WORKING WITH A HIGHWAY MAINTENANCE SIMULATION MODEL ... USING AN INTERACTIVE INPUT MODULE

James M. Pruett and Kok-Kin Kuong Lau, Louisiana State University

The functions related to highway maintenance are often conceptually simple (repair the highway) and administratively complex (alternatives related to priorities, approaches, resources, and many others). Highway maintenance administrators are often faced with questions about which little or no definitive information exists and asked to make the proper decision. For example, if some amount of money is available for equipment which type of equipment should be purchased? How many such equipment units? Where should they be placed and so forth? The dilemma of wanting to do the job well (i.e., make the best decision) and not having sufficient data with which to work is disconcerting at best. The highway maintenance simulation model and accompanying input module described in this paper are intended to help alleviate the highway maintenance administrator's problem by providing an easy to use, flexible highway-maintenance-decision-laboratory in which alternative courses of action may be tested. At the January, 1979 Transportation Research Board meeting, the research required to perform the initial phase and several follow-up phases in the development of the model was presented in the paper "The Systematic Development of a Highway Maintenance Simulation Model." At that time, the model included several simplifying assumptions which made actual considerations regarding highway maintenance operations unrealistic (e.g., one manpower type, one equipment type, etc.). At the January, 1980 Transportation Research Board meeting, the complete simulation model was discussed and presented in the paper entitled "A Highway Maintenance Simulation Model." A description of the model's construction, typical input and output, and some interpreted results (based on an example) were given. This paper includes some of that same information, plus a discussion of the interactive input module. The input module has been added in order to simplify the process of examining different alternatives.

Introduction

Highway maintenance is an important function which is administratively complex. Virtually everything related to highways requires maintenance. There are many types of maintenance activities. There are multiple highway surface types; numerous types of defects, often optional approaches available for defect repair; a spectrum of weather conditions; an infinite number of terrain variations; a divided land work area with often overlapping assignments of responsibility; an ever present element of danger; a variety of equipment types, quantities, and breakdown rates; and, various numbers, levels, and types of manpower and abilities. This sampling of variations does not even mention the human considerations of personalities, interests, absentee levels, and interpersonal relationships. Also omitted from this discussion have been the unique and demanding tasks of planning, priority assignment, scheduling, monitoring, and controlling the maintenance activities. In addition, it should be mentioned that these tasks are all performed in a political arena, supported by the taxpayers' money. There is little question, after even cursory assessment, that administration of highway maintenance activities is a difficult and challenging task.

This paper describes an analytical tool capable of lending order, to some degree, to a number of the dilemmas which are frequently faced by highway maintenance administrators. A highway maintenance simulation model is described which considers many of the interrelated factors already mentioned and provides quantitative output that allows orderly analysis of the situation. In addition, a description of a computer interactive input module is given. The input module was included in order to simplify the input process and, therefore, make it easier to examine alternative decision possibilities.

Model Overview

Model Objectives and Usage

The purpose of the simulation model is to aid users in better understanding the response and behavior of the highway maintenance system under different conditions. That is, to provide highway maintenance engineers with a computer-aided simulation laboratory in which to test and evaluate various alternative courses of action. The input module is intended to simplify the input process, keep users from entering erroneous data (whenever possible), force users to consider all interrelated data values, and to speed the evaluation procedure.

Before discussing the input module, however, a closer look at the idea of how a simulation model may be used is given. Suppose a particular highway maintenance district requests two (5 ton) dump trucks. How might such a request be evaluated? How much would these two trucks really help? Would they cause additional manpower shortages? Would they sit idle too much of the time (and how much is too much?)? The example presented later in this paper deals with this very problem in some detail, but a brief analysis is warranted here.

The district in question would be evaluated thoroughly enough to define the input values required for the model. Such items as the quantity of each equipment type and manpower type available, the absenteeism and equipment breakdown rates, evaluation of work activities (frequency, severity, and location) and travel distances throughout the district are obviously needed if any reasonable analysis is to be made. After these and other values are entered into the model, the current situation can be simulated. Model output should be reasonably close to actual records for some test period (e.g., the last fiscal year), if the model input provided is fairly good and if the district's productivity is near the work standards used for prediction.

Next, the input may be changed to reflect two additional dump trucks and the model rerun. Again, a close look at output values may reveal any number of ideas. For instance, it is possible that the dump trucks were vastly underutilized because of one or more of several possibilities. It may be that insufficient material was available, or qualified equipment operators were unavailable, or that the particular work activities which were to be performed did not require usage of the trucks, or extremely bad weather happened to occur. Each of these possible reasons could be found through evaluation of the output provided. Subsequently, other related situations could be simulated, further enhancing user understanding of the situation.

For example, suppose the previous run of the model indicated that a shortage of equipment operators of type I negated much of the productivity possible by the inclusion of the two additional dump trucks. A third run of the model could be quickly executed with some reasonable increase in the number of type I operators available (e.g., maybe three more). Similar evaluation of performance reports for the district might indicate that the increase in operators (along with the addition of the dump trucks) was precisely the action needed. At this point, administrators charged with evaluating requests from maintenance districts would have a realistic (though certainly not exact) view of the probable results of the possible actions they might take with regard to the district's request for equipment.

It is important to understand that the simulation model is not expected to find the optimum solution for any particular problem, but rather is intended to provide sufficient statistical results to adequately describe the state of the system over a period of time during which a particular course of action was followed.

This simulation model was developed using the FORTRAN based simulation language known as GASP IV (General Application Simulation Program IV). The language was chosen because of its flexibility (and because it was known from the project's outset that the model would probably be modified on numerous occasions) and because FORTRAN compilers are widely available on virtually all large computers.

The Model's Logic

The model's logic (which follows the macro flowchart logic of Figure 1) is described next in an attempt to provide insight into the modeling approach and into the inner workings of the model itself. The simulation is begun by entering the necessary input values. This part of the model is extremely important since it provides the user an opportunity to specify the particular conditions which are to be examined, as well as the values which establish the boundaries of the simulation. An example of the first type of input is the specifying of the number of dump trucks to be used in the simulation, while an example of the second type of input is the value indicating the number of work periods that are to be simulated. Table 1 provides an abbreviated list of the model's input. Once these values are established, the actual simulation process may begin. Because of the crucial nature of this state of the process, the interactive input module was developed. It is discussed later in the paper.

Based on the work activity probability distributions entered as input to the model, a list of work activities which are to be accomplished is generated. Next, calling on probability distributions read into the model in step one (for items such as location and severity of the activity to be performed), a number of identifying parameters are specified for each work activity in the list. These activities are then stored to be called upon when actual scheduling begins.

Emergency activities, if any happen to occur, are generated next. These are not part of the normal sequence of work activities since emergencies occur at unexpected points in time. As such, emergency activities are considered for scheduling during that particular period prior to considering any regular activities.

Weather conditions for the week are generated next. Since the increment of time chosen for use in the model is a half day, ten different weather conditions (one for each period of the week) are generated. These are stored and referred to later.

A special set of weather dependent activities is generated next. On reflection, the reason for such an activity type is apparent. That is, some activities are worked only in specific weather conditions. For example, snow removal is necessary only when it snows. This type of activity is similar to an emergency activity in that its occurrence cannot be anticipated. It is different from an emergency activity, however, in that it is dependent directly on the weather. Once generated, these activities are stored with top priority consideration in the period in which they are to occur.

At this point, the simulation's clock is changed from zero to one. This means that period one is now to be considered for scheduling of work activities. The work activities list for period one is checked. If any work activities exist, the activity with the highest priority is considered first for possible scheduling. This activity may be an emergency activity, a weather dependent activity, or some type of regular activity. Regardless of the activity type, a search of the resources available is made to see if the activity can be worked. This is quite an involved procedure. The reason for the complication is the large number of possible resource combinations capable of satisfying the work activity (i.e., job) requirements. Several factors must be considered. For example, it may be that the work activity can be accomplished through the efforts of more than one crew arrangement (and the most preferred one available should be chosen) and that more than one resource base location may be required to provide the necessary resources. Also, since the resources for an entire work activity must be accounted for, each type of manpower, equipment, and material need must be considered individually against the corresponding resource availabilities, with the existing possibility of resource substitution included in the consideration. If consideration of the work activity is successful and acceptable resources are available to perform the task, the activity is scheduled and each of the resource availability files are updated.

Statistics are collected for the activity and control of the simulation process returns to the question,"Are any more activities to be worked this period?" This question emphasizes the fact that the modeling process discussed so far has dealt with only one activity. Each activity in the work activity list must go through the same process each period during the simulation.

Eventually, after all the possible work activities have been considered, the work period ends. At this point, some of the activities may have been completed, while others are still in progress. The completed activities are removed from the possible work activity list, some statistics are collected, and consideration is given to the question,"Is the week complete?".

If the week is not complete, the period number is increased by one and the activities currently on the work activity list are again considered one at a time. If the week is complete, it is necessary to carry forward all the unfinished activities as part of next week's work activity list. The activities already begun have a higher priority than those which have not yet been started.

Since the week has been completed, the simulation model next asks whether or not the entire simulation process is complete. If it is (and, eventually, of course, it will be), all the final simulation statistics are computed. If the simulation process is not complete, this means that another work week is to begin and the processes of activity generation, emergency generation, weather generation, and so forth are performed again.

The simulation model was designed and developed with the idea of being able to address a wide variety of frequently occurring highway maintenance situations. As such, a large number of statistics are collected during the model's execution and are printed at the conclusion of each simulation run.

Interactive Input Module

Introduction

It became apparent during the development of the model that the most difficult part of the simulation process for the user would be the steps related to developing and entering the model's input. There are several reasons for this. One, the process can be lengthy. The model requires a significant amount of input in order to perform a simulation run. Two, some of the input values must (by necessity) be estimated, if no actual data exists. Poor estimates or errors in the entry of the input could easily lead to erroneous results. Three, modifications to already existing data sets must be made with extreme care so that all remaining interrelated data values are correctly entered and properly sequenced. For example, removal of a dump truck from the equipment availability file must be accompanied by the removal of the truck's characteristics from the data set. Four, changes made in the data necessitate some type of "hands on" (i.e., either via cards or computer terminal) interaction with the computer and with a largely unlabeled set of data values. All of these reasons contribute to a high probability that the user might erroneously modify the data sets in some way. While some mistakes could lead to stoppage of the simulation run (i.e., premature program termination, accompanied by no useable output), other mistakes might easily go undetected, produce erroneous output, and lead to incorrect evaluation and decision making. The interactive input module was developed to circumvent these difficulties.

The Approach

The interactive input module was developed around several important ideas. These ideas were aimed at overcoming the input difficulties which had been encountered and which were described in the previous section.

The first two difficulties (i.e., lengthy input and estimated values) were overcome by presenting the user with an already existing data set (prepared with the aid of Louisiana Department of Transportation and Development highway engineers) to change from. The reason for this approach is quite simple. First, work activities performed by Louisiana highway maintenance personnel are sure to be quite similar to work activities performed by highway maintenance personnel in other states, so that new users would need only to make modifications unique to their situation. Second, it is generally regarded as easier to modify something which already exists than to begin from "scratch." Therefore, the idea of creating a "base data set" and working from it was step one in the process.

Difficulty number three, the problem related to the cascading effect of data changes and proper data sequencing, was not so easily dealt with. In fact, the problem has several aspects to it. One, data value entries cannot be accepted blindly. Values entered must be checked against actual or reasonable limiting values before being accepted. Two, the user must not be expected to be extremely familiar with the data set and must, therefore, be made aware of all related variables which must be given consideration when a particular, single change (e.g., to an equipment unit) is being made. Mainly, it is important that the user not forget any related modifications. Three, once a change has been incorporated, the process of updating all files and sequencing of data values must be performed successfully. These important considerations heavily influenced the organization of the interactive input module.

Difficulty number four, the fact that user-computer interaction is required, led to further consideration of the organization of the input module. Several factors had an influence on the module's design at this point. First, the approach had to be logical - logical in the sense that the user should not be asked to significantly change his thinking pattern in order to use the module. Two, closely related to comment one, the approach had to be useable by non-computer types of people. Three, the module had to have the capability of providing definitions and descriptions for the user.

Beginning with these ideas, the module evolved to include another goal. It must be streamlined enough for the frequent user, but descriptive enough for the novice user. This realization led to the current design format - a statement-alternative approach, with the capability of providing more complete descriptive information about the topic (or variables) being considered.

The Arrangement

The input module is subdivided into seven major input groups: equipment, manpower, material, work activities, base locations, weather, and emergencies. The module permits data changes within each group separately, but allows the user to access each group as frequently as he wishes. For example, if an equipment change of some type is desired (but no other data modifications are warranted), the user may go to the "equipment" section and be led through the data change process. However, if the user later decides to change the way a particular work activity is staffed, he may then go to the "work activity" section and be led through it, as well. The simulation program may be run after each modification.

The interactive input module is appended to the front of the simulation model. Figure 2 describes the relationship between the input module and the simulation model itself. In general, modifications may be made to the existing data set, the simulation program run (or not), and the data modifications retained (or not).

Figure 3 shows a portion of the prompting-response (i.e., interactive) sequence in the equipment section of the input module. User responses are clearly marked.

The next section (EXAMPLE) describes the manner in which the simulation model may be used to aid the decision process. A variety of output values are referenced. None of the statistics claim to be "the" answer. The simulation results must be taken as a whole and examined in light of the particular situation being considered. Table 2 presents a list of statistics provided by the model.

Example

Situation

The situation selected for this example is a fairly typical highway maintenance district. It consists of 30 men and 28 pieces of equipment. The district is currently recognized as producing at a less than acceptable level. There are many reasons for the poor productivity, some of the reasons are external (exceptionally large work load, poor weather conditions) and some are internal (insufficient resources). Highway maintenance engineers are asked to assess the district's activities and current status and to make recommendations for rectifying steps.

Input

The first step is to determine the district's present condition and to collect the necessary input values to allow the simulation model to be run. This step is of extreme importance, since it is on the foundation created by the input values that all future decisions are based.

Some of the input required is readily available and factual (e.g., the number of equipment operators of type 1), while some of it requires research (e.g., weather parameters for each season of the year), and much of it requires good judgment (e.g., the effect that a particular poor weather condition has on an activity). The amount and detail required in the form of input is significant, but the process is simplified considerably by the interactive input module. After the input quantities are entered and the program is run, a close look at the output is warranted.

Output - Initial Run

The initial run is meant primarily to reflect current conditions. In this case, the output was sufficiently close to that expected to be used as the basis for change. Of course, it might be that further fine tuning of input values is necessary before the user can feel comfortable with the output values generated.

The output provided a number of clues concerning the reasons for low productivity. Some of these are listed below:

(1) Unutilized manpower ... The manpower units initially available of the five manpower types specified (foremen, equipment, operator type 1, equipment operator type 2, equipment operator type 3, and labor utility) were 3,9,4,1, and 13, respectively. Significant percentages of each manpower type were not used for productive tasks each period.
(2) Unutilized equipment ... Results similar to those mentioned regarding manpower were found for equipment as well.
(3) Stockouts ... A number of inventory shortages were noted.
(4) Time loss reasons ... Twenty-five activities were defined and some of each were generated. It is expected that not all jobs could be worked, but it is hoped that the higher priority jobs are worked consistently and that only lower priority tasks are held up.
    The initial run showed that of the top six priority jobs, manpower was never a problem, but that the main causes for the job not being worked were lack of equipment, inclement weather, and insufficient material, in that order.

The insufficient equipment problem may be further investigated by determining (at least among the highest priority activities) which equipment units are being required. A brief look at the top six priority jobs from the activity characteristics file shows the following needs (only the first crew option is shown):

	EQUIPMENT TYPE									
Job	1	2	3	4	5	6	7	8	9	10
1	0	3	1	1	1	0	0	0	0	0
2	0	1	0	1	0	0	0	0	0	0
3	1	2	0	1	0	0	1	0	0	0
4	0	3	1	1	1	0	0	1	0	0
5	0	4	0	1	1	1	0	0	0	0
6	0	3	1	1	1	1	0	0	0	0

Each job (work activity) requires at least one equipment unit type 2 and exactly one equipment unit type 4. No other equipment type has as much demand. The difference between equipment types 2 and 4 lies in their availabilities. There are eight equipment type 2 units available, but only one equipment unit type 4. This means that only one of the top six priority jobs can be worked at any one time. An obvious alternative (although certainly not necessarily the best) is to obtain at least one more equipment unit type 4. Since the tool of simulation is being used, a unit of equipment type 4 may be added immediately and the situation revisited.

Output - Run 2

The results of the second run of the model were also quite revealing. Slightly more money was spent on maintenance activities (as expected with one additional piece of equipment), productive manpower utilization was up, productive use of equipment was increased (in fact, the addition of one equipment type 4 unit increased the utilization for all the other equipment units as well), material usage was increased, and successful scheduling of the higher priority jobs increased significantly. So, as a first step, the addition of a single unit of equipment type 4 to the resources of the district appears to be a step in the right direction.

There are more deficiencies, however. There is still significantly more demand for work (i.e., planned work activities) than there are resources to accomplish it. Unavailable equipment is still the primary reason for work stoppage. Manpower and material shortages still exist at a relatively high level. So, what next?

Subsequent Steps

Before considering other possible resource alternatives, a more thorough analysis of the work environment may be warranted. It has been noted that weather conditions contributed heavily to problems of scheduling work activities. A run in which weather parameters are slackened (i.e., statistically improved weather) might be performed to see what effect better weather might have on the situation.

If there is little or no change in the basic problems encountered, the next logical step is to return to those factors which highway maintenance engineers can influence - primarily, those factors associated with scheduling policies and resource levels. An example of effecting scheduling policies may be described by considering a typical work activity's characteristics. Suppose that the work standard for the task of patching the road base specifies that a foreman, two equipment operators of type 1, one equipment operator type 2, one equipment operator type 3, and one laborer are required. If, however, it is common practice for operators to work out of class (e.g., a type 2 operator might perform the work of a type 1 operator), it would not be unreasonable for highway maintenance engineers to group resources (i.e., combine operator types), which might improve scheduling success.

Another similar alternative also deserves mention. Experience has shown that even though the standard work crew may not be available, work may still be successfully accomplished at a rate approximating the standard rate. Such alternative work crew arrangements could be entered as second and third crew options.

The most obvious actions which might be tried by highway maintenance engineers are, of course, those related to varying resource levels. The next step for this particular example would probably deal with an increase in manpower availability, but more detailed analysis might lead the analyst to try any of a number of alternatives.

Simulation performed in this manner does not yield instantaneous results. It is apparent that the analyst is still very much responsible for the alternatives tried and the decisions made. In fact, the process is much like that of actually making the changes in reality, but the time, cost, and hassle factors are reduced to a minimum.

Summary

The highway maintenance simulation model is an attempt to provide highway maintenance management personnel with a laboratory in which various decisions may be tested. As in all laboratory experiments, the results are not exact replicas of real world activity. However, it is apparent that the model is of sufficient detail to provide output values which are reasonable approximations to reality and valuable aids to decision making.

The simulation model is currently operative on the Louisiana Department of Transportation and Development's computer facility. To that extent, it has already been successfully applied. The work currently being done is directed solely toward further development and implementation of the input module and fine tuning of the simulation model. Louisiana DOTD highway engineers are working closely with the researchers to assure appropriate model validation.

References

1. Pruett, James M. and Ertan Ozerdem. The Systematic Development of a Highway Maintenance Simulation Model, Transportation Research Board, Washington, D.C., January 1979.

2. Pruett, James M. and Rodolfo Perdomo. A Highway Maintenance Simulation Model, Transportation Research Board, Washington, D.C., January, 1980.

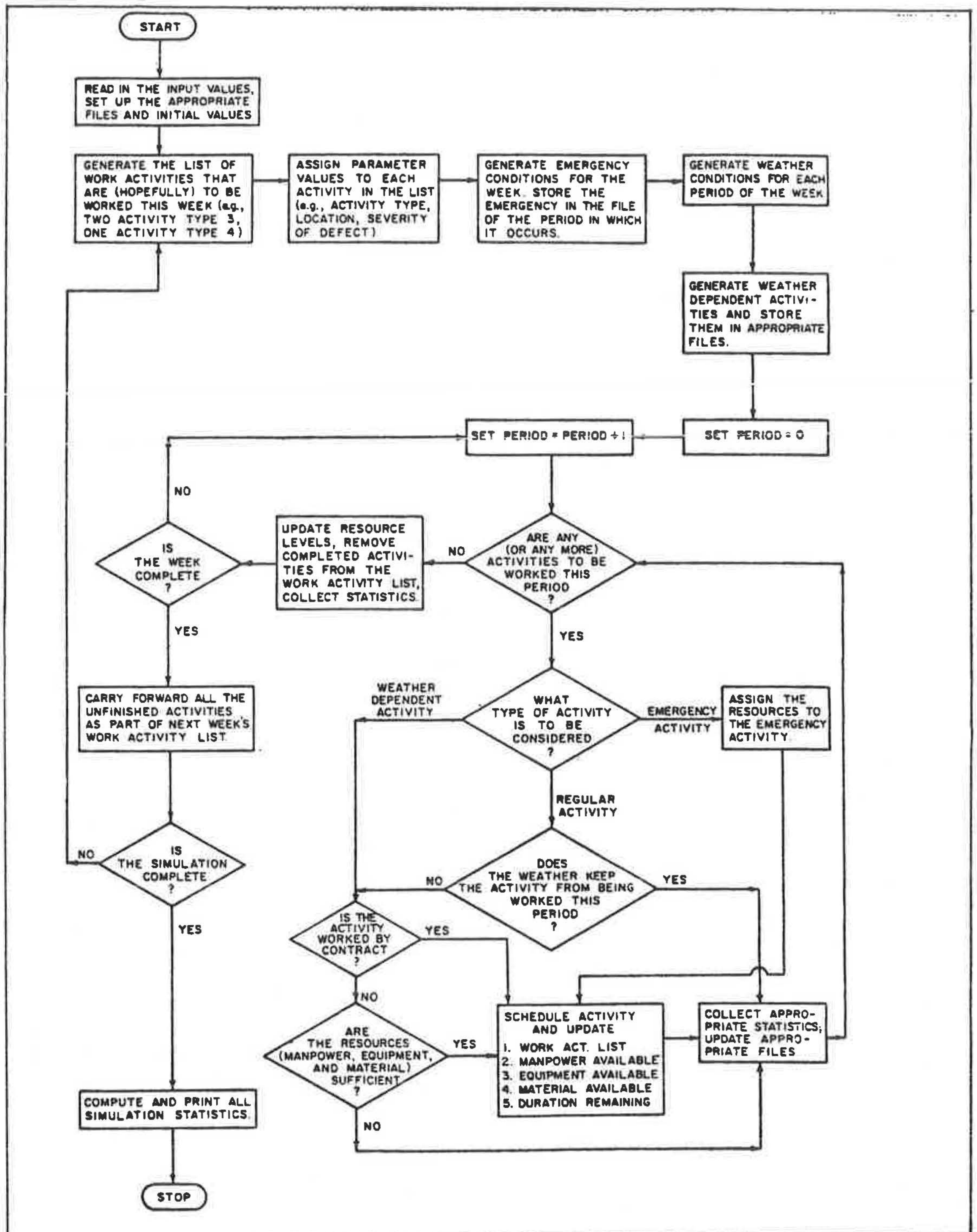

FIGURE 1. MACRO FLOWCHART FOR HIGHWAY MAINTENANCE SIMULATION MODEL

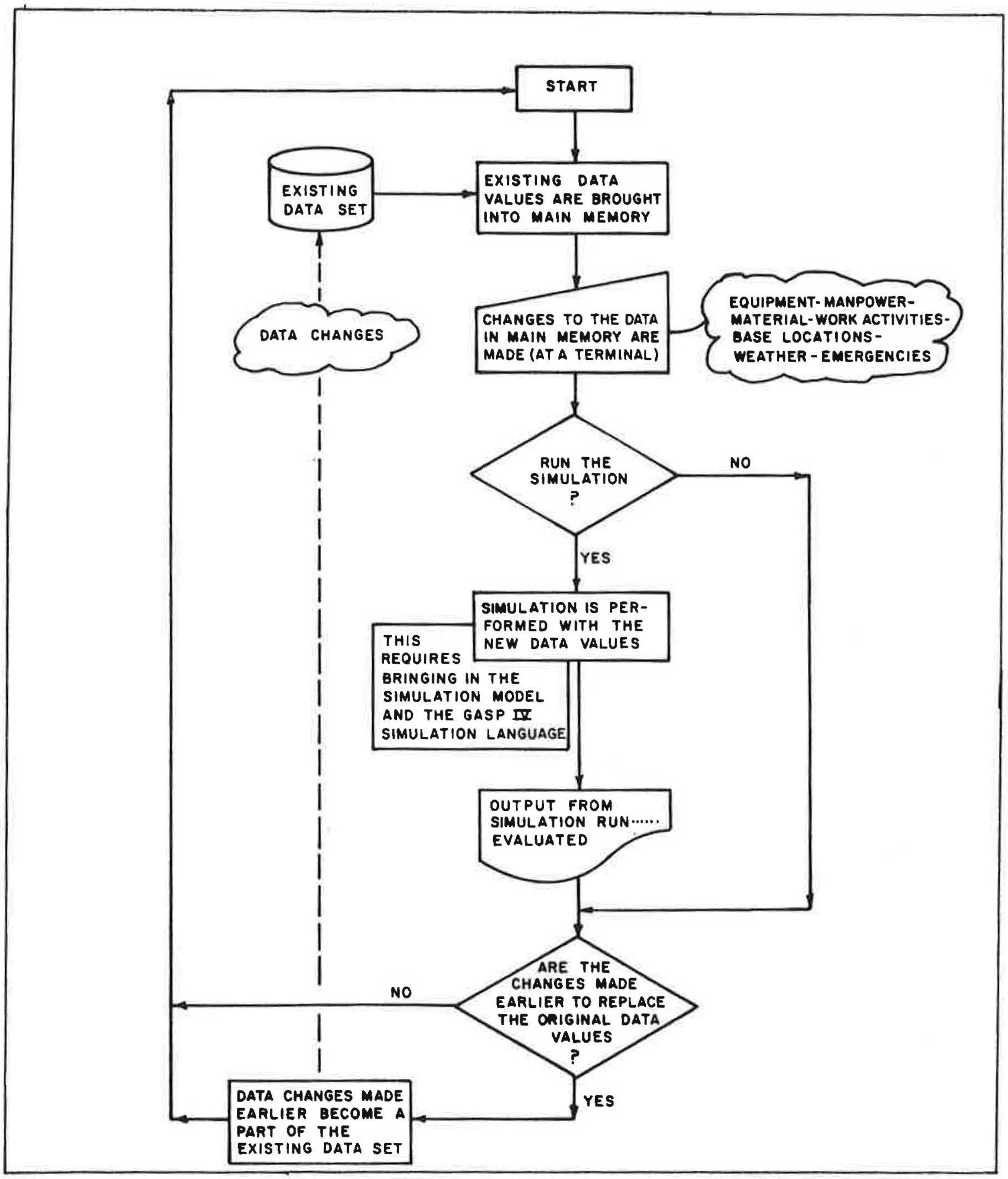

FIGURE 2.
RELATIONSHIP BETWEEN INPUT MODULE AND SIMULATION MODEL

```
  PLEASE ENTER EQUIPMENT TYPE (1, 2, ..., 10). ++
  ?
→ ?
   EQUIPMENT DESCRIPTIONS...
     NO.    EQUIPMENT TYPE.          NO.   EQUIPMENT TYPE.
    ( 1)    PICK UP TRUCK           ( 2)   DUMP TRUCKS (2 TON)
    ( 3)    KETTLE                  ( 4)   ROLLER
    ( 5)    STAKE BODY              ( 6)   MOTOR PAYROL
    ( 7)    GRADALL                 ( 8)   AIR COMPRESSOR
    ( 9)    MOVER (8')              (10)   MOWER (15')
  PLEASE ENTER EQUIPMENT TYPE (1,2,...,10).  ++
  ?
→ 7
  DESCRIPTION... EQUIPMENT TYPE 7
  CURRENT
  GRADALL
  NEW
  ?
→ test name
  NEW/CURRENT
  TEST NAME
  PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)        (2)        (3)       (4)          (5)        (6)
   BREAKDOWN  EQUIPMENT  AVERAGE  NO. PEOPLE      COST   UTILIZATION
      RATE     CAPACITY    SPEED  TRANSPORTED     INDEX      COST
      0.10       0.0        55         2.          0.0        9.89
→ ?
  DESCRIPTIONS OF THE DESIRED VARIABLE MAY BE OBTAINED BY ENTERING
  A QUESTION MARK UNDER THE APPROPRIATE HEADING.
  NOTE ... TO CHANGE A NUMBER TO 0.0, ENTER A NEGATIVE NUMBER.  ( EX, -1. )
  PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)        (2)        (3)       (4)          (5)        (6)
   BREAKDOWN  EQUIPMENT  AVERAGE  NO. PEOPLE      COST   UTILIZATION
      RATE     CAPACITY    SPEED  TRANSPORTED     INDEX      COST
      0.10       0.0        55.        2.          0.0        9.89
→      .15                  40.                               ?
  EQUIPMENT UTIL. COST...
       THE COST IN DOLLARS PER MILE OR PER HOUR CHARGED TO A
       PARTICULAR TYPE OF EQUIPMENT.
  PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)        (2)        (3)       (4)          (5)        (6)
   BREAKDOWN  EQUIPMENT  AVERAGE  NO. PEOPLE      COST   UTILIZATION
      RATE     CAPACITY    SPEED  TRANSPORTED     INDEX      COST
      0.15       0.0        40.        2.          0.0        9.89
→                                     -1.                    12.
      0.15       0.0        40.        0.          0.0       12.00
→    .20
      0.20       0.0        40.        0.          0.0       12.00
→    <return>
  PLEASE ENTER EACH AVAILABILITY MODIFICATION.  ++
```

Figure 3. Prompting Sequence from Interactive Input Module
(Note: → denotes user response)

Table 1. Summary List of Model Input

1. Single-value constants which provide limiting values for the simulation (e.g., number of work activity types, number of years to be simulated)
2. Description of activity types, equipment types, manpower types, and range of weather conditions
3. Distribution parameters for absenteeism and breakdowns of equipment
4. Manpower, equipment, and material costs
5. Resource availability files (manpower, equipment, and material)
6. Equipment characteristic file
7. Point-to-point travel times
8. Work activity characteristic file (specification by activity type for each crew option, equipment, and manpower needs, material needed, performance rate, indicators of effect of various weather types on work activity, etc.)
9. Probabilistic description of weather by season
10. Information regarding preferences of base locations for manpower, equipment, and material ordered by location within the district (or parish).
11. Work activity parameter sets for use in work activity occurrence distributions
12. Parameter sets for weather dependent activities
13. Parameter set for emergency activity duration and time between occurrence specification
14. Simulation specifications - length of simulation, number of files, etc.

Table 2. Summary List of Model Output

1. Input Listing - A complete listing of all model input.
2. Quarterly Performance Report - Report by activity type which includes planned and actual quantities for material and labor hours used, total cost, cost per unit, and hours per unit.

   The Performance Report also includes (for each activity type) labor cost, material cost, overtime labor cost, travel cost, fringe benefits and operational service (contract) costs.
3. Activity Frequency Table - The number of occurrences of each type of work activity in each section of the district (or parish).
4. Manpower Characteristics Table - A summary for each resource base location which lists by equipment type the number of periods worked, the number of absentee hours, the number of overtime hours worked, the average number of manpower units not assigned each period, the absenteeism cost, and stand by cost.
5. Equipment Characteristics Table - A summary for each resource base location which lists by equipment type the number of periods the equipment was in use, the number of hours the equipment spent in transit, the capacity of the equipment, the number of times breakdowns of the equipment occurred, and the average number of each equipment unit not assigned (leftover) to an activity each period.
6. Material Chracteristics Table - A summary for each material base location which lists by material type the average number of times each material was required, the average demand for each material type per period, the number of times an activity could not be worked because of lack of material, and total material demand per year.
7. Time Loss Table - A summary by activity number of the frequency and percentage of the reasons for time loss. Reasons categorized are insufficient manpower, unavailable equipment, insufficient material, and bad weather.
8. Time Loss Breakdown by Resource Type - A more detailed version of the Time Loss Table described in number 7. The table summarizes for each activity, the number of times that each equipment and manpower type caused a delay.
9. Manpower Substitutions - A summary of the manpower substitutions performed during the period simulated. The number of times (work periods) that equipment operators of type i were used when less qualified operators (type j) would have been adequate.
10. Overall Work Activity Statistics - Summary statistical values for each activity regarding its overall time in the system, including the number of occurrences, the average time length of occurrence, longest and shortest activity time span, and others.