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Notice: The opinions expressed in this paper are those of the authors and not necessarily those of the Texas State Department of Highways and Public Transportation.

Abridgment

Field Investigation of Resource Requirements for State Highway Routine Maintenance Activities

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The first phase of a comprehensive study to identify potential cost and energy savings in routine maintenance activities on the state highway system in Indiana is described. In this phase the current highway routine maintenance standards of the Indiana Department of Highways were reviewed and updated based on data collected in the field, and guidelines for estimating equipment fuel consumption were established. The needs for different resources (materials, labor, and equipment) used in various routine maintenance activities (types, rates of consumption, and frequencies of use) were identified. Energy consumed in each activity was determined as the number of gallons of fuel required to produce one production unit of an activity. The preliminary data analysis indicated that there is a potential for considerable cost and energy savings through better assignment of equipment in different activities. The information developed in this phase can be used directly by the Indiana Department of Highways in preparing their annual maintenance program.

Inflation and price increases have significantly affected the routine maintenance expenditures for the state highway system in Indiana. For example, the total expenditure on routine maintenance activities in 1976 was $47 million, whereas in 1981 the expenditure increased to about $70 million (1,2).

The recent increase in price for all petroleum-related materials includes such derivatives as motor fuel, asphalts, and tars. Motor fuel is the material with the greatest price increase, and it is critical to any maintenance activity because of the dependence of the equipment fleet on it. For instance, the maintenance equipment fleet of the Indiana Department of Highways (IDOH) consumed about $2.6 million worth of motor fuel in 1976, and in 1981 this increased to about $6.0 million. In addition the portion of total material costs assigned to motor fuel has increased with time; for example, 18 percent of the total material costs was assigned to motor fuel in 1976 as opposed to 28 percent in 1981.

From the foregoing observations it is evident that motor fuel must be considered a special resource that needs to be controlled. This can be achieved only through detailed information on equipment use and associated fuel consumption. Many studies have been initiated in the past on the general topic of energy use by maintenance equipment (3-10). However, the information available does not provide either the degree of variability of fuel consumption among different equipment types or the variability of fuel consumption by the same equipment type when used in different maintenance activities. Furthermore, the current standards of equipment use by IDOH are measured by the number of hours or miles for which a piece of equipment is used. These measures cannot provide useful information about fuel consumption unless other supporting rates are developed. Such rates as miles per gallon and gallons per hour are useful in recognizing the amount of fuel consumed as well as the degree of use of a piece of equipment.

The objective of the study reported in this paper is to update the current standards of maintenance resource needs and to establish new standards for fuel consumption by maintenance equipment. This information can then be used in efforts to achieve maintenance cost and energy savings. The study was sponsored by the Federal Highway Administration and IDOH and the results obtained will be of use to IDOH in programming routine maintenance activities.

STUDY METHODOLOGY AND DATA-COLLECTION PROCEDURE

The existing system of maintenance data recording was used with some modifications. The current reporting system of IDOH consists of filing work records on a crew day card. Information recorded on such cards includes activity type, location, date, number of crew members and corresponding man hours, equipment used and corresponding miles or hours, materials used and corresponding quantities, and total accomplishment (production units).

For 6 weeks during October through November 1981, data were collected from selected subdistricts representing the six districts of IDOH. This period was considered unique in that most maintenance activities were performed during this time. Nevertheless, some activities could not be included: activities that are not applied at that time of the year (for example, snow and ice removal); activities with low occurrence, such as seal coating; and activities of administrative nature, such as training, stand-by time, and so on.

The current data-recording system by using crew day cards does not include any information about the amount of fuel consumed by different equipment types. Consequently the subdistrict managers were instructed to fill each piece of equipment with fuel before and after each job. The difference was then to be recorded on the same crew day card with other associated activity data.

*Deceased.

The gross sample size was about 1,400 jobs. After a screening process to check the validity of the data, about 200 jobs were excluded.

Forty-nine maintenance activities were covered in this phase of the study (see Table 1 for names of activities). Thirty-nine different materials were found to be the most frequently used in practice. The labor force was grouped into six categories. Seventy-nine different equipment types were used in routine maintenance. Units of measurement for types of fuel-consuming equipment were miles per gallon or gallons per hour. Production of other equipment types was measured by number of miles or hours.

RESULTS OF THE STUDY

Resource requirements for each routine maintenance activity in terms of materials, labor, and equipment were analyzed. In this effort three categories of information were developed:

1. The type of each resource element used in

Table 1. Summary of resource cost analysis (5, 11).

Activity	Unit of Measure	Man Hours per Production Unit	Cost per Man Hour[a] Material	Fuel	Total
Roadway and shoulder					
Shallow patching	Tons of mix	13.0	2.1	0.8	8.7
Deep patching	Tons of mix	5.3	5.2	1.4	12.8
Premix leveling	Tons of mix	3.2	8.3	1.2	15.6
Full-width shoulder sealing	Foot miles	3.7	21.0	2.6	29.7
Sealing longitudinal cracks and joints	Linear miles	8.8	4.2	1.1	11.6
Sealing cracks	Lane miles	25.6	4.1	1.1	11.0
Cutting relief joints	Linear feet	0.5	2.2	3.1	11.4
Spot repairing of unpaved shoulders	Tons of aggregate	1.2	3.4	1.4	10.8
Blading shoulders	Shoulder miles	1.7	0.0	2.1	8.1
Clipping unpaved shoulders	Shoulder miles	26.6	0.0	2.3	8.5
Reconditioning unpaved shoulders	Shoulder miles	27.7	14.7	2.7	23.5
Joint and bump burning	Bumps removed	3.9	0.05	0.7	6.7
Other	Man hours	1.0	4.5	0.7	11.0
Roadside					
Machine mowing	Swath miles	1.1	0.0	1.1	6.9
Brush cutting	Man hours	1.0	0.0	1.0	7.0
Herbicide treating	Man hours	1.0	15.9	1.1	22.9
Seeding and/or fertilizing	Man hours	1.0	0.3	0.3	6.5
Topping, trimming, or removing long trees	Trees	20.8	0.0	1.3	7.4
Stump removing	Stumps	3.7	0.0	1.6	7.6
Spot mowing and hand trimming	Man hours	1.0	0.0	1.1	7.0
Right-of-way fence repairing	Linear feet	0.3	7.2	0.6	13.5
Other	Man hours	1.0	0.0	1.3	7.2
Drainage					
Cleaning and reshaping ditches	Linear feet	0.1	0.0	1.7	6.9
Inspecting minor drainage structures	Structures	0.6	0.0	0.5	6.4
Pipe replacing	Location	58.6	11.5	1.4	18.9
Motor patrol ditching	Ditch mile	42.6	0.0	2.2	8.4
Cleaning minor drainage structures	Structures	4.8	0.0	1.2	7.2
Other	Man hours	1.0	5.4	1.0	12.3
Bridges					
Bridge repairing	Man hours	1.0	2.1	0.7	9.0
Bridge deck patching	Square feet	1.3	0.4	1.2	7.4
Traffic control					
Subdistrict sign maintenance	Man hours	1.0	6.1	1.3	13.6
Painting pavement messages and special markings	Man hours	1.0	2.9	0.9	9.8
Guardrail maintenance	Linear feet	2.0	3.3	0.9	10.2
Other	Man hours	1.0	0.0	1.4	7.3
Winter and emergency					
Emergency maintenance	Man hours	1.0	1.1	1.3	8.5
Stockpiling winter materials	Man hours	1.0	0.0	1.2	6.9
Other	Man hours	1.0	0.2	0.6	6.7
Public service					
Roadside park, rest area, and weigh station maintenance	Man hours	1.0	0.0	0.8	6.4
Work for state institutions	Man hours	1.0	4.7	0.8	11.3
Full-width litter pickup	Right-of-way miles of pass	3.7	0.0	0.5	6.2
Spot litter pickup	Man hours	1.0	0.0	1.1	6.8
Roadway cleaning	Man hours	1.0	0.0	1.1	5.7
Other	Man hours	1.0	0.0	0.6	6.3
Other					
Materials handling and storage	Man hours	1.0	0.0	3.6	9.6
Detour maintenance	Man hours	1.0	0.0	1.0	7.1
Other support activities	Man hours	1.0	0.0	2.7	8.8
Special maintenance	Man hours	1.0	38.8	2.2	47.1
Special maintenance	Man hours	1.0	9.6	0.8	16.7
Special maintenance	Man hours	1.0	16.0	2.4	24.7

[a] All costs are based on 1981-1982 prices.

each activity, for example, the type of materials or equipment that has been found to be used in the field in accomplishing an activity;

2. The frequency of use of each resource element when employed in an activity (use factor) (for example, a use factor of 0.5 means that the corresponding resource element is used 50 percent of the time); and

3. The rate of consumption of each resource element when used in an activity, for example, the number of units of a certain material required to produce one production unit of an activity. Man hours required to produce one production unit of an activity is used as the rate of consumption of the labor resources. The rate of consumption associated with equipment may be the number of gallons consumed by this equipment to produce one production unit of an activity or it may be given in terms of number of miles per gallon or gallons per hour consumed when this equipment is used.

Activity-Material Interactions

The frequency of use (use factor) was defined as follows:

$$f_{ij} = M_{ij}/N_j \tag{1}$$

where

f_{ij} = use factor of material i in activity j,
M_{ij} = total number of times material i was used in all jobs of activity j, and
N_j = total number of jobs of activity j.

The rate of consumption of a particular material to produce one unit of an activity was defined in terms of quantity. These rates were calculated as follows:

$$R_{ij} = m_{ij}/P_j \tag{2}$$

where

R_{ij} = rate of consumption of material i when used in activity j,
m_{ij} = total number of units of material i used in activity j, and
P_j = total number of units produced of activity j.

The average material cost per production unit of an activity was estimated from the following:

$$CM_j = \Sigma f_{ij} * R_{ij} * c_j \tag{3}$$

where

CM_j = average material cost to produce a unit of activity j,
f_{ij} = use factor,
R_{ij} = rate of consumption, and
c_j = unit cost of material j (in 1982 dollars).

Activity-Labor Interactions

As stated earlier, six labor categories were found to be used in maintenance activities. The frequency of use (use factor) of each category in each activity was given the value 1 or zero. A value of 1 was given if the category was included in the corresponding activity and the value of zero if not. Finally, the rate of consumption was determined in terms of number of workers in each labor category required to accomplish an activity and in terms of number of man hours needed for one production unit of an activity.

Activity-Equipment Interactions

One of the major thrusts of this study was to provide the maintenance division of IDOH with reliable information concerning equipment fuel consumption. The information is expected to provide the necessary background for developing new standards for equipment costs. The subsequent discussion in this paper will focus only on fuel-consuming equipment types.

The computation of the use factor of a piece of equipment in an activity was similar to the procedure expressed in Equation 1.

Two rates of consumption were considered. The first is the number of gallons of fuel consumed by a piece of equipment to produce one production unit of an activity. This rate was employed directly to calculate the average fuel cost per production unit.

The second rate is concerned with the operational aspect of the equipment. Miles per gallon or gallons per hour are conveniently used for this purpose. The results showed considerable variation between different equipment-activity combinations. That is, not only do different equipment types have different rates of consumption but also the consumption rates for the same equipment type may vary considerably when the equipment is used in different activities. These rates were calculated by using the same procedure presented in Equation 2.

Equation 3 was employed to calculate average fuel cost per production unit of an activity.

RESOURCE COST ANALYSIS

Number of man hours, material quantities, and number of gallons of fuel consumed by maintenance equipment types were estimated for each routine maintenance activity. These data were then used to estimate the cost of each of the resource elements to perform one production unit of each activity. In Table 1, a comparison of resource consumption by different activities is shown. Man hours was chosen as a common unit for this comparison. On this basis, full-width shoulder sealing, reconditioning unpaved shoulders, and herbicide treating are the most material-consuming activities. On the other hand, cutting relief joints, materials handling and storage, and other support activities are the most fuel-consuming activities.

Statistical tests showed that the average rates of consumption of labor, materials, and fuel are significantly different from one location (subdistrict) to another.

IMPLICATION OF RESULTS

The detailed information on resource requirements for various maintenance activities can be used for a systematic evaluation of areas in which cost and energy savings can be achieved. For example, the variability of fuel consumption between different equipment-activity combinations observed in this study indicates that considerable savings can be obtained through better management of equipment. An illustration is activity 272 (roadside park, rest area, and weigh station maintenance). The current standards specify that a dump truck be used for this activity. However, the field observations made in this study indicated that a dump trick was used in only 50 percent of the jobs, whereas a flatbed truck was used in the other 50 percent.

The average number of gallons consumed by a flatbed truck to produce one production unit of activity 272 is 0.5, whereas 0.25 gal is consumed by a dump

truck for the same purpose. It is clear that 0.25 gal could have been saved per production unit each time a flatbed truck was used instead of a dump truck. Considering the total production for activity 272 in 1981 (21,056 man hours), about 2,600 gal could have been saved during fiscal year 1981. Similarly it was found that an extra 5,908 gal was consumed as a result of using a dump truck in 18 percent of all jobs of activity 276 (spot litter pickup), whereas a pickup truck could have been used in the operation of this activity.

These examples were two of many cases in which the actual frequencies of equipment use deviated from IDOH standards. The savings mentioned are based on these deviations. However, the deviation observed might have been caused by the inherent nature of the jobs performed. In this case the current equipment use standards may be updated to comply with the actual field requirement and to help in better monitoring and evaluation of field work.

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Abridgment

Determining Maintenance Needs of County Roads and City Streets

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Two types of street and road maintenance needs in the San Francisco Bay Area are documented: ongoing maintenance, or what is necessary on an annual basis to keep roads in adequate condition, and backlog costs, or what is necessary to bring roads back to adequate condition that had deteriorated due to deferred maintenance. Estimates of need for both types of maintenance are then compared with actual expenditures for the Bay Area's 9 counties and 92 cities to determine funding shortfalls. It was found that the local road system was not being adequately protected. Ongoing maintenance expenditures only covered about 60 percent of what was needed. Seventy-five percent of the shortfall was in preventive maintenance. This deferral of maintenance had led to a backlog of road deterioration by which 20 percent of the roads were classified as being in fair to poor condition. These findings led to three major recommendations: maintenance practices needed to be improved, the problem needed to be communicated to the public, and more revenue was required. Significant steps have subsequently been initiated for all three types of maintenance. A simple and straightforward method of measuring need is presented, not to generate project-level decisions but to provide ballpark estimates of aggregate revenue requirements. The methodological and technical study was extended to an action program to carry out the three recommendations. Popular summary reports, a slide show, legislative principles, and actions to improve maintenance practices have all been subsequently developed.

The San Francisco Bay Area includes roughly 5 million of California's 23 million people in 9 counties and 92 cities. The largest cities are San Jose in the South Bay, Oakland and Berkeley in the East Bay, and San Francisco in the West Bay. These four cities had dominated the Bay Area, sustaining almost 70 percent of the region's population through 1940. By contrast, the four northern counties have had the bulk of their growth occur in the last 30 years. Santa Clara County, in the south, has increased its population by 50 percent in just the last two decades.

The Bay Area has more than 17,000 miles of city streets and county roads. This represents more than 92 percent of all roads in the region after the 1,400 miles of state highways are included. Roughly one-fourth of the local system is contained in Santa Clara; another one-fourth in the four northern counties of Marin, Napa, Solano, and Sonoma; and the remainder in the four central counties of Alameda, Contra Costa, San Mateo, and San Francisco.

FINANCING LOCAL STREETS AND ROADS

Since 1963 Californians have been taxed 7 cents per gallon of gasoline. Roughly half of this amount is returned to cities and counties to be used for streets and roads. About one-third of total revenues comes from the gasoline tax, another one-fourth