

CHAPTER 6 - SUPPORT ACTIVITIES

INSTRUMENTATION

Equipment Requirements

Measurements are vital in any research effort to determine physical relationships precisely and effectively. The measurement of pavement roughness (serviceability) and road geometry are important variables throughout this study. All of the surveys and experiments involve these variables in one way or another. In the road user costs surveys and traffic experiments, the costs must be related to pavement and road characteristic measures. In the pavement performance and maintenance studies, roughness and serviceability are dependent variables used to define performance and to describe the effect of maintenance. Finally road geometry must be related to observed pavement behavior.

Fuel consumption is another important variable and special attention is needed for these measurements, both on the experimental vehicle studies and in certain of the road user costs surveys for internal checking and model calibration.

A variety of so called traffic measurements are involved in the study: a) vehicle counters, b) vehicle weighing systems, c) speed measurements, and d) tachographs for speed profiles. This equipment records vehicle operating data and traffic volume and weights for all phases of the study requiring measurements as outlined in the detailed chapters.

Another set of important measurements relate to pavements. These include: 1) pavement deflections with both the Dynaflect and Benkelman beam devices, 2) pavement distress measurements such as rut depths, skid resistance, surface looseness, etc. and 3) a variety of material testing ranging from field CBR tests to repeated load stiffness testing. A complete control soils laboratory will be set up to coordinate materials testing for all test sections.

Finally, there will be miscellaneous tests of various kinds which will be developed as needed. Examples of these include rain-gauges, both volume and intensity and wind measurements to evaluate possible effects of wind resistance on speed and fuel consumption.

For each of the measurements a careful study of available equipment has been made. Where possible and within the budget limits of the project the best or most appropriate equipment available to accomplish the job has been purchased (Table 14). A brief description of each piece of equipment is included below. A later project report will cover instrumentation, equipment and procedures in detail.

1. Surface Dynamic Road Profilometer System - This profilometer, first developed by General Motors Corporation, uses an inertial reference system to insure long term accuracy and stability of the measurements. The measured profile can be 1) analyzed in detail, 2) used to calibrate other roughness devices, and 3) used to evaluate serviceability and performance.

2. Mays Road Roughness Meters - Four of these devices are available for routine measurements. Although inadequate as primary measurements, they can be calibrated regularly and used for the majority of the pavement roughness measurements.

3. Road Geometric Survey Vehicles - Two vehicles will be instrumented to record road geometrics at reasonable vehicle speeds. They will also contain a Maysmeter (Item 2 above) and will be capable of evaluating routes of the user vehicles being surveyed for good correlation.

4. Dynamic Scales - A weighing-in-motion system developed at Texas University is capable of weighing passing traffic at normal highway speeds without stopping the vehicles. Axle spacing, vehicle length, and vehicle speed are also recorded electronically.

TABLE 14 SUMMARY OF PROJECT EQUIPMENT

1. Surface Dynamics Road Profilometer System
2. Mays Road Roughness Meters (4 each)
3. Road Geometric Survey Vehicles (2 each)
4. Dynamic Scales (WIMIA)
5. Static Scales (2 each)
6. Traffic Counters, Manual and Automatic (25 and 10 each)
7. Fuel Consumption Meters
8. Tachographs (20 each)
9. Vehicle Speed Meters (4 each)
10. Vehicle Distance Odometers (20 each)
11. Lapsed Time Cameras (2 each)
12. Dynaflect Deflection Device
13. Benkelman Deflection Beams (6 each)
14. Rain Gauges (10 each)
15. Wind Measurement Devices (3 each)
16. Stop Watches (Several Types, 50 total)
17. Resilient Modulus Repeat Loads Test Machine
18. Splitting Tensile Test Machine
19. Soils Laboratory

5. Static Scales - Four standard load-o-meter wheel weight static scales are available for field weight determination and calibration as needed.

6. Traffic Counters Manual (25 each) and Automatic (10 each) - It will be necessary to determine traffic movements for the test sections in both the user costs experiments and the pavement experiments. A system of traffic records will be established.

7. Fuel Consumption Meters (15 each) - Several types of fuel meters are being examined. One type will be used for the controlled experiments. Another simple continuous flow meter will be installed in some of the user vehicles being studied in the survey.

8. Tachographs (20 each) - A tachograph is a device which is equipped with a clock so that it can record the speed of a vehicle continuously on a graph. This will be used to obtain the speed profiles on the user survey vehicles.

9. Vehicle Speed Meters (4 each) - Radar speed meters are necessary for measuring the test vehicle speeds, for sampling the travel speeds of the vehicle population and for developing the acceleration and deceleration curves for different vehicles.

10. Vehicle Distance Odometers (20 each) - Electronic distance measuring devices which can economically be installed in test vehicles or user vehicles being surveyed with minimum trouble and labor.

11. Lapsed Time Cameras (2 each) - 16mm movie cameras are adapted to take single shot photographs at prefixed intervals or when triggered.

12. Dynalect Deflection Device - Measures the deflection of a pavement under a dynamically oscillating load. This equipment is fully automated and is able to measure deflec-

tions considerably faster than in the case of the Benkelman beam.

13. Benkelman Deflection Beams (6 each) - This is the standard device used for measuring pavement deflections under a wheel load in Brazil, and these results will be correlated with those of the Dynaflect.

14. Rain Gauges (10 each) - Simple rain gauges will record precipitation at several of the test sections as required throughout the tests.

15. Wind Measurement Devices (3 each) - Wind direction and speed may affect the speed and fuel consumption of test vehicles. It must therefore be determined during test runs.

16. Stop Watches (Several Types - 50 total) - Time will be recorded for speed studies and other research as required.

17. Resilient Modulus Repeat Load Test Machine - The resilient modulus, which is a fundamental pavement design parameter for the subgrade, is determined with the repeated load triaxial apparatus. The confining pressure is variable but constant during a test and the axial load can be varied cyclically.

18. Splitting Tensile Test Machine - When an increasing diametrically opposite knife-edge load is applied to a cylindrical sample, the sample will break in half, and with this equipment the failure forces are measured and then the tensile strength may be calculated.

19. Soils Laboratory - The control soils laboratory has been set up to control the work which will be carried out for the project by other agencies. The laboratory is fully equipped to carry out standard soils laboratory tests such as:

1. Granulometry
2. Liquid limit and plasticity index
3. Laboratory CBR tests
4. Laboratory density analysis
5. Moisture content determinations

Correlation tests will be run to compare the results of the other laboratories with our control laboratory in order that consistent results will be obtained during the work in the various regions.

Calibration

This project will require careful use of equipment throughout the 36 months of measurements. Calibration and testing procedures will be established for each piece of equipment and carefully documented to help insure that uniform measurements will be made during the full term of the Project.

Documentation

For future studies of the data and possibly in future research, it will be essential to have good records of data acquisition and instrumentation procedures. A detailed set of data forms and instrument calibration procedures will be established. These will make easier to document the accuracy of the data. At about mid-term of the project a detailed instrumentation report will be prepared to describe equipment and procedures. This will insure accuracy and also record the information for future use.

COMPUTER SUPPORT GROUP

Computer Requirements for the Project

The main tasks of this group are: to develop a computer data bank for storing all data and to provide support for computer analysis and programming for the three study years of the project.

Due to large amounts of data to be processed and the number of analysis to be done, the Project needs to have access to a computer system with certain basic characteristics such as:

1. Good core capacity (512 K bytes or better), capable of handling a data management system and some large engineering programs;
2. Available basic compilers (FORTRAN IV, ANS COBOL, PL/I, ASSEMBLER);
3. Available statistical and mathematical routines;
4. Available data management system routines;
5. Available system utility programs;
6. Teleprocessing capabilities.

The ideal working condition for this project would be to have a remote job entry terminal (RJET) that could access a large computer system which has these characteristics.

Evaluation of Computer Installations

Since September 1975 we have been searching for a computer installation capable of handling project data processing needs, not only from the machine capacity point of view but also with regard to related data processing services and overall efficiency. After visiting several of the computer installations here in Brasília in late September we agreed that the installations most suitable to the project needs were:

1. The IBM System 370/158 OS/VS used by the Senate Data Processing Center;
2. The Burroughs B 6700 used by the University of Brasília Computer Center.

These systems were recommended because they met the basic characteristics required for our analysis and data processing needs.

GEIPOT has a working agreement with the installations shown in the table below.

Project personnel have been using the facilities at the University to adapt statistical and engineering programs, as well as the TRRL-MIT-IBRD Highway Cost Model System. The services at the University have not been totally satisfactory.

In February 1976, we started using the IBM 370/145 at Companhia Auxiliar de Empresas Elétricas Brasileiras (CAEEB), which is small for the project needs (252 K of memory). It is too early to evaluate their services, but they seem efficient and business oriented.

We have not had the opportunity to use the facilities at Companhia Brasileira de Alimentos (COBAL) or at Departamento Nacional de Estradas de Rodagem (DNER). We do not expect to have a great amount of work for the COBAL computer center, but we do expect to use extensively the DNER computer facilities.

To process our data at DNER computer center the data will be recorded in cassettes and sent by pouch to Rio for processing. This procedure will go on until we have our computer terminal in operation.

Mr. Diamant, director of DNER computer center, will be personally contacted in mid March about establishing procedures to handle the Project data.

Terminal Facilities

During their December 1-5, 1975, meeting in Brasilia the Expert Working Group (EWG) strongly recommended to GEIPOT that the Project should have an electronic data processing capability within our offices in GEIPOT (see Appendix 6.2).

Staff personnel of the project computer group together with Dr. Grover Cunningham, EWG member, visited the computer installations with which GEIPOT has agreements. The purpose of these visits was to make an assessment of their capabilities, experience and support for remote job entry terminals (RJET). As it turned out none of them had a RJET in operation. The University of Brasília has been experimenting with RJET but they do not have any as part of their regular operations. The installations at the University of Brasilia and DNER have the equipment to support RJET, but no experienced personnel in software and teleprocessing to provide terminal technical support.

In addition to the computer installations we visited two local banks that are using Olivetti data entry equipment to record and transmit data to their headquarters in other cities through the local and long distance telephone lines.

Conversations were also held with personnel from the telephone companies TELEBRASILIA (local telephone lines) and

EMBRATEL (long distance lines) to run a check on costs, lead time needed to obtain a line and other technical details regarding data transmission through their lines.

The next step was to get cost information on terminal equipment from different manufacturers, specifically from Burroughs, Olivetti, and IBM that maintain offices in Brasilia. We were able to get some information from Olivetti and IBM, but none from Burroughs.

With this information in hand on Thursday December 11, 1975 project staff personnel together with Dr. Grover Cunningham of TRDF and Dr. Per Fossberg of IBRD, visited the DNER computer facilities in Rio de Janeiro, in particular José Diamant, Director of the DNER computer center. We explained to him the purpose of our visit and our interest in setting up a RJET, and were pleasantly surprised at the enthusiasm he showed for working with us.

Mr. Diamant showed us their computer facilities, and informed us about time available and future plans for expansion including installation of terminals for the DNER district offices. He also indicated that DNER had ordered 32 Olivetti's DE 523 (Data Entry Terminals) and the possibility that the Project could obtain two of these machine on a loan basis.

On January 15 the Brazilian Directors of the Project met with Mr. Diamant, at the Ministry of Transport, here in Brasilia. At that meeting Mr. Diamant agreed to loan one Olivetti DE 523, and it was received on January 22, 1976.

Olivetti was requested to prepare a proposal for peripheral equipment for the DE 523 to function as a RJET. On February 6, 1976 we received the proposal from Olivetti. This proposal was forwarded to the Brazilian project director for appropriate action.

As of this writing the outlook for the prompt installation of a RJET is not promising. All the peripherals needed for the Olivetti DE 523 to function as RJET have to be imported and GEIPOT is experiencing difficulties in obtaining such equipment due to the Government restrictions on importations.

Other alternatives are being studied to find a solution to this problem. Table 15 summarizes the current facilities.

Computer Programs

The computer programs for statistical analysis brought from the University of Texas have been converted and are operational on the Burroughs B 6700.

The Road Transport Investment Model for Developing Countries (TRRL Program) was compiled and executed with the Yala-Busia test data. On February 9, 1975, from EMBRAPA we obtained a magnetic tape with the BMD statistical package. Currently we are working to have this package operational on the CAEEB, IBM system 370/145 OS/VS. We also hope to have this system in operation in the DNER computer by late March. Programs for analysis of the weight-in-motion (WIM) data as well as programs to analyze the pavement deflections are being revised to have them operational in the IBM System 370/145 OS/VS. The programs relating to analysis of profilometer data will have to be modified for the new profilometer, and make them operational in IBM equipment. This task is being undertaken by TRDF in Texas.

Pre-Pilot, Pilot and Full Scale Studies

During the pre-pilot and pilot studies, for the pavement, user costs surveys and experiments, computer support will progress as follows:

- a) develop and design forms for data collection;
- b) keypunch, record, verify and edit data for storage and analysis, and
- c) use of statistical programs for data analysis.

Currently this section is involved in developing the programming needed for route control of bus companies for Goiás, Minas Gerais and Distrito Federal.

For the full scale study the production of input formats and software packages will progress in the same order as the study program.

Personnel and Supplies

Because Brasília is not a good market to find top qualified personnel, it has been and will continue to be difficult to recruit personnel. In the data processing field a good programmer and keypunch operator are required to complete the staffing requirements of this group.

Another area that will need special attention is the ordering of data processing supplies. In general the suppliers in Brasilia do not carry a good inventory and the lead time for ordering supplies manufactured in Brazil is about ninety days.

TABLE 15 COMPUTER SYSTEMS AVAILABLE*

Computer Installation	Type	Model	Location
University of Brasília	Burroughs	1130	Brasília
University of Brasília	Burroughs	B 6700	Brasília
Companhia Brasileira de Alimentos (COBAL)	Burroughs	B 6700	Brasília
Companhia Auxiliar de Empresas Elétricas Brasileiras (CAEEB)	I B M	370/145	Brasília
Departamento Nacional de Estradas de Rodagem (DNER)	I B M	370/145	Rio de Janeiro

* GEIPOT was unable to effect a working agreement with the Director of the Senate Computer Center. See Appendix 6.1 for available hardware and software.

STATISTICS AND ANALYSIS GROUP

The main objective of the Project is to examine the interrelationships between the three components of road transportation: construction, maintenance and road user costs. The actual relationships will then be set into a model which will predict the combination of design and maintenance which produces the minimum total transportation costs for any road section. Therefore, it is of major importance to develop prediction equations with reasonable accuracy that will relate the three components, and do so under a wide variety of conditions.

The final analysis procedure that will be used to develop the many prediction equations will be regression analysis. However, to arrive at the best equation in all situations, analysis of variance approaches will be utilized first. The functions of the statistics and analysis group are two-fold: 1) to propose designs for the various experiments which will allow the development of prediction equations while at the same time reducing data collection: 2) to analyse the data according to the design procedure set up.

The number of the factors that effect the various dependent variables is in the most cases very large. Simple analysis procedures would require an enormous amount of effort in the field, more than would be possible by this study team. The experimental designs assist in reducing the overall size of each experiment, but in most instances become very complicated to analyse.

A list of the experiments that have been planned is given below. This list is then followed by a short explanation of each experimental design.

Pavement Performance and Maintenance Experiments

1. The development of pavement performance relationships for surfaced roads.
2. The development of pavement performance relationships for unsurfaced roads.
3. The investigation of pavement performance of surfaced roads with soil cement base.
4. The effect of annual rainfall on pavement performance of surfaced roads.

5. An investigation of the effect of rainfall intensity on the pavement performance of unpaved roads.

Road User Costs Experiments (Traffic Studies)

1. The effect of dry or wet conditions on the acceleration, deceleration, and steady state speeds on negative and positive grades.
2. Investigation of the differences of free speed measurements on various gravel types.
3. Development of free speed, steady state prediction curves on positive grades.
4. Deceleration phase on positive grades.
5. Free speeds in different geographic areas.
6. Acceleration phase on positive grades.
7. Speed/length curves for negative grades (pilot).
8. Calibration of simulation model for free speeds.
9. Speed/capacity relationships from field data.
10. Calibration of simulation model for capacity & field data operation.
11. Fuel consumption relationships.
12. Calibration with road users.

Road User Costs Surveys

1. Pilot study to check sampling frames for buses, trucks and cars;
2. Updating of procedures based on pilot study results.

Pavement

The development of the performance relationships for paved roads will be accomplished by analysing a one-half replicate, split plot design with star points and covariates. The use of the one-half replicate minimizes the number of test sections while allowing full analysis to be performed on the major factors. The split plot decreases the number of total test sections by one half since each location is divided (or split) so that two forms of maintenance can be performed on each location. By including star points curvature relationships can be investigated as well as linear effects. Covariates, which are simply measured at each section will add strength to the prediction equations while not increasing the number of test locations.

In the development of the performance relationships for unpaved roads a full factorial will be utilized. The number of controlled factors is less in this experiment than in the main

study for paved roads. Thus, a full factorial with star points will most efficiently describe serviceability. By using star points, curvature can be added to the regression equations for the quantitative independent variables.

The investigation of pavement performance of surfaced roads with soil cement base will be carried out in a satellite study. This approach is proposed for two reasons, (1) most soil cement base roads are not in areas near Brasilia and (2) by placing soil cement in a satellite the efficiency of the main study on surfaced roads is greatly increased since it is possible to run a one-half replicate design there. The soil cement sections that are tested in the satellite will be compared to sections with other bases by means of factorial analysis of variance procedures.

In a satellite study a small number of test sections will be tested in Bahia where rainfall is very low. These sections will be compared against identical sections with higher rainfall (from the main study) by means of analysis of variance procedures. Again, a split plot design is used to analyze maintenance.

The effect of rainfall intensity on paved roads will be investigated on a small scale. The testing has been limited to a total of eight sections because of the expense involved in the equipment. Various levels of intensity will then be related to deterioration by means of regression analysis.

Traffic

It is proposed to study dry and wet conditions on a small scale. The same sections will be tested when it is raining and when it is dry. The factorial design is therefore called a split plot. Differences in the speed for each vehicle class will be compared across various road factors and against wet and dry conditions. From this analysis, regression procedures will follow to develop the prediction equations for free speed.

The main study for free speeds will test only one type of

gravel, lateritic. However, there is a possibility that other gravel types may have a different effect on speeds. Therefore, a satellite study is proposed to investigate other gravel types in Paraná and Minas Gerais. The analysis will follow factorial procedures, gravel type and roughness with a split plot for the various vehicle classes. Prediction equations will then be developed for free speeds by regression analysis.

For the development of free speed steady state speed curves on positive grades it is proposed to use a full split plot factorial design, followed by regression analysis. The split plots decrease the total number of different road sections that must be tested. This is very important because a completely randomized design procedure would necessitate the investigation of too many sections.

In order to develop the full deceleration curve for positive grades each vehicle class must enter the test section at their maximum speeds. Therefore, the test sections must be chosen carefully. A split plot factorial will again be used for this analysis. In addition, the travelling length up the grade where each vehicle class decelerates to steady state will be estimated. By joining analysis (3) & (4) it will then be possible to develop the full deceleration curve for positive grades.

Trip length purpose in different geographic areas may have a significant effect on free speeds. Therefore, in a satellite study various locations with different geographic areas will be tested. The speeds of all vehicle classes will be measured on each location. The design is therefore a nested split plot factorial. Differences in speeds across various geographic areas which have different trip purposes can then be examined for each vehicle class.

For the acceleration phase on positive grades the Projects' fleet of test vehicles will be used. In all of the previous experiments described above actual road users will be measured. Using test vehicle alters the design and the inferences. For the acceleration phase on positive grades, the design is a split plot with nesting. However, here the vehicles constitute the

whole plot and all other effects represent the split plots. This is different from previous experiments discussed. The actual prediction equations will be developed by means of regression analysis.

A number of different speed patterns can exist on negative grades depending on the road itself and on the vehicle class. In order to identify clearly some of these speed patterns a pilot study will be carried out first. The design is again a split plot factorial in which actual road users are measured. This pilot will produce information which can then be used to develop a full experimental approach for speeds on negative grades.

Once the free speed curves have been developed for short homogeneous sections they must be tested and calibrated against longer runs over heterogeneous sections. This will be done in two ways (1) by measuring speeds of our own vehicles over 3-5 km heterogeneous sections and comparing their average speeds with the simulated speeds; (2) by measuring speeds of actual road users who have tachographs installed in their vehicles and comparing the measurements to our estimates.

The objective for the analysis of speed/capacity data is to determine the flow/composition combination for any road section where free speeds are reduced to operating speeds. The analysis procedures are based on the split plot design that will organize the study. Regression analysis will be used to predict the speeds of any vehicle class under various flow/composition levels on a variety of road sections.

A simulation model has been proposed for the development of capacity situations on different road sections. These simulated results will be compared through factorial analysis with the capacity data collected in the field. In this way the accuracy of the simulation model can be examined; The fuel consumption relationships will be developed by the use of the project vehicles. As in the experiment on acceleration on positive grades, a split plot design will be used with the test vehicles forming the whole plot. Fuel consumption can be predicted for the vehicle classes at different speeds by means

of regression techniques.

As with the calibration of free speed with road users, the fuel consumption equations must also be checked against users driving over heterogeneous routes and by the project's fleet driving over similar routes. Data from the users will be accumulated by the survey staff.

Users Survey

Sampling plans have been proposed for the bus, trucks and cars surveys which must be checked in a pilot study for applicability and practicality. If the proposed plans will fulfill the objectives of the survey then the full scale survey will begin. If not, new approaches must be developed.

Based on the outcomes of the pilot studies revisions will be made as needed in the sampling design approach. Presently, Dr. Wade Clifton and Paul Moore are giving assistance in the development of sampling frameworks for the road user costs surveys. Updated versions of the survey procedures will be established after the results for the pilots are analyzed.

WORK PLAN AND SCHEDULE

The work plan and schedule shown in Figure 25, 26 and 27 outlines the activities of the instrumentation, computer and statistics support groups.

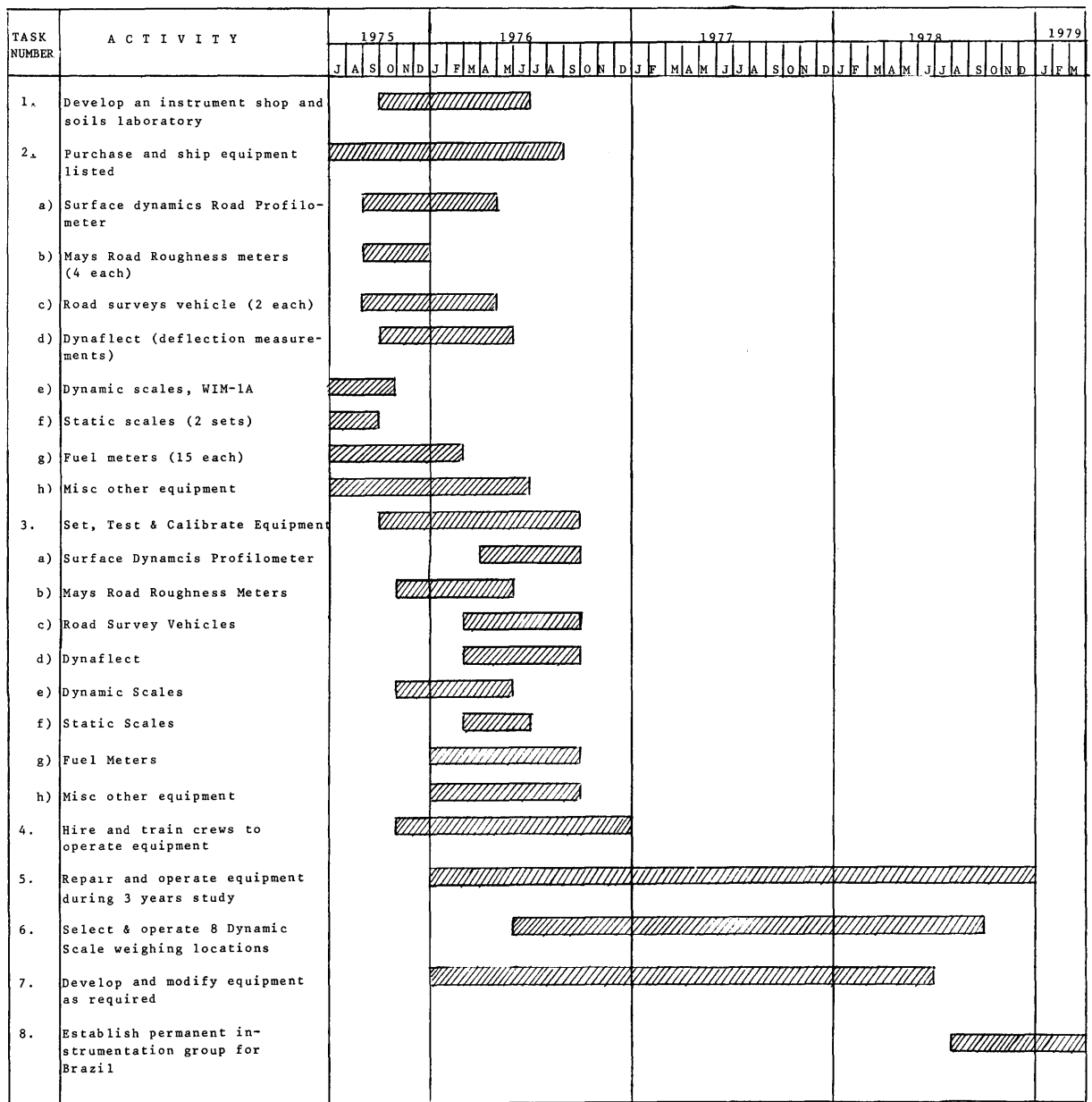


Figure 28. Instrumentation Work Plan and Schedule

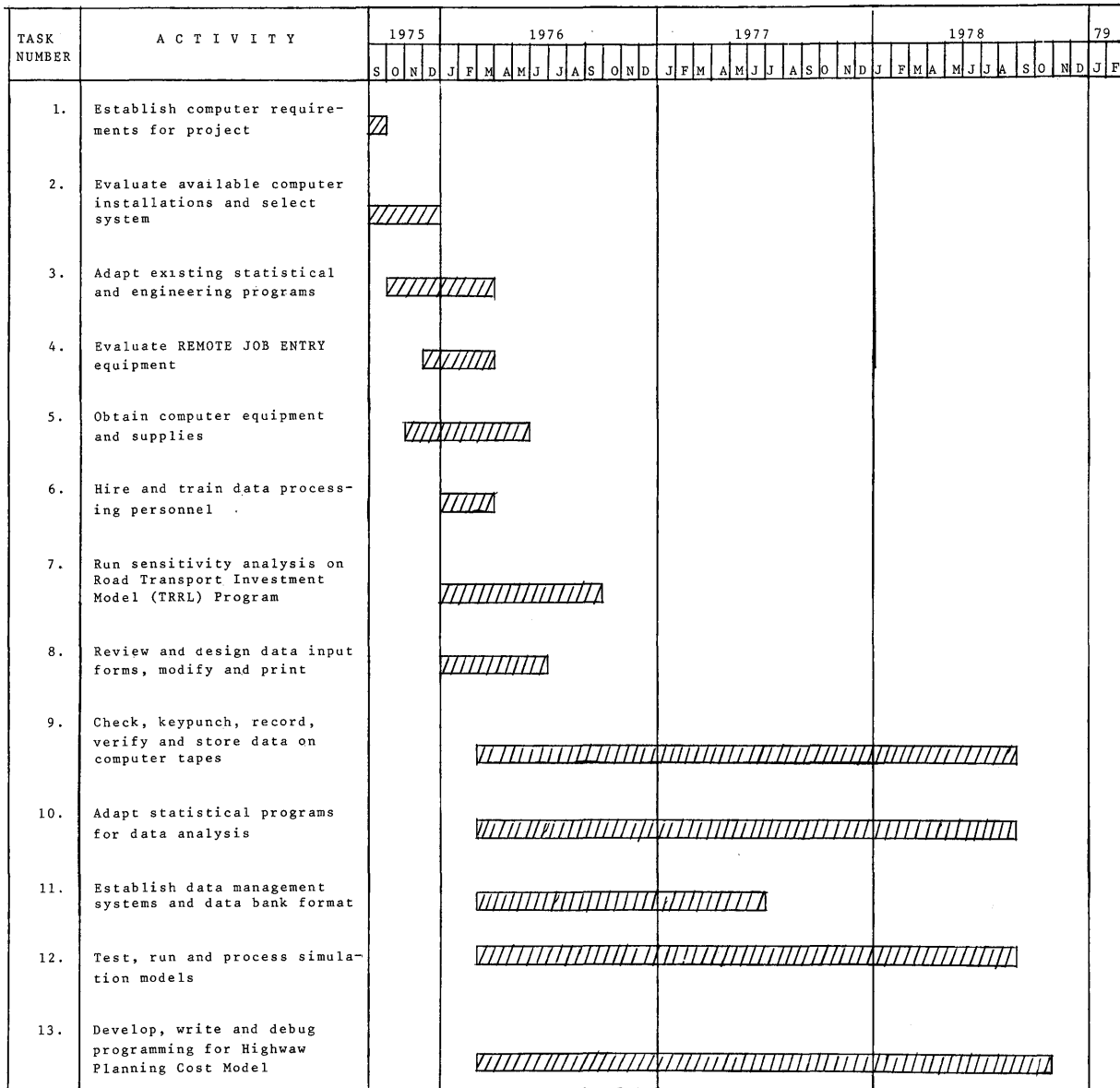


Figure 29. Computer Support Work Plan and Schedule

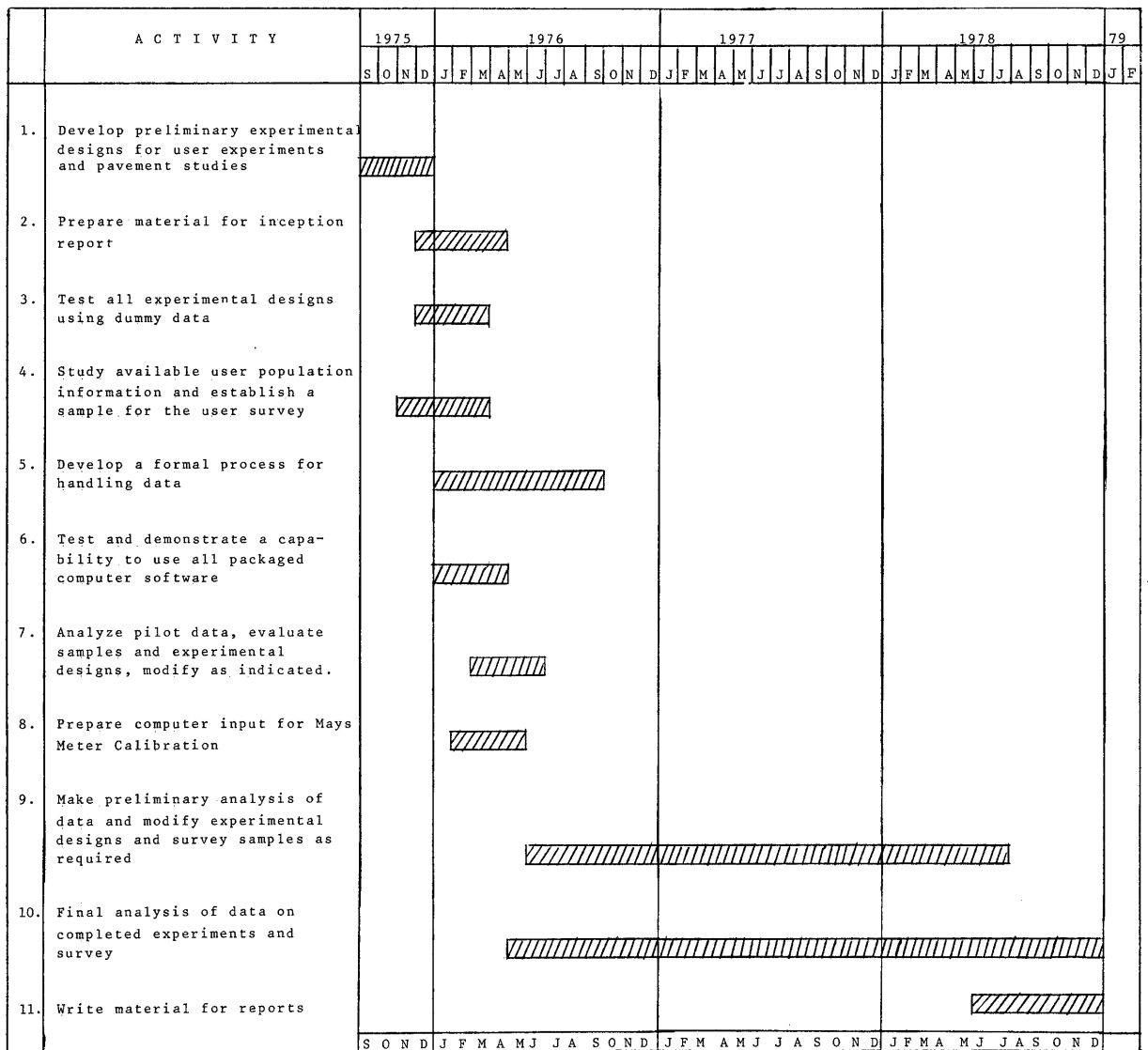


Figure 30. Analysis Support Work Plan and Schedule