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Maintenance Systems: Estimating Maintenance Costs, Solid-Waste Disposal Systems, Maintenance Station Locations, Manager Training, and Equipment Management

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Subject Areas

11	Transportation Administration
12	Personnel Management
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CONTENTS

FOREWORD

The papers in this RECORD have in common the application of systems logic to the selection of a maintenance policy. They are concerned with minimizing the cost of transportation while maximizing the use of the maintenance dollar, determining current and future equipment needs, and developing a regional approach to the problem of solid-waste disposal at recreation facilities and along highways.

Industrial engineers and systems personnel as well as operating personnel will find these papers of interest. Progress toward a better understanding of the interrelationships between administrative policies and on-site effects is demonstrated, and the reports indicate that a closer working relationship between systems personnel and operating personnel would result in a better understanding of maintenance needs and a more thoughtful consideration of the effects that operating decisions have on subsidiary activities.

Alexander and Moavenzadeh suggest that it is erroneous to measure highway maintenance costs without reference to other factors—that maintenance costs are directly related to the design and operation of highways. Based on this, they have developed a maintenance cost model as part of a total-cost model, which shows potential for use in predicting maintenance costs.

Kirby and Hirsch present an analysis of solid-waste disposal methods that are currently being tested by the U. S. Forest Service. The problems of storing, collecting, transporting, and disposing of refuse in rural areas are examined, and a mathematical model example is included.

Hayman and Howard report on the use of optimization models to determine where maintenance stations can most economically be located. A sanding and a plowing model are given, and it is suggested by the authors that this technique could be applied successfully to other maintenance functions.

In abridged papers, Patterson discusses the general applicability of systems logic to maintenance programs, and Burke reports on a training program for highway maintenance managers.

A detailed study of equipment management, based on a case history in New York State, is presented by Morris. Each element of equipment management is outlined, and the need for proper interaction among the elements is stressed.

In the final paper, Delp reports that employee morale and productivity were improved by applying performance standards to repair shop activities.

PREDICTING MAINTENANCE COST FOR USE IN TRADE-OFF ANALYSES

John A. Alexander, University of Maine; and
Fred Moavenzadeh, Massachusetts Institute of Technology

There are opportunities for lowering the cost of highway transportation by analytically considering the cost of future maintenance during highway design. Selection of maintenance policy can also be approached as a problem of minimizing the cost of transportation. Suitable techniques for predicting future maintenance cost are required, however, to quantitatively consider these trade-offs. This study considers the trade-offs between maintenance costs and other highway costs by looking at maintenance as one part of the overall system instead of treating maintenance as an independent problem. Systematic analysis was aided by developing a method of predicting future maintenance cost for a specified environment, design, traffic load, and maintenance policy. The estimating method is based on simulation of the total process from design through operation and maintenance, for the economic life of the project. The physical cycle of deterioration and repair is simulated in sufficient detail to allow specific adjustments to be made. The model can be adapted to a wide range of conditions. Preliminary use of the model on actual projects has illustrated its potential for incorporating future maintenance costs into the design process and in exploring the effect of competing maintenance policies on total transportation cost.

•RECENT study in the area of highway maintenance has been devoted almost entirely to increasing the effectiveness of either the individual maintenance operation or the management of the maintenance organization. The question addressed by most studies is: How can the maintenance operation be done more efficiently?

These studies have approached highway maintenance as if it were a separate problem, independent of the larger problem of providing highway transportation. This may be a proper assumption if the study objective is limited to improving the efficiency of maintenance management and operation. However, the design and construction of a highway influences the type and quantity of maintenance required. Conversely, the type and quantity of maintenance performed affects road-user cost as well as the need for reconstruction. The two major trade-offs involving highway maintenance can be expressed as questions:

1. What is the best balance between initial system cost and future maintenance cost?
2. How much maintenance should be done on existing systems?

For every highway design problem there is a variety of solutions, all of which involve various mixes of construction cost, maintenance cost, and user cost. The problem is to find the mix or strategy that will give the lowest total cost, not necessarily the lowest construction cost or the lowest maintenance cost.

Sponsored by Committee on Maintenance and Operations Costs.

The overall objective of this study was to develop the quantitative techniques needed to analyze the major trade-offs involving highway maintenance. This type of analysis requires a method of estimating future maintenance cost. Therefore, a major objective of the study was to develop a method of estimating future maintenance costs of alternative strategies for providing highway transportation.

STUDY APPROACH

Because maintenance demands are tied closely to the overall operation of the system, we developed a method of estimating future maintenance cost based on a simulation of the total highway system. A large computer-based model was designed to simulate the construction, maintenance, and operation of a specified highway segment. The development of the maintenance-cost submodel described in this paper was carried out in close cooperation with the work done on compatible submodels for estimating construction and user costs. Although the work on construction and user-costs prediction was an integral part of the overall study, this paper will discuss only the maintenance-cost submodel and its relationship to the total-cost model.

The study was limited to the simulation of low-volume 2-lane roads. This reduced the complexity of economic analysis because many complications, such as congestion, accident losses, and traffic delays as a result of maintenance operations, are not important for low-volume roads. Another factor that made low-volume raods an attractive choice for this study was the importance of maintenance costs in relation to construction and user costs.

Low-volume roads are a common and important class of roads in most countries. For example, of the 3.7 million miles of roadway in the United States in 1968, 2.0 million miles (or approximately 57 percent) were unpaved. Another 23 percent were low-volume paved roads (1). Approximately 80 percent of all roads in the United States are of the type dealt with in this study. In less developed countries, low-volume roads are of even greater relative importance and in many cases are the only type of road available.

Although this study is limited to one class of roads, the principles used are valid for other types of roads and other types of civil engineering facilities. The study strongly suggests that similar techniques could be developed for other systems.

TOTAL-COST MODEL

Although this study is principally concerned with maintenance cost prediction, it is also part of a larger study directed toward prediction of total transportation cost. The framework and operation of the total-cost model will be briefly discussed to clarify its operation and to show the operation of the maintenance model within the larger model.

The total-cost model consists of three individual submodels that are programmed within the overall model framework. The submodels predict the construction, maintenance, and user costs that make up the total cost. The operation of the overall model is straightforward. Figure 1 shows the cycle of operation.

The steps used to examine a series of proposed strategies for a given project are shown in Figure 1. Input variables define the project to be analyzed. (Length, terrain, soil, climate, traffic demand, discount rate, and local unit costs for labor, equipment, and materials are specified.) In step 2, other input variables are used to define the construction and maintenance strategy to be tried. (Grade, alignment, widths, depth of surfacing, maintenance policy, and reconstruction schedule are defined here.)

Based on this information, the submodels within the total-cost model estimate the construction, maintenance, and user costs for each year of the analysis period. This is indicated in steps 3, 4, and 5 of Figure 1. The model then totals and discounts these costs to find the current value of the total transportation cost for the strategy specified. The model user can then evaluate a series of strategies on the basis of their predicted total costs.

This cycle of operation, although simple, allows the submodels to interact with each other to simulate the physical relationships among construction, maintenance, and traffic. By making the individual cost predictions year by year for the analysis

Figure 1. Total-cost model operation.

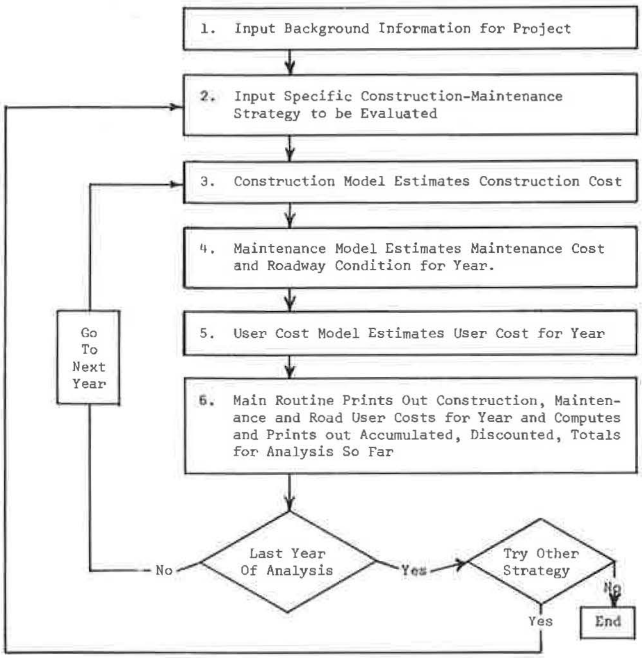


Figure 2. Typical maintenance model.

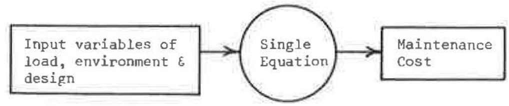
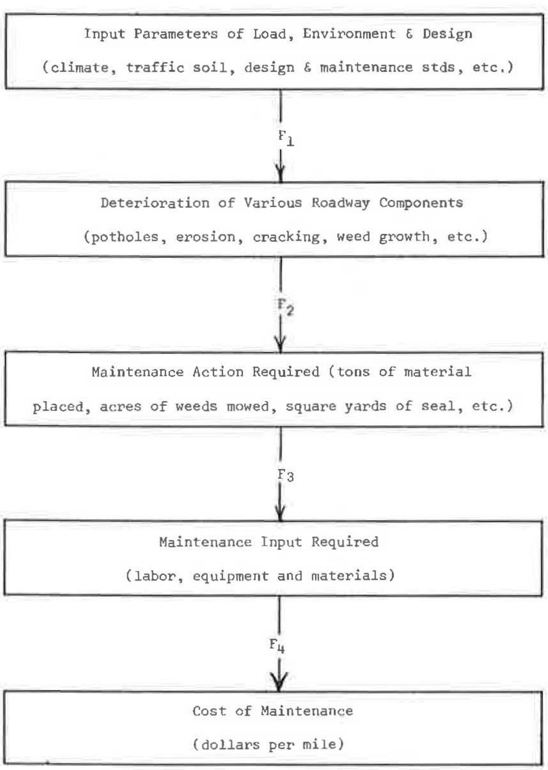


Figure 3. Relation between parameters and cost.



period, the submodels are able to base their annual predictions partly on information generated by the other models. By using this method, we can simulate some of the feedback characteristics of the physical system. For example, prediction of maintenance cost and roadway condition for each year is influenced by the volume and type of traffic predicted for that year by the user-cost model as well as by the description of the roadway specified by the model user. The user-cost model in turn estimates individual vehicle costs for each year as a function of the roadway conditions predicted by the maintenance model and the physical design of the road. Thus, the overall model estimates costs by simulating the major interaction among construction, maintenance, and use of the road instead of attempting to make independent estimates of the construction, maintenance, and user costs for the analysis period.

The variables that influence the behavior of a system are all of a random nature whether they are associated with environment, load, maintenance policy, or the system itself. Therefore, any predictions of system behavior should ideally be made by a probabilistic model that takes the uncertain nature of these variables into consideration. However, the small amount of information available on many of the variables did not seem to justify the additional sophistication of a probabilistic model. Instead, the advantages of simplicity and economy of a deterministic model were chosen for this study. The current model uses the average values of the variables and predicts maintenance cost and roadway condition in terms of point estimates.

MAINTENANCE MODEL

The maintenance model forms the central part of the study. As an integral part of the total-cost model, the maintenance model allows future maintenance costs to be considered as a design parameter. In addition, the ability to estimate future maintenance costs allows the question of maintenance policy to be analytically explored. Both of these capabilities are needed to systematically consider the trade-offs concerning highway maintenance.

Many highway maintenance studies have proposed methods of predicting future maintenance costs. Most of the estimating methods developed during these studies are based on past, local experience and are usually no more than rough projections for estimating the next year's budget. However, a few recent studies have attempted to devise more reliable methods. These studies have resulted in a variety of mathematical equations or models for estimating highway maintenance costs (2, 3, 4, 5, 6).

After reviewing the available models, we concluded that not one had been developed to help analyze the trade-off opportunities between maintenance and other costs or benefits and that none is suited for this use. Further, we found that the models are valid only for the geographical area for which they were developed. All of the models reviewed can be represented diagramatically as shown in Figure 2. The input variables are plugged into a single equation that estimates total maintenance cost. All of the models have built-in biases that represent conditions in the individual study area. This is a necessary adjustment if the model is to be valid. However, most of the biases are incorporated into the coefficients and exponents of the single equation that makes up the model. There is no way to adjust for changed conditions. This is a serious drawback if the model is to be useful over a wide range of geographical and economic conditions.

The total-cost model function of the maintenance model is to predict maintenance cost and roadway condition (as functions of design, environment, traffic volume, and level of maintenance) for each year of the analysis period. Maintenance cost affects the total cost directly. Roadway condition has an indirect effect through its influence on user cost. The model is of general use only if it can make these predictions for a wide variety of designs, environments, and traffic loads.

To predict maintenance costs and roadway conditions for a wide range of situations requires a model that simulates the physical relationships involved. These relationships should be simulated in sufficient detail to allow the model to respond realistically to changes in design, environment, loads, and maintenance policy. It was decided that the overall relationship among these variables and the resulting prediction of maintenance cost and roadway condition should be broken down into more easily understood subrelationships.

The framework that evolved corresponds to the basic physical relationships that exist in the sequence of events from deterioration to repair. These fundamental relationships are shown in Figure 3.

The function shown as F_1 represents the deterioration rate of the highway. The deterioration rate is affected by four types of variables: (a) environment (climate and soil); (b) loads imposed on the system (traffic volume or number of equivalent loads); (c) design of the system; and (d) level of maintenance (maintenance policy).

Rate of deterioration can be measured by such quantities as amount of cracking, number of potholes, cubic yards of soil deposited in ditches, and inches of vegetation growth. The relationship F_1 is the most difficult part of the maintenance model to predict accurately.

Function F_2 (Fig. 3) is the relationship between the extent of deterioration and the amount of maintenance action required. Maintenance action can be measured by tons of patching material placed, acres moved, and square yards of area bladed. Such relationships depend heavily on the maintenance policies and procedures being used. For instance, the size of the pavement area to be sealed in relation to the size of the area that is cracked depends on maintenance policies. Finding the function to accurately represent this relationship is closely tied to the problem of selecting and specifying maintenance policy. In the current model, it is possible to adjust the function to meet local conditions. The explicit representation of this function also makes it possible to explore the effects of various maintenance policies.

Function F_3 (Fig. 3) determines the expenditure of maintenance effort that is needed to accomplish the maintenance action found to be required by the model. Maintenance effort is measured in terms of labor, equipment, and material in the current model. Finding F_3 functions between actions needed and effort required is essentially a problem of measuring the productivity rates for the various operations.

The F_4 functions are the appropriate unit prices for labor, equipment, and material for the location involved. This is a separate problem in itself; however, the model allows the model user to specify the unit prices based on the best available information. Either market prices or shadow prices that represent real economic costs can be used.

A fairly complex framework is needed to provide the level of detail shown in Figure 3. The four functions shown in Figure 3 must be determined for each type of deterioration to be analyzed. This results in a model that is too large and complex for manual use. As a result of this complexity, the model was developed as a computer simulation, which allows the construction of a complex—but manageable—model.

The maintenance model is designed such that it can deal with four categories of maintenance; it also can sum the quantities and costs of labor, equipment, and materials. For each of the four categories of maintenance activity (surface, drainage, shoulder, and vegetation control), the model explicitly represents the types of physical relationships shown in Figure 3. The model deals with the problem of finding deterioration, quantity of work, required input, and monetary cost as individual parts of the actual physical sequence. As a result of this structure, the model can be adjusted to match changes in the variables that may affect maintenance cost. For instance, changes in the costs of labor, material, or fuel can be applied to corresponding, recognizable factors in the model in terms of dollars per unit (hour, ton, and gallon). Similarly, variations in design can be represented by using different side slopes, pavement types, and surface thicknesses. The operation of the model is shown in Figure 4.

The maintenance model is made up of approximately 800 Fortran statements; therefore, a detailed line-by-line explanation is not practical. Instead, the basic structure has been described. A more detailed description is given elsewhere (7).

In summary, the significant characteristics of the maintenance model are as follows:

1. The problem of estimating cost is broken down into its component parts (deterioration, maintenance policy, productivity, and unit costs), which gives the model flexibility.

2. The behavior of the total system is taken into account instead of treating maintenance as an independent function.

Figure 4. Maintenance model diagram.

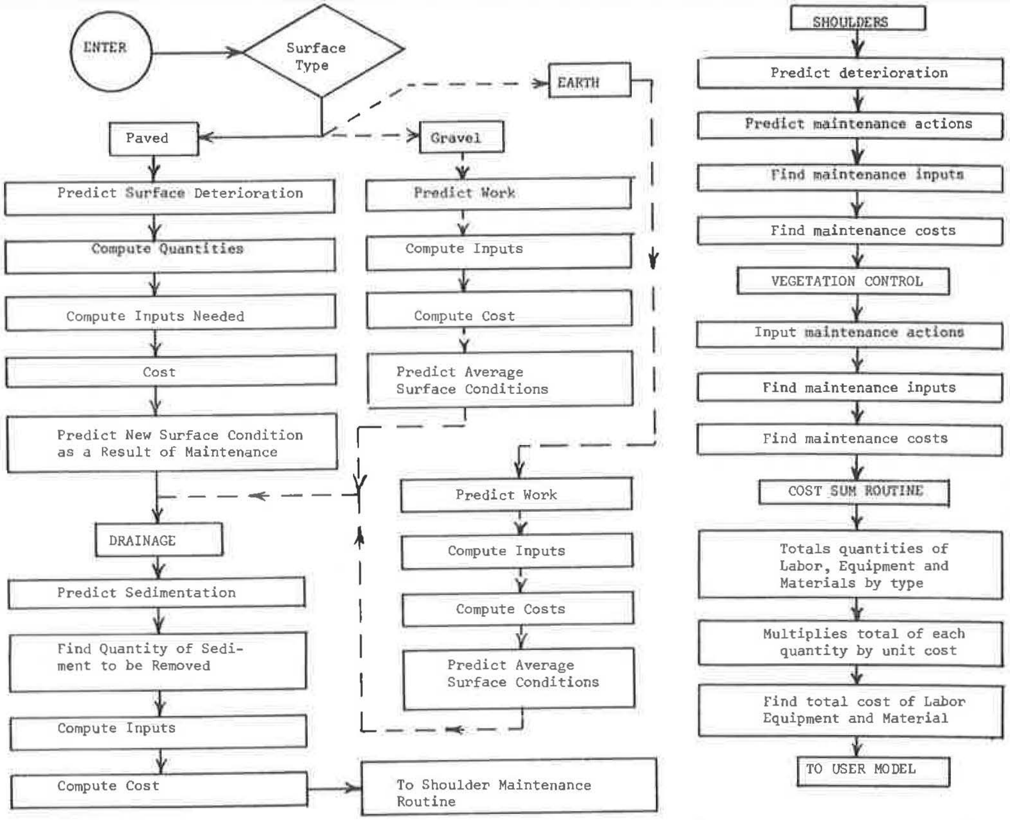


Table 1. Pavement design results.

Structural Number of Pavement	Present Worth of Costs (thousands of dollars per km)			
	Construction	Maintenance	User (adjusted)	Total
1.13	16.2	7.5	22.2	45.9
1.25	18.4	3.3	21.8	43.5
1.44	20.0	2.7	21.8	44.5
1.78	22.0	2.1	21.4	45.5

Table 2. Blading frequency results.

Blading Frequency (vehicles per blading)	Present Worth of Costs (thousands of dollars per km)			
	Construction	Maintenance	User (adjusted)	Total
1,000	13.7	4.4	18.4	36.5
2,000	13.7	3.2	18.4	35.3
3,500	13.7	2.1	20.6	36.4
12,000	13.7	1.4	33.7	48.8

APPLICATION OF MODEL

Two example problems are presented that show how the model can be used as a decision-making aid. The first problem involves a trade-off between initial system cost and future maintenance cost. The second problem shows how the model might be used to select a maintenance policy.

In both examples, present worth of total cost for a 20-year analysis period is the criterion used for judging competing strategies. The user cost is adjusted to account for the change in consumer surplus among strategies. The examples are based on a 2-lane road in Burundi, Africa. The unit costs used for labor, equipment, and material are typical for central Africa. The discount rate used for the present-worth calculation is 8 percent.

Example Problem 1

Most pavement design research has been directed toward finding the depth and type of pavement needed to withstand the effects of future traffic for a given design period. The design period is usually fixed; e.g., 20 years is a common design period in the United States. The possible benefits of a longer or shorter design period are usually not considered. Although pavement design affects future user and maintenance costs, the designer normally has no satisfactory method of analytically considering these costs during the design of a pavement. The use of this model, with its simulation of the system for an analysis period, allows the questions of length of design period and effect on user and maintenance costs to be explored.

Simulation runs were made for example problem 1. Four pavement design strategies were tried. The strategies represent a span of design life of 5 to 35 years as found by a conventional design method. Pavement maintenance policy was the same for all pavements. The traffic demand function specified for this project resulted in average daily traffic of 60 to 160 vehicles over the 20-year analysis period. (The difference in traffic growth is a result of the price elasticity of demand and the difference in user costs among the various surfaces.) Twenty percent of the total vehicles are heavy trucks. The results of the simulation runs are given in Table 1.

Of the designs examined, the pavement with a structural number of 1.25 results in the lowest total cost. This represents a design life of approximately 10 years, after which a resurfacing was simulated by the model. Variations in the proposed pavement designs resulted in substantial changes in both the estimated costs for maintenance and the costs to the users. As mentioned, conventional pavement design methods do not consider maintenance and user costs. At best, the designer can make only crude estimates of these future costs.

This example shows how, by using the present model, maintenance and user costs can be considered along with construction costs at the design stage.

Example Problem 2

Surface maintenance is by far the most costly type of maintenance operation for most gravel roads. Maintenance of the surface usually consumes more than half (and sometimes practically all) of the maintenance cost. Typically, most of the surface maintenance cost is needed for periodic blading or dragging of the road to prevent or remove corrugations and to move gravel back toward the center of the road.

As a result, the cost of maintaining a gravel road will be heavily affected by how often it is bladed. The frequency of blading also affects the level of service provided by the road and thus the cost to the user. These two relationships result in a trade-off between maintenance cost and user cost. Such a trade-off can be studied by using the model.

A series of runs was made in which blading frequency was varied and the resultant present worth of the cost for a 20-year analysis period was observed. The road used in this example starts with a gravel surface 15 centimeters deep. Average daily traffic varies from 50 vehicles during the first year to 135 vehicles during the twentieth year. Ten percent of the vehicles are medium trucks. All input variables except blading frequency are held constant for the series. Results of the runs are given in Table 2. The construction cost is the same for all runs and therefore is not needed to find the blading frequency that gives the lowest cost.

The maintenance strategy of blading once every 2,000 vehicles resulted in the lowest total cost. It appears that total transportation cost is relatively insensitive to frequency of blading in the range between 1,000 and 3,500 vehicles per blading. For this situation, it is probably not within the accuracy of the model to locate, more exactly, the frequency of lowest cost.

Although this example specifically examines the frequency of blading gravel roads, the model can be used in a similar fashion to evaluate alternative maintenance policies involving other maintenance operations simulated by the model.

It should be noted that the results shown in these two examples are based on a particular combination of roadway design, traffic volume, unit prices, and discount rate for capital and may not be valid for other situations.

SUMMARY

The objective of this study was to devise systematic and practical techniques to allow consideration of two fundamental questions of highway maintenance:

1. What is the best balance between initial system cost and future maintenance cost?
2. How much maintenance should be done on existing systems?

Systematic analysis of maintenance policy was aided by developing a method of estimating future costs and effects of maintenance. The maintenance model developed during this study estimates costs and effects as functions of traffic, environment, maintenance policy, and the physical characteristics of the system.

An overall model framework was designed. The maintenance model operates within this larger framework where it contributes the simulation of roadway deterioration and repair to the simulation of the total system. Three other submodels for estimating construction and user costs and volume of traffic were designed as part of the larger study. The three submodels operate within the total-cost model to estimate the present worth of the total cost of providing transportation by using a specific strategy. By using the model, alternative strategies for a project can be quickly and easily evaluated on the basis of present value of total transportation cost.

In designing the maintenance model, we did not attempt to relate maintenance cost to combinations of the significant variables by using regression analysis. Instead, the physical cycle of deterioration and repair was simulated as realistically as possible, and maintenance cost and roadway condition were estimated on the basis of this simulation. The cycle of deterioration and repair was divided into the individual physical activities that make up the cycle. These activities were simulated individually and then combined in the maintenance model to simulate the total physical system.

The structure of the model appears to be conceptually sound. The model responds reasonably to variations in design characteristics, traffic loads, and environmental descriptions. No major inconsistencies were encountered during the numerous runs made for calibration, sensitivity analysis, and example problems. The structure of the model, which bases the maintenance cost estimates on the overall simulation of roadway behavior, appears to provide a practical way of estimating future maintenance cost. Most of the advantages of this model over other methods of estimating maintenance cost are made possible by the flexible structure of the model, which allows individual physical relationships to be explicitly simulated.

Another advantage of the maintenance model is that it can be adjusted to meet the requirements of a wide variety of local conditions.

The type of model structure used also allows the accuracy of the model to be improved as new information is gained about the individual relationships. Thus, new information from a variety of sources may be used to improve the model.

The model's immediate usefulness is dependent on its accuracy. Accuracy is difficult to assess because there is no standard against which to compare model estimates.

However, the calibration runs, sensitivity analysis, and other work with the model during the course of the study give a general idea of model accuracy. Based on the work done during this study, the model appears to be accurate enough for use in the early planning stages of project development. The model is not sufficiently developed to be used as a production model. However, an analyst who understands the current limitations of the model could use it to make preliminary evaluations.

The model could also be used for more detailed design work on selected projects. The model should be useful for exploring a wide range of strategies and for selecting the ones that promise lowest transportation costs. However, the strategies suggested by the model should be used only if they satisfy the requirements of other tests.

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ANALYSIS OF SOLID-WASTE SYSTEMS IN A RURAL SETTING

Malcolm W. Kirby and Ernest Hirsch, U. S. Forest Service

The U. S. Forest Service is currently upgrading the solid-waste disposal methods used in its 153 national forests. The technique consists of collecting refuse at camping and picnicking areas by using trucks. The trucks then haul the solid waste to conveniently located sanitary landfills where it is compacted and buried. Preliminary analysis of this approach in a test forest showed that cost savings of as much as a third are possible. To minimize total cost, we have constructed a deterministic crew-scheduling model that consists of a mixed integer linear programming formulation. Areas to be serviced are introduced as nodes in a network, and connective roads constitute the network links. The necessity for servicing all camp areas, the limited capacity of trucks, and the limited working day of crews serve as a set of constraints. In addition, crews start and end their tours at headquarters. Costs are associated with both the total network coverage and the landfill operation. The variables under management control, such as crew size, truck capacity, and collection frequency, are tested parametrically; i.e., the optimum schedule is evaluated each time a parameter is changed. The procedure permits an integrated regional plan to be compared with a collection of subregional plans.

•IN 1970, the national forests hosted more than 172 million recreation visitor-days. Visitor-days are the product of the number of visitors and their lengths of stay divided by 12 hours. Currently, more than $12 million annually is spent to handle solid wastes, the bulk of which is created by recreational visitors.

About 96 percent of these costs are for collection and hauling. The introduction of higher standards of disposal at centrally located sanitary landfills necessitates higher expenditures for transport as well as for disposal. Hence, more comprehensive methods for analyzing solid-waste systems are needed to keep costs to a minimum.

The goal of this study is the development of methods for examining alternative plans and schedules for storing, collecting, transporting, and disposing of refuse in a rural setting. The rural setting is characterized by widely dispersed waste generating points with small volumes at each point. This sharply contrasts with the urban setting where waste generating points are so closely spaced as to present nearly a continuous distribution along a city street. Refuse resulting from harvesting timber and constructing roads is not within the scope of this study.

Refuse is generated largely during short recreation seasons that last only 3 months in some places. Hence, the collection schedule must be changed, sometimes monthly, to conform to the seasonality of use. Refuse is usually stored in cylindrical cans (often with disposable plastic liners) that are handled manually or in large metal bins that are handled mechanically. Compaction of refuse is never done at the site of generation. Special containers are sometimes used to keep the solid waste safe from wildlife.

Sponsored by Committee on Roadside Maintenance.

Refuse is transported in open trucks or compactor trucks periodically; pickup cycles vary in frequency from daily to weekly depending on the attractiveness of the refuse to animals and its unattractiveness to visitors. Although transfer stations are not presently used, our methods of analysis permit that possibility.

In the more densely used recreation areas where a truck makes more than one daily trip to the landfill, the trip may be made by only part of the crew while the remainder services storage containers. This permits hauling to be separated from container servicing. However, if the two tasks are not coordinated, double handling becomes necessary. In this case, a transfer station that employs mechanical handling is usually necessary because the thin plastic liners will not tolerate the abuse of double handling. It is our assumption that many designers will choose a system configuration in which the two tasks are performed by the same crew. For the present, this is the hypothesis used throughout our study.

Disposal by incineration is not currently preferred. Because the composition of recreational solid waste is high in moisture and low in flammability, the large amount of energy required for volume reduction by means of incineration is very expensive. Therefore, the preferred method of disposal is the use of a sanitary landfill with unloading, compacting, and covering all being accomplished on the same day.

METHODS OF ANALYSIS

Waste generating rates were examined in a 1969 field study described by Spooner (5). His results established a direct functional dependence of the amount of generated waste on the number and activity of visitors using a recreational facility. The results can be used without regard to geographical location. These findings permit the U. S. Forest Service to estimate the amount of waste by counting people.

Collection times were obtained from a report by Little (2) and from our own field studies. Collection times depend on crew size, truck size, and number of clustered containers that are empty. The number of containers needed depends on the frequency of collection as well as on the frequency of campsite use.

The time required for a tractor to compact and cover material at landfills was studied by Little (2). He found that the total cost consists of a fixed setup cost for readying equipment and terrain augmented by linear function of the amount of material.

The most difficult part of the analysis is selecting routes; there are many alternatives, and each requires a large number of calculations. Our approach is to fix the landfill locations, crew sizes, collection frequency, and truck size and then determine crew route schedules. This is repeated by using a different choice of landfill location and/or crew size to obtain alternative solutions whose costs may be compared.

We recognized the stochastic nature of recreation use. Spooner (5) indicated that use varies during any week as well as over the entire season. Use also varies among locations. However, we chose to treat the design as a deterministic problem rather than a stochastic problem because schedules and facilities cannot be changed as frequently as use varies. We feel, however, that economies can be obtained by changing the schedule, for example, each month or two. This can sometimes be accomplished by closing some campsites during slack periods or by sealing containers. We also found situations where it is cheaper to permit partial servicing of a campsite on one tour (leaving the remainder for the next tour), thereby using more effectively the available truck capacity and time. We call this the "partial pickup" policy in contrast to the "total pickup" policy that does not permit partial servicing of a campground.

Whenever the schedule permits the landfill to be operated less frequently than daily, the dozer-tractor may be engaged elsewhere for other tasks. This permits a dozer to be shuttled between landfills. A simple break-even analysis indicates when the cost of a number of trips for one dozer is less than the cost of using two dozers.

The methods developed may be used to examine regional systems, which yields the costs to each agency. Regional programs are often desirable because of economies of scale and because publicly owned land is often the only feasible place available for disposal. (Federal agencies cannot legally contract for disposal by private entrepreneurs if their method does not meet federal standards.) The ability to examine regional and subregional systems is useful for exploring the effects of changing crew headquarters locations.

We use the notion of system boundaries to locate generating sites and landfills that appear as nodes on a transport network. The network defines our system boundaries, and it may be arbitrarily partitioned into several subsystems whose boundaries may be compared with existing administrative boundaries. Partitioning may also simplify the computations where natural clusters of generating points are separated by very long distances—a situation typically encountered in a rural setting.

Locating landfills by the use of the centroid notion (found in classical mechanics) was not useful because the travel time between a generating point and the landfill is only defined along links of the transport network. We also found that landfills must be located with a cautious eye toward potential groundwater pollution and future uses of the site Hence, it became necessary to treat the landfill locations as parameters subject to change from time to time rather than as variables.

COST DIFFERENCES

We tested 11 different configurations on the Texas National Forests by means of hand computations. (The construction of access roads to the landfill was not included in the cost.) We found, during the 6-month peak season, changes in (a) truck capacity, amounting to about \$6,000; (b) number of landfills, about \$2,000; and (c) frequency of collection, about \$7,000. The least expensive configuration cost \$19,200, and the most expensive cost \$29,400.

MATHEMATICAL MODEL EXAMPLE

Space permits only one problem to be presented—the partial pickup problem formulated as a zero-one, mixed-integer linear programming problem whose solution would yield the optimal schedule for routing crews so as to minimize total collection cost. This problem and the total pickup problem are not tractable by the usual solution methods because of their large scale. In a future publication, we shall discuss some approaches for solving them.

The version of partial pickup problem presented here assumes that the landfill is sufficiently close to crew headquarters such that the travel time between headquarters and the landfill is negligible. The reason is for simplicity of exposition. This assumption means there is only one type of tour, one that originates and ends at headquarters. Where the headquarters is not close to the landfill, there are two types of tours—those that originate at headquarters and those that originate at the landfill. We also assume a single truck size, single crew size, and single collection frequency. The length of the working day is fixed; there is no overtime option or penalty for unused crew time.

Notation

T_{ij} = least travel time from point i to point j (in minutes) and point 0, the origin, is the headquarters location;
t_j = service time at point j (in minutes);
w_j = waste production at point j (in cubic yards);
d = maximum working time per day (in minutes);
v = volume capacity of the truck (in cubic yards);
y_{jk} = fraction of site j serviced by crew k;
$x_{ijk\ell}$ = fraction of the link between i and j that is used by crew k on the ℓth leg of its tour;
N = number of crews; and
M = number of waste generation points.

Constraints

1. $\sum_{j=1}^{M} w_j y_{jk} \leq v, \quad \text{for } k = 1, 2, \ldots, N$

Explanation: Crew k may not exceed its truck capacity during its tour.

2. $\sum_{i=0}^{M} \sum_{j=0}^{M} T_{ij} \sum_{\ell=1}^{M+1} x_{ijk\ell} + \sum_{j=1}^{M} t_j y_{jk} \leq d, \quad \text{for } k = 1, 2, \ldots, N$

Explanation: Crew k may not exceed its maximum daily working time during its tour.

3. $\sum_{k=1}^{N} y_{jk} = 1, \quad \text{for } j = 1, 2, \ldots, M$

Explanation: Each site must be fully serviced.

4. $\sum_{j=1}^{M} x_{0jk\ell} = 1, \quad \text{for } k = 1, 2, \ldots, N$

Explanation: Crew k must start from the origin (headquarters) during the first leg of its tour.

5. $\sum_{i=1}^{M} \sum_{\ell=2}^{M+1} x_{i0k\ell} = 1, \quad \text{for } k = 1, 2, \ldots, N$

Explanation: Crew k must return to the origin after the first leg of its tour (note that there are zero maximum of M + 1 legs on a crew tour if the crew services all waste generating points).

6. $x_{0jk_1} - \sum_{i=0}^{M} x_{jik_2} = 0, \quad \text{for } \begin{matrix} j = 1, 2, \ldots, M \\ k = 1, 2, \ldots, N \end{matrix}$

Explanation: Crew k going from the origin to some point j during the first leg of its tour must depart from point j during the second leg of its tour.

7. $\sum_{i=1}^{M} x_{ijk\ell} - \sum_{i=0}^{M} x_{jik(\ell+1)} = 0, \quad \text{for } \begin{matrix} j = 1, 2, \ldots, M \\ k = 1, 2, \ldots, N \\ \ell = 2, 3, \ldots, M \end{matrix}$

Explanation: Crew k arriving from point i (other than the origin) at point j during the ℓth ($\ell > 1$) leg of its tour must depart from point j during the ($\ell + 1$)th leg of its tour. Its destination may, however, include the origin.

8. $\sum_{i=0}^{M} \sum_{\ell=1}^{M} x_{ijk\ell} - y_{jk} \geq 0, \quad \text{for } \begin{matrix} j = 1, 2, \ldots, M \\ k = 1, 2, \ldots, N \end{matrix}$

Explanation: If crew k is to service site j (either fully or in part), crew k must arrive at site j prior to the (M + 1)th leg of its tour. [If there exists an (M + 1)th leg on the tour, it would constitute a return to the origin.]

9. $x_{ijk\ell} = 0 \text{ or } 1, \quad \text{for all } i, j, k, \ell$

Explanation: Either crew k travels along a link during the ℓth leg of its tour or it does not.

10. $y_{jk} \geq 0, \quad \text{for all } j, k$

Explanation: The fraction of site serviced by crew must be non-negative. It is guaranteed not to exceed unity by constraint 3.

11. $i \neq j$ for any $x_{ijk\ell}$
Explanation: A crew does not stay at a point during a leg of its travel.

Objective Function

$$\text{Minimize} \sum_{i=0}^{M} \sum_{j=0}^{M} T_{ij} \sum_{k=1}^{N} \sum_{\ell=1}^{M+1} x_{ijk\ell}$$

Explanation: Because total service time at each site is fixed, the cost of this service is constant, and its contribution need not appear in the objective function. Because traveling cost is proportional to travel time, it suffices to minimize the latter.

Comment

To investigate the problem fully, we have to consider several parameters:

1. If N is too small, the problem becomes unfeasible and the number of crews must be increased, whereas an N that is too large may actually be inefficient and should be reduced, one crew at a time until unfeasibility is reached.
2. Factors that affect service time (t_j) and waste volume (w_j) at each site must be considered. These factors are seasonal use, collection frequency, and crew size (which affects service time only).
3. Varying truck sizes should be investigated because they affect constraint 1.

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DISCUSSION

W. B. Drake, Kentucky Department of Highways

I want to congratulate the authors for an interesting analysis of collection systems for solid waste in the national forest setting. This type of analysis should enable the proper economic decisions to be made when sufficient historical data have been compiled.

There are some similar situations and decisions pending currently in the Kentucky Department of Highways. We have numerous parks, forest lands, and recreational areas in Kentucky. Our litter pickup cost, which has been increasing in recent years, amounted to $1,520,714 for fiscal year 1970-71.

There has been a concerted effort made by anti-pollution commissions and environmentalists to eliminate or minimize water and air pollution from open dumps, sanitary landfills, and minimum-efficiency incinerators. The result has been that many small governmental agency dumps and disposal areas have been closed for noncompliance, which leaves some areas with only private means for the disposal of solid waste.

An interesting situation occurred along these lines recently. One of our highway administrators was vacationing at a privately developed commercial campsite on a major lake. There was displayed on the mirror in the bathroom a detailed map with the following instructions:

> Please leave this cabin in the same condition that you found it. You are to take your trash and garbage in the plastic bags provided to the Department of Highways litter barrel shown on this sketch.

Although the purpose of the litter barrels is to collect trash and litter from cars traveling the highways, we find many instances where the barrels are being misused. The story is told that an enterprising citizen in one area was using his small pickup truck to assist some of his neighbors in hauling their litter to our barrels.

We are most interested in the recent action of some state highway agencies to eliminate public garbage collection and disposal. These contrary thoughts arise from doubts that highway departments can or should afford the burden of providing a public disposal system.

Innovations from the standpoint of convenience and public obedience are desirable. Perhaps optimization from a systems point of view will eventually and more clearly define the tasks, costs, and responsibilities involved in the collection and transportation of solid waste to a disposal facility. Again, it appears to me that further innovation may be necessary.

Charles F. Riebe, National Park Service

It appears that the authors have developed a deterministic model that partially satisfies the stated goal. The mathematical model presented in their report includes only those variables or parameters that provide for the collection and transportation of refuse and seems to exclude the capability of specifically examining scheduling, storage schemes, and disposal operations. This does not negate its usefulness for examining alternative refuse collection schemes and their respective costs.

The model is limited by several valid constraints that are specifically stated, but there are also some restrictions that result from the basic assumptions that may affect the sensitivity and effectiveness of the model.

Perhaps the greatest value of the paper is the idea of a regional collection scheme that includes several subregions. I have interpreted this idea to mean that regions should be composed of different public and private jurisdictions rather than just geographical locations under one jurisdiction or managerial authority.

The authors point out the desirability of such a scheme because of economies of scale and the possibility of public land being the sole source of a disposal site.

It is time for collecting agencies to begin considering the problem in terms of rural waste, i.e., waste from all rural sources—forests, parks, recreation sites, rural households, and the connecting roads and roadsides. This would, of necessity, have to be considered on the basis of individual regional schemes and would require great initiative.

It appears that the mathematical model presented is sufficiently general to be applied to a regional scheme involving several managerial or supervisory jurisdictions bound together under a common agreement for collection and disposal of waste. One limitation in its use would be the requirement for a single headquarters and a single disposal site. It is possible that several points of origin and disposal should be considered in any such regional scheme because of the constraints that could result from using only one. The model presented has a headquarters location but does not include a disposal site; however, a collection site variable or parameter could possibly be used as a substitute. This may result in reduction of sensitivity of the model in its present form.

Further study needs to be done of staging points and rural collection practices. We can safely assume that those who dispose of household waste in roadside cans in rural areas either do not have satisfactory disposal systems locally or are just plain inconsiderate. I can recall a situation where roadside cans were continually used for household waste because the home owners considered the price of 40 cents to incinerate a 32-gallon can of trash too high. When local authorities arrested several violators for such practice, the garbage was then strewn along the roadside or found in the brush.

The problem of household waste being disposed of in roadside litter barrels could be examined by the mathematical model developed by Kirby and Hirsch.

If the highway department became the waste collection and disposal authority by agreement of those involved, collection schemes could be developed and examined on a cost basis that would be in the best interest of all those concerned.

Although I have not personally tried the model presented, it is my opinion that it will provide a satisfactory method for examining alternative schemes of waste collection in rural areas. Further analysis may indicate that other variables are desirable and that the assumptions made in developing the model are too restrictive.

AUTHORS' CLOSURE

The authors wish to thank Drake and Riebe for their interesting discussions. Riebe deserves credit for extending the discussion of regional systems that our paper briefly introduced. He raises questions about some of the details of our approach that we will clarify briefly. First, the term disposal site could be substituted for landfill. A disposal site then may be either a landfill or a transfer station. If it is the latter, the transfer stations become the service locations of another network. The second network, with its own collection routes and disposal points, may be treated separately from the first network. Our approach may be used for analyzing each network in turn. Viewed in this way, the analysis of the first network is independent of the type of disposal point—landfill or transfer station.

The reason for presenting the mathematical formulation with one headquarters and one disposal point is that it is the simplest of several cases we have analyzed in this way. This formulation is useful in its own right for networks that can be partitioned naturally, i.e., networks characterized by widely separated clusters of collection points. In such a case, each cluster is treated separately. Where such natural clustering does not exist, other more complicated versions are required.

The general approach described in the paper is being used currently in the U. S. Forest Service—smaller systems by means of manual calculations and larger systems by means of a computer program named SOWAD (solid-waste design). This program is designed for the multiple headquarters and multiple disposal situation. It employs a heuristic logic rather than a mathematical programming formulation because there appear to be no feasible methods for solving large-scale problems of the type formulated in our paper.

MAINTENANCE STATION LOCATION THROUGH OPERATIONS RESEARCH AT THE WYOMING STATE HIGHWAY DEPARTMENT

Robert W. Hayman, Colorado State University; and
Clyde A. Howard, Wyoming State Highway Department

•THE typical roadway maintenance station in the state of Wyoming is charged with the general and total maintenance of assigned roadways from the time of their completion to their eventual replacement or reconstruction.

Snow removal and surface maintenance account for a large percentage of maintenance expenditures. The remainder of the budget is spent on less costly activities such as signing, lighting, and centerline painting.

Over the years, maintenance equipment and procedures have improved, along with the other elements of the highway industry. Despite this progress, maintenance stations have remained essentially the same. Modern highway management has recognized the need for a reevaluation of the maintenance system, particularly with respect to the locations of the stations themselves. Population characteristics have changed, and it is felt that the current requirements for servicing the central portion of the state need particular attention.

A formal study of this problem was initiated in the spring of 1970; the results of the study are reported in this paper. The principal issue is the specification of required locations of maintenance bases in order to provide the required services in the most economical fashion. The study was allowed to assume that any existing station could be removed and that new facilities could be built when such construction was justified by economics and service requirements.

Initially, the study was to be directed to the west-central portion of the state. However, the methodology of the study and the particular techniques developed for producing a solution were to be applicable, whenever possible, to any other region within the state.

The problem was eventually reduced to two mathematical models that were optimized according to the standard techniques of mathematical programming. Computer programs were developed that convert familiar physical parameters, as they apply to any specific case, to the problem form required by the solution methodology.

SELECTION OF THE OBJECTIVE FUNCTION

The technical development of the entire study revolves around determination of the program objective, which was decided on by management and operations research personnel. The objective was as follows: Define the locations of the required maintenance stations, within the boundary of the study, such that the sum of operational and depreciation costs is an absolute minimum. Many other alternatives were considered; among the more notable was the maximization of various service benefits.

IDENTIFICATION OF CRITICAL MAINTENANCE ACTIVITIES

Typical annual budgets were analyzed to determine the current patterns of expenditures, which were classified according to the various maintenance activities. Subsequently, an effort was made to associate each of the activities with some fraction of the cost of the maintenance station itself. For example, some cost fraction of the physical

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plant exists only for the purpose of housing and maintaining snowplow units; in fact, this particular fraction was 20 to 30 percent. This task was completed in a very subjective manner and remains open to debate.

The next step in attempting to define critical activities was to define, for each of the major activities, the manner in which operating costs varied as a function of location of the operating base for the activity. The most obvious variable was the amount of travel required to reach the work site from a particular base station.

The strategy in all of this is to reduce operation costs for each activity by using the most favorable base location for the activity. Cost savings, if any, could be used for the construction and maintenance of new facilities. Because the optimization objective is to minimize the sum of operating and depreciation costs, we are looking for a physical system configuration that produces a savings that is at least as great as the costs of building and maintaining the required group of physical facilities.

Most of the standard maintenance functions enjoyed little or no operational savings as a function of location of the operating base. In fact, only one set of activities promised to generate sufficient savings to pay for its share of the physical facility; this was the snow removal program. Accordingly, it was determined that the mathematical models for the optimization need only consider this set of activities, together with their proportionate share of the cost of the physical plant.

DEFINITION OF PROGRAM CONSTRAINTS

The primary source of information used for definition of program constraints was Policy and Procedure Directive 70-2, Maintenance Division, Wyoming State Highway Department.

For purposes of the optimization study, maintenance services were divided into two types: sanding and plowing. Separate models were developed to optimize these services independently. In addition to optimizing station location and vehicle assignments, the sanding model provides the optimum locations for stockpiles of sanding material.

Constraints on the Sanding Operation

The language of the Policy and Procedure Directive was abstracted to provide the first four constraints; the last four constraints were identified through interviews with maintenance department personnel.

1. Sanding must begin before the snow has accumulated to ¼-in. depth on the roadway;
2. For a design storm, all roadways entitled to sanding services must be entirely sanded before the snow accumulates to some stated depth depending on the class of service assigned to each roadway;
3. Sanding shall be performed continuously until the entire facility has been sanded or until the snow has accumulated to the maximum depth associated with constraint 2;
4. Sanding material shall be applied to the entire driving surface at the application rate of 2,000 lb per 2-lane mile;
5. The traditional concepts of maintenance district boundaries were to impose no restriction on station location or equipment work assignment;
6. Any sanding unit could be assigned to any work location within the geographic domain of the model;
7. There is no restriction on the number of sanding units assigned to any base station; and
8. Within each of the service classifications, A through E (defined in Policy and Procedure Directive 70-2), provision should be made for service priorities on the basis of relative traffic density.

Several of these constraints are either ambiguous or require further interpretation before they can be paraphrased in mathematical terms. The necessary discussion is given in the subsequent paragraphs.

Of primary importance is the definition of a design storm. It is not expected that constraint 2 could be met for all storm stituations. Consequently, the maximum storm intensity to be accommodated (the design storm) was defined to be a continuous snowfall accumulating at the rate of ½ in. per hour. For any storm of higher intensity, all roadways could not be completely sanded before the snow depth has accumulated to the limiting depth, at which time sanding would be terminated and plowing begun.

It is a physical impossibility to begin sanding all parts of a roadway at the same time. Accordingly, constraint 1 must be interpreted at less than literal value. This condition was redefined to mean that the sanding units would be deployed to their work assignments before the snowfall has accumulated to ¼-in. depth.

Constraints 1 and 2, taken together with the definition of the design storm, mean that all sanding must be completed within a specific time period, following the beginning of a storm. For example, for a class A roadway, the maximum snow depth allowed during sanding is 2 in. Accordingly, for the ½-in.-per-hour design storm, sanding must be completed within a 4-hour period measured from the storm beginning.

Service priorities are provided within each class of service (constraint 8) by reducing allowable service times for high-priority roadways. No particular effort was made, in this study, to establish a procedure for setting service priorities on the basis of traffic density, and no specific policy was found to exist within the department. However, the optimization study does provide for this feature by using variations of the allowable service time around the 4-hour nominal time limit.

Other elements given in the list of program constraints are taken at their face value, and no other arguments are imposed on the solution to the problem. The solution is guaranteed to meet these requirements, assuming that equipment performance and cost data are correct.

Constraints on the Plowing Operation

The Policy and Procedure Directive provided the major guidelines in assembling the first four constraints; constraints 5 through 8, as applied to the sanding program, were imposed on the plowing program.

1. Plowing operations begin when snowfall has accumulated to some minimum depth established for each class of service to be provided;
2. For class A facilities, sufficient equipment shall be deployed and remain in continuous service, in order that the roadway be kept bare;
3. The roadway is defined to mean normal driving lanes and passing lanes;
4. For class B service, plowing shall be continuous throughout the storm, and sufficient equipment shall be made available so that the entire roadway may be cleared "soon after the storm subsides";
5. For class C service, sufficient equipment shall be available to clear the entire roadway "soon after the end of the storm";
6. Maintenance station boundaries impose no restriction on the problem solution;
7. Any plow can be assigned to any roadway within the geographic area considered;
8. There are no limitations on the number of plow units that can be based at any given maintenance station; and
9. Service priorities may be applied to any of the facilities falling within service classes A through C.

As in the case of the sanding program, several of the program constraints required translation to more specific form.

First of all, the design storm used for the plow model is a continuous snowfall of ½ in. per hour. It should be pointed out that the duration of the snowstorm is not a factor that the model is required to consider. Service constraints require either continuous service, with an associated continuous result (keep the road bare), or desirable service levels to be achieved following the end of the storm. A collection of equipment designed to keep the roadway bare for 1 hour will also keep it bare throughout a design storm of indefinite duration. The essential difference between servicing a 1-hour storm and a 100-hour storm would be the personnel required to operate the equipment. The 100-hour storm is obviously more costly to service, but the cost differences are independent of the location of the maintenance stations and are therefore of no consequence to the current study.

Constraint 2 was taken directly from the Policy and Procedure Directive and needs considerable restructuring in order to be at all realistic. If the definition of "bare roadway" is that absolutely no snow is allowed to accumulate at any point on the driving surface, then a continuous circulation of plows, moving end-to-end, would not fulfill the requirement for the design storm. A more reasonable requirement would be to limit the average snowfall accumulation to some minimum depth, chosen such that traffic could negotiate the roadway at all times. A satisfactory statement on the average depth requirement is a matter for continued debate; for purposes of this study, the maximum average accumulation of snowfall was taken to be 2 in., and a 4-in. accumulation was the absolute maximum allowed to accumulate at any point on the roadway. The computer programs that solve the problem are designed to accept these numbers as conditions on the solution produced.

Constraints 4 and 5 state that the entire roadway shall be cleared "soon after the storm subsides." Obviously, a strict definition of the word soon must be supplied. The general scheme employed is as follows:

	Class of Service		
Priority	A	B	C
1	2	4	10
2	3	6	14
3	4	8	18

It should be emphasized that the numbers shown here are not the result of current departmental policy. For purposes of the optimization study, the emphasis was placed on developing the mechanics of providing for these management features.

DEVELOPMENT OF THE OPTIMIZATION MODELS

The Policy and Procedure Directive represents a relatively new philosophy for snow control programs in the state of Wyoming. Previous policy was directed almost exclusively to snow control by plowing. It had been suspected that the quality of service could be upgraded at little or no increase in maintenance cost through a more extensive application of abrasive-liquefacient material (referred to as sanding) to the roadway. In Wyoming, it has been found that the roadway frequently may be maintained in satisfactory driving condition through the application of sanding material, with no plowing required. Some storm situations require both sanding and plowing, and some require plowing exclusively. Accordingly, it was decided to build two models—one that optimizes station locations according to the sanding requirements and one that optimizes according to plowing requirements. The management hoped that the station location solutions would be the same in both cases. The models are developed in the following two sections.

Sanding Model

The normal work pattern followed in the case of a general storm is a simple progression down the roadway with each truck returning to the nearest stockpile for reloading when empty.

Figure 1 shows the time required to complete the sanding of a given centerline mileage of roadway when various numbers of trucks are assigned to the task. The completion times shown correspond to that time when the last vehicle has returned to the starting point.

The most critical working relationships in the optimization model require that all of the information shown in Figure 1 be reduced to a single closed form equation.

Figure 1. Sanding completion time.

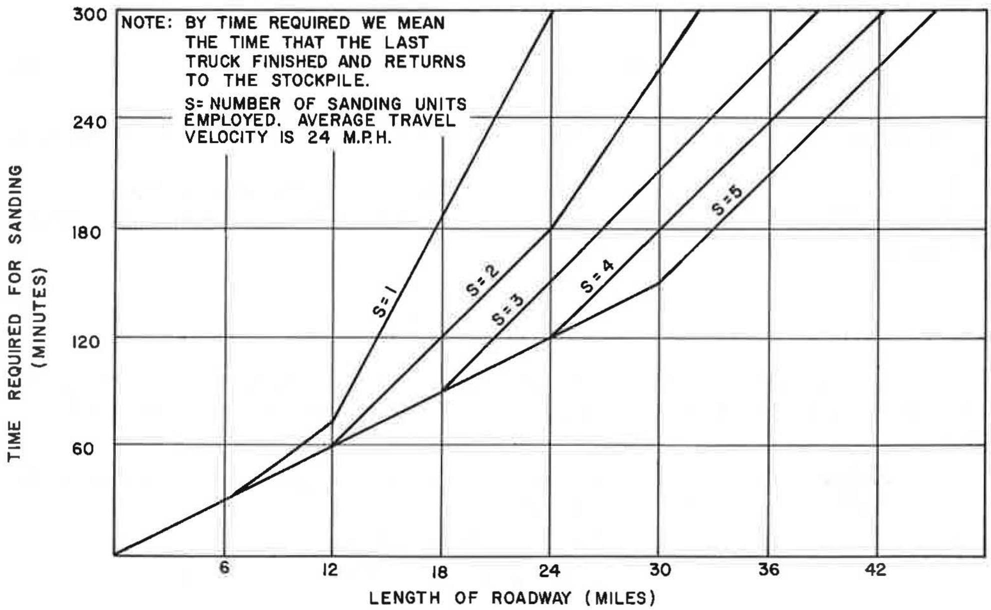

Table 1. Composition of study area, roadway designation, and fixed data applied to the final solutions.

Roadway Number	Centerline Mileage	Service Class	Plow Passes to Clear Roadway	Plow Service Time Limit (hours)	Allowable Snow Depth Before Plow Required (in.)	Service Time Limit for Sanding (min)
1	12.2	B	4	8	2.5	240
2	12.2	B	4	8	2.5	240
3	11.8	B	4	8	2.5	240
4	11.8	B	4	8	2.5	240
5	10.1	B	4	4	2.0	210
6	10.1	B	4	4	2.0	210
7	15.8	B	4	6	2.0	300
8	15.8	B	4	6	2.0	300
9	13.7	B	4	6	2.0	300
10	13.7	B	4	6	2.0	300
11	13.7	B	4	6	2.0	300
12	8.2	B	4	4	2.0	210
13	9.0	C	4	18	10.0	330
14	12.0	B	4	4	2.0	210
15	12.0	B	4	4	2.0	210
16	19.0	C	4	12	10.0	330
17	15.8	C	4	10	10.0	330
18	15.7	C	4	10	10.0	330
19	16.3	B	4	6	2.0	210
20	16.3	B	4	6	2.0	210
21	16.2	B	4	6	2.0	240
22	16.2	B	4	6	2.0	240
23	8.2	B	4	6	2.0	210
24	14.0	B	4	6	2.0	210
25	15.9	C	4	10	10.0	270
26	9.0	B	4	2	2.0	300
27	9.1	B	4	6	2.0	300
28	17.5	C	4	10	10.0	330
29	11.2	B	4	6	2.0	270
30	11.2	B	4	6	2.0	270
31	14.7	B	4	8	2.5	270
32	14.7	B	4	8	2.5	270
33	14.7	B	4	8	2.5	270
34	15.1	B	4	8	2.5	270
35	15.2	B	4	8	2.0	270
36	12.3	B	4	8	2.0	270
37	12.2	B	4	8	2.0	270
38	9.3	B	4	6	2.0	270
39	16.0	B	4	6	2.0	270
40	15.9	C	4	10	10.0	300
41	16.3	B	4	6	2.0	270

In the case of a single sander, the relationship between the total miles driven and the centerline miles sanded may be suitably represented by a quadratic:

$$D = 0.17m^2 + m \tag{1}$$

where D is the total distance driven, in miles, and m is the centerline distance sanded, in miles.

Furthermore, if we assume that the total travel may be equally divided among S sanding units, each traveling at V mph, the total time required to complete the sanding mission would be

$$T = D/VS = (0.17m^2 + m)/VS \tag{2}$$

Equation 2 is not quite complete for working purposes because the sanding units may have to travel some distances between the stockpile and the roadway to be sanded. Therefore,

d = "dead-haul" travel distance in miles between the stockpile and the beginning of the roadway section to be sanded and
n = number of trips required to sand "m" miles of roadway.

To account for n trips over the dead-haul distance, we revise Eq. 1 to give

$$T = 2n\ (d + 0.5m) + 6n/VS \tag{3}$$

Time Constraints

Several constraints previously identified relate to the elapsed time allowed to complete the sanding operation. With proper interpretation and specification of parameters, these conditions may be satisfied with the following development. The necessary terminology is identified as follows:

- s = number of proposed locations for maintenance stations;
- r = number of roadway sections to be serviced within the domain of the model;
- p = number of proposed stockpiles;
- S_{ij} = the number of sanding units based at maintenance station i and assigned to work from stockpile j;
- S_{jk} = the number of sanding units assembled at stockpile j to effect the servicing of roadway k;
- n_{jk} = the number of loads of sanding material to be hauled from stockpile j and distributed on roadway k;
- t_{ij} = the time spent by the S_{ij} in traveling from station i to stockpile j;
- T_k = time available to complete the sanding of roadway k measured from the beginning of the storm;
- M_k = the centerline mileage of roadway to be sanded; and
- d_{jk} = the dead-haul travel distance in traveling from stockpile j to roadway k.

The basic strategy is to deploy S_{ij} sanding units from station i to stockpile j. Thereafter, n_{jk} loads of material are to be hauled from stockpile j to roadway k by using S_{jk} sanding units.

In the execution of this strategy, the time of arrival of the sanding vehicles at a particular stockpile will vary, depending on the origin station for the trucks. In other words, t_{ij} will vary with i for any j. Temporarily, assume that the t_{ij} is the same for all i and some particular j. Call this average time $\overline{t}_{ij}$. The time available for productive work on a given roadway, measured from the beginning of a storm, is

$$(\text{time available})_k = T_k - \overline{t}_{ij} \tag{4}$$

S_{jk} sanding units will be deployed from stockpile j to roadway k and will distribute n_{jk} loads of sanding material. The time required for this may be computed from Eq. 3.

In order to accomplish the service within the specified time frame, it is required that

$$2n_{jk} (d_{jk} - 0.5M_k) + 6n_{jk} \le (T_k - t_{ij}) VS_{jk};\ j = 1,\ldots, p \text{ and } k = 1,\ldots, r \quad (5)$$

The variables in this constraint are the n_{jk} and S_{jk}, of which there are a total of 2 x p x r. The set of these constraints consists of p x r separate inequalities.

The substitution of the travel time averages $\bar{t}_{ij}$ for the actual t_{ij} must now be reconciled. The answer for the substitution is iterative programming. The reason for the substitution is that the model size would have had to be increased to keep a proper count. The number of variables and constraints would have been multiplied by i in the process, and no substantial gain in the accuracy of the model or in the amount of useful physical information would have been derived. As it happens, there are very few cases where more than one station services from a given stockpile, and it was not difficult to iterate to the correct combination.

Model Efficiency Constraints

Although they were not required to satisfy the theoretical behavior of the model, two time constraints were developed for the purpose of accomplishing substantial reduction in the size of the model as it applies in any particular case. It is possible to state, without interacting with other constraints in the model, that

$$T_k - t_{ij} \ge q_1;\ i = 1,\ldots, s \text{ and } j = 1,\ldots, p \text{ and for any } k \quad (6)$$

and

$$d_{jk}/V \ge q_2 \quad j = 1,\ldots, p \text{ and } k = 1,\ldots, r \quad (7)$$

The relations in Eq. 6 state that t_{ij}, time spent in traveling from station i to stockpile j, must be something less than the time allotted to sanding the roadways to be serviced from stockpile j. If this is not the case, then no sanding unit should be deployed from station i to stockpile j. In other words, if $T_k - t_{ij} < q_1$, then $S_{ij} = 0$. Similarly, if too much time is consumed by dead-haul in servicing roadway k from stockpile j, there will be none left for the useful work. The time for one-way passage over the dead-haul distance is d_{jk}/V and must actually be consumed $2n_{jk}$ times. Consequently, if $d_{ij}/V < q_2$, then the quantities S_{jk} and n_{jk} could be set to zero. Actually, instead of setting the S_{ij}, S_{jk}, and n_{jk}, and n_{jk} to zero, they are discarded before being built into the final form of the optimization model. The q_1 and q_2 numbers were conservatively chosen so that potentially valid variables were not discarded.

The remaining constraints required for the optimization model follow quite simply.

Work Quantity Constraint

The worst storm situation must be used as a basis of argument; this would be a storm that covers the entire domain of the model at any given time. The set of constraints (defined in Eq. 5) do not, by themselves, require that the total roadway system be covered; they simply provide that any work undertaken must be completed within a given time frame. The requirement for total sanding coverage will be given in terms of the number of loads of material required to service each and every roadway in the system. In order to cover any roadway k with the type of equipment being used, the number of loads of material required are

$$n_k = 0.17\ M_k \quad (8)$$

These materials may be transported from any stockpile within the system. Accordingly, it is required that

$$\sum_{j=1}^{p} n_{jk} \geq 0.17M_k;\ k = 1,\ldots,\ r \tag{9}$$

The constraints defined in Eqs. 5 and 9 ensure that all roadways are sanded within the required time allotment.

Equipment Continuity Constraint

So far, S_{jk} units have been used to deliver n_{jk} loads of material from stockpile j to roadway k. It remains to assemble the correct number of sanding units at any stockpile. This is accomplished by dispatching the required number of units from the various maintenance stations. Therefore,

$$\sum_{i=1}^{s} S_{ij} \geq \sum_{k=1}^{r} S_{jk};\ j = 1,\ldots,\ p \tag{10}$$

is required.

Constraint Summary and Observations

The sets of constraints defined in Eqs. 5, 10, and 11 complete the constraint requirements for the model.

The total number of variables in the problem are $(s \times p) + (2 \times p \times r)$. There are $(p \times r)$ constraints in the Eq. 5 set, r constraints in the Eq. 9 set, and p constraints in the Eq. 10 set. The rejection of candidate variables based on the relationships shown in Eqs. 6 and 7 is the only way of obtaining a practical solution for geographic areas of any size.

In the section of this paper giving original definition to the constraints on the problem, there were 8 requirements given for the sanding operation. All of these conditions are satisfied through the modeling constraints shown in Eqs. 5, 9, and 10.

In the solution of the model, the variables S_{jk} and S_{ij} were not restricted to integer values. The total number of trucks required at any stockpile would be

$$S_j = \sum_{k=1}^{r} S_{jk};\ j = 1,\ldots,\ p \tag{11}$$

and the total trucks required from any maintenance station would be

$$S_i = \sum_{j=1}^{p} S_{ij};\ i = 1,\ldots,\ s \tag{12}$$

After the final summations of Eqs. 11 and 12, one must round upward to the nearest integer value.

A final point concerns the original objective of defining the most favorable (economical) locations of the maintenance stations themselves. The station locations are hidden in the variables S_{ij}. If the final solution to the model gives $S_i = 0$, for any i, then a station is not required at location i. Similarly, if $S_j = 0$, for any j, then a stockpile would not be required at location j.

Objective Function

During the investigation, a range of amortization costs was studied for their effect on the final solution, and a higher value was assumed for a new station.

The terminology applied to the constraint development is carried over to this section, with the following additions:

C_i = the station amortization costs to be applied to each of the S_{ij} (dollars per unit);
C_{ij} = unit time cost in traveling from station i to stockpile j and return (dollars per hour);
C_{jk} = unit time cost for trucks plus loaders involved in the sanding mission from stockpile j to roadway k (dollars per hour);
P_j = the unit cost of the sanding material, delivered to stockpile j (dollars per ton);
d_{ij} = the distance traveled from station i to stockpile j; and
V_{ij} = the travel speed from station it to stockpile j.

The total cost Z of a given sanding mission can be computed as follows:

Z = cost in deployment of the S_{ij} (including station amortization)
+ cost of delivering the material from stockpile j to roadway k
+ cost of the sanding material

where

$$\text{Cost of deployment} = \sum_{i=1}^{s} \sum_{j=1}^{p} C_i S_{ij} + \sum_{i=1}^{s} \sum_{j=1}^{p} 2C_{ij} (d_{ij}/V_{ij}) S_{ij} \tag{13}$$

$$\text{Cost of delivery} = \sum_{j=1}^{p} \sum_{k=1}^{r} C_{jk} \left[2n_{jk} (d_{jk} + 0.5m_k) + 6n_{jk}\right]/V_{jk} \tag{14}$$

$$\text{Cost of material} = \sum_{j=1}^{p} \sum_{k=1}^{r} p_j n_{jk} \tag{15}$$

Only two terms in these expressions should require any discussion. The quantity d_{ij}/V_{ij} in Eq. 13 is the time required to travel between station and stockpile. The travel velocity may be appreciably higher than the effective working velocity, but this is debatable because of weather conditions. The quantity $2n_{jk} (d_{jk} + 0.5m) + 6n_{jk}/V_{jk}$ in Eq. 14 represents the total truck-hours spent in servicing the various roadways, regardless of the actual number of vehicles involved.

Finally, we wish to minimize

$$Z = \sum_{i=1}^{s} \sum_{j=1}^{p} \left[C_i + 2C_{ij} (d_{ij}/V_{ij})\right] S_{ij} + \tag{16}$$

$$\sum_{j=1}^{p} \sum_{k=1}^{r} C_{jk} \left[2n_{jk} (d_{jk} + 0.5\, m_k) + 6n_{jk}\right]/V_{jk} + P_j n_{jk}$$

subject to the constraints given by the relations shown in Eqs. 5, 9, and 10.

PLOWING MODEL

The optimization model for the plowing operation is not as complicated as the one for the sanding operation and will be discussed briefly.

Considerations in the Type of Facility

The Policy and Procedure Directive defines two separate strategies according to classification by type of roadway. Class A facilities are to be kept bare throughout the storm period. Classes B, C, and D must be completely cleared within some reasonable period following storm termination. These two types of treatment require different constraints in the optimization model.

Nomenclature

The following symbology is used for constraint development:

S_{ij} = the number of snowplow units dispatched from station i to clear roadway j;
M_j = centerline mileage for roadway j;
V_t = the average plow velocity in reaching the work site;
V = the average plow speed under working conditions;
T_j = the allowable time for clearing roadway j;
d_{ij} = the distance in miles from station i to the centroid of length of roadway j;
P_j = the number of plow lanes required to clear the roadway, from shoulder to shoulder;
D = critical snow depth;
R = rate of snowfall used for program design purposes;
t = time, in general;
s = the number of potential maintenance stations; and
r = the number of roadway stations to be serviced.

Constraints for Class A Facilities

For a class A roadway, the Policy and Procedure Directive states that the roadway must be kept bare at all times. In reality, this would be a physical impossibility; the specification was modified to require that the snowfall should not be allowed to accumulate beyond a certain critical depth, D. For a design storm, the snowfall intensity is defined as R. Then, the snow accumulation, during any time, t, would be

$$\text{Accumulation} = R\,t \tag{17}$$

Specifically, we wish to know when the snow will accumulate to D, the critical depth. From Eq. 17:

$$t = D/R \tag{18}$$

The distance a plow will travel, at some working speed V, during time, t, is

$$V\,t = V\,D/R \tag{19}$$

If a group of plows, all traveling at V, were to follow one another down the roadway and were spaced according to Eq. 19, the maximum snow accumulation between them would be D. This is the effect desired. The total length of roadway to be plowed, for roadway j, would be

$$P_j\,M_j \tag{20}$$

Therefore, the required number of plows is

$$S_j = P_j M_j R/VD \tag{21}$$

For the optimization model,

$$\sum_{i=1}^{s} S_{ij} \quad P_j M_j R/VD; \qquad j = 1, \ldots, r \tag{22}$$

is required. Furthermore, the S_{ij} defined by Eq. 22 must be available for the duration of the storm.

Constraints for Class B, C, and D Facilities

Class B, C, and D roadways must be cleared within some "reasonable" time following the storm termination; call this time T_j. Any snowplow must be able to reach the work site and complete the assignment in this time. Thus, the time available for work is

$$T_j - d_{ij}/V \tag{23}$$

Once on site, the plow must clear M_j centerline miles on roadway j, and each mile of centerline requires P_j lanes to be cleared. The total mileage to be cleared is therefore $P_j M_j$. Assume that the mileage may be equally distributed among S_{ij} plows; the mileage assignment for each plow is

$$P_j M_j / S_{ij} \tag{24}$$

The time required to accomplish this is

$$t = (P_j M_j / S_{ij})/V \tag{25}$$

and must be accomplished within the time prescribed by Eq. 23. It is therefore required that

$$(P_j M_j / S_j)/V \leq (T_j - d_{ij}/V) \tag{26}$$

and

$$S_j = \sum_{i=1}^{s} S_{ij}; \qquad j = 1, \ldots, r$$

Model Efficiency Constraints

In order for any S_{ij} to have productive work time available, after reaching the work site, it is required that

$$0 < (T_j - d_{ij}/V) \leq q_1 \tag{27}$$

where q_1 is some conservatively chosen time value. This procedure significantly reduces the numbers of the problem variables and, in no way, compromises the final solution.

In the constraint model, the optimization variables are the S_{ij}, and there are s × r potential variables. There will be a total of r constraints.

Objective Function

Once again, the objective is to minimize cost. The total cost Z of a single mission is as follows:

Z = cost of deployment of the S_{ij} to the work site (including station amortization)
+ cost of operating the S_{ij} during the plowing operation (including the operator).

where

$$\text{Cost of development} = \sum_{i=1}^{s} \sum_{j=1}^{r} C_i S_{ij} + \sum_{i=1}^{s} \sum_{j=1}^{r} C_{ij} (d_{ij}/V) S_{ij} \tag{28}$$

where

C_i = station amortization cost (dollars per sanding unit) and
C_{ij} = the hourly time costs for snowplow and operator (dollars per hour).

In the case of the snowplow operation, the operating costs are all the same, once a work site has been reached. Even though this cost is real, it has no relationship to the different choices for the S_{ij}; consequently, the on-site operating costs were not computed. The final form of the objective function, therefore, is

$$\min Z = \sum_{i=1}^{s} \sum_{j=1}^{r} \left[C_i + C_{ij} (d_{ij}/V)\right] S_{ij} \tag{29}$$

APPLICATION AND RESULTS

Existing stations were included as variables to see if the model would include or reject these sites.

For both models, there were 15 proposed station sites and 41 roadway sections. For the sanding model, there were 15 stockpiles located at the station sites and 6 additional stockpiles.

There are originally 2,037 variables and 917 constraints in the sanding model and 615 variables and 41 constraints in the plowing model. To assemble this much data by hand each time the model is run is a difficult task; therefore, two FORTRAN computer programs or model builders were written. These programs compute all coefficients, reject unfeasible combinations of data, and assemble the final matrix of coefficients into a form usable as input to the Simplex Algorithm being used to solve the problem.

Several solutions were made for each model in order to examine the effect of variation in critical data. The fixed data that applied to the several solutions are given in Table 1. Solutions for two variations of the sanding model are given in Table 2. The results for five variations of the plowing model are given in Table 3.

CONCLUSIONS

The results of the study allow the following conclusions to be made:

1. The location of maintenance stations by means of mathematical optimization appears to be feasible. The use of linear programming techniques to produce a solution rather than the use of integer programming techniques is valid when multiple units such as snowplows are used. Rounding up to the next higher integer value provides a measure of reserve that was not considered in either model.

Table 2. Control data and associated optimal solution for the sanding program.

Station Number	Amortized Station Costs (dollars per unit) S1[a]	S2	Station Required S1	S2	Number of Sanders Required S1	S2	Stockpile Serviced S1 and S2	Stockpile Required S1 and S2	Roadway Serviced S1 and S2	Stockpile Number
1	5	5	Yes	Yes	1	1	1	Yes	1	1
2	20	30	Yes	Yes	1	1	2	Yes	2, 3	2
3	5	5	Yes	Yes	—	1	3	Yes	4, 5	3
4	20	30	No	No	—	—	—	Yes	6, 7	4
5	20	30	Yes	Yes	—	1	5	Yes	8, 9	5
6	5	5	Yes	Yes	2	2	6, 18	Yes	11	6
7	5	5	Yes	Yes	3	3	4, 7, 16	Yes	12-14, 38	7
8	20	20	Yes	Yes	2	2	8, 21	Yes	15-17, 24, 26	8
9	5	5	Yes	Yes	2	2	9, 20	Yes	20, 21, 23, 25	9
10	20	30	Yes	Yes	1	1	10	Yes	41	10
11	5	5	Yes	Yes	1	1	11	Yes	22	11
12	20	30	Yes	Yes	1	1	12	Yes	29-31, 39, 40	12
13	5	5	Yes	Yes	2	2	13, 19	Yes	33, 34	13
14	20	20	Yes	Yes	1	1	14	Yes	35, 36	14
15	20	20	Yes	Yes	1	1	15	Yes	37	15
								Yes	27, 28	16
								No	—	17
								Yes	10	18
								Yes	32	19
								Yes	19	20
								Yes	18	21

Note: Unit cost of sander was $10 per hour.
Unit cost of operator was $5 per hour.
Effective working speed of sander was 24 mph.
Unit cost of stockpile was $4.80 per hour.
Unit cost of material delivered to stockpile was $2.50 per ton.

[a]S = solution.

Table 3. Control data and associated optimal solution for the plowing program.

Station Number	Amortized Station Costs (dollars per mission) S1[a]	S2	S3	S4	S5	Station Required S1	S2	S3	S4	S5	Number of Plows Required S1	S2	S3	S4	S5	Roadway Serviced S1	S2	S3	S4	S5
1	5	5	5	5	5	Yes	Yes	Yes	Yes	Yes	1	1	1	1	1	1, 2	1, 2	1, 2	1, 2	1-3
2	20	30	30	30	40	No	No	No	No	No	—	—	—	—	—	—	—	—	—	—
3	5	5	5	5	40	Yes	Yes	Yes	Yes	No	1	1	1	1	—	3-5	3-5	3-5	3-5	—
4	20	30	30	30	30	No	No	No	No	No	—	—	—	—	—	—	—	—	—	—
5	25	40	40	40	40	Yes	No	No	Yes	No	1	—	—	1	—	9	—	—	9	—
6	25	40	40	40	25	Yes	Yes	Yes	Yes	Yes	1	1	1	1	1	10, 11	10, 11	10, 11	10, 11	10, 11
7	5	5	5	5	5	Yes	Yes	Yes	Yes	Yes	5	6	6	6	8	6-8, 12-15, 27-30, 38, 40	6-9, 12-15, 27-30, 38-40	6-9, 12-15 27-30, 38-40	6-9, 12-15 27-30, 38-40	4-9, 12-15, 27-32, 38-40
8	20	30	30	30	30	Yes	No	No	No	No	1	—	—	—	—	26	—	—	—	—
9	5	5	5	5	5	Yes	Yes	Yes	Yes	Yes	4	5	5	5	5	16-21, 23-25	16-21, 23-26, 41	16-21, 23-26, 41	16-21, 23-26	16-21, 23-26, 41
10	20	30	30	30	30	Yes	No	No	Yes	No	1	—	—	1	—	41	—	—	41	—
11	5	5	5	5	5	Yes	Yes	Yes	Yes	Yes	1	1	1	1	1	22	22	22	22	22
12	20	30	30	30	30	Yes	No	No	No	No	1	—	—	—	—	31, 39	—	—	—	—
13	5	5	5	5	25	Yes	Yes	Yes	Yes	Yes	2	3	3	2	1	32-36	31-37	31-37	31-36	33-35
14	25	40	40	40	40	No	No	No	No	Yes	—	—	—	—	1	—	—	—	—	36
15	25	40	40	40	40	Yes	No	No	Yes	Yes	1	—	—	1	1	37	—	—	37	37

Notes: Unit cost of plow was $15 per hour for solutions 1 and 2 and $10 per hour for solutions 3 through 5.
Unit cost of operators was $5 per hour for all solutions.
Plow travel speed (dead-haul) was 40 mph for solutions 1, 2, 3, and 5 and 30 mph for solution 4.
Average working speed of plows was 24 mph for all solutions.

[a]S = solution.

2. The construction of two separate models to solve the problem of station location also appears feasible. More station locations were required to satisfy the requirements of the sanding model than were required by the plowing model. This was undoubtedly due to the great amount of dead haul required in the sanding model.

3. In the plowing model, amortization costs seem to have a greater influence on station location than do the other parameters.

4. Values for points on the perimeter of the models are invalid because work requirements outside of the model area are not considered.

5. In only one case in the plowing model was an existing station location rejected. This was probably caused by assigning a high amortization cost to that station.

6. Optimization techniques should also be applied to other maintenance functions such as sealing and mowing. It is hoped that this paper will provide a stimulus to other agencies to develop these techniques.

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THE USE OF SYSTEMS LOGIC IN PLANNING MAINTENANCE PROGRAMS

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ABRIDGMENT

•THE underlying logic used in systems analysis can be of great value to engineers and planners. Although it is a simple technique and is easy to use, systems analysis is a very effective tool. Because it is a process as well as a tool, the successful use of systems analysis is dependent on the sequence in which each step is taken. Frequently, planners put "the cart before the horse" and arrive at the right solutions to the wrong problems. By using systems analysis, the planner can avoid such mistakes.

The steps that make up the process of systems analysis follow this general order: determine purpose; translate purpose into functions; translate functions into requirements; generate and select candidate solutions; and translate requirements of selected solutions into specifications.

The process is the same regardless of the type or order of system being analyzed. For example, the roadside rest system is a part of the highway system, which is a part of the overall national transportation system. The national transportation system in turn is part of the overall social system.

Because the roadside rest area maintenance program has its beginnings in the architect's design, the maintenance engineer all too often feels that he has inherited a situation over which he has no control. This feeling is not necessarily justified; every system, including roadside rest systems, is made up of interrelated subsystems. Each subsystem affects the overall system as well as other subsystems. In a very real way, the person responsible for planning the maintenance of a roadside rest area can influence the overall program, including basic policy.

In conclusion, it must be remembered that the analysis of a system is not the end product of a system. Systems analysis is only a technique, and a technique is only a tool. It is an effective tool, however, because it helps the engineer to organize and apply the inherent good sense he already possesses.

Sponsored by Committee on Roadside Maintenance.

THE TECHNOLOGY OF EFFECTIVE MANAGEMENT TRAINING

Clyde A. Burke, Roy Jorgensen Associates, Inc.

ABRIDGMENT

•A COMPREHENSIVE project is being conducted to research and develop a curriculum for highway maintenance managers. An essential part of curriculum research concerns the technology of effective management training, i.e., the selection of appropriate training methods and the identification of ways to increase training effectiveness. For this research, a survey was taken of the state highwaydepartments and 128 industrial firms and military agencies. Letters, questionnaires, structured on-site interviews, and samples of management training materials have provided data for the design of a curriculum.

An analysis of questionnaire replies and sample training materials indicates that most highway departments do not provide formal management training for their maintenance supervisors. By contrast, the typical industrial manager is being trained with materials and techniques designed to increase his capability to benefit from training. More than 70 percent of the industrial firms that were surveyed use programmed instructional materials, and slightly more than 50 percent conduct management seminars. Eighty-five percent of the firms regularly use three or more techniques; 41 percent use five or more methods, including programmed instruction, seminars, role playing, case studies, and management workshops.

TRAINING PRINCIPLES

An analysis of the most effective training materials and techniques indicates that several principles are applicable to training in highway departments:

1. Management training materials must communicate to supervisors the ways in which work is to be done. For example, if work schedules are to be prepared in a certain way or if work is to be controlled by a given procedure, the training materials must say so—loud and clear.
2. The subject matter for training should be limited to that which supervisors need in order to perform their jobs. The use of unnecessary materials impairs the effectiveness of any training program.
3. The subject matter for training must have the approval and support of top management. Much of the long-term effectiveness of training depends on the extent to which top management officials encourage their supervisors to apply the training to everyday decisions and tasks.
4. Training materials must be tailored to accommodate the management practices of the organization and to meet the learning characteristics of the persons being trained. The variations in management techniques and learning characteristics indicate that training should be designed to meet the separate needs of each level of maintenance management.
5. The purpose of training is to improve job performance. Therefore, the effectiveness of training should be determined before it is used. An evaluation of training effectiveness should begin with trial-run measurements of gains in knowledge, skills, and abilities that enable supervisors to improve performance.

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SURVEY CONCLUSIONS

One of the most obvious conclusions was that training effectiveness can be increased by using appropriate instructional methods. The technology is such that almost any technique can be adopted to suit the needs of maintenance agencies. The real task, then, is to isolate the techniques or combinations of techniques that will contribute optimally to the supervisors' understanding of the subject matter. The use of programmed instructional materials is a very effective method.

Significant advancements also are being made in instructional media. A wide variety of visual aids and equipment is available. Here again, the task is to isolate the media that facilitate the learning process.

Another task is to increase the rewards associated with successful learning. Training is rewarding when the benefits are obvious. It is rewarding when it enables a supervisor to do his job in ways that lead to increased responsibilities and salaries. At the same time, it is necessary to reduce apprehensions associated with past learning experiences—apprehensions related to teachers, textbooks, and grading systems.

Finally, efforts should be made to broaden the scope of management training in state highway departments. The differences between state highway departments and industrial organizations—in terms of their training programs—suggest that more work needs to be done to implement formal training programs for all levels of maintenance engineers and supervisors.

EQUIPMENT MANAGEMENT IN NEW YORK STATE

A. I. Morris, Tilford Nemour, Inc.

•DURING the past several years, much has been done to improve highway maintenance programs; at the same time, very little has been done to upgrade equipment programs.

Nothing can more easily frustrate highway maintenance productivity than defective equipment.

Furthermore, the prevalent lack of meaningful equipment data undermines the maintenance engineer's case for reorienting his fleet toward improved productivity.

The current trend is to more technologically advanced equipment. This reinforces the demand for skilled maintenance, diagnosis, repair, and control.

Equipment management is now firmly established as a discipline in itself. The various interrelated elements that make up this discipline are shown at random in Figure 1. Too often, the interaction among these elements is not fully appreciated. When the elements are treated as distinct, self-contained units, maximum productivity becomes elusive.

CASE STUDY

The New York State Department of Transportation has a combined highway maintenance and equipment management budget of $100 million and a fleet investment of $60 million. In 1969 the department initiated an extensive program to improve effectiveness in both areas. In New York State the highway maintenance program and the equipment management program are separate entities; each has its own director who is responsible for its management. The state, furthermore, is divided into 10 regions (equivalent to divisions or districts in most other states), each of which has a regional highway maintenance engineer and a regional equipment manager.

The highway maintenance management study was conducted primarily by in-house personnel. Because of its broad technical scope, the equipment study area was contracted to consultants.

PRE-STUDY EVALUATION

Before the project started, regional highway maintenance engineers cited examples of how their work plans were disrupted by equipment breakdowns. No single factor consistently emerged as the major cause of the work delays. There were, however, several factors that were repeatedly mentioned: lack of parts; state-imposed procurement procedure delays; outdated mechanical knowledge; unqualified operation; and inadequate preventive maintenance.

On a more pervasive scale was the problem of data "pollution." The prevalence of endless computer printouts, derived from error-prone input, clouded all considerations and had unjustly impaired the equipment management program's credibility in essential dealings with its customers (highway maintenance personnel) and with fiscal authorities.

There was no question but that the staff was dedicated and competent. In fact, staff members had previously attempted to improve certain aspects of the operation. However, these efforts did not result in any noticeable effect because the interrelated nature of the problem areas was not understood.

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The results of the preliminary evaluation underscored the need for the participation of an unbiased third party—one with the technical expertise and authority to effect better understanding and cooperation among management and related state agencies.

PROJECT OBJECTIVES, STRATEGY, AND ORGANIZATION

A preliminary survey identified the scope of the project. Aside from its technical aspects, the project was required to revise completely the control process and information system to aid operating managers. As has been indicated, the project was also required to reinforce constructive relationships between the equipment management program and the program users, fiscal authorities, and state agencies.

The objectives of the program were to upgrade all policy and practice of the equipment management program and, at the same time, to produce tangible improvements in the daily application of the program. Both objectives were clearly founded on the central issue of effecting significant improvement in the level and quality of service provided to the highway maintenance program. In this respect, no factor was more germane than the time lost to users because of equipment failure. It was, therefore, agreed by all concerned to monitor the primary thrust of the project's progress in terms of downtime. Because the data necessary for downtime measurement had to be gathered manually on a monthly basis, we selected a significant control sample of the 10 types of equipment most critical to highway maintenance work plans. The equipment selected represented approximately 50 percent of the fleet investment and consisted of large dump trucks, small dump trucks, gradalls, graders, shovel loaders, sweepers, mowers, small stake trucks, crawler shovels, and truck cranes.

In the sample, the level of downtime prior to project commencement was found to be 10.5 percent. A goal of 5 percent downtime was set to be achieved by December 31, 1970. Such an improvement would increase total fleet capacity available to users by an extent equivalent to the acquisition of $4 million of new equipment. Because the term downtime has a negative connotation, we decided to use the complement of the above percentages (i.e., a starting base of 89.5 percent and a goal of 95 percent) and to express the indicator as fleet uptime, from which the project derived its name as "project uptime."

We agreed to apply a further challenge that would most likely result in higher shop productivity. To this end, a second indicator, called "mechanic uptime," was established. Of all the hours that direct labor personnel (i.e., mechanics and skilled tradesmen) were available for work, it was found that only 69.5 percent was spent on equipment repair. In this instance, a goal of 85 percent was set to be achieved by December 31, 1970. An extensive training program that was initiated to improve mechanic efficiency made a 100 percent goal impractical.

The challenge presented by the preceding two indicators served to clarify the project strategy. First, all equipment management personnel were required to provide better service to the highway maintenance program. Second, these personnel had to do more with what they already had in terms of manpower. Third, all recommended changes had to result in improved service and productivity.

It is evident that the project thus placed heavy emphasis on implementation and tangible results. The project was extended over a period of 28 months to ensure that the transition was both orderly and effective. The project was organized such that the New York State Department of Transportation was able to make a maximum input. Other input was made by the four consultants. All changes were developed and implemented by task groups that had been carefully chosen and assigned to each program facet. The task groups usually consisted of one consultant and several New York State Department of Transportation personnel. The active participation of department personnel had the intended effect of securing ready acceptance for all suggested changes.

INTERACTION OF PROGRAM FACETS

In some states, including New York, the equipment management organization is not connected with the highway maintenance organization. There are cases, too, where certain facets of the equipment management program, such as procurement and parts service, are undertaken by the highway maintenance organization or by other agencies. Some states prefer centralized control over operations, whereas others favor decentralized control. It is possible to have as many variations as there are personal preferences in organizational control. An approach used in one state could well prove ineffective in another.

People, not organizational structure, determine the success of an operation. Similarly, the system of program control should not dictate organizational strucutre—rather, it should be of such advanced design that it can accommodate any combination of structural preferences. This design constraint was wisely imposed by New York State and was tested during the program. A change of commissioner occurred during "project uptime." The management styles and organizational preferences of the two executives involved could not have been more distinctly different, and yet the change did not affect the new program control system.

The system's flexibility was made possible by the identification of a matrix common to all equipment programs concerned with optimum output in terms of quantity, quality, and cost of service—regardless of organizational structure surrounding them.

An equipment management program consists of 14 essential facets that must work well as an integrated group. The interaction of the facets is shown in Figures 2 and 3.

As shown in Figure 2, an equipment management program includes within its scope a provision for shop facilities, which in turn accommodates preventive maintenance and repair activities. These latter facets are seldom made to interact with one another to the extent that they should. The repair activity too often consists of emergency work. Where such a condition exists it confirms that the preventive maintenance program is not effective. One of the most important roles of a preventive maintenance program is to anticipate major repairs and to schedule them into the shop in such a manner that disruption to user work programs is minimal. Another is to ensure the controlled use of shop capacity, 75 percent of which should be absorbed by such prescheduled repair work.

A production control system is needed to preserve a balance of service orientation. The purpose of the system is to balance the flow of work and the availability of labor and parts. This in turn enables dependable return dates to be promised to the user.

The ability to assume such a commitment requires that the productivity of the labor force be predictable. It follows that this can only be achieved if labor skills are maintained through training. Currency in technological advances and methods of repair must be maintained. If training is ignored, diagnostic capability deteriorates, and unreasonable labor costs and equipment downtimes result. Although training goes a long way toward securing the most flexible labor capacity, the varied mix of job-shop operations for multipurpose fleets will always demand close supervision. This, coupled with a need to balance the levels of field and shop service with the functions of inspection, testing, distribution, and parts supply, calls for clear definition and understanding of individual organization responsibilities. Figure 3 shows the relationship among the facets of the labor element and shows how they interact with the central maintenance and repair activity of a shop.

Parts supply represents the second primary element in the maintenance and repair activity that directly influences the availability and reliability of fleet units. Minimum disruption of user work programs and realistic return dates cannot be expected if parts availability is not under control. Responsiveness in this regard can be maximized by using the least restrictive procurement methods and the most efficient parts inventory control. Figure 3 shows the flow of interaction necessary among the foregoing facets for the most beneficial effect on the maintenance and repair activity.

It is possible to establish repair accrual performance standards (RAPS) for each type of equipment in terms of the cost of labor and parts. These standards are an important requirement for monitoring the cumulative repair history of individual units and for identifying those that deviate unreasonably from the norm. Such units

Figure 1.

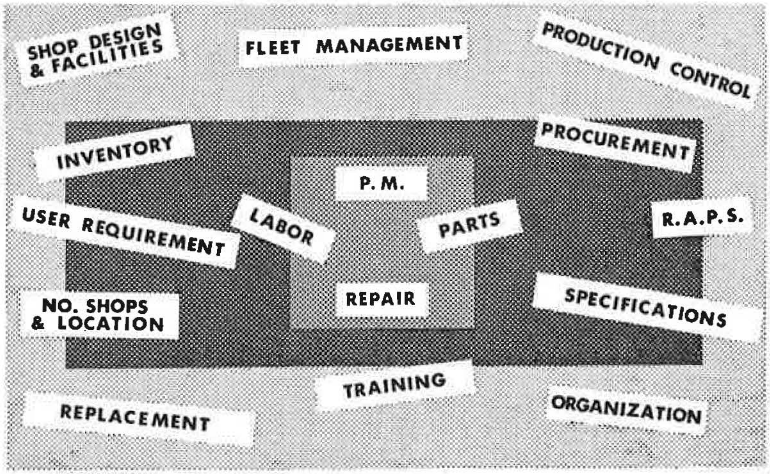


Figure 2.

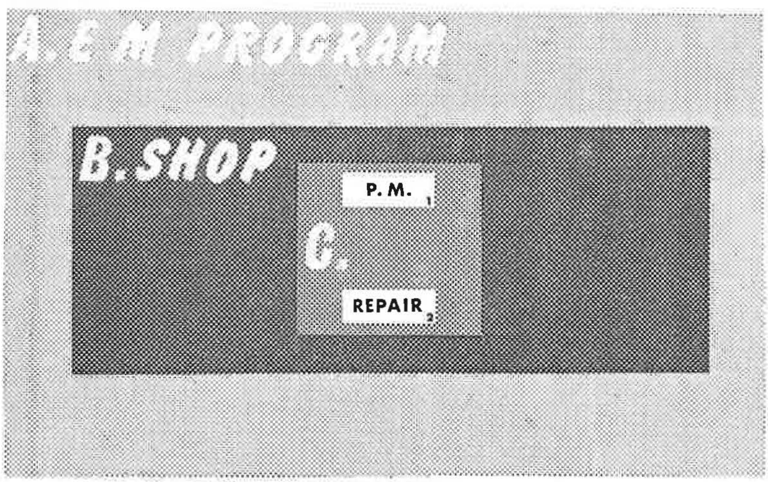
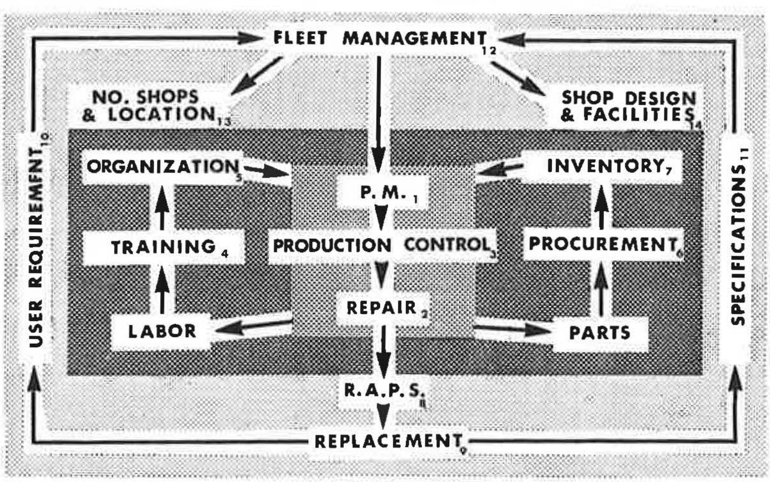


Figure 3.



can disrupt user work programs and cause unacceptable repair costs. Repair history data, derived from work-order activity in shops, also have a direct bearing on replacement decisions. Figure 3 shows the origin and relationship of RAPS and replacement.

As with fleet additions, replacement should not be considered without careful reference to user requirement and the specifications (or more properly, research, development, test, and evaluation) function. Furthermore, the efficacy of these interfaces should be monitored by a fleet management system that can do the following:

1. Recommend which acquisitions, disposals, and interregion transfers are necessary to meet all user requirements and, at the same time, minimize fleet investment;
2. Provide a rapid means of responding to budget cutbacks and for probing the effect of alternate-use criteria on fleet size; and
3. Monitor performance against plan in terms of use, downtime, reserve, transfers, acquisitions, and disposals.

Such a fleet management system becomes the means for expressing the equipment management program interface with the highway maintenance program. It also serves to identify optimum size, mix, and deployment of a fleet.

Fleet size, mix, and deployment have an important bearing on the remaining two facets: number and location of shops and shop design and facilities. Too frequently, shops are improperly designed and located to provide economic service. There is also a tendency for shops to be poorly equipped. Any correction proposed in this general area can involve costly expenditures. Where the foregoing conditions exist, it is not uncommon to find an impasse in understanding between fiscal authorities and operating management. To avoid the folly of pathwork solutions, we must provide fiscal authorities with well-documented criteria and a sound, long-term correction plan.

In contrast to the random sequence of the elements as shown in Figure 1, the foregoing discussion has attempted to order the various facets of the equipment management matrix by identifying their essential relationships. Figure 3 recapitulates the overall flow of these relationships—all irrevocably geared to the central purpose of providing an optimum level, quality, and cost of service to the highway maintenance program.

The following sections discuss in some detail each facet of "project uptime." Also discussed is the program control system that reduced the level of "data pollution" to one document that was available within days of the close of each 4-week reporting period.

PREVENTIVE MAINTENANCE

Preventive maintenance is a much abused term. Like thrift, it is rare to find anyone ready to contest its merit, and yet few can force themselves to practice it. The enthusiastic support that preventive maintenance usually enjoys during the initial justification process soon wanes once it is funded. If preventive maintenance is improperly practiced, it will not decrease the need for emergency repairs. When this occurs, the preventive maintenance area is generally the first function to have its manpower diverted to meet the crisis. Furthermore, fiscal authorities, always hesitant to accede to requests for more manpower, initially fund such programs only partially. Consequently, preventive maintenance tasks usually produce inadequate results, which in turn tend to discourage further funding. Thus, if management does not deploy assigned capacity correctly, programs related to preventive maintenance are likely to show poor results.

The primary objectives of preventive maintenance are to minimize the incidence of unscheduled repair and to govern (i.e., preschedule) the flow of repair work into the shops.

In pursuit of the first objective, preventive maintenance categories, tasks, frequencies, and time standards should be meaningfully established and updated. This requires a thorough grasp of the equipment technology and end-uses involved. As was the case in New York, where funding for preventive maintenance manpower is temporarily restricted, it is important to concentrate the effort on only the most critical types of equipment, which can thus enjoy full benefit from the program. If no other way can we build up confidence in the program to secure sufficient funding.

The second objective seldom receives the emphasis that it should. If this objective is met, there is sufficient time for the user and the shop to decide when a unit may best be withdrawn from service.

PRODUCTION CONTROL

Mechanics have a natural and proper aversion to administrative procedure, but their supervisors should not. Good mechanics are skilled, high-priced tradesmen who deserve quality supervision. In a shop, they collectively represent a valuable resource that requires substantial further investment in support facilities, tools, and inventory. Their work involves drawing out of service expensive equipment that is the backbone of even more costly programs.

In medium- and large-sized shops, the foregoing and the varied nature of job-shop work add up to a convincing case for formalizing the coordination and expediting process. There are innumerable options in choosing a system to meet this need. It can be as basic or sophisticated as circumstances warrant.

Equipment breakdowns, or unscheduled repair, will always be a factor in shop work, but 75 percent of the total load should consistently relate to jobs for which it is possible to establish advance notice. This enables repair work to be arranged in a priority sequence responsive to the needs at hand.

A production control system also ensures efficient assignment of manpower, enables users to be given prior notice of unavoidable delays, and allows essential parts to be pre-assigned.

REPAIR

The New York State Department of Transportation has one central (engine rebuild) facility and 10 regional shops (with an average of 12 bays each). Each regional shop controls about six residency garages each of which has one or two bays. This extensive network of service justifies periodic evaluation against related strata of work load. Although not wholly representative of the pattern currently applicable to New York, Figure 4 shows the type of stratification referred to. Because of the loss of capacity associated with moving units from the field to a shop, the types of work included in levels 4 through 6 (Fig. 4) would appear to be best undertaken at residency facilities that are as near as possible to the highway maintenance work area. Level 3 includes work that should generally be contracted to commercial facilities for various reasons, whereas level 2 includes work that should generally be done at a shop. Finally, level 1 suggests a scope of work that can best be handled by a central facility.

Such a stratification of work load requires that a cost-effectiveness evaluation be made for each type of job. Once the strata are established (Fig. 5), the clarification of needs in many other areas is possible. For example, one would not provide tools, work space, personnel, or training for work classified in level 3.

Time standards for each significant type of work should be developed. In so doing, care should be exercised not to adopt manufacturers' flat rates too readily because state equipment often includes additional devices that sometimes impede access to other components. In any event, flat rates should never be developed without the participation of the people who will be responsible for applying them. Where flat rates do not exist, supervisors should nonetheless be required to set standard times based on their experience and good judgment. The cumulative impact of deviations from standard can be used by management as an indicator of overall shop efficiency and of areas in which training may be deficient.

TRAINING

By virtue of the significant number of man-hours reserved during the project for training, it is evident that New York State recognized the importance of its catch-up

Figure 4.

Figure 5.

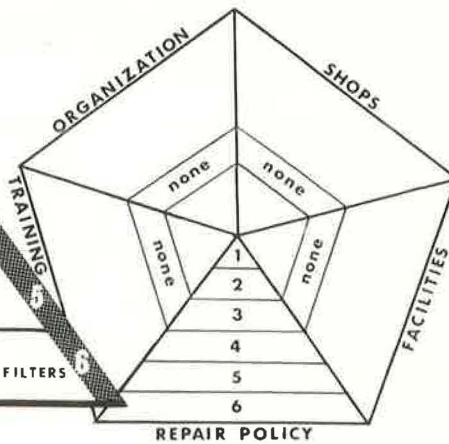
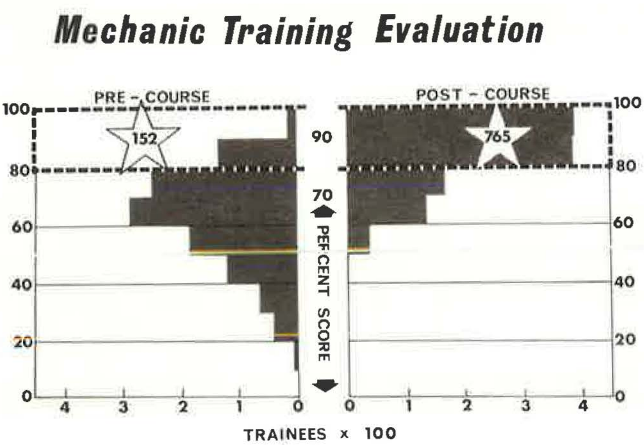


Figure 6.



program to improve the technical knowledge of its mechanic work force. The priority areas, selected by the training task group in consultation with all shop managers, were hydraulics, air brakes, gas engine tune-up, transmissions, diesels, and welding.

With some notable exceptions, many training courses available from manufacturers are, unfortunately, thinly disguised sales promotions. In recognition of this, the New York State Department of Transportation required the consultant to negotiate with more than 10 major manufacturers to tailor each course to the specific needs of New York State. Almost 1,000 course units were delivered as a result, all at convenient locations within the state.

An unusual feature of the program was the manner in which its effectiveness was monitored. Special pre- and post-course tests were developed and given to each trainee. Figure 6 shows that, whereas only 152 trainees returned scores in the 80 to 100 percent range before training, as many as 765 achieved these levels in their post-course tests. On a statewide basis derived from individual scores, the average trainee improved his score by 35 percent. A 25 percent increase in the trainees' technical knowledge would have been normally expected from such a training program.

ORGANIZATION

The realignment of duties to effect a more streamlined organization was one of the two principal concerns of this facet of the project. The second related to the development of a more acceptable and practical basis for each of the many points of interface between equipment management program personnel and highway maintenance program personnel.

PROCUREMENT

The procurement objective was to isolate, develop, and test a practical method by which to overcome costly parts delays within the framework of the state's established procurement procedure.

Of the various methods studied, the task group selected the open-contract approach. In cooperation with the Office of General Services, this approach was tested successfully for a period of 6 months. Such contracts are now being awarded on as many items as possible.

INVENTORY

The purpose of the inventory subproject was to purge all accumulated scrap and obsolete items from inventory as well as to develop and install a system that would ensure the maintenance of parts inventory levels commensurate with the frequency of normal demand.

In addition to the generally accepted requirements for this important facet of shop operations, the system developed and installed by the inventory task group provides for minimum and maximum stock levels. In the case of New York State, the considerable effort that was necessary to clean out parts rooms and to take inventory produced immediate improvements in service. The new system ties in closely with production control, and, although it is still seriously undermanned because of statewide austerity, it has brought about a noticeable drop in downtime caused by parts delays.

REPAIR ACCRUAL PERFORMANCE STANDARDS

A repair accrual performance standard, for a particular type of equipment, is the cumulative standard cost of repair that can be expected to accrue under normal circumstances during useful life. The pattern of such a cost is illustrated by the solid line in Figure 7. RAPS are the foundation on which many important decisions in the New York State equipment management program are made. Although the basic concept of RAPS remains constant, values for the same equipment may vary from state to state because of, for example, differring direct labor rates.

If RAPS serve as the norm, it becomes possible to test the behavior of each comparable unit in a fleet and, by exception, to identify those units that exceed tolerable limits (Fig. 7, dotted line).

REPLACEMENT

Many factors can influence the determination of the economic replacement point of an item of equipment. Among these are age, utilization, repair costs, operating costs, depreciation, and downtime for maintenance. Because of the variety of methods for collecting some of these data, the fluctuating and unpredictable nature of certain factors, and the various accounting theories for treating depreciation and labor cost, it is not surprising that many states take the maximum-age approach to this complex problem. This method is simple, it enables long-range forecasting of replacement requirements, and it avoids the expense of large-volume data collection and processing. The method does, however, have one serious limitation; it treats all items in a group similarly. Units that should be scrapped, for economic reasons, before the prescribed age limit are generally repaired at great cost, and units that can contribute productive service beyond the age limit are arbitrarily disposed of when it falls due. This method imposes the punitive, cumulative cost of double jeopardy, and yet it is in common use among many large fleet operations.

It is possible to operate a replacement system that has most of the desirable qualities of the maximum-age method but none of its hidden and costly drawbacks. In this, both operating costs and preventive maintenance costs are excluded from consideration on the basis that deviations in either should initiate repair action, or modify maintenance frequencies, rather than influence the replacement point. Downtime is a factor that may be considered according to the circumstances and the cost of the equipment involved.

In the case of the New York State fleet, such a system is applied concurrently with the RAPS monitoring process. For this, the method establishes a maximum permissible cost curve (Fig. 8) that, when intersected by the repair accrual of any unit, determines the point at which it should be withdrawn and replaced by another. The system forecasts this intersection in order to accommodate the lead time, which encompasses fiscal approval, procurement procedure, and manufacturers' delivery cycles. In this way, it exerts an influence to keep the fleet purged of units that require unreasonable repair costs and that might disrupt highway maintenance work plans.

FLEET MANAGEMENT

Although the replacement subsystem protects the program from ineffective units, there is an even greater need to ensure that the fleet is of an adequate size and mix to accomplish the highway maintenance program. Because of the absence of meaningful data in this area, many highway departments and their fiscal authorities misunderstand and disagree about fleet management. As long as this vacuum exists, the budget examiner must be expected to harden his position in limiting fleet size. The highway maintenance engineer is then faced with a fleet of improper mix and size and an increased work load.

In New York, this dilemma was avoided by designing a fleet management system that would provide the following:

1. A rapid method by which to translate minimal input data of user requirements into (a) optimum inventory for each major equipment type, (b) transfers from region to region, which are necessary to minimize fleet investment, and (c) the quantity and scheduling of acquisitions to minimize cash flow yet still honor all stated user requirements;
2. A simple and rapid procedure to identify where and when cuts to user work programs can best be made (with a view to doing least harm in the face of budget cutbacks);
3. A monitor of fleet performance every 4 weeks, showing in detail deviations from established plans in terms of capacity consumed; and
4. A method that will economically and rapidly allow either highway maintenance or equipment management to assess the effect that different criteria for use and repair would have on fleet size.

Figure 7.

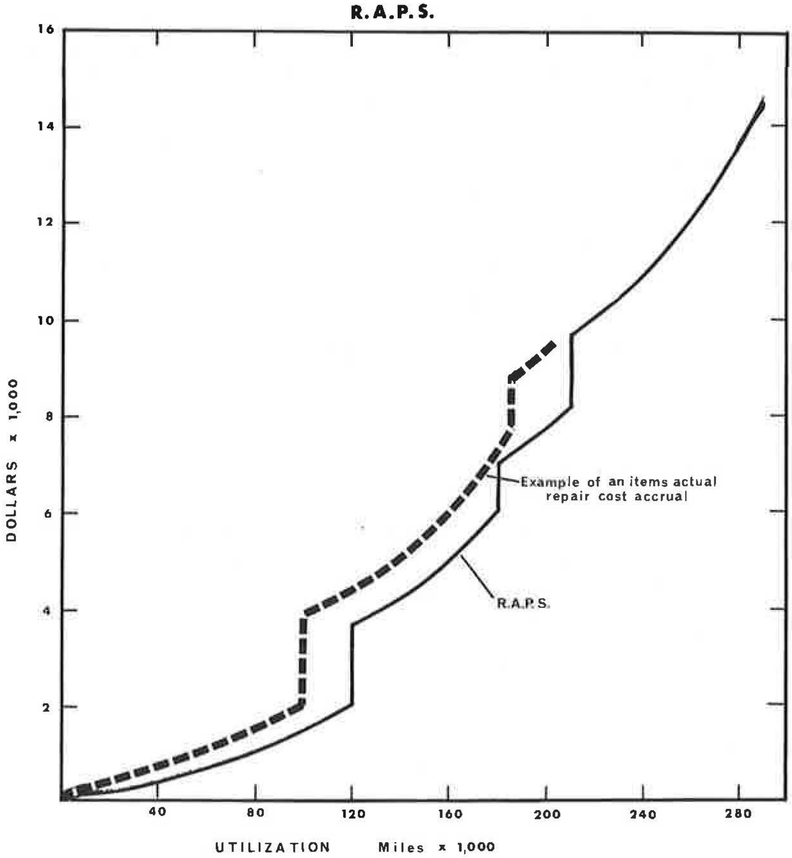
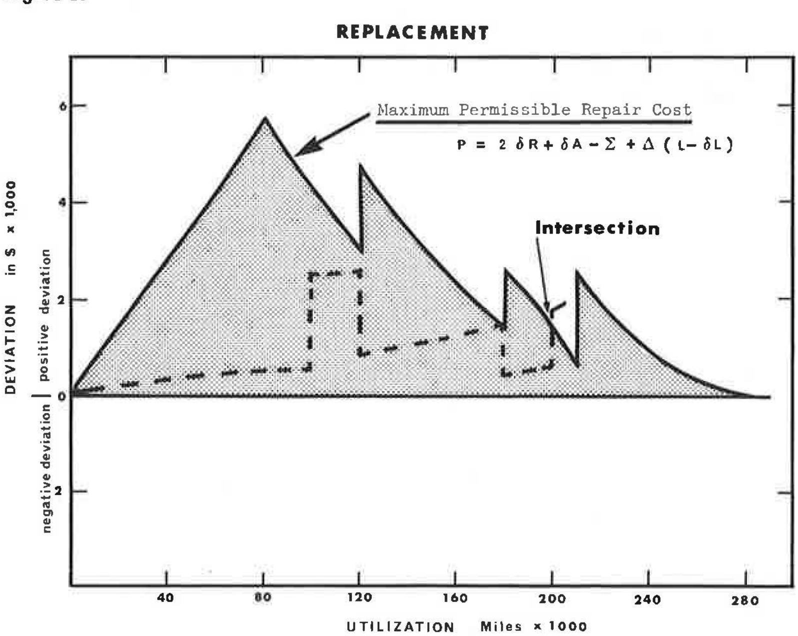


Figure 8.



NUMBER AND LOCATION OF SHOPS

The questions of size and location with regard to building a new shop arise sooner or later in every equipment management program. The investment, in itself, is not minor; if the plans are ill conceived, the shop will generate many punitive costs as the years go by. Any attempt to consider the problem other than in a statewide context produces such an impenetrable fog that a consensus is usually impossible to achieve. As a result, the issue tends to be shelved, and the existing operation of the shop in question becomes increasingly worse with a corresponding effect on the level of service to users of equipment.

In recognition of these difficulties, New York State approached the problem in the following manner: The level of service required from shops is irrevocably tied to the highway maintenance work load. It is possible to define this work load over the next 20 to 25 years with some certainty in terms of future concentrations of density. By using a statewide pattern, it is relatively simple to establish the ideal number and location for all shops in a state. This pattern can then be used as a master plan to provide optimum levels of service to all users and from which a decision concerning any particular shop emerges with clarity.

SHOP DESIGN AND FACILITIES

A most trying aspect of program management in government is the treadmill created by budget cycles. The time left for managing program operations seems to diminish each year as the concern over how tax dollars are spent increases.

A significant part of this time and energy loss can be overcome by using a well-conceived and documented facilities manual. Once the types of facilities and tools that should exist in every shop (Fig. 9) are approved by fiscal authorities, such a manual serves as a catalog for the gradual upgrading of facilities. The only problem then remaining for the budget process to resolve is whether the payback in relation to other demands justifies a priority claim on available funds.

PROGRAM CONTROL SYSTEM

Another important accomplishment made by New York State is represented by the advanced and sophisticated program control system it has installed. The words advanced and sophisticated suggest complexity; however, quite the opposite is true in this case. Data on program performance, in terms of quantity, quality, and value indicators, are now published every 4 weeks on a single-report format (Fig. 10a) common to all levels of management from shop supervisor to commissioner. Furthermore, most managers are concerned with only 1 page of that format, which includes plan, actual, and deviation data for the current period and the year to date. Reports are now also timely and accurate. Program personnel brought an input error rating of 40 percent down to a consistent statewide average of 4 percent. Reports are now required to be in the hands of front line supervisors no later than the morning of the eleventh working day after the close of a period.

Another unusual feature of the control system is that each supervisor or manager is required to identify the cause of any major deviation and also the action he proposes to take to correct it. He is allowed 2 days to forward this to his superior.

The system was designed such that managers should not have to use pencil and paper to figure out what went wrong with their operation. In case of need, however, a second level of reports is provided (Fig. 10b). These were designed, principally to be used for planning purposes, because a competent manager should not have to refer to an information system to learn about major problems within his operation.

CONCLUSION

It would be wrong to conclude that the New York State equipment management program is now perfect in every way. However, it came a long way during the 28 months of the project, and its path to even greater achievement is clearly drawn. By December 31, 1970, it managed to improve its fleet "uptime" from 89.5 percent to more

Figure 9.

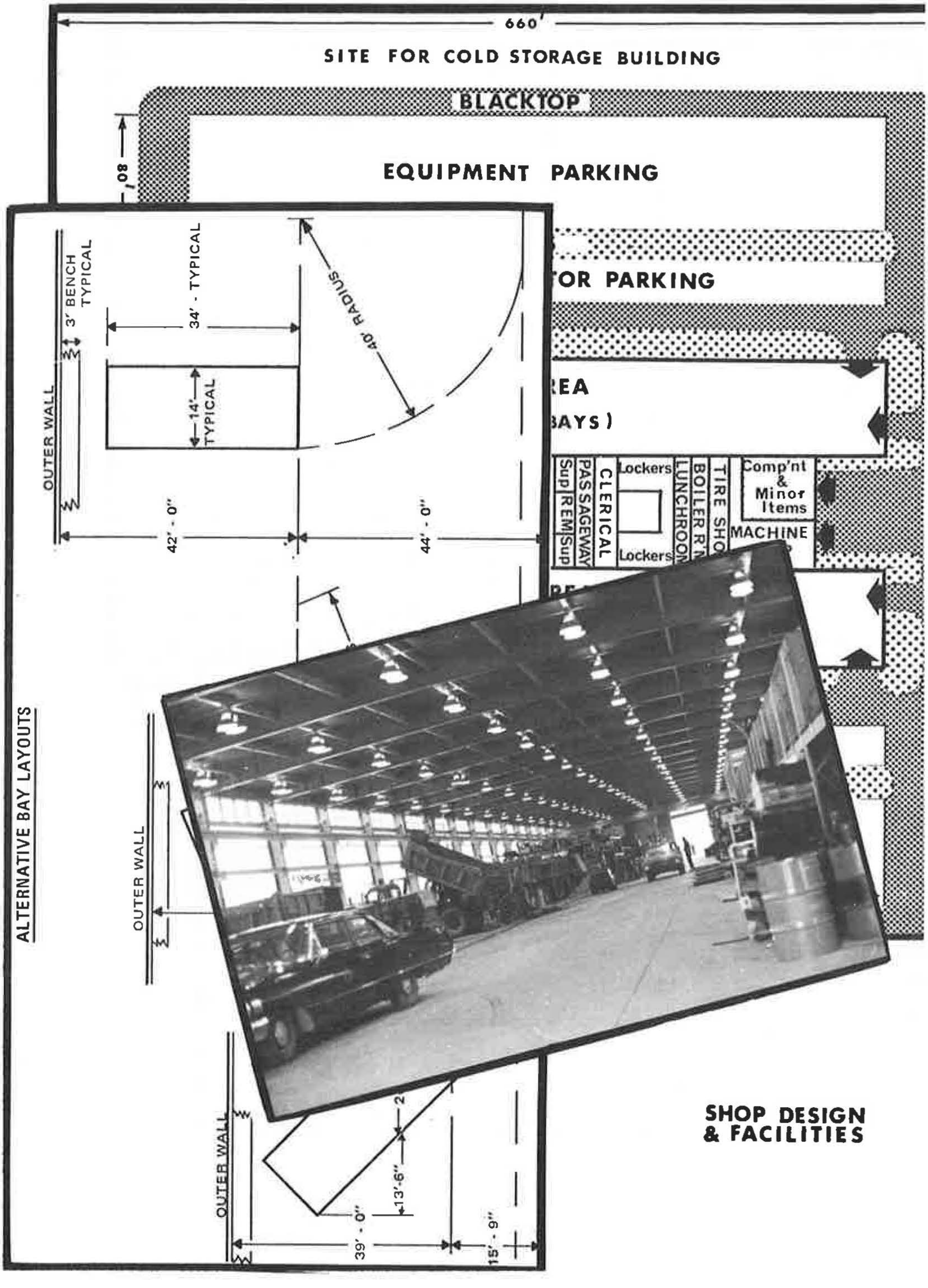
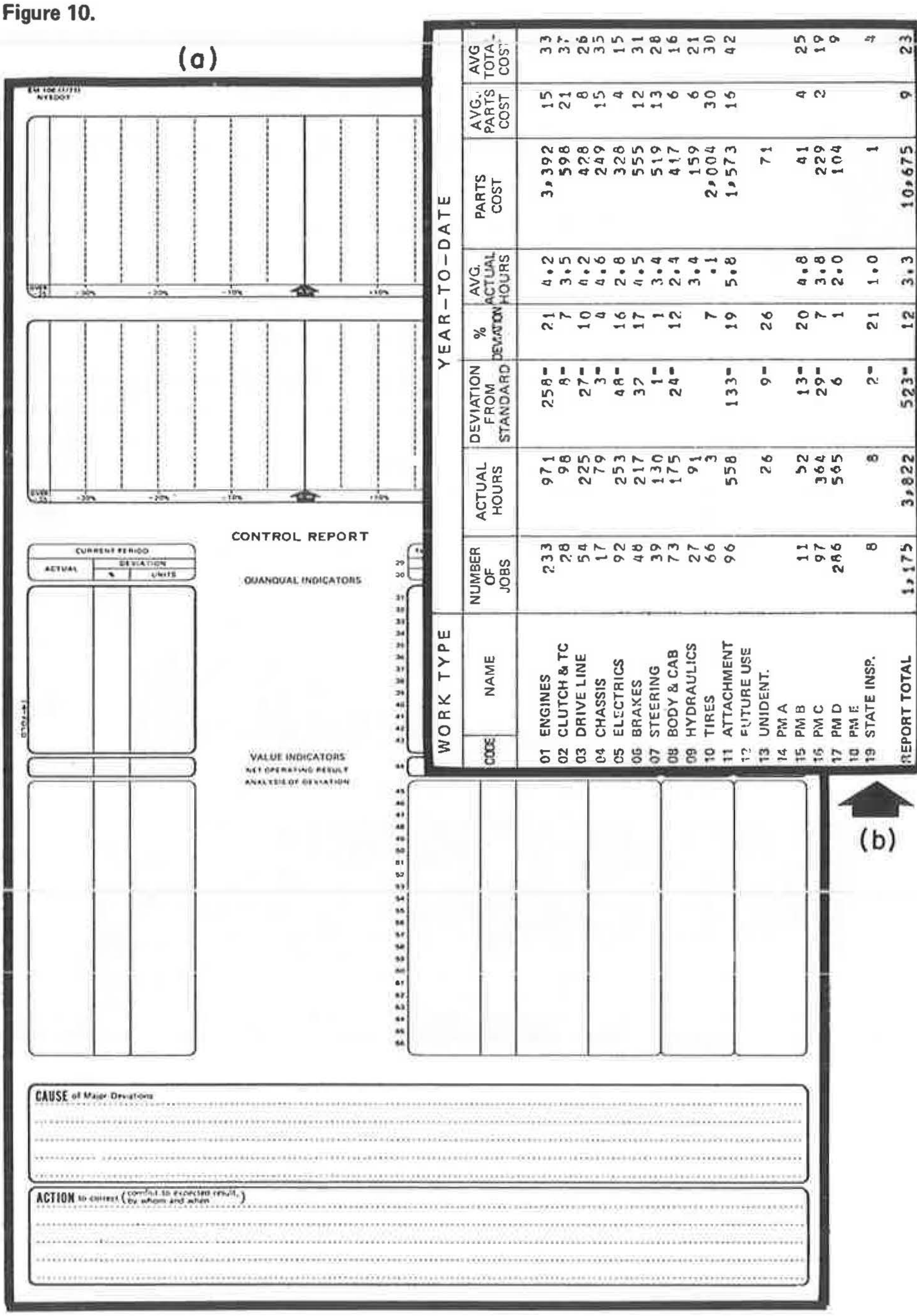

660'
SITE FOR COLD STORAGE BUILDING
BLACKTOP
80'
EQUIPMENT PARKING
OR PARKING
EA
AYS)
Sup
REM
Sup
PASSAGEWAY
CLERICAL
Lockers
Lockers
LUNCHROOM
BOILER R
TIRE SHO
Comp'nt & Minor Items
MACHINE
3' BENCH TYPICAL
34' - TYPICAL
40' RADIUS
14' TYPICAL
OUTER WALL
42' - 0"
44' - 0"
ALTERNATIVE BAY LAYOUTS
OUTER WALL
OUTER WALL
13'-6"
39' - 0"
15' - 9"
SHOP DESIGN & FACILITIES

Figure 10.



WORK TYPE		YEAR-TO-DATE							
CODE	NAME	NUMBER OF JOBS	ACTUAL HOURS	DEVIATION FROM STANDARD	% DEVIATION	AVG. ACTUAL HOURS	PARTS COST	AVG. PARTS COST	AVG TOTAL COST
01	ENGINES	233	971	258-	21	4.2	3,392	15	33
02	CLUTCH & TC	28	98	8-	7	3.5	598	21	37
03	DRIVE LINE	54	225	27-	10	4.2	428	8	26
04	CHASSIS	17	79	3-	4	4.6	249	15	35
05	ELECTRICS	92	253	48-	16	2.8	328	4	15
06	BRAKES	48	217	37	17	4.5	555	12	31
07	STEERING	39	130	1-	1	3.4	519	13	28
08	BODY & CAB	73	175	24-	12	2.4	417	6	16
09	HYDRAULICS	27	91			3.4	159	6	21
10	TIRES	66	3		7	.1	2,004	30	30
11	ATTACHMENT	96	558	133-	19	5.8	1,573	16	42
12	FUTURE USE								
13	UNIDENT.		26	9-	26		71		
14	PM A								
15	PM B	11	52	13-	20	4.8	41	4	25
16	PM C	97	364	29-	7	3.8	229	2	19
17	PM D	286	565	6	1	2.0	104		9
18	PM E								
19	STATE INSP.	8	8	2-	21	1.0	1		4
	REPORT TOTAL	1,175	3,822	523-	12	3.3	10,675	9	23

than 93 percent. Although this was slightly short of target, the program exceeded its goal of 85 percent for mechanic "uptime" well ahead of schedule.

The general body of the work force not only took sincere interest in the project but also revealed itself to be responsive to constructive leadership and challenge. Most importantly, the program personnel have regained their confidence and pride. This was restored by the unequivocal evidence of their own achievement.

REPAIR SHOPS WORK REPORTING PROCEDURE

LaRue Delp, State Highway Commission of Kansas

ON July 1, 1971, Kansas began an activity-oriented repair shops work accomplishment reporting procedure. The term activity-oriented means that the work in the repair shop is classified by general types. No effort is made to sharply define the work. It can be compared to the old country barber shop. The barber measured his day's work by the number of haircuts and shaves performed. He was not concerned with the type or difficulty of haircuts.

Commercial repair shops tend to specialize by brand and type of equipment. These shops have developed complex work procedures and flat-rate books that facilitate repetitive procedures. Current flat-rate books are so detailed that rates are broken down to tenths of an hour for specific operations. A typical example is a flat rate of 0.8 hour to replace a steering knuckle on a passenger car.

In contrast, the highway equipment repair shop is like the old-time barber shop. It works on anything that comes in the door: passenger cars, station wagons, trucks, motor graders, wheel tractors, front loaders, crawler tractors, mowers, air compressors, and augers.

State highway commission repair shops measure their work in simple basic units that are common to all vehicles. The activities involved in the repair of tires, ignitions, and engines are essentially the same for all vehicles.

LABOR CLASS CODES

The labor class codes for vehicle repairs consist of six major classifications: (a) service, (b) power plant, (c) power train, (d) suspension, (e) cab, and (f) body and chassis.

Each of the six major classifications is subdivided (Appendix). Subsidiary charges, which are charged directly to a specific vehicle, make up a seventh classification.

WORK GENERATOR CODE

For good management control, a thorough knowledge of how work originates is required. This can be done by using a work generator code (Appendix). Each repair is classified as one of the following: (a) scheduled repair; (b) unscheduled repair; (c) road call; (d) accident repair; (e) equipment preparation and alteration; or (f) miscellaneous equipment repair.

REPORTING AND FEEDBACK

The record-keeping system is simple. The mechanic maintains a weekly pencil copy of a report that is computer tabulated. There is no clerk or bookkeeper between the mechanic and the computer. The mechanic's report consists of four items: (a) vehicle number, (b) reason for repair, (c) nature of repair, and (d) hours required.

The computer tabulations consist of the following five general reports:

1. Shop tabulation consists of all work performed within a specific shop and is compared to the average work performed in all shops;
2. Vehicle tabulation lists all work performed on a vehicle for the life of the vehicle;

Sponsored by Committee on Maintenance Equipment.

3. Vehicle type or class is coded in the vehicle number, which makes it possible to compare makes of vehicles;

4. Mechanic tabulation shows all the work performed by each mechanic and how he rates with a state average; and

5. Work source printout shows the percentages of work created by various conditions.

PROGRAM OBJECTIVES

The repair shops work accomplishment program is designed to meet many objectives. The following are a few of these objectives:

1. Development and implementation of time-rate standards;
2. Capability of quantitatively measuring the work performed by a mechanic;
3. Revision of the mechanic staffing pattern;
4. Quantitative comparison of preventive maintenance and emergency repairs;
5. Development of a logical parts inventory; and
6. Logical determination of specification writing, i.e., how much special equipment should be installed after purchase and how much should be required as original equipment.

SUMMARY

This is a preliminary report of a computerized work accomplishment method of shop repairs and vehicle management for maintenance operation in Kansas. It is intended to give a preview of the program in its initial stage. The comprehensive program covers all of the functions of about 160 mechanics and service personnel who work in 34 shops that are located throughout the state.

APPENDIX

WORK GENERATOR AND LABOR CLASS CODES

WORK GENERATOR CODES

(How Work Originated)

1. Scheduled repair
2. Unscheduled repair
3. Road call
4. Accident repairs
5. Equipment preparation and alteration
6. Equipment repairs without KSHC number
7. Subsidiary Charges
8.
9. Other

LABOR CLASS CODES

(Type work performed)

010. SERVICE
- 011. Lubrication and oil change
- 012. Change tires, tire service, tire balancing
- 013. Change battery or battery service
- 014. 600 hour or 12,000 mile service check
- 015. Pump Island service
- 016. Washing and Cleaning
- 017. Pool Car Delivery
- 018.
- 019. Other

020. POWER PLANT
- 021. Engine
- 022. Ignition system, coil, distributor, plugs & wires
- 023. Electric system (less lights & instruments but including starting and generator system)
- 024. Fuel System
- 025. Cooling System
- 026. Exhaust System
- 027.
- 028.
- 029. Other

030. POWER TRAIN
- 031. Clutch
- 032. Transmission (Including PTO)
- 033. Propellor Shaft
- 034. Differential, Tandem, or Final Drive
- 035. Mechanical System
- 036. Hydraulic System
- 037. Pneumatic System
- 038. Auxiliary Pumps (Asphalt, water, etc.)
- 039. Other

040. SUSPENSION
- 041. Steering System
- 042. Brake System
- 043. Wheels
- 044. Springs and Shocks
- 045.
- 046.
- 047.
- 048.
- 049. Other

050. CAB
- 051. Painting, All Types
- 052. Lighting System
- 053. Instruments
- 054. Heating and Air Conditioning System
- 055. Accessories
- 056. Glass
- 057.
- 058.
- 059. Other

060. BODY & CHASSIS
- 061. Body
- 062. Frame
- 063. Blades & Paddles
- 064. Liners
- 065. Brooms
- 066. Valves & Piping
- 067.
- 068.
- 069. Other

070. SUBSIDIARY CHARGES
- 071. Shop Cleanup
- 072. Repair to Shop Equipment
- 073. Rework
- 074. Waiting for Parts
- 075. Leave (All types)
- 076. Training
- 077. Yard Maintenance
- 078. Road, Bridge and Bldg. Maintenance
- 079. Other

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