NATIONAL BUREAU OF STANDARDS REPORT

9938

A SIMULATION OF A HIGHWAY MAINTENANCE OPERATIONAL UNIT



U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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A SIMULATION OF A HIGHWAY MAINTENANCE OPERATIONAL UNIT

by

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PREFACE

This report is submitted by the Technical Analysis Division (TAD) as the final report on a study of "The Application of Systems Analysis to Highway Maintenance." The study was sponsored by the Office of Research and Development of the Bureau of Public Roads (BPR) in accordance with their authorizing memoranda dated March 24, 1967 and July 3, 1967.

The study was conducted in two phases. Phase I, covering the period January 1, 1967 to July 1, 1967, was essentially a broad examination of highway maintenance and the identification of problem areas where systems analysis techniques appeared to offer some promise. At the conclusion of the Phase I period, it was recognized by BPR and TAD that in order to realize the greatest benefit from the study, it would be necessary to channel the remaining resources for the study into a single problem area; the one selected was the development of a simulation model of a typical highway maintenance depot. Such a simulation, if it could provide measures of the effects of the variables which significantly influence the productivity and effectiveness of a depot, would be valuable to highway maintenance management. The Phase I final report, dated June 30, 1967 summarizes this portion of the study.

The effort during the Phase II portion of the study, in the period July 1, 1967 to July 23, 1968 concentrated on structuring and developing the simulation model. The model is described in this report.

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Available resources for the study did not permit the development of the model to reach its full potential. However, a modular approach to the design of the model allows for future incorporation of additional features, and the work accomplished has been documented so that resumption of development may be undertaken with a minimum of effort.

The TAD team on this project consisted of W.F. Druckenbrod (Project Leader), H.D. Bouland, W.G. Hall, * and J.A. Yurow. The team wishes to express its appreciation for the valuable guidance and assistance provided by M.J. Kilpatrick, R. McQuate, and W.N. Records of BPR, and for the cooperation and assistance of the Maryland State Roads Commission personnel of the Upper Marlboro, Maryland highway maintenance unit. Appreciation is also expressed for the valuable assistance in structuring the model offered by other members of the TAD staff.

Mr. Hall is with the Operations Research Section of the Applied Mathematics Division in NBS.

A Simulation Model Of A Highway Maintenance Operational Unit

I. Purpose

The purpose of this report is to describe a simulation model of a highway maintenance operational unit (or depot), developed to provide highway maintenance management with a quantitative means of evaluating the effect of different job scheduling and resource allocation policies on the productivity of a highway maintenance unit. This research was sponsored by the Office of Research and Development of the Bureau of Public Roads (BPR), under a task assignment entitled "Feasibility of Operations Research Techniques for Highway Maintenance."

The report also contains a summary discussion of the Phase I effort accomplished under this task assignment.

The supplement to this report contains machine oriented information such as the flow charts and the computer program augmented by pertinent explanatory notes and information.

II. Discussion of Phase I Effort

The original intent of this study was to determine the feasibility of applying operations research or systems analysis techniques to lower the cost or improve the quality of highway maintenance operation.

A. Systems Analysis or Operations Research Techniques

Systems analysis, or operations research, is the application of various techniques to identify the sub-elements of a system, define their characteristics, and analyze their interactions, for the purpose of determining whether the total system is achieving an optimum or desired performance. The meaning of optimum or desired performance could range from the actual physical performance of the system to its economic or benefit/cost performance.

In system analysis the essence of the real-life system may be represented by a model of all the relevant variables in the system. The model is developed, and the consequences of changing the key variables in the model can be determined by the application of one or more of the following operations research techniques: (1) by analytical formulation, (2) by simulation, and (3) by specialized techniques.

1. Analytical Formulation

Analytical methods require a broad definition of the system, and a set of simplifying assumptions, in which the relationships between elements are expressed by means of mathematical formulas. Analytical methods can provide well defined formulations which may be employed to produce "optimum," or best solutions according to specified criteria. The formulas used in analytical methods may be based on the statistical analysis of empirical data, or on theory. Statistical analysis yields insights into relationships between variables. Because of the large number of uncontrollable variables in real life, this approach may be difficult. On the other hand, an operation may be explored through mathematical formulas constructed on the basis of theory. Such formulas relate the output of the system to its inputs. The parameters in the formulas may be obtained empirically. Under the heading of analytical approaches we list: linear programming, inventory models, queueing theory, sequencing models, replacement theory, etc., some of which are discussed in more detail later in the report. Further details regarding all of these methods can be found in most texts on the fundamentals of operations research (21).

2. Simulation

In a computer simulation the computer represents the dynamic behavior of a system. The computer simulation exercises the interaction of a large number of time-dependent variables. The operational game can also be a type of simulation. In a game, human participants play roles and make decisions within constraints specified by a prepared scenario. Such decisions are usually based on experience, and the decision process may be too involved to be represented in a computer simulation. A

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game can provide more flexibility than a computer for studying systems where human behavior is important.

3. Other Methods

Some problems do not lend themselves to solution by analytical formulation or simulation methods. Here other techniques can be useful.

One such technique, that is useful where variables cannot be quantified, involves a ranking procedure based on expert consensus. For example, Honeywell Incorporated, uses a method called PATTERN (Planning Assistance Through Technical Evaluation of Relative Numbers) in which a committee of experts ranks programs vertically, in terms of national objectives, and horizontally, in terms of timing and state-of-the-art. The Rand Corporation has experimented with a similar approach-called the Delphi Method. Using this method, a committee of experts may arrive at a consensus, through trial-and-error and in a feedback process.

B. Highway Maintenance

Highway maintenance includes the performance of tasks such as patching roads, mowing grass in right-of-ways, grading road shoulders, maintenance of drainage ditches, maintenance of road side landscaping, maintaining communication signs and traffic signals, repair, and maintenance of bridge structures and guard rails, road patrol and inspection, and similar functions required to preserve the public's investment in

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the highway system. In addition to these functions, highway maintenance includes other tasks such as snow removal, salting, and sanding operations, erection of snow fences, and emergency repair required by accidents or natural disasters. To a limited degree, highway maintenance also accomplishes minor road improvement programs, although most major programs are funded as new construction. Highway maintenance problems have not received the management attention and the benefit of research and development effort in the same degree that have the planning and development of new highways. Rather, it has enjoyed little or no status as a career field, and has depended to a large extent on maintenance personnel at the working level for the development of improvements in performance. However, because of the continuing increase in highway mileage and the growing public demand for safer and better maintained highways, these methods can no longer suffice. More sophisticated methods are required for identifying, analyzing, and correcting out-dated management and operational procedures.

In considering the application of systems analysis or operations research techniques to highway maintenance, the highway maintenance system might be regarded as consisting of three levels; (1) the national, (2) the state, and (3) the operational levels.

1. National Level

Considerations at the national level might include: (1) maintenance requirements for the national highway network, (2) the fifty state highway departments, (3) the Bureau of Public Roads, and (4) the

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constraints represented by the nation's natural, political and socio-economic environments. Because of the difficulty in identifying and quantifying these considerations particularily in view of the lack of information and firm guidance on national policy and implications, it was decided that it would be premature to attempt comprehensive analysis at this level.

2. State Level

Considerations of a highway maintenance system when viewed at the state level might include: (1) resources available to the state highway department such as, men, funds, materials, equipment (constructive agents), (2) the natural and socio-economic environment in which the department operates (destructive agents and constraints), (3) the existing state highway system, and (4) present and future user requirements (as related to benefits). The three following questions could be of concern to a maintenance manager at the state level:

- (1) What should be the overall quality level of highway maintenance?
- (2) What should be the long-term future investment policy; i.e., should more effort be put into higher quality construction and into research to achieve long-term reductions in maintenance cost?
- (3) To what degree should maintenance operations be decentralized, e.g., how many depots or individual operating units should there be and of what size? What maintenance operations should be handled at the state level?

The question regarding the appropriate quality level of highway maintenance may be answered by the application of benefit-cost techniques. The cost of different levels of maintenance quality can be determined by engineering estimates. Benefits might be estimated by: (1) economic analysis of transportation, (2) operational games, (3) consensus techniques, (4) user questionnaires, and (5) other user or consumer market research techniques. On the question of future investment policy, again the application of benefit-cost anlaysis (with careful consideration of discounting future benefits and costs) can be used to determine best means for reducing future maintenance costs. As an example, a preliminary model for comparing trade-offs between highway maintenance and construction costs is presented in Appendix A of the Phase I Final Report (29). The evaluation of efforts to be put into research is somewhat more difficult. However, some answers may be obtained through expert opinion ratings and similar techniques. The question of how many depots a state highway maintenance agency should maintain is similar to the problem of how many warehouses a company needs to distribute its products, on which considerable research effort has been expended. Various techniques are applicable to this type of problem, such as, linear programming methods, the transportation algorithms (21) and simulation Appendix B of the Phase I Final Report (29) shows an example of how the transportation method may be applied. Some work has also

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been done on the location of warehouses using the "Centroid" or "Center of Gravity Method" which involves a common concept frequently used in physics and mechanics. The Management Science Staff of Standard Oil of Ohio developed a computer program (22) to determine the optimum location of warehouses. Examples of the use of these methods are also presented in Appendix B of the Phase I Final Report.

3. Operational Level

Finally, consideration of the highway maintenance system at the operational level would include the men who operate a local depot (or operational unit), the equipment and materials stored there, and the highways of a local geo-political subdivision of a state for which the unit is responsible. Highway maintenance jobs are scheduled in these operational units, manpower, equipment, and material resources are allocated, and the assigned resources are utilized in accomplishing the jobs. There are a number of operations research methods for solving problems associated with those functions. Some of these are:

Problem	Standard Analytical Method
allocating resources (man-machine mixes)	assignment problem, transportation algorithm (both of which are special cases of linear programming)
routing crews through a network	network theory, linear programming

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Problem	Standard Analytical Method
scheduling jobs	inventory models, queueing theory
replacing maintenance equipment	replacement models

Other analytical methods of operations research may be applied to solve highway maintenance problems. Appendix C of the Phase I report presents a preliminary mathematical model which serves to identify which of the following strategies, on the basis of cost, is the most useful for resurfacing roads.

- (1) To patch as failures occur with no resurfacing;
- (2) To patch and resurface at fixed intervals;
- (3) To patch when failures occur, but resurface at fixed intervals;
- (4) To patch at fixed intervals with no resurfacing; and,
- (5) A combination of the above strategies

Many highway maintenance operations involve traveling on a road (or highway) network. These operations, such as route inspection, snow clearing, salting, and sanding, etc., may be approached as problems of minimizing the total distance traveled in the network, under certain constraints (one-way roads, returns for gas and repairs, reloading of material, etc.) Appendix D in the Phase I Final Report shows an optimum method for traveling a network, starting at one point and returning to the same point in the network, so that:

- (1) Each one-way path is traveled at least once;
- (2) Each two-way path is traveled in both directions--at least once in each direction; and

(3) The total distance traveled by a vehicle is a minimum.

Linear programming might be applied to highway maintenance problems, such as snow removal techniques and the de-icing of roads. A straightforward application of linear programming might be used to find the mixture of salt and calcium chloride which is most effective under given constraints. Such linear programming studies would have to be preceded by statistically designed experiments to determine the effectiveness of different mixtures of calcium chloride and salt for dissolving ice, under different levels of other variables such as moisture, temperature, wind velocity, and other weather parameters (some of which may be treated as random variables). One may consider the minimization of a total cost function which includes the cost of chemicals, labor, and equipment, plus the cost of failing to remove the ice from the road, as a criterion in such a linear programming study.

Dynamic programming methods are another example of methodology for the solution to operating problems of highway maintenance. In dynamic programming allocation decisions are applied sequentially, so that the long-run effectiveness of management policies are optimized. This technique would be applicable to highway maintenance problems in cases where a series of sequential commitment of resources, or of consecutive decisions, must be made. Unlike linear programming, dynamic programming techniques have not been systematized to the point where a problem can be formulated and solved very quickly.

Analytical methods serve to obtain optimum solutions in specified situations. A broader approach to the problem lies in the use of computer

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simulation studies. A computer simulation represents the real-life-interaction among the factors that enter into the operation of a highway maintenance depot, men, materials, and equipment. The simulation serves to highlight existing problem areas in the operation of an enterprise. In some instances, through repeated trials, it can also provide optimum solutions. The simulation of a highway maintenance depot can be used to test management procedures and to provide a framework for the study of maintenance-management problems.

C. Phase I Findings

Generally, analytic techniques are more applicable at the operational level of highway maintenance where measures and interactions are better defined. Other less quantitative approaches may be applicable at the national and state levels. Figure II-1 shows a matrix of problems and candidate techniques for solving them.

Perhaps, theoretically, an analysis of the highway maintenance system should start at the "top" analyzing the national system in a broad sense. For example, it could establish and analyze national highway maintenance goals and then work "down" from there. However, it must be borne in mind that while an analysis of the broadest system (national) may result in significant payoffs to the public, the precision in defining important variables and their functional relationships may be difficult. On the other hand, from a more practical point of view, the analysis should probably start at the "bottom" by analyzing the operational unit, because at this level problems are more tractable to rigorous analysis and more data may be available. Ideally, complementary studies at perhaps each level are needed, with ample feedback as progress is

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Figure II.1 Problem - Technique Matrix

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made. Because of limited resources, TAD chose to start by analyzing the operational unit for the following reasons:

- Because of the general commonality of those units to all highway maintenance operations, the study would have maximum utility. All highway maintenance functions, whether they are being performed on state, county, or local community, highways, roads, or streets are accomplished by operational units with somewhat common characteristics.
- (2) Since those units actually use most of the funds allocated for highway maintenance, an improvement in their efficiency and/or the quality of their operations would have a significant impact on highway maintenance.
- (3) A more rigorous, quantitative analysis may be made at this level of the highway sub-system than at a higher level, because the required input data are more readily obtainable.
- (4) An in-depth analysis of maintenance depot operations will necessarily consider and reflect variations in highway maintenance management policies and direction.

A computer simulation model of an operational unit can be very useful for making this analysis, because of the large number of variables and the dynamic conditions prevailing in a highway maintenance depot. Computer simulation is one of the most significant advances in the field of management science in the past decade. It provides the ability to determine the effect of employing alternate policies to such problems as inventory, resource allocation, distribution, equipment replacement, etc., on the effectiveness of a complex system, without disrupting its operation and in a fraction of real time. The principal general benefit of the highway maintenance operational unit model is to assist highway maintenance management in the selection of those operational and management policies which will result in the highest productivity of the unit for a given level of resources. For example, the model can provide answers to questions like: what is the effect of increasing the number of twoton trucks available to the unit? Similar questions could also be asked regarding the effect of changing the number of personnel, mowing machines, etc., or it can answer also questions concerning the effect of simultaneous changes in the controllable variables of the depot, like: would the purchase of units of a certain type of equipment increase the effectiveness of a depot to a greater extent than the addition of labor to the depot's labor supply? This second type of question relates to significant trade-offs, when interchangeable resources of two or more kinds are available.

The application of an operational unit simulation model will also result in another broad benefit in the highway maintenance area by stimulating the collection of meaningful operational data. It is anticipated that the model will be useful in identifying and defining the kind of data needed for comprehensive analyses, and should also result in a degree of standardization in the type and form of data collected by the various highway maintenance agencies that use the model. Thus, it could establish a more effective basis for conducting meaningful comparative analyses between different operational units.

In approaching the design of the simulation (model), the general philosophy of the project team was that the model should be sufficiently flexible to be used by most state highway agencies for evaluating the effect of employing alternate management, operational, and resource

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allocation policies on the effectiveness of their highway maintenance operational units (highway maintenance garage or depot). In addition, for practical purposes, the model should be as simple as possible, but should be capable of reflecting the effect of changing any significant variable within the operational unit being simulated.

The following sections of this report discuss and present in detail the simulation model of a highway maintenance operational unit.

III. Discussion

The actual maintenance of the nation's roads and highways is performed by units structurally and operationally similar to the highway maintenance operational unit simulated by the model described in this report. Units may differ in the number of men and equipment assigned to them and in the mileage and types of roads under their jurisdiction, but they all have the following common characteristics:

- 1. The unit is responsible for performing a variety of highway maintenance tasks on the road net of a geopolitical subdivision such as a state or a county. Some tasks can be anticipated and scheduled with a reasonable degree of accuracy, but many of them occur randomly and although experience may provide some basis for estimating the workload imposed by those tasks, a specific job cannot be identified and scheduled except on a short range basis.
- 2. The work which a unit plans is subject to delays and reduced productivity in its execution. This results from adverse weather conditions, time spent in traveling to and from job locations, equipment malfunctions, matching of crews to jobs, material shortages, employee absenteeism, the time spent in training personnel, interuptions of scheduled work by unforeseen, high priority jobs, and a host of other day-to-day problems.
- 3. The unit's effectiveness and productivity is responsive to its parent highway department's management policies and philosophies with respect to unit location, unit jurisdiction, and resources available to the unit.

The highway maintenance manager has traditionally based his decisions and policies on intuition arising from past experience. There is little or no quantitative information available to tell him how the above characteristics affect the productivity of his highway maintenance operational unit. The expansion of the nation's highway system and the growing emphasis on highway and traffic safety have focused attention on the increasing importance and cost of highway maintenance. Tomorrow's highway maintenance manager requires more powerful aids in utilizing his resources in the performance of highway maintenance tasks in order to do an effective job and to keep the cost of doing the job within reason. The highway maintenance operational unit simulation model described in this report is a step toward offering the highway maintenance manager the kind of assistance he will need. It does this be making available to him a tool for measuring the effect, on unit productivity, of different management policies for scheduling highway maintenance tasks and deploying his available resources to accomplish those tasks.

The lack of good data on the productivities and costs of various crew combinations in performing highway maintenance tasks creates a problem in achieving immediate maximum utilization of the model. These data are required in order to obtain true measures of unit effectiveness under different policies for job scheduling and crew allocation. Analysis of data collected by a few states indicated poor intrastate correlation between different crew mixes and their productivity for specific maintenance jobs. As a result, the model assumes values of crew productivity based on both the existing data and expert judgment. The importance of collecting experimentally controlled crew productivity data cannot be overemphasized, if highway maintenance is to make significant strides in increasing the efficiency of highway maintenance units.

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IV. General Description of the Model

The model is designed to simulate the interactions of significant variables of a typical highway maintenance operational unit, and to estimate the results of these interactions. The user of the model may enter inputs to the model peculiar to his unit such as: the road network under its jurisdiction, the number and distribution of its men and equipment, its crew productivity and cost factors, and its workload in terms of job types.

The model consists of three main elements which interface with each other: (1) the input element, (2) the allocation element, and (3) the output element.

A. <u>Inputs</u> - Inputs to the model consist of the jobs to be performed by the unit, the roadnet that the unit maintains, the manpower and equipment resources of the unit, and the weather.

Jobs - The highway maintenance jobs are classified into three categories:

- 1. <u>Heavy Maintenance</u> those specific jobs which can be anticipated and scheduled. For example, this category (see List of Jobs, Page 34) includes jobs such as mowing, snow fence erection and removal, etc., which are known to occur on a repetitive basis and for which the workload is known with a reasonable degree of accuracy. Also included are major projects which are planned and budgeted in advance, such as, a major road resurfacing project, or a shoulder improvement program along a large portion of a road or highway.
- 2. <u>Regular Maintenance</u> those jobs which can be anticipated but cannot be identified specifically and planned except on a relatively short term basis (a few days or a couple of weeks). This category (Job List, Page 34) includes jobs such as surface patching, shoulder repair, and others, which can be expected from experience to occur, but the specific size, types, and location of the work to be done on a single day cannot be determined until the need for it is actually discovered.

3. <u>Special or Emergency Maintenance</u> - those jobs cannot be anticipated and can be planned only on a very short term basis (a matter of hours). This category (Page 35) includes such jobs as emergency repairs required following manmade or natural disasters. These occur randomly and result in critical situations that require immediate action on the part of the unit. Snow and ice removal are also included in this category, because although these jobs can be anticipated during the winter in certain parts of the country, their actual occurrence can be predicted only on a very short range basis.

Jobs in the above three categories are described on the job cards by <u>type</u> (surface patching, mowing, shoulder patching, etc.), <u>size</u> (tons of surface patching material, acres to be mowed, linear miles of shoulder patched, etc.), and <u>location</u> (the numbered grid in the unit's road network in which the job occurs). The job cards also show type of road; the minimum and maximum time allowed for doing the job, a deadline for job completion; and a date of discovery of the job.

<u>Resources</u> - Another input to the model is the unit's inventory of resources (men and equipment) available for accomplishing the jobs. This inventory is a listing of the various crew combinations, i.e., men and equipment, that can perform specific types of jobs. For each crew combination that can perform a specific job, productivity and cost factors for performing a unit of work are also entered on the inventory cards.

<u>Roadnet</u> - Another input to the model is the network of roads under the unit's jurisdiction. This is defined by superimposing a grid composed of square cells over the unit's network of roads. The cards for the roadnet contain an identification number for each cell, the highway route number of each road in the cell, the types of highways, and the mileage of each highway to the nearest 1/10 of a mile.

<u>Weather</u> - The weather as it actually occurred in the unit's area during a selected calendar year is entered in the model. The weather for the selected year is divided into nine categories based on temperature and precipitation. For each day of the year, the weather for the day is represented by one of the nine categories.

- B. <u>Weekly Plan</u> The computer uses the above input data to generate a weekly work plan. The plan is a rough one and serves as a basis against which to''score'' the work actually done. To make the plan, the computer:
 - 1. Multiplies all resources by the number of workdays in the week to get total weekly resources.
 - 2. Parcels out these resources in the form of crews to jobs which are either past due or may be foreseen within the ensuing week.
 - 3. Reduces the resources available for the plan as it parcels them out.

When it parcels out resources to jobs, the computer attempts to assign the crew type having the least unit cost (cost per work unit) for the given type of job. The computer, however, does not keep track of the crew assignments that it makes in the plan. It only depletes the week's resources as <u>though</u> the assignments were made. The computer keeps track of the actual assignments only during the actual workdays.

C. Daily Work

Each simulated day:

- 1. The computer ranks jobs for selection.
- 2. It identifies candidate crews for each job in the ranking.
- 3. It tries to assign to the job, the candidate crew with the lowest unit cost for the job.*
- 4. When it finishes assigning these crews it tries to assign additional crews from left-over resources.

The basic procedure may be complicated by:

- 1. The occurrence of weather conditions which do not permit planned jobs to be done.
- 2. The occurrence of weather-created jobs or emergency jobs.

Cost here includes travel time. Costs are based on an 8-hour day. Productivities refer to production rate at the job site.

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- 3. Employee absenteeism.*
- 4. Equipment failure.*

The preceding contingencies are treated as follows in the model:

- In the event weather conditions on a particular day or 1. days of the week preclude the performance of some or all scheduled jobs, the job backlog (heavy and regular maintenance) is searched for jobs that can be performed under the prevailing weather conditions. The crews assigned to the scheduled jobs that can not be performed are reassigned to jobs that have been identified as possible to perform under the prevailing weather conditions. Crew assignments are made in the same manner as for the weekly schedule; i.e., the least cost, compatible crews are matched to the jobs until either all available crews are assigned or all possible jobs have crews assigned. If all possible jobs have crews assigned and unassigned resources are still available, those resources are assigned to miscellaneous jobs such as yard maintenance, equipment maintenance, etc. When weather conditions permit the resumption of the weekly schedule of tasks, those tasks are initiated with the previously scheduled crews. Planned work that was not completed during the week is added to the workload to be scheduled for the following week.
- 2. When a special or emergency job occurs, it will be accomplished by a crew that can complete the job within the time allowed, at the least cost. The time spent by the crew at its originally assigned job is reduced by the time it spends on the emergency job, including roundtrip travel time and set-up time. In effect, an emergency job is treated as if it were executed at either the end or the beginning of a day.

An important factor in the productivity of a highway maintenance operational unit is the amount of time that the crews spend in traveling between the depot and job sites. The simulation model deals with this by including

These do not occur in the present model, but could be added without no conceptual difficulty.

time spent in travel in the cost of assigning a crew to a specific job.

Crew travel times from the unit headquarters to any cell are entered as input by the user. Travel times as input to the present model were calculated using the Moore Minimum Path Algorithm.*

The computer maintains an accounting of the work planned and the work completed on a daily basis. Scheduled work that was not completed at the end of a given week remains in the job inventory and is subject to inclusion in the next weekly plan. There is no limit to the number of weeks that can be simulated, as long as there are appropriate jobs remaining in the job inventory.

- D. <u>Outputs</u> The simulation model is designed so that outputs required to meet specific needs may be obtained. Initially a daily,** weekly,* and annual summary containing the following information is printed out:
 - 1. Labor hours and cost by labor classification.
 - 2. Equipment hours and cost by equipment type.
 - 3. Work units planned, accomplished and carried over.
 - 4. Daily weather conditions.

The model in its present form does not treat procurement, availability or cost of maintenance materials.

The following sections of this report contain a detailed description of the highway maintenance operational unit simulation model, the computer program and the rules governing its operation. The Maryland State Roads Commission

** The user may surpress these if he wishes.

^{*} For details of the Moore Minimum Path Algorithm, see the "Traffic Assignment Manual," U.S. Department of Commerce, June 1964, pp. V-7 to V-12.

unit at Upper Marlboro, Maryland was used as a representative unit while developing the model. Its road network and resources are used in the detailed description of the model that follows.

V. General Description of the Unit Simulated

As previously stated, the simulation model is designed to accept as inputs the particular characteristics of any typical highway maintenance operational unit. In developing the model, the Maryland State Roads Commission unit at Upper Marlboro, Maryland was used as a representative unit.

This unit and the unit at Laurel, Maryland maintain the approximately 350 miles of interstate, federal and state highways in Prince Georges County. Prince Georges County has a population of about 500,000 and encompasses an area of approximately 500 square miles. Its topography is flat to mildly rolling, typical of the Atlantic Coastal Plain. Its average January temperature is 33° and the average June temperature is 74°. Mean annual precipitation is 40 inches and mean annual snowfall is 16 inches.

Since the combined jurisdiction and resources of the Laurel and Upper Marlboro units are atypically large compared to most units, it was decided to use only the Upper Marlboro unit in developing the simulation model. The Upper Marlboro unit is responsible for that portion of Prince Georges County that is south of U.S. Route 50, which runs east and west across the county. Its jurisdiction includes U.S. Route 50 and contains a total of about 220 miles of interstate, federal and state highways. See Figure V-1.

The Upper Marlboro unit's depot is located on Route 408 about two miles west of the community of Upper Marlboro. It is approximately centered, north and south, but is several miles east of the east-west center line of



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_ 24 _



() 1957 IVS R.C 199/CE \$ 11


its jurisdiction. The depot area consists of a yard for the storage of equipment and material, and adequate building facilities for housing administrative, maintenance, warehousing and other operational functions of the unit.

Road maintenance equipment is assigned to the unit by the state highway commission. The unit pays a fixed hourly rate for the equipment when it is in use. This rate does not include fuel, oil and maintenance. The equipment is assigned to the unit on a quasi-permanent basis. Two or three items of less frequently used equipment are shared on an equal time basis with the Laurel unit. Table V-1 is a list of the unit's equipment and the hourly operating cost of each item of equipment. The hourly operating cost is the state hourly rental rate adjusted upward to include an estimated hourly operating cost of the equipment. The cost of the equipment operator is not included.

The unit has 94 men who are employed to perform highway maintenance jobs. Of these, seven are foremen; each foreman being responsible for a crew of about six men. There is a total of 23 men employed in the three motor equipment operator classifications. Motor Equipment Operator I personnel are truck drivers. Motor Equipment Operator II personnel are qualified to operate all equipment, except a crane which requires a Motor Equipment Operator IIIclassification. Table V-2 shows a list of personnel employed in highway maintenance operations and the average hourly wage rate for the five principal categories of personnel.

Table V-1

Upper Marlboro Highway Maintenance Unit Major Equipment List

Туре	Number	Operating Cost 1/ \$/hr.
Trucks 1/2 T. Pick-Up 3 T. Dump Screen Side	3 24 2	\$1.00 2.40 1.30
Grader	4	7.80
<u>2</u> / Bull Dozer, D-Z	1	3.50
Roller	5	3.90
<u>2</u> / Grada11	1	13.00
Front End Loader	5	4.90
2/ Mobile Sweeper	1	7.20
Asphalt Paver	1	10.40
Tar Pots	4	.60
<u>2</u> / Crane	1	13.00
Mowers Sickle Bar-5 ft. Rotary-7.5 ft.	6 3	1.00 1.00

1/ State Rental Rate Adjusted to Include Fuel, Oil, and Maintenance
2/ Shared With Laurel Unit - Available Approximately Half Time

Table V-2

Upper Marlboro Unit Personnel Employed In Highway Maintenance Operations

Classification	Number	Average Hourly Rate
Foreman	7	\$3.45
Motor Equipment Operator I	23	2.50
Motor Equipment Operator II	4	2.85
Motor Equipment Operator III	1	3.25
Laborer I Laborer II Highway Maintenance Man I Highway Maintenance Man II Cement Finisher	$ \begin{array}{c} 19 \\ 6 \\ 13 \\ 19 \\ 1 \end{array} \right\} $	2.00

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Highway maintenance jobs for the unit originate by order from the State Roads Commission office, through inspection patrols made on a daily basis by unit supervisors, and from complaints by highway users. The unit superintendent makes out a schedule of work every Thursday which assigns crews for the following week. This schedule is submitted to the highway maintenance engineer in the State Roads Commission office in Baltimore. At the end of each week, a progress report comparing work accomplished to work scheduled is also prepared. Overtime work must be authorized by the State Roads Commission office. Pay for overtime work is at the normal hourly rate.

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VI. The Simulation Model

A. <u>Purposes</u> - In addition to serving its general purpose of providing maintenance management with measures of the effect on the productivity of a highway maintenance operational unit, of different management policies for job scheduling and resource assignment. The simulation model should be able to provide answers to specific problems that are of concern.

A major problem in the entire field of highway maintenance management is the lack of operational data that will provide valid measures of alternative management policies and decisions. A few states have initiated efforts to collect data on the resources required to accomplish various maintenance functions, but analysis of these data indicates nonuniform objectives and inconsistencies which do not contribute greatly to the total picture. Widespread use of the highway maintenance operational unit simulation model by the various highway agencies, state, county, and municipal, could stimulate the collection of more meaningful and uniform data on highway maintenance. Therefore, an important specific purpose of the model is to identify the kinds of data that should be collected and to encourage the collection of these data on a carefully controlled basis.

Given the availability of required input data for his particular operation, the simulation model, in a week or two, and without disrupting maintenance operations, should provide the highway maintenance manager with solutions to specific problems such as the following:

1. Operational Planning - The model can provide management with a means of testing different workload schedules for compatibility with available manpower and equipment combinations, and will assist in determining the most efficient use of resources. It can show the effects of adverse weather, and equipment shortages on planned operations, and can aid in determining alternative plans. It can assist in forecasting when and how much idle crew time might occur with a particular schedule or operational plan. It can assist in determining whether overtime is a better way of handling an anticipated backlog problem than hiring additional manpower. It can assist in equipment procurement decisions by providing a means of forecasting the benefits (positive or negative) of new equipment on unit productivity.

- 2. <u>Post Operation Analysis</u> As an aid to better future planning, the simulation model can provide a means of replaying selected situations as they actually occurred in the field, and testing alternatives to determine whether a better solution to a given problem was available.
- B. Input Details

Weather

Weather is arbitrarily divided into nine categories based on temperature and precipitation:

Weather Type Designation	Temperature (Degress F)	Precipitation
W ₁	<u><</u> 32	0
^W 2	<u><</u> 32	trace to 2 inches of snow, ice, etc.
W3	<u><</u> 32	more than 2 inches of snow
W ₄	33-80	< 0.1 inch
₩ ₅	33-80	0.1 to 0.5 inches
W ₆	33-80	> 0.5 inch
^W 7	> 80	< 0.1 inch
W ₈	> 80	0.1 to 0.5 inches
Wq	> 80	> 0.5 inch

The simulation uses weather data of 1964 from the U.S. Weather Bureau Station at Friendship Airport, Baltimore, Maryland (the closest such station to Upper Marlboro). That year was selected because it was a recent year in which temperature and precipitation varied little from normal. The weather for any day is represented by the average temperature for the day and the total precipitation for the day. For example, on January 24, the average temperature at Friendship Airport was 39° and there was a total of .09 inches of rain. So for the 24th simulated day, the weather is type W_4 . The daily weather conditions were put on punch cards as follows:

Column	Content
1 + 2	The weather type. (09 equivalent to W_9)
3-5, 6-8, 9-11, etc.	The day of the year that one or more days of a weather type <u>begins</u>
At the end of each card, the follo	owing code was used:
998 = end of (card

999 = end of deck

For example, if there was W_3 weather on January 12 and 13, February 11, (the 42nd day of the year) February 18 and March 21, the card form for this would be shown in columns 1 thru 17 as follows:

03012042049081998

The Highway Network represented in the simulation is shown in the foldout map (Figure V-1). A grid with squares each approximately two square miles, is superimposed upon the network so that road segments are in one of 94 cells. The mileage of each road segment in each cell was determined. This information is on punch cards as follows:

Column

Content

Highway Route Number (999 indicates end of this kind of data input)

1-3

Column	Content
4	Type of highway 1 = primary 2 = secondary 3 = interstate
5-7	Zone number
8-10	Center-line miles of the highway in zone, specified to nearest 1/10 of a mile
11	Blank
12-14	Zone number (999 indicates end of card)
15-17	Miles in Zone

(etc., up to 10 zones with mileage - Columns 5-73)

The zones are indicated in the sequence in which the road goes through the zone; this is <u>not always</u> the sequence from the lowest to highest zone number. For example, Route 414, a secondary road, starts in zone 37 with 2.1 miles in this zone; then goes to Zone 38 with 0.8 miles; and ends in Zone 28 with 1.8 miles. The card form would be shown in Column 1 thru 24 as follows:

41420372.1 0380.8 0281.8 999

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C. Job Types

A total of 23 different job categories are used:

Designation	Туре	Units
	Heavy	
1	Spot overlay	Tons
3	Reshape unpaved shoulders	Shoulder miles
4	Erect snow fences	Linear feet
5	Remove snow fences	Linear feet
6	Paint center line & edge lines	Pass Miles
7	Machine unpaved drainage ditches	Feet
8	Repair drainage structures	Number of structure
9	Clean & reseal joints & cracks	Gallons
10 -	Mowing	Acres
	Regular	
101	Seal patching paved surface & shoulders	Tons
102	Premix patching paved surface & shoulders	Tons
103	Aggregate patching unpaved shoulders	Tons
104	Blade unpaved shoulders	Shoulder miles
105	Hand clean drainage ditches	Linear feet
106	Hand clean drainage structures	Number of structures
107	Paint pavement markings	Square feet
108	Clean signs	Number of signs
109	Pick-up of litter	Acres

Designation	Туре	Units
110	Sweep paved surfaces & shoulders	Pass miles
111	Repair sign	Number of signs

Designation	Emergency	Units
1000	General emergency	Standard Crew Hours
2000	Salting & sanding	Not applicable
3000 3500	Snow plowing Snow clean up	Not applicable
The card for	n for job types and related information	is shown as

follows:

Column	Contents
1-4	Job type designation number
5	Blank
6-14	Indicates if the job type can be done on a day when the weather is of a particular type: 1 means the job type can be done, and 0 indicates the job type can't be done. The column position indicates the weather type:
	Column No. Weather No.

<u>Column No.</u>	Weather No.
6	1
7	2
8	3
•	•
•	•
14	9

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Column	Content
15	Blank
16-24	Indicates if a job type can be done one day after a day of a particular weather type (D-1).
25	Blank
26-34	Indicates if a job type can be done two days after a day of a particular weather type (D-2).
35	Blank
36-44	Indicates if a job can be done three days after a day of a particular weather type (D-3).
45	Blank
46-48	Indicates the first day of the seasonal period for which this type of work can be done. January 1 equals day 001.
49	Blank
50-52	Indicates the last day of the seasonal period for which this type of work can be done.
53-55	Indicates the garage time or setup time for the job type in hours and tenth of an hour.

For example, the job type reshaping unpaved shoulders (3) cannot be done on a day of weather types 1, 2, 3, 6, or 9; and cannot be done if the day before was weather type 2, 3, or 6 and cannot be done if the weather 2 days before was either type 2 or 3 and cannot be done if the weather three days before was type 3. But on a seasonal basis it can be done any time of the year. The setup time for this type of work is 1/2 hour. This information will be shown in the Columns 1 thru 55 as follows:

0003 000110110 100110111 100111111 11011111 001 3660.5 Note that this particular year, 1964, was a leap year.

D. Jobs

A "job" is a job type more specifically defined in terms of a location, quantity of work, and time the work is created or discovered. In general a job is that portion of a job type that must be worked on, more or less, on consecutive days once it is started; sometimes one day's work of a job type is considered a job.

In practice a depot does many small jobs in a year. For example, a depot may do 4000 tons of job type 102, premix patching, in a year. But the average size of a job of this type may be 20 tons which makes a total of 200 jobs of this one type of work. To accommodate this situation, yet avoiding punching thousands of cards, one of the following two methods was used to create small jobs: (1) a job type is broken down into sets of jobs, say all the jobs on a particular highway and then this set of jobs is allowed to be interrupted by other jobs as indicated by a high interruption index (given in columns 44 and 45 of the job cards) or (2) the job type is broken into specific small jobs which are re-created periodically. The job card gives the recurrence period (given in columns 40-42). The size and locations of jobs were determined by obtaining information from a depot manager about the annual quantity of each type of job and the general pattern of these job locations. The annual quantities were allocated to portions of the highway network using one or more of the following methods.

- 1. In proportion to the center-line-miles, see Table VI-A.
- 2. In proportion to lane-miles.
- 3. All jobs to one highway system or to a particular set of roads, for example, job type 105 occurs on all secondary roads and job type 110 occurs on Route 458, 4, and on Beltway Interchanges.
- 4. Random allocation, e.g., for emergency jobs.

	•		~	_								-		į	-	•			- 3	58 -		
te	Ratio: C. L. Miles To Total C.L. Miles Of The Net- Work	8.4	0.4																			
3 Interstat	Ratio: C. L. Miles To Total C.L. Miles Of This Type	95.9	4.1																			
Type	Center Line Miles	18.6	0.8																			19.4
	Rt. Number	495	295																			
	Ratio: C. L. Miles To Total C.L. Miles In The Net- Work	6.6	6.9	0.7	0.2	1.3	0.2	3.2	1.9	1.2	2.1	5.8	3.7	6.2	3.1	1.1	3.1	0.3	0.2	0.1		
econdary	Ratio: C. L. Miles To Total C.L. Miles Of This Type	13.8	14.5	1.5	0.4	2.7	0.5	6.7	4.1	2.5	4.4	12.6	7.7	12.9	5.5	2.3	6.4	0.6	0.4	0.2		
Type 2 S	Center Line Miles	14.6	15.4	1.6	0.4	2.9	0.5	7.1	4.3	2.7	4.7	12.8	8.2	13.7	6.8	2.4	6.8	0.6	0.4	0.2		106.1
	kt. Number	381	382	218	972	458	714	408	994	337	414	223	373	214	556	459	704	637	631	973		
mary	Ratio: C. L. Miles To Total C.L. Miles In The Net- Work	10.8	6.3	1.2	6.5	5.9	6.3	6.5														
Type 1 Pri	Ratio: C. L. Miles To Total C.L. Miles Of This Type	24.8	14.5	2.7	14.9	13.6	14.5	14.9														
	Center Linc Miles	24.1	14.1	2.6	14.4	13.2	14.1	14.5														97.0
j	t. Number	301	202	3	50	5	4	210														al

Type 3 Interstate

Type 2 Secondary

The day a job is created or discovered is determined for most regular maintenance jobs by selecting randomly one of the 366 days of the year. Most heavy maintenance jobs are created on the first day of the year. For general emergency jobs the location, time of creation, and the recurrence period were randomly selected. Sanding jobs and snow plowing jobs are generated within the simulation for the entire road network (sanding for weather W_2 and plowing for weather W_3).

The following information is also specified for each job:

- the minimum time for completing the work after it is started; this is to prevent an unrealistically large crew or number of crews being assigned to any one job,
- (2) the maximum time for completing the work after it is started; this is to prevent assigning unrealistically small crews to any job, and (3) a deadline which represents the maximum number of days from the creation or discovery of a job to the completion date.

The information is shown in card form as follows:

Column	Content
1-4	Job type designation number
5	Maintenance type 1 = emergency 2 = heavy 3 = regular
7-12	The quantity of work specified in the work units given on Page
13	Blank
14-16	<pre>Specifies location: 000 = job is zone oriented 1-990 = route number 991 = entire primary system 992 = entire secondary system 993 = entire interstate system</pre>
17	Blank

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Column	Content.
17	Blank
18-19	Starting zone for the work. 0=all zones for specified road
20	Blank
21-22	Ending zone for work. 0=job all in starting zone (or all zones if starting zone equals 0); if not 0, indicate the last zone for specified highway
23	Blank
24-26	Minimum allowable time in days to do the job after it is started
27	Blank
28-30	Maximum allowable time in calendar days to do the job after it is started
31	Blank
32-34	Deadline for completing the job in calendar days after it is discovered
35	Blank
36-38	Date the job is created or discovered. (January 1 equals day 001)
39	Blank
40-42	Interval in days for recurring jobs
43	Blank
44-45	Interruption index 10 = not interruptable 20 = interruptable by emergency only 30 = interruptable by higher priority

40 = interruptable by same priority

Suppose there was a 7 ton seal patching job (regular maintenance job 101) discovered on January 13 on Rt. 495 in Zone 38, and we want:

- the job to take at least 2 hours but not more than 1 day to complete after the work is started, and
- (2) the job to be finished within 60 days after it is discovered, and
- (3) the job is interruptable by emergency jobs only and the job recurs every 30 days. This information is punched in Columns 1 through 45 as follows:
 - 01013 000007 495 38 00 002 001 060 030 20

E. Resources

The resources that the depot has available for jobs are described in Tables 1 and 2. This information is in the following punch card format:

Column	Content
1-12	Name or abbreviation of name of resource
13-15	The code number for the resource listed below.
16	Blank
17-19	The quantity of the resource in the inventory.
20	Blank
21-24	The hourly wage or rental of the resource.
The coding number for resource	es are as follows:
Code Number	Туре
1	600 gallon towed distributor
2	Dump truck
3	Roller
4	Asphalt Paver

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Column	Туре
5	Motor Grader
6	Towed Broom
7	Farm Tractor
8	Air Compressor
9	Pickup Truck
10	Truck and Paint Stripe Machine
11	Flat Bed Truck
12	Front-end Loader
13	Grada11
14	100 Gallon Towed Asphalt Kettle
15	Power Spray Rig
16	Screenside Truck
17	Mobile Sweeper
18	Sickle Bar - 5 ft. Mower
19	Rotary - 7.5 ft. Mower
101	Motor Equipment Operator I
102	Motor Equipment Operator II
103	Motor Equipment Operator III
104	Laborers
105	Foremen

Suppose the depot has 5 rollers at a rental and operating rate of \$3.90 per hour. This information would be shown in Columns 1 through 24 of the cards, as follows:

Rollers 003 005 00390

F. Crews

For each job type, there are from 1 to 6 combinations of resources that make a crew. The number and type of each resource in the crew and the crew's productivity rate in units of work per hour is coded on cards as follows:

Column	Content
1-4	Job type (9999 indicates end of job types)
5-9	Productivity in work units per hour
10	Number of Equipment Operators I
11	Number of Equipment Operators II
12	Number of Equipment Operators III
13-14	Number of laborers
15-16	Equipment Code No. (98 indicates end of crew, 99 indicates end of all crews for job type)
17-18	Number of pieces of equipment of type specified above
19-20	Equipment code number

(etc. up to 6 types of equipment and quantities thereof, Column 15 to 38 start in Column 41 for the next crew.

For example, two of three acceptable crews for reshaping unpaved shoulders, Job Type 3, are as follows:

Resource Type	Number of Resources	
	<u>Crew A</u>	<u>Crew B</u>
MEO II*	1	2
MEO I	2	2
Laborer	3	4

^{*} Motorized Equipment Operator, Class II

Resource Type Number of		Resources	
	<u>Crew A</u>	<u>Crew</u> B	
Motor Grader	1	2	
Dump Truck	2	3	
Roller	1	1	

Productivity (shoulder miles per hr.) . 8

1.3

This information would be shown in Columns 1 through 28 and 41 through 68 as follows:

0003000082100305010202030198 00030000132200405020203030198

G. Input Lists and Arrays

Many of the inputs to the simulation and their punch-card formats have already been discussed. The present section explains the lists and arrays in the FORTRAN program into which these data are placed. The explanation is in the form of a series of tables arranged in approximately the same order as the DIMENSION statements in the FORTRAN computer program. Each table contains the names of arrays and explains the use of these in the program. A list or array having a name which begins with any of the letters I, J, K, L, M, or N contains fixed point or integer data. Lists or arrays beginning with any other letter contain either alphanumeric or real-number (floating point) data. Arrays containing alphanumeric data are followed by the word "Hollerith." A table distinguishes with an asterisk those arrays into which the computer reads data from an outside source--punch cards or tape--as opposed to arrays containing internally computed data.

One-Dimensional Arrays

Table VI-B Miscellaneous Arrays

Name of Array	Explanation
*MON	Hollerithmonth name
*IDM	Number of days in the month
KON	Constants used to determine the weather feasibility of a job
NHOL	Index of Holidays
JUNK1	Temporary storage maximum length - number of days in the year + 3
JUNK2	Temporary storage maximum size = number of days in longest month
XJUNK	Temporary storage maximum size same as JUNK2
*DWEEK	Hollerithdays of the week
*HE1	Hollerithtemporary storage maximum size, number of different types of equipment in the depot
*HE2	Hollerithsame function as HE1
*IW	Weather type for each day of the year
JIND	Indicates whether job can be done

Table VI-C contains the name and index number of each of the logical gates. These determine which data will be read as input or printed as output. If, for example, an input gate value is unity, the computer reads data for the variable corresponding to the gate. If it is zero, it does not read any data. The array IGATE contains the input gate values and the array IOUT contains the output gate values. The array HOL contains the Hollerith names of the variables corresponding to each element in IGATE and IOUT. Table VI-C lists the index of each gate value and the variables affected by it.

Table VI-C

Input/Output Gates

Index	
1	HOL
2	IOUT
3	Personnel inventory
4	Equipment inventory
5	Job types - basic crews
6	Highway zone list
7	Weather
8	Travel times
9	Recurring jobs (at initialization)
10	Input or real jobs
11	Recurring jobs (at inventory time)
12	Snow plow job (at inventory time)
13	Snow clean job (at inventory time)
14	Light snow (at inventory time)
15	Not used
16	Weekly plan
17	Daily report
18	Weekly report

Table VI-D contains arrays concerning the equipment inventory of the depot. The number of types of equipment owned by the depot is IX4. This number is computed internally in the input phase of the program.

Table VI-D

Equipment Inventory

Array	Explanation
*IEQI	Equipment identification numbers
*IEQNO	No. of pieces of this type
*EQC	Hourly cost of this type
NDEQT	Daily analog of IEQNO - in inventory
ISEQ	No. of pieces of equipment in use on special jobs

Table VI-E summaries arrays relating to type of job, four of these arrays, IWA, IWB, IWC, and IWD need additional explanation. These arrays contain weather codes for each job. The weather code is a string of nine numbers. Each number is either zero or unity. The position of the number in the string refers to one of the nine weather types, reading the string from left to right. If a number is zero, then weather of this kind prohibits doing any job of the given type. If the number is unity, then this weather does not prohibit jobs of this type.

For certain kinds of jobs, not only today's weather but yesterday's weather and weather up to three days ago may prohibit doing a job. Allowing for this contingency there are <u>four</u>, nine-digit strings, one in each of the above arrays. The parameter IX5 gives the number of different job types which the depot may do.

Table VI-E

Job Types

Array	Explanation
*ITTYP	Job type code
*IWA	Weather code for TODAY - 3
*IWB	Weather code for TODAY - 2

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Array	Explanation
*IWC	Weather code for TODAY - 1
*IWD	Weather code for TODAY
*IESD	Earliest starting day in the year
*ILD	Latest starting day in the year
*SUT	Set up time (in hours)
ICRS	Starting index of crew in basic crew li
ICRN	Ending index of crew in basic crew list

Table VI-F lists the arrays dealing with the composition of the basic maintenance crews. The number of basic crews is given by the value of the variable IX5C. The list of equipment belonging to crews is indexed by the variable IX5E.

Table VI-F

Basic Crews and Associated Equipment

Basic Crew List	IX5C
*PROD	Productivity in wu/hr
*IE01	# equipment operators I
*IE02	# equipment operators II
*IE03	# equipment operators III
*ILAB	# laborers
IEQS	Starting index for equipment type
IEQN	Ending index for equipment type
HCST or HCOST	Hourly cost of crew
*IEQ	Equipment type
*INO	Number of pieces used

The computer automatically sets up an indexing scheme connecting job types, basic crews and equipment. This scheme is illustrated in the following chart. The first column of this chart lists the job types, the second column: indicies of the job types, the third column: indicies of basic crews, the fourth column: indicies of equipment used by crews. The chart shows that a job type may index several crews which can do it. The crews are marked by <u>starting</u> and <u>ending</u> indicies shown by arrows in the crew list. A crew may have several kinds of equipment which it needs to do a type of job. These are marked by starting and ending indicies in the equipment list.

JOB TYPE	INDEX	BASIC CREW INDEX	EQUIPMENT INDEX	
101	1	1 2	1 2 3	
202	2	3	4 5	
302	3	4 5 6	6 7 8 9	
407	4	7	10 11 12	

Table VI-G lists the arrays which describe the highway network. The number of entries in each of the first three arrays is given by the present value of IX6. The highways pass through reference zones shown on the foldout map at the beginning of this report. The number IX6Z gives the number of zones which constitute all the highways in the area of jurisdiction of the depot. The number IX8 gives the total number of zones constituting the district. The number IX8 differs from IX6Z because several highways may pass through the same set of zones. Also, some zones may have no highways passing through them.

Table VI-G

Highways and Zones

Arrays associated with IX6:

Array

*IHY

*IHYS

*IHYN

Arrays associated with IX6Z:

Array

*IHZ

*DLZ

Explanation

Explanation

Highway route number

Starting zone of highway

Ending zone of highway

Zone index

Miles of highway in zone

Arrays associated with IX8:

Array	Explanation									
*TT	Travel time from depot to indicated zone (input in minutes - converted									
	internally to hours)									

Table VI-H lists arrays dealing with prototypes of recurring, heavy maintenance jobs. The computer reads the prototypes from punch cards and then generates a recurring pattern of jobs from them. The value of IX9 is the number of prototypes.

Table VI-H

Prototypes for Recurring Jobs

Array	Explanation
*IRTYP or IRTPE	Job type
*IRMT	Maintenance type (not used as such in this model)
*RPR	Work units of job
*IRLC	Location
*IRSZ	Starting Zone
*IRNZ	Ending zone
*IRMIN	Minimum time
*IRMAX	Maximum time
*IRDL	Deadline
*IS	Day of transfer to inventory
*IRPER or IPER	Period of recurrence
*IRNT	Interrupt index not used
XMULT	Correction factor (initialization)
Table VI-	<u>I</u>
Inventory of	Jobs
Array	Explanation
*IVTYP	Job type
*IVMT	Maintenance type (not used) $\frac{1}{2}$

Interrupt index (not used) $\frac{1}{}$ *IVNT

 * <u>1</u>/The present formulation does not use this input information

Table VI-J concludes the one-dimensional arrays. The arrays in this table contain data about "JOB X" residual man-hours. Each array contains three elements giving the daily, weekly, and yearly residuals, respectively.

Table VI-J

Residual (JOB X) Man Hours

Array		Explanation
XJL	Job	X labor hours
XJE1	Job	X - MEO - I hours
XJE2	Job	X - MEO - II hours
XJE3	Job	X - MEO - III hours

Two-Dimensional Arrays

Table IV-K lists arrays which have two indexing variables. The first column gives the array name, the second column: the two indexing variables, the third column: an explanation of the purpose of the array.

Table VI-K

Respective Indexing Variables

Array		Explanation
ICREW	job and crew	Gives crew indexes of 1 to 6 crews assigned to job
SLH	type of output report and type of job	Man hours, laborers
SE1H	type of output report and type of job	Man-hours, MEO - I
SE2H	type of output report and type of job	Man-hours, MEO - II
SE 3H	type of output report and type of job	Man-hours, ME 0 - III

WUA	type of output report and type of job	Work units accomplished
WUP	type of output report and type of job	Work units planned but not accomplished
WUC	type of output report and type of job	Work units presently carried
TCL	type of output report and type of job	Total cost, labor
TCE	type of output report and type of job	Total cost, equipment
EQTOT	type of output report and type of job	Total equipment hours

H. Three Dimensional Arrays

There is only one three-dimensional array: EQH. Its indexing variables represent type of output report, type of job, and type of equipment respectively. The array contains hours of equipment usage for each type of equipment.

VII. The Simulation Program

The FORTRAN computer program can be divided into four phases: (1) the input phase, (2) the daily execution phase, (3) the output phase, (4) the planning phase. Table A indicates the FORTRAN statement numbers in the program which mark the beginning and the end of each phase. These statement numbers are in order of appearance, <u>not</u> in cardinal order. A positive number in parenthesis following a statement number indicates a number of lines after the line having the statement number in the program. A negative number in parentheses indicates a number of lines before the statement number.

Table VII-A

Phase	Extent
Input	410 (-4) to 105
Daily execution	105 to 770
Output	770 to 766 (1)
Planning	2022 to 3091 (3)

The details of each phase follow:

A. Input Phase

The input phase is composed of two parts. The first part comprises statements which instruct the computer to read or to calculate values once and for all. The second part comprises statements which instruct the computer to read or calculate values at the beginning of each simulated day or each simulated week. Figure VII-1 is a flow chart of the major operations in the first part of the input phase. A number within a flow chart symbol is the





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FORTRAN statement number of the beginning of the indicated operation. A number in parentheses has the same meaning as in Table VII-A.

Figure VII-2 is a sample computer print resulting from the first six PRINT instructions in the flow Chart (first 6 asterisks). In the example, the line labeled MAXIMA shows the maximum allowable units for each group of arrays. For example, the arrays IHY, IHYS, and IHYN all have IX6 elements in them at any time. If the maximum value of IX6 is 25, as shown, then none of these arrays should have more than 25 elements in it. If any of the arrays contain more than 25 elements, this causes the computer to indicate an error.

The line labeled HOLIDAYS shows the holidays for the year. These are the days 1, 53, 150, 185, etc. for this particular year. The line labeled INPUT shows the input gate. As set here, this gate contains a string of ones.

The line labeled OUT shows the output gate. This gate instructs the computer to print all but two of the possible outputs. Printing of these outputs is controlled by the digits in positions 12 and 13 of the gate. The computer will also print the outputs, if the zeros in these positions are replaced by ones.

The lines labeled FOREMEN to LABORERS give the personnel or manpower inventory of the depot. The line labled LABORERS indicates that the depot has 58 laborers, each paid at a rate of \$2.00 per hour.

The remaining lines give the equipment inventory. The depot in question has, for example, 24 dump trucks, which cost \$2.40 per operating hour. The dump truck has identification number 2 and is also number 2 in the list of equipment.

Figure VII-2--Results of first 6 print instructions

MAXIMA	IX	(4=	2	0		r X 5	5=	2	0		IX	(50	=	ç	90		IX	(58	=	20	00		I>	(6=	:	25	5
HOLIDAYS		1	53	1	50	18	85	21	5	31	0	32	24	35	59												
INPUT 1 1	1	1	1 1	- 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
OUT 1 1	1	1.	1_1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PERSONNEL I	NV	'EN	ITOR	Y	NL	JME	BER	A s	VA	IL	.AB	BLE	Δ	NE) }	10L	IRL	.Y	RA	A T E	-						
FOREMEN EQ OP 1 EQ OP 2 EQ OP 3 LABORFRS			7 23 4 1 58	•	3 2 2 3 2	45 50 85 25	5	•														f					
EQUIPT TOWED CISTR DUMP TRUCK ROLLER ASPHALT PVE MOTOR GRADE TOWED BROOM FARM TRACTO AIR COMPRES PICKUP TRUC	RB ER ER A DR SS		123456789		1 2 3 4 5 6 7 8 9	â	145141923	1	1. 2. 3. 0. 7. 1. 2.	20 40 90 40 80 25 50				·													
FICKOP TRUC TRK+PNT STE FLT-BED TRC FRNT-END LE GRADALL TOWD ASPH & POWER SPR E SCREENSDE T MOBILE SWEE SICKLE-BAR ROTARY HOWE	APKR TGKPMR	1 1 1 1 1 1 1 1	90123456789	1 1 1 1 1 1 1 1 1	90123456789		51251412163	1	1 7 1 4 3 1 7 1 1 1	20 20 90 60 75 20 00 75 20 00							•		- -				· ·				

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Figure VII-3 is a sample print resulting from the instruction to print job types. The first five job types in this figure have the labels EMERGENCY to SNOW CLEAN. The sixth job type is not labeled. Each line of print representing a job type is followed by one or more lines indicating the basic crews associated with the job type.

The lines indicating job type have the following format:

- 1) A label explaining the job type
- 2) An identification number of the job type (from the array IVTYP).
- 3) A number showing the position of the job type in the list of job types (the index I of the job).
- Four strings of ones or zeroes representing the kinds of weather which permit or prohibit the assignment of one or more basic crews to the job type (from the respective arrays IWA, IWB, IWC, and IWD).
- 5) Two numbers showing the days of the year marking the beginning and the end of the "season" for the job type. (From the arrays IESD and ILD, respectively.)
- 6) A number giving the set-up time in hours for the job.
- 7) A number giving the starting index, in the list of basic crews, of the first crew associated with the job type. (From the array ICRS.)

It is well to note here that no matter what job types the user chooses to put into the computer program <u>he must always place the cards for the</u> <u>EMERGENCY, TRAFFIC SERV(ices), LIGHT SNOW, SNOW PLOW, and SNOW CLEAN job types</u> and their associated crews in the first 5 positions of the job-type portion of the data deck. The other job types and crews may follow in any order so long as cards representing the basic crews immediately follow each job-type card. In the example, the job type in sixth position (unlabeled) has identification number 3. The first of the strings of nine digits indicates that the depot manager may not assign crews to jobs of this type if any of the weather types 1, 2, 3, 6, or 9 occurred three days ago.* The last string prohibits assignment if weather type 3 occurs <u>today</u>. The reader may verify for himself that the net result of the four strings is to prohibit jobs of this type if weather of types 1, 2, 3, 6, or 9 occurred today or up to three days ago.

The next two numbers in the example show that jobs of this type may be started as early as day zero but may not be worked after day 366. This means, of course, that jobs of this type may be done any time of the year. The next number .5 tells that the set-up time for jobs of this type is .5 hours. Last, the number 14, tells that the first basic crew associated with this job type is number 14 in the list of all crews.

The lines in Figure VII-3 representing the basic crews have the following format:

- 1) The position number of the job type in the list of types (the index of the job).
- 2) The index of the crew in the list of crews.
- 3) The productivity of the crew in work units per hour (from array PROD).
- 4) The number of equipment operators of lowest classification in the crew (from array IE01).

^{*}The weather restrictions for jobs of the last 3 types are not used in the model. These jobs are handled in a manner different from the rest.
10 3 9 14 N പം 1 370 -.0 1 370 -.0 E01 E02 E03 LAB HR COST EQUIPMENT INDEX AND TYPE-NUMBER 1 370 -.0 AND TYPE-NUMBER 1 370 -.0 TYPE-NUMBER EQUIPMENT INDEX AND TYPE-NUMBER 370 -.0 TYPE-NUMBER EQUIPMENT INDEX AND TYPE-NUMBER n 0 366 2 ----S AND AND 00000000 0000000000 00000000 00000000 00000000 00000000 0000000000 111111111 ·---000110110 100110110 100110111 110111111 0 --------0 0 0 0 C EQUIPMENT INDEX EQUIPMENT INDEX EQUIPMENT INDEX 2 2 ທ ~~~ ~~~~ N 10 01 10 00000000 000000000 000000000 11111111 111111111 Figure VII-3--Results of printing job types 14-16 2 1-1 2 4 3 50 10- 10 12 13 θ σ 11-11 2 81 12-13ы М - + •9 -- /--6 5-E01 E02 E03 LAB HR C0ST EO2 EO3 LAB HR COST LAB HR COST E02 E03 LAB HR COST E01 E02 E03 LAB HR COST 4.90 10.30 22.00 0000000000 2.50 2.50 6.90 4.90 3.25 8.90 30.35 6.90 2.00 8.90 2.00 JOB TYPES AND BASIC CREW DATA <u>م</u>ا . н 0 ~ 3 01 0 0 -0 11 0-E02 E03 0-0 0-1-0-**°** 01 01 01 -01 0 0 0 111111111 0000000000 01 0011 0 0 0 0 01 01 E01 EO1 01 E01 01 01 0 \sim 4 01 ю 9 2 3500 5 PRON PRON 3000 4 1.0 1.0 .1 PROD PROD C•• PRON 0... 0... • C • 0... 6. PROD • 0.1 0.1 0.1 2000 3 2 JOB CREW 2 10 25 CREW 9280 CREW 14 CREW CREW 3 11 12 CREW TRAFFIC SERV SNOW CLEAN LIGHT SNOW ENERGENCY SNOW. PLOW JOB JOB **J**0B **JOB 10**B N 3 NN オオオ S S S S

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() :-[]

- 5) The number of equipment operators of next lowest classification in the crew (array IE02).
- 6) The number of equipment operators of highest classification in the crew IE03
- 7) The number of laborers in the crew (from array ILAB)
- 8) The nominal hourly cost of the crew
- 9) The starting and ending indexes of the equipment used by the crew (from arrays IEQS and IEQN, respectively).
- 10) One or more pairs of numbers, the first of each pair representing the index in the equipment and the second representing the number of pieces employed by the crew (from arrays IEQ and INO, respectively

Consider for example the first crew of the job already discussed. The column labeled CREW gives 14 as the index of this crew in the crew list. The JOB column tells that this crew is for the sixth job type in the list of job types. The productivity, given by the column labeled PROD, is .9 work units per hour. The crew contains 2 equipment operators of Class I (lowest), 1 equipment operator of Class II and none of Class III (highest). It also contains 3 laborers. The crew costs \$30.35 per hour and uses the three types of equipment listed in positions 14, 15, and 16 in the equipment list, (array IEQ). These three pieces of equipment are (1) 5 (motor grader), (2) 2 (dump truck), (3) 3 (roller),* and the corresponding numbers used of each are 1, 2, and 1.

Figure VII-4 reproduces the output resulting from printing highways and zones. Each line of print corresponds to a highway. The items in a given line are:

See Figure VII-2

Figure VII-4-- Results of Printing Highways and Zones

HIGHWAYS AND CORRESPONDING ZONES

83 2.0						- 63	3 -
74 2•0		• .					
67 2.3					•		
59 2.2		82 1.5					
50 1.6	94 1.4	91 1.6	34 1.0				
51 1.2	93 2•0	86 1•3	33 1•2				
42 1 • 0	92 2•5	8 7.9	25 2•2				
34 3 2•1	89 2 .1	78 2.5	24 1.0				
34 2.0	86 1.3	70 1.4	17				
26 2 .1	85 1•9	69 1.0	16 2.0				
19 2.0	76 •8	60 2•5	9 1.8				28
13 2•0	75 8.1	51 2.4	8 2 .1				29
3 1•6	74 •5	50 • 3	7 2.4	6 2•6	21 1.6	21	21
13	22	32	1 +1	ç42	th 3	t; t;	2.17
1	14	23	33	42	24	11 17	54
301	381	382	202	б	215	972	458
-	N	ŝ	t 1	S	ى	2	α
ZONE	ZONE	ZONE	ZONE	ZONE	ZONE	ZUNE	ZONE

- 1) The word ZONE
- 2) A number showing the position of the highway in the highway list (the array IHY)
- 3) The route number of the highway (from array IHY)
- 4) Two numbers giving the starting and ending indexes of the highway in the zone list (IHZ)
- 5) One or more numbers giving the zones through which the highway passes (taken from array IHZ)
- 6) Immediately below the numbers in 5) is a corresponding set of numbers giving the number of center-line miles of highway in each zone.

Highway 202, for example, is number 4 in the highway list. It passes through 9 zones listed in the array IHZ. The array lists the zones from position 33 to position 41. These zones are 7, 8, 9, 16, 17, 24, 25, 33, 34. The interested reader can verify this if he turns to the fold-out map accompanying this report. He will see that highway 202 begins in the upper right-hand corner of zone 7 on the map and passes sequentially through the zones listed. In this example, the number of center-line miles in zone 7 for highway 202 is 2.4, the number in zone 8 is 2.1, etc.

Figure VII-5 reproduces a computer print of the weather calendar. The first line of this calendar gives the day of the month and the first column gives the year. A number in a particular row and column of the calendar gives the weather for a particular day of the year. For example, on April 15, the weather is type 4.*

Figure VII-6 reproduces a portion of a computer print of the table of travel times. Each line of this table consists of several pairs of numbers.

For a definition of weather types, see Page

Calendar
f Weather
oduction o
-5Repro
Figure VII

WEATHER CALENDAR

31	4	J		J		t		9	t		t		đ
30	J	4		ഗ	4	4	8	4	4	4	4	ഗ	4
29	N	2	S	2	4	4	4	4	đ	ഗ	4	¢	4
28		2	4	~	4	4	2	4	2	t	4	-	4
27		4	4	~	S	4	2	4	t	9	4	t	4
26		-	4	4	S	t	4	2	t	9	t	t	t
25		t	2	t	4	4	4	2	t	9	t	t	4
24		t	-	t	4	4	9	4	4	4	4	t	9
23		4	4	S	4	. t	t	4	2	t	4	4	S
22		9	-	4	t	t	t	t	t	t	t	9	t
21		4	4	4	t	t	S	t	t	t	t	t	t
20		t	-	t	4	4	t	~	~	t	4	t	t
19		t	-	2	S	4	4	S	2	4	4	-	4
18		4		Ю	ഗ	4	2	S	4	t	4	. 1	-
17		ß	4	4	S	t	8	4	4	4	4	ß	S
16		-	S	t	S	t	ഗ	2	4	ഗ	4	ഗ	-
15		-	ю	4	4	4	t	4	t	4	t	t	t
14		-	t	t	t	t	t	2	4	t	ß	t	t
13		-1	ഗ	t	t	t	t	2	ഹ	t	S	t	-
12		1	~	t	ഗ	t	æ	t	4	t	t	t	N
11		-	4	ហ	9	4	2	4	t	t	4	4	¢
10		ю	N	t	4	ഗ	4	ഗ	4	പ	4	4	\$
δ	æ	ю	-1	4	4	t	4	S	4	4	4	t	9
80	YEA	-1	n	4	4	, '	4	4	4	2	4	t	4
2	÷16	t	2	t	4	4	4	4	t	¢	4	4	
9	EDI	9	4	t	t	4	4	4	4	4	t	4	4
S	REC	4	4	S	S	t	t	9	4	t	4	t	4
t	۵. س	ŝ	t	t	S	đ	t	t	9	t	t	t	-
ю	s S	ഗ	9	4	9	t	ഗ	t	t	t	t	4	t
~	DAY	4	4	t	t	t	4	4	4	t	t	t	ഗ
-	Ш	3	t	đ	4	t	t	4	t	t	t	t	S
	LAST THR	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	001	NON	DEC

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Figure VII-6--Computer print of trevel times

	•						TRAVE	EL TI	KE TO 2	CONE							
1 .4	S	•	643	ы	•43	t	• 43	ى ك	.37.23	9	• ع	7	• 43	ŝ	•37	σ	• 37
11*****	**	12++*+	**	13	• 30	14	• 43	15	•37 23	16	• 30	17	• 30	18	• 23	19	ю
21 .2	S.	22 .	22	23	• 23	24	• 32	25	•15	26	•15	27+-	* * * * *	28	. 32/9	29	• 20
31 .1	<i>ي</i> د	32****	* *	33	•10	34	• 0 A	35*3	* * * * *	36	.47	37	• 4 0	38	.35	39	• 27
41 .0	7	****	*	543	• 07	**11	* * * *	45	• 48	4643	* * * * *	47	.32	48	• 23	49	•17
51 .0	7	52****	**	53**	****	54	• 53	55	.42	56	• 38	57	• 45	584	*	59	u, ₽
61++++	اد	****29	¥ ₩	63	•57	64	• 45	65 # 1	* * * * *	66	. 42	67	• 25	68	• 23	69	•
71 .5	S	72 .	48	73	• 52	74	• 32	75	.32	76	.37	+17	* + * + *	78	.27	79	() () ()
81 .5	8	82	55	83	.42	84 **	* * * * *	85	0 t1 *	86	• 38	В7	.32	88	.33	в9	513
91 .4	C	. 66	47	93	•53	++ + + 5	* * * * *						•) •		•

*

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The first number in each pair is the number of a zone on the highway map. The second number is the time in fractions of an hour from the maintenance depot to the zone. If there are no roads within a zone or the roads in the zone are not under the depot jurisdiction, then asterisks replace the travel time. If the travel time to a zone is for the zone of the maintenance depot itself, then asterisks replace the number of the zone also. In the example table, travel is prohibited to zones 11, 12, and 44 (among others). The depot is located in zone 42.

Figure VII-7 shows a portion of the computer print of recurring-job prototypes. The number in each line gives:

- 1) The position of the prototype in the list.
- 2) Its identification number (array IRTYP).
- 3) Its maintenance type (array IRMT).
- 4) The number of work units in the prototype-created job any time it occurs during the year (array RPR).
- 5) The location of the job (array IRLC).
- 6) The starting zone of the job (array IRSZ).
- 7) The minimum time for the job in days (array IRMIN)
- 8) The maximum time for the job in days (array IRMAX)
- 9) The deadline time for finishing the job once it is started in days (array IRDL)
- 10) The date of transfer of the recurring job into the working inventory (array IS)
- 11) The number of days in the period of recurrence of the job (array IRPER)
- 12) The interrupt index of the job (IRNT)

Figure VII-7 -- Computer print of Recurring Job Prototypes

1	2-0	16.00	991	0	-0	1	1	1	1	1	-0
2	8 2	•10	495	0	0	4	7	366	0	11	30
3	8 2	•10	495	0	. 0	4	7	366	0	2	30
4	8 2	•10	495	0	0	4	7	366	0	4	30
5	8 2	.10	495	0	0	4	7	366	0	91	30
6	8 2	•10	295	0	0	4	7	366	0	222	30

In the illustration given, the prototype job in position 1 has identification number 2. This prototype creates jobs having 16 work units. It creates them for location 991. This is a special code indicating that these jobs will have no particular location. The computer will set the starting and ending zones of the job equal to the zone of the depot.* Other prototype jobs give specific locations. The prototype job in position 2 creates jobs on route number 495. The starting and ending zones of all the prototype jobs shown are zero. This is another special code. There is no zone zero. A starting zone of zero following a highway location number indicates that the job comprises the entire highway given in the zone list IHZ. If the job comprises only a portion of a highway, the starting and ending zones should be explicitly given. A prototype job for a portion of Route 202 (see Figure VII-4) could specify starting and ending zones of 9 and 25 respectively. The other possibility, not illustrated here, is to specify jobs for a particular zone no matter which highways pass through it. The location number for such a job is zero. The zone is its starting zone.

The minimum and maximum times for the prototype job in position 1 are both equal to 1 day. For the one in position 4 they are 4 days and 7 days respectively. The minimum time is a constraint preventing the simulated depot manager from putting a large number of basic crews on a job to do it as quickly as possible. It keeps him from assigning too many resources to

^{*} The jobs, in fact, represent traffic service jobs such as fixing traffic lights, and doing jobs which must be done periodically but which may be in many different locations.

the job.* The deadline of the first prototype job is one day and the deadline of the second one is 366 days. The jobs created by the second prototype have effectively no deadline. All of these prototype jobs create jobs which enter the job inventory at the beginning of the year. The first prototype creates a job on day 1 and the succeeding prototypes create jobs on day 0. Jobs created by prototype number 1 occur once every day. Those created by prototype number 2 occur once every 11 days. The interrupt index--zero for the first prototype and 30 for all the others--is not used in this program formulation. It could be used in a priority scheme for selecting jobs.

Figure VII-8 is a block flowchart of the second part of the input phase. The explanations within the blocks are only approximate and need more explanation.

- 1) <u>Clear Daily (and possibly weekly) Output Arrays</u> The computer clears several arrays in which it accumulates data summaries computed during the simulated day. The arrays which accumulate data summaries for output at the end of the week are cleared after the weekend. Arrays which accumulate data summaries for the day are cleared at the beginning of each day.
- 2) Count Unfinished Jobs In Inventory The computer counts the number of unfinished jobs remaining in the inventory. It uses this count to determine later whether or not the inventory is filled to capacity.
- 3) <u>Check for Weekend or Holiday</u> The computer advances the day of the year and the day of the week. It checks to see if the new day is a holiday. If it is, the computer stores this information to determine the workload for the day or the week.

Inasmuch as the deadline date sets an upper limit on the time to do the job, there seemed no need to use the maximum time in the present formulation of the program. Future users might see a potential use for this array, perhaps in controlling the mimimal size of a crew assigned to the job.

Input Phase Part 2



- 4) Set Resource Inventory Multiplier The computer uses this multiplier to calculate the resource available (a) to make up the weekly plan and (b) to assign resources to jobs during the day. At this point a multiplier, called MULT, is set in preparation for possible planning.
- 5) Find Space in Job Inventory for Job The computer searches the job inventory for an empty space. It can read new jobs into slots occupied by jobs which have been accomplished or can add new jobs at the end of the inventory list. If the computer must add the new job to the end of the list, it checks to see if the inventory is close to capacity. If it is too close to capacity, the computer withholds the job from the inventory. The computer treats recurring and read-in jobs identically. It reserves two special, extra slots in the inventory for weather-generated jobs. Different treatments were desirable because a read-in or recurring job may be simply deferred until there is room to enter it in the inventory, whereas a weather generated job which cannot go into the inventory is lost for good.
- 6) Read Job The computer reads a job from the input deck.
- 7) <u>Date of Job Acceptable</u> If the date of the latest read job exceeds today's date, the computer ceases to read jobs from the input deck. Note that jobs must be placed in the input deck in chronological order.

When the computer has read the last acceptable job from the data deck it attempts to generate jobs from the recurring-job prototypes which it read in part one of the input phase.

- 1) <u>Starting Date Acceptable</u> The computer checks the starting date on the job prototype to see if it is acceptable. On the first day of the first week, starting dates within the first seven days are acceptable. On succeeding days, only a starting date which is exactly one week away is acceptable. Note that the time criterion for inclusion differs from that of the read jobs. Recurring jobs are assumed to be predictable for planning purposes; hence one may plan to do a job not yet "discovered." Read jobs are assumed to occur unpredictably and cannot be assigned in a plan until the discovery date.
- 2) Find Space in Job Inventory for Job Same as in (5) above
- 3) Enter Job in Inventory The computer places the job information from the prototype into analogous arrays of the job inventory.

- 4) <u>Subroutine HZONE</u> The program calls the subroutine HZONE. This subroutine prorates the amount of the job over the appropriate zones of the highway specified by the job.
- 5) <u>Compute Time on Job</u> The computer calculates the effective workday for the job. It subtracts the set-up time for the job and the round-trip travel time for the job from 8 hours. The remainder is the amount of time which any crew assigned to the job will have available to work on it.
- 6) Generate Next Job from Prototype The computer tries to create another job from the same prototype. It adds the recurrence period of the prototype to the starting date to get a new starting date. The computer then checks the starting date of the new job. If the starting date of the new job is unacceptable, the computer looks for the next prototype.
- 7) Last Prototype? The computer checks to see if it has just used the last prototype in its list. If it has not, then it continues as in steps (1) through (6) above. If it has, then it goes on to the next step.
- 8) <u>Planning Day?</u> The computer checks the day. If it is a day on which to plan for the week and the weekly plan has not been made, then the computer goes to the planning phase of the program. If it is not such a day, the computer checks the day's weather.
- 9) Check for Job-Creating Weather Weather may create jobs: (1) snow plowing, (2) sanding (light snow). In case (1) the computer creates a follow-up job for the next day, (3) snow clean-up. These jobs receive special treatment in crew assignment. They are the only jobs which may be done on weekends or holidays.

When the computer has concluded the above steps, it enters the execution phase of the program.

B. Execution Phase

The execution phase is the largest in the simulation. It comprises almost half of the approximately 1500 FORTRAN statements in the main program. Owing to its size, it seems reasonable to discuss it in four component parts: (1) job selection, (2) special jobs, (3) crew selection, (4) output preparation.

1) Job Selection

Job selection, in this program, is a two-stage process. In the first stage, the computer <u>checks</u> each job in the inventory to see if it may be done "today." In the second stage, the computer <u>ranks</u> the jobs in the inventory to establish a priority scale for assigning crews. Figure VII-9 is a rough flow chart of the first stage. It shows that two things may eliminate a particular job from consideration. The starting or discovery date of the job may be later than the present simulated day or the day's weather may prohibit assigning crews to the job. The array indicating acceptance or rejection of a job is JIND. If the element in this array corresponding to the job is equal to zero at the end of the checking stage, the job is accepted. If the element is equal to 9, the job is rejected. For one particular type of job JIND may have a value of unity, namely the emergency job. Crews are not assigned to emergency jobs as they are assigned to others. Emergency crew assignments are made after the ordinary crew assignments are completed.

In addition to the array JIND, another array IDELTA appears for the first time in the checking stage. The element in IDELTA corresponding to a particular job is usually the algebraic difference computed by subtracting an estimated completion date for the job (IETC) from the deadline date (IVDL). If the element is positive or zero, the indicated job will beat or meet its deadline. If the element is negative, the job will exceed its deadline. There are special cases in which the value of the element in IDELTA is not computed as above. In these cases the computer gives the element a value of

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10000 days, which is very large in comparison with the usual values. The numbers in JIND and IDELTA determine how crews will be assigned to corresponding jobs. The crew selecting procedure distinguishes between accepted jobs and rejected jobs. Further, it distinguishes between jobs which already have crew assignments from preceeding days and jobs which have no prior crew assignments. Anticipating the crew-assignment discussion, the following table summarizes the possible combinations of JIND and IDELTA element values and the meaning of each in the context of crew assignment.

Table VII-B

Combinations of Element Values - Arrays JIND and IDELTA

Element in 	Element in IDELTA	Meaning
0	0 <u><</u> n < 10000	Job is acceptable; one or more crews already assigned; job meets or beats deadline
0	n < 0	Job is acceptable; one or more crews already assigned; job will not meet deadline
0	10000	Job is acceptable; no crews yet assigned
9	10000	Job unacceptable
1	10000	Emergency job*

This combination of values for elements in JIND and IDELTA may have another meaning after crew assignment. At this stage, however, the explanation given is sufficient.

The second stage of job selection is ranking. The subroutine RANK orders (ranks) the jobs in the job inventory preparatory to the assigning of crews. Figure VII-10 shows a computer listing of this subroutine and the portion of the main program which calls for it. The figure shows that, before entering the subroutine, the computer places the elements of the array IDELTA into the array JUNK1. This permits the subroutine to rank jobs in order of the value of IDELTA,* jobs which are acceptable (JIND = 0) are ranked, lowest to highest, by IDELTA values, and jobs which are unacceptable (JIND = 9) remain in the order in which they originally appeared in inventory. The result of this is that the latter jobs remain in a block at the bottom of the job inventory. If the computer encounters one of these jobs, it is assured that the jobs which follow are also unacceptable.

Jobs do not have to be ranked by IDELTA values. There are other ranking policies which could be tested for their effect on the output of the model. Some of them require only a change in one FORTRAN instruction, the instruction which places the element of an array into JUNK1. Some arrays which could be placed in JUNK1, instead of the array IDELTA are:

- 1) IDTE the discovery day of the job.
- 2) IVDL the deadline date of the job.
- 3) IVMT the maintenance type
- 4) IVNT the interrupt index

In case two IDELTA values are equal, the corresponding jobs are ranked by discovery date. If discovery dates are also equal, the program logic happens to be such that the positions of the two jobs in the inventory will be reversed.

Figure VII-10--Reproduction of Subroutine RWK and Lead-in Instructions

SURROUTINE RANK COMMON TIIXI0 IVLC(30).IVSZ(30).TTJ(30).TT(100).CPR(30).VPR(30).JI 1ND(30).JUNK1(370).IDTE(30).JRANK(30).IVNZ(30) GO TO 134 IF (IDTE(J2).6T.IDTE(J1).AND.JIND(J1).NE.9) IF (JUTK1(J2)-JUNK1(J1))174・173・134 IF(JIND(J2).E0.9) GO TO 134 JUNKI (I) = IDELTA(I) URANK (J) = URANK (I) DO 134 J=I,IX10 DO 135 I=1, IX10 I2=JRANK(J) JRANK (1)=12 J2=JRANK (J) J1=JRANK(I) C RANK BY IVELIA JRANK (I)=I CALL RANK CONTINUE CONTINUE 1516=0 **RETURN** END • 133 174 173 134 135

2) Special Jobs

During the checking of jobs (see (1) above) three types of jobs receive special treatment. These are the job types having identification numbers 2000, 3000, and 3500. They are respectively, Light Snow, Snow Plowing, and Snow Clean-up. The computer assigns crews to these jobs before any others. On days when these jobs occur, they usually occupy all of the men in the depot.

The job called "light snow" and the job called "snow plowing" are mutually exclusive. If one occurs, the other will not. It is possible, however, to have a "snow clean-up" job on a day of snow plowing or light snow. This is because the occurrence of a snow plowing job automatically creates a snow clean-up job on the following day. Whenever a snow cleanup job and one of the other two weather-created jobs are in inventory together, the other weather-created job receives priority. Remaining resources, if there are any, can work on snow clean-up. (The special job assignments are handled by statements 110 through 486.) The rules for assigning crews to the special jobs are the same as those for assigning crews to other jobs. These rules are explained below.

3) Crew Selection

There are three kinds of crew assignments in the simulation (a) assignment of crews to normal jobs, (b) assignment of crews to special jobs, (c) assignment of crews to emergency jobs. Each kind of assignment needs separate discussion.

(a) Assigning crews to normal jobs

Most of the time a job will pass through a six-stage assignment process. The output of this process is a list of crews assigned to the job. The list is a single row of the array ICREW. The first index of this array refers to a particular job and the second index refers to the crew. The element ICREW (2,4) in ICREW would refer to the 4th crew assigned to the job ranked number 2 in the inventory.* The stages of the process are (i) releasing auxiliary crews, (ii) checking for the acceptability of permanent crew assignments, (iii) reducing the resource inventory, (iv) calculating crew costs, (v) adjusting permanent crew assignments, (vi) adding auxiliary crews.

- (i) The computer releases all auxiliary crews for all jobs during the job checking process (statements 453(2) through 453(5). These crews are distinguished from permanent crews by a minus sign preceeding them in the array ICREW. (The terms <u>auxiliary</u> and <u>permanent</u> crews are defined in (v) and (vi) respectively.
- (ii) The computer checks the feasibility of retaining all presently assigned permanent crews. If any permanent crew assignment cannot be made, due to resource restrictions, then all permanent crews are released to the resource inventory (statements 106 through 131).
- (iii) The computer subtracts from the resource inventory those men and equipment needed for each job (statement 126(3) through 129(-3).
 - (iv) The computer calculates the cost of each basic crew in dollars per work unit. It then ranks the crews from cheapest to most expensive (statements 163(-1) through 164).
 - (v) The computer does one of two things, depending on whether it is trying to add to crews already assigned to a job or whether it is putting crews on a job to which no crews have yet been assigned. The first crews to be assigned to a job are the permanent crews. Permanent crews remain assigned to a job

The reader should be careful to distinguish between the index of the crew in ICREW and the index of a crew in the list of basic crews. The fourth crew in ICREW for job number two, might be number 25 in the list of basic crews.

until either (1) the work week ends or (2) the job is completed. This procedure is a compromise between retaining continuity in crew assignments and getting permanently "stuck" with a low productivity or high-cost crew on a big job. Crew continuity is not important in assigning the crews but recognition of it in the simulation allows it to do essentially what a manager would do, i.e., assign an acceptable crew to a job and forget about the job until the next planning opportunity, until the job is completed, or until the resource inventory is over-committed.* Permanent crew assignments are not erased simply because a job cannot be done on a particular day. For example, light snow generates a job which uses all resources for one day, but the permanent crew assignments for other jobs are not changed. If there are as yet no crews assigned to the job, the computer looks at the lowest cost basic crew (from (iv)) and attempts to assign this crew to the job. If the resources are sufficient for the crew, the computer places the index of the basic crew in the appropriate row of ICREW. It then re-computes the value of IDELTA for the job to see if the job will now meet its deadline. If it does meet its deadline, the computer goes to the next job repeating the above. If it does not meet its deadline, the computer assigns another crew to the job by attempting to match the crew type of last assigned crew. If there are not enough resources remaining to make the match, the computer tries to assign the next lowest cost crew. The computer continues by attempting to match crews or by moving to the next lowest cost crew until one of four things happens: (1) the computer exhausts the list of basic crews for a particular type of job, (2) the cost of the next lowest cost crew is too great (here, more than 15 percent higher than the lowest cost crew), ** (3) the job meets its deadline, (4) more than 6 crews are

Over committing of resources can occur if a crew is permanently assigned to a job but cannot work on it because of weather conditions. When the weather clears up, the computer may find that the crew is still committed to work on the original job but has not finished its work on the substitute job.

^{**} The user may alter this percent if he wishes (see FORTRAN Statement 275(2)).

needed to meet the deadline.* It then goes to the next job.

If the job already has some crews assigned to it and does not meet its deadline when the computer first looks at it on a particular day, then the computer attempts to match the first crew in the existing assignment and continues as above.

- (vi) When the computer has completed all of the steps in (v), there may still be persons and equipment remaining in the resource inventory. The computer attempts to use some of these resources on jobs. It goes through the list of jobs one at a time trying to add one more crew by matching the first, second, etc. existing crews to the resource inventory. If there are enough resources for a match, the computer adds one more crew to the list in ICREW and places a minus sign before the index of the crew. It then moves on to the next job. The computer goes through the list of jobs again and again until it cannot add a new crew to any job in the list. The computer may not be able to add a crew if: (1) the estimated time of completion is less than the minimum time for the job (IVMIN), (2) there are already 6 crews on the job, (3) there are insufficent resources to match any pre-existing crew. The additional crews so assigned are the auxiliary crews.
- (b) Assigning Crews to Weather-Created Jobs

Before the computer assigns crews to normal jobs it assigns crews to the weather-created jobs in the inventory. It assigns crews to a job created by light snow (number 2000) or to snow plowing (3000) before it assigns them to snow clean-up (3500). (FORTRAN statements 139(9) through 436(3).) For these jobs, unlike normal jobs, the assigned crews are not marked down in a list. Each assigned crew simply contributes a number of man and equipment hours, representing one day's work, to a large pool of man and equipment hours. For example, if a crew consists of one Equipment Operator III; two laborers and a truck, then one day's work (8 hours) for this crew contributes 8 man-hours for equipment operators III, 16 man-hours for laborers and 8 truck-hours.**

** The present model assumes an 8-hour day for jobs 2000 and 3500. It assumes. a 10-hour day for job 3000.

This is the limitation in the present model. The user may place a higher limit on the number of crews if he wishes. He needs to replace the number 6 in the appropriate FORTRAN statements by any other integer or he may replace it by a parameter which he reads into the computer during the input phase. He must also change the second number appearing in the DIMENSION statement for ICREW. (See, in particular, FORTRAN statements 453(3), 119(1), 129(1), 130(1), 144(-1), 142, 170(-4), 206(3).)

The man-hours and equipment-hours represented by the crews assigned to special jobs are subtracted from the respective totals. Thus, if in the above example, there were 10 Equipment Operators III, 20 laborers and 15 trucks, then there were originally 80 man-hours for the equipment operators III, 160 man-hours for laborers and 120 truck-hours. After assigning one of the above crews there remain 72 man-hours for equipment operators III, 144 man-hours for trucks.

The absolute numbers of equipment operators III, laborers and trucks are also subtracted from the resource inventory. Thus, in the same example, there would remain 9 equipment operators III, 18 laborers and 14 trucks in the resource inventory after one crew assignment.

(c) Assigning Crews to Emergency Jobs

The assignment of crews to emergency jobs (number 1000) takes place after the assignment of crews to normal jobs. (FORTRAN statements 3000 to 222.) The computer searches the entire job inventory to see if there are any emergency jobs to be done on the simulated day. If there are one or more emergency jobs, the computer assigns crews. It looks for men to do the emergency job in the pool of man-hours called Job X. This pool consists of all the man-hours for the various classes of labor which remain after all normal job assignments are completed. If the number of man-hours required for the emergency job is not available from the Job X pool, then the computer tries to take crews away from normal jobs.* The computer examines the crews assigned to normal jobs by looking, first for auxiliary crews working at all locations and second, for permanent crews at all job locations. The computer picks job locations in order of their travel times from the depot, because it assumes that the crew must return to the depot for new equipment before it can do the emergency job.

^{*} Although the resource necessary for an emergency job may be only part of those in an already assigned crew, the computer will take the whole crew off the job. The mechanism of the assignment is (1) to select a crew for the emergency from a job to which it has already been assigned, (2) to transfer the resources of this crew into job X, and (3) to iterate the attempt to make up an emergency crew from the job X pool. Appendix A exhibits an alternative procedure for obtaining these resources. It is possible that there may not be any men or equipment which can do the emergency job. This will occur if there is light snow or snow plowing, in the present model. The reason for this is that the crews for these jobs are purposely arranged to use up all of the resources in inventory. The user could, of course, change the basic-crew input cards for these jobs so that some resources remain.

The work units of the emergency job are always <u>expressed</u> in hours on the input cards. Thus, if a crew is taken from a normal job and placed on an emergency job, the number of hours the crew will spend on the emergency job, including travel time, is immediately known. From this it is possible to compute and tabulate immediately the number of man and equipment hours that the selected crew will spend on the normal job and, therefore, its contribution to production on that job. When the computer tabulates production for the day, the production of the remaining crews is simply added to the tabulation for the job type. The computer tabulates production of the selected crew on the emergency job using the time for the emergency job specified on the input Card.

If crew(s) for the emergency job are taken directly from the job X pool, the man-hours in this pool are simply reduced by the man-hours used for the specified duration of the emergency job.

(d) Preparing for Output

When the computer leaves the execution phase and enters the output phase of the program, it has data available from the preceeding phase. These data include: the crew assignments, the jobs worked, the crew productivities and the crew costs. From these data the computer can calculate the work accomplished, the planned work remaining, the unfinished jobs still in the inventory, the man-hours and the equipment-hours expended on each type of job, and the labor and equipment costs associated with these hours. Before it calculates these quantities, however, it must adjust some of the data which it uses to calculate them. This is illustrated in the following example.

Suppose that three basic crews have been working on a job which should take them three and a half days. Suppose further that today is the last day of the job. Assume that each crew has a productivity of 2 units per hour and suppose that the set-up time for the job is a half hour and the round-trip travel time to the job is a half hour. Further, suppose that there are 28 units remaining in the job. Given the preceeding information, the computer has calculated the time on job or the "effective day" of the three crews. This would be:

time on job = 8.0 hrs. - 0.5 hrs. - 0.5 hrs. = 7 hrs.

The three crews working together for the time on job can do:

3 crews x 2 units/crew-hour x 7 crew-hours = 42 units

This means that if the computer uses the information available to it "uncritically" it will over-calculate the work done on the job.

In reality a foreman, seeing that a job is not a full-day's work for all the men on the crew, can switch some of the men (and equipment) to another job. The computer tries to take a similar action. If it finds the number of crews greater than necessary to complete the job, it finds the minimum number of crews, such that, if one more crew were added, the job would be overdone. It takes the remaining crews and tries to place them on a job of similar type. If it cannot so place them, it places the crews in the job X pool. The man-hours in the job X pool are then used as "fill-in" help for crews already assigned to jobs in a way similar to the assignment of auxiliary crews in the execution phase.*

In the above example, the reader can see that only two crews are necessary to finish the job exactly. The computer would try to assign the third crew to a job of the type to which it was formerly assigned. Failing this it would place the crew in the job X pool where it would add manhours equal to 8 times the number of laborers, etc., to the pool.

1) Output Phase

When the computer has made the adjustments indicated above, it is prepared to print the day's results. These appear in a report like that shown in Figure VII-11. The report heading indicates whether it reports production for the day, the week or the year.**

The aiding crew does not appear in ICREW. It simply affects the output results. ** The heading in the illustration also shows that this day is Wednesday, and that it is in week 0. It also shows that this is the second day of the year and that the day's weather was type number 4.

Figure VII-11--Reproduction of Daily Report

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Figure VII-12 -- Reproduction of Weekly Plan

W.U. • 00 0.00 18 000 17 000 PLANNED 48.0 1.1 1000.0 V' • 11 • 16 4 0 0 PAYROLL 15 000 547.20 858.89 351.00 COST TOTAL 1757 14 000 13 210 429.98 292.50 432.00 3405.60 **C**05T 1154 LABOR 12 000 3 WORK DAYS 11 000 1560.0 144.0 135.0 191.1 470 EQ OP 3 TOTAL EQUIPMENT SUMMARY 10 000 **21.**2 • 6 • 000 21 ω 000 0 FO OP 2 96.0 WEEK C C O 0 ~ 000 Ś o c c WFEKLY PLAN EU OP 1 48.0 42.5 45.0 408.0 135 5 000 LABORERS t 000 96.0 90.06 127.4 1n56.0 313 B 000 48 64 0 2 TRAFFIC SFRV B JOB X LAROR $c \circ c$ ----TOTALS INUEX TYPE NAME 115.20 428.91 58.50 COSTS 108 2 8 108 ΤΥΡΕ 101

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TOTAL

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2) Planning Phase

Normally, at the beginning of each simulated week, the computer makes a plan for the week. It plans to do work on all jobs in the job inventory which either are left over from the preceeding week or have "discovery dates" within the ensuing week. Emergency jobs, and all weather created jobs except the snow clean-up job are unplanned. The weekly plan generated in this phase is illustrated by the sample in Figure VII-12. The plan has the same format as the daily report given in Figure VII-11. The difference between the report and the plan is in interpretation of the numbers. The numbers in the report are actual hours and costs; the numbers in the plan are projected hours and costs.* There is one kind of inconsistancy which may appear in the weekly plan, although the user may never notice The work units planned may not be consistent with the labor and equipit. ment hours planned. This is because the computer puts into "work units planned" the smaller of the results from (1) projecting work units for the week and (2) the actual work units in the inventory. This prevents a weekly report at the end of the ensuing week from showing an excess of planned over actually accomplished work units that is due to grossly overoptimistic planning. Such an excess should only be due to not accomplishing a realistic plan.

[&]quot;With the exception of "work units carried," which are actual numbers.

VIII. Error Prints

It is expected as a fact of life that future users of this simulation will make mistakes in punching the large number of data cards required by the simulation. The programmers tried to anticipate this by including error prints and error conditions in the program. The programmers philosophy in defining error conditions is that errors detected during the first part of the input phase will halt the computer and print an error message. Errors detected thereafter will cause an error print and the ignoring of the erroneous data card. The error prints and their meanings follow in alphabetical order.

IN MAIN PROGRAM

ERROR, IRPER (=IPER) IS ZERO, COMPUTER WILL GO IN AN ENDLESS LOOP-the period of every recurring job must be non-zero. Check the formats of the recurring job prototypes to see if they are properly punched.

THE FOLLOWING JOB IS IN AN INACCESSABLE ZONE, IT HAS BEEN SKIPPED-the travel-time table shows which zones are inaccessable, check to see that no job is located in any of these zones. If this print is preceeded by a print of an SZ number (SZ1 etc.), check the comment above this number in subroutine HZONE.

INVENTORY BACKLOGGED _____ DAYS ON DAY _____ the computer tried to add a job to the inventory but found it almost full. It is temporarily withholding the job from the inventory and will put it in at first opportunity. JOB TYPE IS UNDEFINED--the type of job listed on the input job card is not listed on any of the job-type cards. Check both types of cards for punching errors.

NUMBER OF BASIC CREWS EXCEEDS MAXIMUM--there are more basic crews in the input deck than allowed by the DIMENSION statement.*

NUMBER OF EQUIPMENT TYPES IN INVENTORY EXCEEDS MAXIMUM--there are more types of equipment listed in the resource inventory than allowed by the DIMENSION STATEMENT.*

NUMBER OF HIGHWAYS IN ZONE LIST EXCEEDS MAXIMUM--there are more highways listed in the zone list (IHY) than allowed by the DIMENSION Statement.

NUMBER OF JOB TYPES EXCEEDS MAXIMUM--there are more job types in the input deck than allowed by the DIMENSION statement.*

NUMBER OF ZONES IN ZONE LIST EXCEEDS MAXIMUM--there are more zones in the zone list (IHZ) than allowed by the DIMENSION statement.

READ JOBS OUT OF SEQUENCE LAST IN ON CURRENT JOB IS DATED at least one job is out of sequence in the input deck. The computer continues as if nothing has happened.

And arrays included in the same input grouping.

RECURRING JOB TYPE IS UNDEFINED--a recurring job in the input deck has a type number which does not coincide with any type number in the job type list.

WEATHER DAY DUPLICATE--the input deck specified two types of N_1 N_2 N_3 weather for the same day. The computer places the last designated weather in the calendar and gives the weather type replaced (N_1) , the day of the year (N_2) , and the weather type replacing (N_3) .

WEATHER JOB SKIPPED DAY _____INVENTORY IS FULL--the computer could not place a weather-generated job in inventory because it was full. The job is ignored. The dimensions of all arrays relating to jobs should be increased on future runs. Increase correspondingly the value of INVMAX.

IN SUBROUTINE HZONE

The error prints from this subroutine are numbers preceeded by SZ. A print of the erroneous job follows after the SZ print.* These SZ numbers appear in the listing of HZONE together with a comment relating to the error. The SZ numbers and explanations of the comments follow in numerical order. (They are not in numerical order in the subroutine HZONE).

Immediately after the SZ print will be the print THIS JOB IN AN INACCESSABLE ZONE, IT HAS BEEN SKIPPED. In this case, the print may be ignored. Immediately following it is the print of the job.

SZ1--NO ZONE GIVEN FOR ZONE-ORIENTED JOB--if a job has a location of zero, this means it takes place in one zone. The number of the zone must be found in the "starting zone" position of the card. SZ2--this error message was removed.

SZ3 --ENDING ZONE OF JOB IS NOT ON ZONE LIST--check the ending zone of the job and the zones in the list of zones to see if either is incorrect.

SZ4--JOB LOCATION IS NOT ON HIGHWAY LIST--the job is specified for a highway which is not on the highway list (IHY).

SZ5--STARTING ZONE OF JOB IS NOT ON ZONE LIST--check the starting zone listed on the job card and on the list of highways to see if either is wrong.

SZ6--MILES OF JOB COMPLETED IS GREATER THAN LENGTH OF HIGHWAY--the computer is making a calculating error. This should not happen.

Appendix A - Emergency Crews

Suppose the emergency crew is to consist of one equipment operator I, two laborers, and a truck. Suppose further that the computer can not make up such a crew from the job X pool. It would search among all job locations for the closest job having an <u>auxiliary crew</u> from which to make up the emergency crew. If there are no auxiliary crews available, the computer will again search all job locations for the closest job having a <u>permanent crew</u> from which to make the emergency crew.* Suppose the computer finds a job with several auxiliary crews assigned to it. Call these crews, A, B, and C. The computer will check crew C first to see if an emergency crew can be made from it. The composition of each of the three auxiliary crews is shown in the table below.

	C	omposition of Crews		
Crew	<u>No. of E.O.I.</u>	Number of Laborers	Number of Trucks	
A.	3	4	3	
В	3	5	3	
С	4	6	4	

In the present model, the computer will take crew C away from the job, even though it more than meets the requirement for the emergency crew. In the above example, however, if the emergency crew were taken away from crew C, it would be most nearly like crew A. The remaining assignment on the job

It may be possible to use an optimization process here, detecting crews so as to minimize productivity losses.

after subtracting the emergency crew from crew C would then be A, B, and A rather than A and B only. This suggests the possibility of reading a "Table of Transitions" into the computer to which it would refer when taking emergency crews away from normal jobs. The table would show, for each crew type, the type of crew which would remain if the men and equipment needed to do the emergency were removed. The productivity of the reduced crew would replace the productivity of the former crew in the daily tabulations.

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