Help for Highway Maintenance Administrators - A Highway Maintenance Simulation Model

James M. Pruett, Ph.D., P.E., Rodolfo Perdomo

Department of Industrial Engineering, Louisiana State University, Baton Rouge, Louisiana

Abstract

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 described in this paper is intended to help alleviate the highway maintenance administrator's problem by providing a flexible highway-maintenance-decision-laboratory in which alternative courses of action may be tested.

The simulation model is the result of a two-year project sponsored jointly by the Louisiana Department of Transportation and Development and the Federal Highway Administration, with a scheduled completion date of September, 1979.

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 question.

The idea of simulation is very straightforward. A logical model of the system is developed. The set of unique interrelationships which comprise the system are included in the model and the desired model results are specified. Assumptions are made. An appropriate simulation language is chosen and the model is coded for computer entry. The possibility for varying the input to the model is included. Data is collected. Distributions which describe probabilistic situations within the system are researched and developed. All these factors are entered into the model and the situation is considered (simulated) over time. The results may then be examined and decisions made.

The advantages of such an approach are readily apparent. Without making a binding decision (which may require money, time, and resources), the user can examine the probable results of incorporating each of several alternative courses of action. The final decision can then be made after the results have been evaluated and compared.

CH1437-3/79/0447-0453$00.75 © 1979 IEEE

1979 Winter Simulation Conference

This paper is concerned with describing the highway maintenance simulation model and the resulting model output. A discussion of the model's structure is presented first, followed by a look at the model's output and its use.

The simulation model is the result of a two-year project sponsored jointly by the Louisiana Department of Transportation and Development and the Federal Highway Administration, with a scheduled completion date of September, 1979.

MODEL STRUCTURE

The highway maintenance simulation model has evolved to its current state. Part of its evolution was planned and part of it has been developed to meet needs which were not recognized initially. Earlier versions of the simulation model included a number of simplifying assumptions which have since been modified to make the model more realistic. For example, at one time the model considered only one type of manpower, one type of equipment, and one type of material, whereas the current model version includes consideration involving multiple types of each. Nevertheless, the basic modeling approach has remained constant throughout the duration of the project. A comparison of several simplifying assumptions from the early stages of the model's development are presented along side of the current model status in Table 1. The table is intended to illustrate the evolutionary processes which the model has undergone and to provide a glimpse into the level of detail included.

The simulation model was developed using the FORTRAN based simulation language known as GASP IV (General Activity 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.

The key to understanding the model lies in gaining a basic understanding of the files which are utilized. Table 2 presents a list of the files employed. File 1, the event file, contains the events which are to be processed by the model. GASP IV dictates that file 1 be used in this manner. Files 2 through 11 are the work period files [A work period represents a half day (four hours) in the model]. That is, file 2 contains work activities which are to be performed during the first period of the week, file 3 contains activities which are to be performed during the second period of the week, and so forth. File 13 contains interruptable activities which have not yet been scheduled. (Interruptable activities are activities which may be preempted at any subsequent scheduling period by an activity of higher priority, even though the interruptable activity has not been worked to completion.) Activities in file 13 are moved to the next period's file and considered after the activities already in that file have been examined for possible scheduling.

In general, the simulation model accesses the files described as follows: A list of the activities which are to be worked is created and stored in file 2, the first period's work file. These activities are removed from file 2 one at a time and considered for scheduling. A decision is then made regarding the activity - either it can be scheduled for work or it cannot. If it can be scheduled, that fact is noted and it is placed in file 3 for work continuation next period or, if the work activity is complete after the current period, it is removed from the model. If it cannot be scheduled, the activity is placed in next period's file and is considered again next period. This process of file manipulation is performed on each activity during each work period until the simulation is complete.

MODEL 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 innerworkings 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 3 provides an abbreviated list of the model's input. Once these values are established, the actual simulation process may begin.

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 in file 2 to be called on 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, the time period during which the emergency is to occur is also generated. This is handled in the model by placing the emergency activity, an activity with a very high priority, in the file for the particular period during which it is to take place. As such, it is considered for scheduling during that 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 in an array 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 placed in the file for the period in which they are to occur with top priority.

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 work activities. The file containing work activities for period one is checked. If any work activities are in the file, the activity with the highest priority is removed 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 resource files is made to see if the activity can be worked with the resources available. 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 the work activity is successful in securing acceptable resources 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 file 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 (first, activities in the next work period's file and, then, activities in file 13) 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 and printed. 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.

As should be apparent at this point, the simulation modeling approach is very direct. Like most simulation models, the highway maintenance simulation model is complex primarily because of the interrelationships existent in the physical situation, that is, in the actual highway maintenance program itself.

MODEL OUTPUT

The simulation model was designed and developed with the idea of being able to address a wide variety of frequently occurring highway maintenance dilemmas. The following list presents a number of situations which the model is capable of considering.

1. Manpower, Equipment, and Material Questions. Probably the most basic of all considerations are those dealing directly with resources. For example, what effect would the addition of two equipment operators have? Or, what effect would the reduction of one equipment unit type 2

have? Or, how would doubling the availabilities of material type 3 effect the district's performance?

2. Cost Considerations. What effect would an increase in manpower costs have on the overall cost figures for the district? In considering equipment from two companies, each with different performance and cost figures, which equipment type would be more appropriate?

3. Absenteeism, Breakdown. Each industry seems to have expected absentee rates, but what benefit would be gleaned by a maintenance district if absentee rates could be reduced by some significant percentage? Similar questions could be asked with regard to equipment failure.

4. Performance Rate Considerations. Standard performance rates for the completion of each activity type may be varied (up or down) in order to examine the effect which such actions have on overall productivity.

5. Inventory Policies. Inventory policies are closely allied to the previously mentioned material considerations, but differ in that reorder points, minimum stock levels, and order policies are examined.

6. Overtime Policies. The model permits overtime work on specified activities in order for users to analyze trade offs between time and cost.

7. Effect of Weather and Seasonality. Weather is of primary importance to highway maintenance operations. As such, it is appropriate to vary weather parameters in order to determine if particular policies are affected significantly by changing weather conditions.

8. Contract vs. Non-Contract. Contract work is often performed to reduce the work load on existing crews and to accomplish the work in a more timely manner. A year's work load may be examined both with and without a contract labor force in order to determine the effectiveness of the venture.

9. Location of Resource Bases and Material Base Location Sites. Travel time is a significant factor in highway maintenance operations. As such, one important consideration is the location of the resource base locations and material bases within the maintenance district. It is possible to locate such a facility in different locations and then to evaluate the changes in performance for each locality.

10. Activity Priorities. It is obviously of significant importance to work activities in some order of preferred priority. However, specification of job priorities can influence overall productivity because of the product mix and conflicting resource needs. As such, it is possible to rearrange job priorities and examine the resulting productivity indicators.

In order to be able to successfully differentiate between various alternatives, such as those specified in the list just shown, a large number of statistics are collected during the model's execution and are printed at the conclusion of each simulation run.

None of the statistics actually 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 4 presents a list of output statistics provided by the model.

MODEL USE

The model is used by considering various alternative courses of action, eventually choosing from among the alternatives the most appropriate one for implementation in the highway maintenance district. An example is presented in order to clarify the manner in which the simulation model may be used.

Suppose that a highway maintenance district is recognized as being somewhat under productive. Highway maintenance engineers are asked to assess the district's activities and current status and to make recommendations for rectifying steps.

After collecting the necessary data for use in the model, the engineers run the program for the current situation. Such a run establishes a basis for comparison both with actual information about the district's operations and with subsequent runs of the simulation model.

It may be that the model output from the initial run will provide a number of clues regarding the reasons for the district's under productivity. Or, it may be that one or more possible alternatives have already been decided upon by the engineers involved in the process. Either way, the next step is to modify the input and run the model again. Suppose that the initial run had indicated that insufficient manpower was available to perform the district's tasks at an acceptable level of efficiency. The first follow up run might be submitted with a slight increase in key manpower units. The results might indicate that once manpower is increased to a more suitable level, equipment shortages are recognized. Run three might be submitted with increases in the number of appropriate equipment units. Results might indicate that once a balance of equipment and manpower is reached, productivity might be expected at a more acceptable level. Or, results might indicate that increasing the level of these particular equipment units adds little to the district's productivity and that other alternatives should be tried.

It is apparent that simulation performed in this manner does not yield instantaneous final results. In fact, those responsible for analyzing the situation are very much responsible for the alternatives tried and the decision made. However, the process is much like that of making the changes in reality, but the time, cost, and hassle factors are reduced to a minimum.

SUMMARY AND CONCLUSIONS

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 replicates 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. As such, it has already been successfully applied. The work currently being done regarding the model may be classified as fine tuning. This includes such work as improvement in the form of output presentation, improvement in the input procedure, and complete documentation of the model.

REFERENCES

A number of documents were used in the early stages of the development of the model. However, since they were not used in the preparation of the paper, they are omitted from the References section. References will be supplied upon request.

CONSIDERATION	EARLY MODEL	CURRENT MODEL
Number of possible work activities	5	Unlimited number
Weather	good,bad	Graded weather types and severity; some weather dependent activities
Seasons	1	Any number (typically, four)
Manpower, equipment, material	1 type of each	Multiple types of each; detailed differentiation in terms of capabilities for each resource category.
Resource locations (manpower, equipment, material)	1	Multiple locations possible for each; may be considered individually

Table 1. Abbreviated comparison of the Level of Detail Included in Early Model Development with Current Model Status

FILE	CONTENTS
1	Event file (specified by GASP IV)
2	Work activity list for period 1
3	Work activity list for period 2
4	Work activity list for period 3
	⋮
10	Work activity list for period 9
11	Work activity list for period 10
13	List of work activities which have been generated, but which have not yet been scheduled and are interruptable.

Table 2. Files Utilized in the Highway Maintenance Simulation Model

1. Single-value constants which provide limiting values for the simulation (e.g., number of work activity types)
2. Descriptions 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. Distribution describing frequency and location of occurrence of each work activity type and emergencies
11. Information regarding preferences of base locations for manpower, equipment, and material ordered by location within the district (or parish).
12. Work activity parameter sets for use in work activity occurrence distributions
13. Simulation specifications - length of simulation, number of files, etc.

Table 3. Summary List of Model Input

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, and travel cost.
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 manpower type the number of periods worked, the number of absentee hours, the number of overtime hours worked, and the average number of manpower units not assigned each period.
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 Characteristics Table - A summary for each material base location which lists by material type the average number of each material type remaining in inventory, the number of times each material was required, the average demand for each material type per period, and the number of times an activity could not be worked because of lack of material.
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. Overall Work Activity Statistics - Summary statistical values for each activity regarding 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.

Table 4. Summary List of Model Output

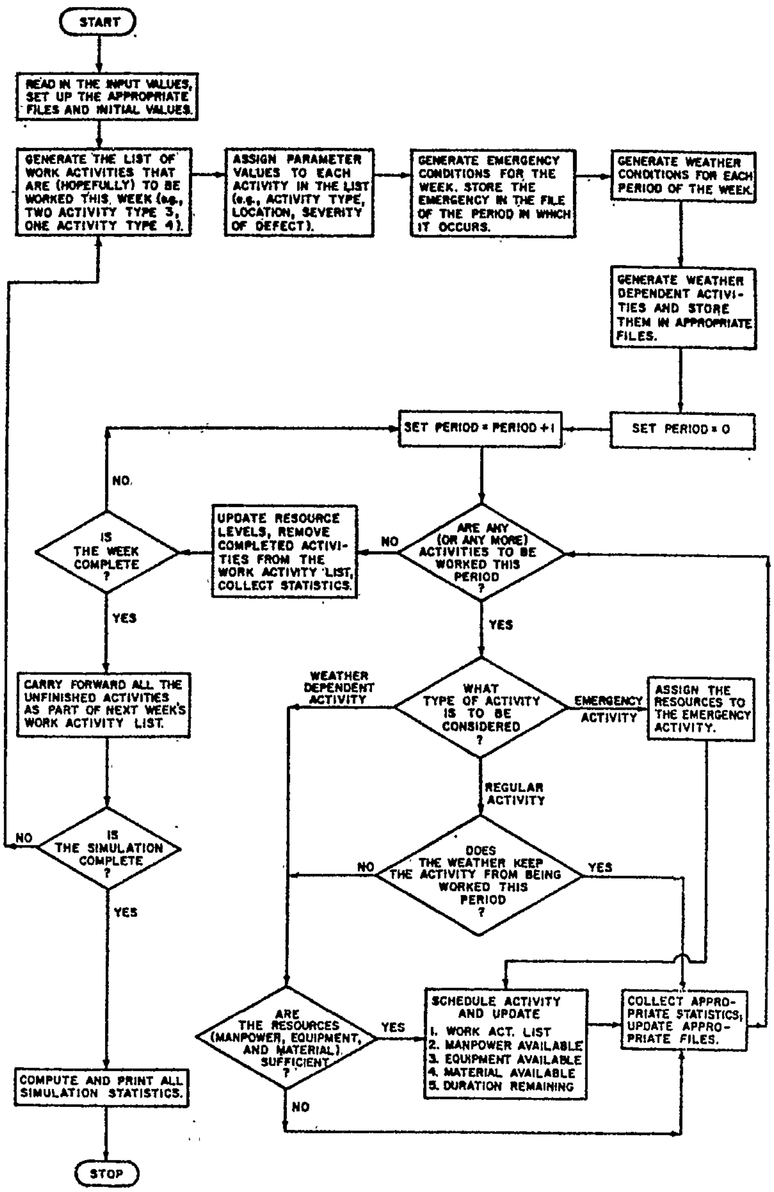

FIGURE 1. MACRO FLOWCHART FOR HIGHWAY MAINTENANCE SIMULATION MODEL

James M. Pruett is an associate professor in the department of industrial engineering at Louisiana State University in Baton Rouge, Louisiana. A registered professional engineer in Louisiana, Dr. Pruett has done work for Texas Instruments, Western Electric, Ethyl Corporation, and IBM among others. His primary interests lie in the areas of computer-aided decision making techniques and project management.

Rodolfo G. Perdomo recently received his master's degree in industrial engineering from Louisiana State University. Mr. Perdomo plans to pursue a career in the area of sugar cane processing.