carried out (Figure 26).

<table>
<tr><td colspan="2" rowspan="4"></td><td colspan="4">TRAFFIC (ADT)</td></tr>
<tr><td colspan="2">LOW</td><td colspan="2">HIGH</td></tr>
<tr><td colspan="2">VERT. GEOM.</td><td colspan="2">VERT. GEOM.</td></tr>
<tr><td>FLAT</td><td>STEEP</td><td>FLAT</td><td>STEEP</td></tr>
<tr><td rowspan="2">AGE</td><td>NEW</td><td></td><td></td><td></td><td></td></tr>
<tr><td>OLD</td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 26 Experiment Design for Cement Treated Bases

The Effect of Annual Rainfall on the Performance of Surfaced Roads

During the discussions with engineers in Brazil it became evident that the surfaced roads in the drier parts of the country, viz the Northeast of Brazil, performed better than in other parts of the country. This difference in performance is attributed to the drier climate. In order to study the effect of low rainfall, i.e. less then 100 mm per annum, a satellite study will be carried out in Bahia. This will consist of finding all the base - surface type combinations used in the main experiment. Only treatment combinations, i.e. levels of factors, that match those in the main part of the investigation will be used. One of these combination will be repeated to compare with the replication of the 10 sections in the main part of the experiment. The analysis of variance would then be:

Source	df
Rainfall (R)	1
Treatment comb. (T)	4
Rainfall x Trt. comb. (RxT)	4

Within error from mainstudy (W_1)	10
Within error from satellite (W_2)	4
Maintenance (M)	1
Maint x Rainf (MxR)	1
Maint x Trt comb (MxT)	4
Maint x Trt comb x Rainf (MxRxT)	4
Within error (W_1xM)	10
Within error satellite (W_2xM)	4

The Effect of Rainfall Intensity on the Performance of Unpaved Roads

In the report on the Kenya study (Ref.10) it was indicated that rainfall intensity affects the deterioration of unpaved roads, but that a further study of this topic would be required. The effect of rainfall intensity on the deterioration of unpaved roads will be studied in a satellite study which is to be carried out in the same geographical area as the main study using some of the locations of the main study. It is envisaged that initially eight laterite sections in the vicinity of Brasilia will be studied. These sections will consist of two levels of traffic, vertical geometry and horizontal geometry. The rainfall per day, which will be used as a covariate, will be measured by raingauges which will be set up at each location. The dependent variable which will be studied is the serviceability index which will be measured at frequent intervals, possibly daily.

GENERAL EXPERIMENTAL DESIGN CONSIDERATIONS

To fill all the requirements of the experimental design the following locations would be required for the complete analysis of the pavement deterioration study:

a. Surfaced roads

Fractional factorial with star points and replicates	70
Soil cement base satellite study	8
Annual rainfall satellite study	5

b. Unpaved roads

Full factorial, using 4 surface type materials with star points and replicates		70
Rainfall intensity satellite study		8
Total	140 +	21

Since each location will consist of 2 adjacent test sections, a maintenance and a nil-maintenance section, it is considered that these 2 sections are equivalent to the time and labour requirements of about 1.4 sections which are geographically separated. Therefore, in the main study there will be the equivalent of 196 sections. During the planning of the project it was estimated that resources would be available for about 200 sections, thus the two figures correspond reasonably well. The satellite studies are equivalent to about 30 sections, and within the scope of resources for the pavement study these would be able to be handled.

EQUIPMENT

The equipment which will be used on this project is some of the most sophisticated of its type in the world at present. A list of the main equipment related to the pavement aspects of the study, and which may also be used in the other study areas, are given below. Initial activities related to the calibration of this equipment are discussed in the section on pilot studies and the scheduling of this work is indicated on the workplan and schedule.

Surface Dynamics Profilometer - this equipment measures the wave forms of the road surface, and analyses the road surface according to wave form theory based on work done at the University of Texas (Ref. 26.27) to provide a serviceability index of the pavement or a standard roughness measurement.

Maysmeters - this equipment when fitted into a vehicle measures the summation of the movement of the vehicle body relative to the rear axle as the vehicle moves over a road section. This measure of roughness is correlated against the profilometer for standardization (Ref. 28).

Weigh-in-motion system - this system is capable of weighing vehicles at normal highway speeds. It also takes the dimensions of the vehicles and its velocity as it passes over the sensing transducers.

Static wheel weighing scales - four static wheel weighing scales are also available in addition to the dynamic system.

Dynaflect - measures the deflection and deflection basin of the pavement under a cyclic dynamic load.

Benkelman beams - this is the standard device for measuring static deflections of pavements under normal highway loads. These static deflections will be correlated with the Dynaflect so that the model of pavement deterioration obtained may have widespread applicability.

Road rater - this is another instrument which measures the deflection under a dynamic load, but its load measuring characteristics differ from the Dynaflect. This equipment is available from consultants in Brazil, and a correlation will be obtained with the results of the other two types of deflection measuring devices.

Control soils laboratory - a laboratory will be set up and equipped to carry out the standard soil tests under controlled conditions. In addition, specialized equipment, will be imported from the United States and will include splitting tensile test apparatus and repeated load triaxial equipment.

PRE-PILOT AND PILOT STUDIES

Pre-Pilot Studies

These studies include activities related to procurement and calibration of equipment and training of personnel which must be carried out before the equipment can be used in the pilot studies.

a) Maysmeters - this is the first time that Maysmeters will be installed in vehicles produced in Brazil, and since these vehicles are lighter in weight than the vehicles generally used in the United States, research has to be conducted with the local vehicles. This will consist of determining the effect of 1) tyre pressure 2) load 3) variations of time on the roughness results. These tests will be conducted on road sections with the widest range of roughness available.

b) Benkelman beam - at present no temperature correction curve has been developed for deflection by the Benkelman beam for the Brazilian conditions. These correction curves will be developed during the training of personnel phase.

Pilot Studies

The pilot studies are primarily aimed at:

a) Obtaining sections of the quality required for the experimental design in the field, and perfecting the system of section selection;

b) Setting up the procedure for carrying out the field and laboratory tests in the main study;

c) Obtaining realistic dummy data for a pre-analysis of the experimental design. The pilot studies follow basically the same procedure for the surfaced and unpaved experiments. The pilot studies will consist of selecting three locations for the surfaced and three locations for the unpaved experiments. In the case of the unpaved sections initial material tests will be carried out on many possible test sections in DF in order to obtain a full spectrum of materials which are generally used. In the DF there are no specifications for the quality of the wearing surface gravel, and we expect to find a wide range of material properties. The following activities are planned, but these may change during testing.

1) Select possible sections from construction plans and traffic statistics

2) Verify traffic counts

3) Verify the materials used in the sections by taking samples by coring and augering at one point/location and then analysing these samples in the laboratory

4) Mark and survey the sections if they fill a block in the design

5) Carry out in-situ material tests (3 test pits and 8 core holes per location) and take samples for laboratory analysis

6) Take at least 7-day counts at each location

7) Measure the deflection with the Benkelman beam at 20 points per location per lane

8) Measure the roughness on each section, and determine the frequency of roughness measurements required on the unpaved roads

9) Carry out pavement distress surveys on surfaced section

10) On the unpaved sections carry out a survey for gravel loss determination, and measure the looseness of surface materials.

Another activity during the pilot study phase is to run the weigh-in-motion system, WIM-1A, at a location to debug any problems, to train personnel and to obtain sample data for the pre-analysis.

EXTENDED STUDY CONSIDERATION

Investigating the Roughness of Newly Constructed and Overlayed Roads

In the main part of the study roads of different ages will be used. The roughness of many newly constructed roads will be measured to establish some quantitative measure of the roughness of the study roads when new. This will at the same time give a quantitative measure of the present construction quality.

During the discussions with the maintenance personnel of the different road departments, no clearcut existing policy on when to overlay could be determined. In order to quantify levels of roughness at which roads are currently overlayed, the roughness of roads currently awaiting overlay will be measured before and after overlaying.

All of the results obtained after overlaying will indicate the improvement in riding quality achieved and it will also be used as the roughness at time zero in the pavement deterioration model for roads that have been overlayed.

Pavement rating scale

To calibrate the serviceability index obtained by the surface dynamic profilometer with Brazilian conditions a limited rating experiment may be run probably during the second year of the project.

INTERFACE WITH ROAD USER COSTS EXPERIMENTS AND SURVEYS

The measurement of pavement surface properties (roughness, rut depth, etc) will also serve as independent variables in the road user costs experiments and surveys. Thus ultimately the models can be related, and user costs, speed, etc can be predicted as a function of pavement design and maintenance variables.

WORK PLAN AND SCHEDULE

The work plan and schedule for the pavement performance and maintenance study is shown in Figure 27.

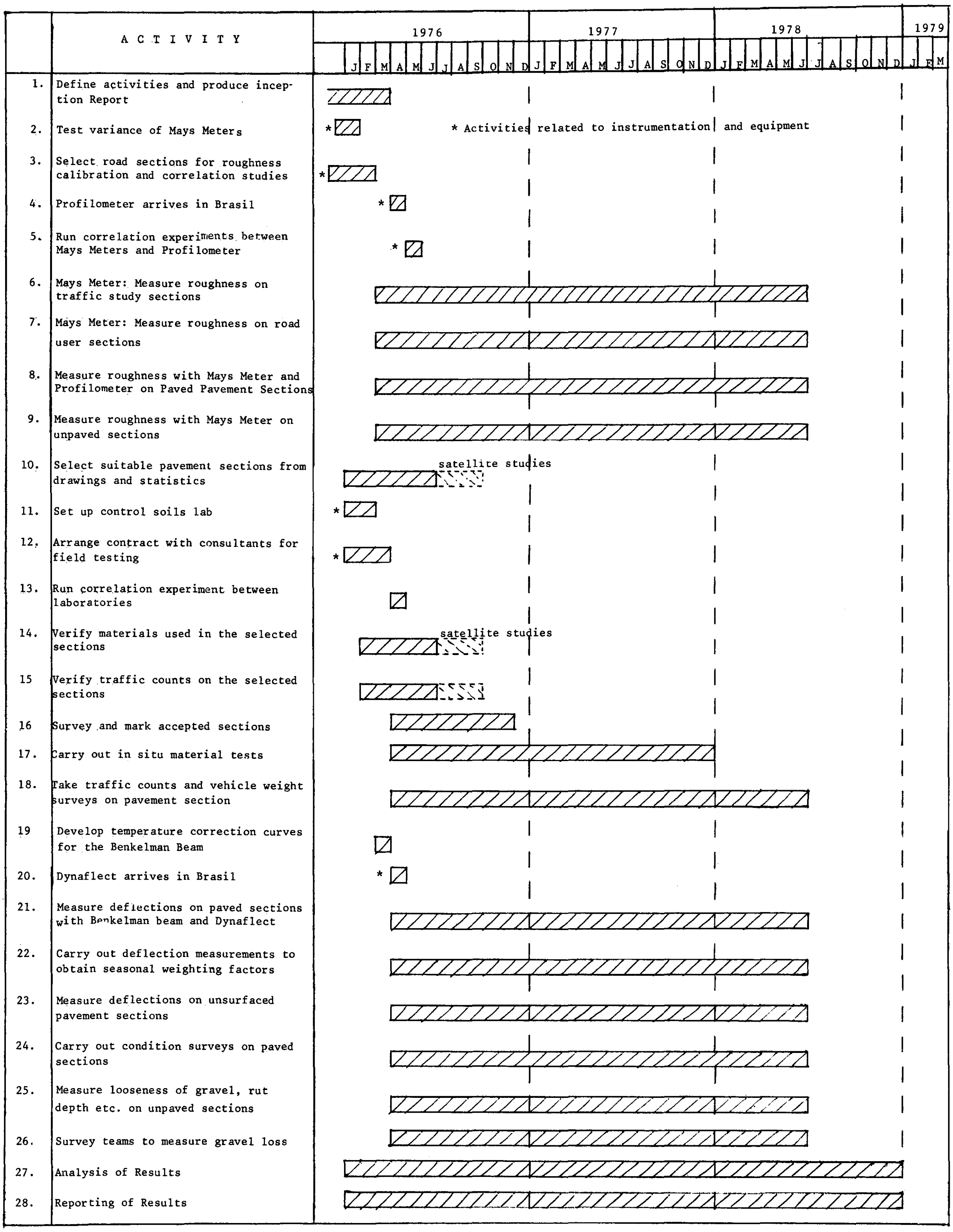

Figure 27. Pavement and Maintenance Work Plan and Schedule