Abridgment

Analysis of Fuel Consumption in Routine Maintenance of State Highways in Indiana

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In this paper is presented an analysis of trends in fuel consumption in highway routine maintenance based on data from the Indiana Department of Highways for FY 1982, 1983, and 1984. The purpose of the analysis was to identify routine maintenance activities and associated types of equipment with which a high volume of fuel consumption is associated so that energy conservation efforts could be directed to these elements. It was found that pavement- and drainage-related activities and hauling equipment were the major elements that should be considered first. A set of possible conservation strategies involving these elements is also presented.

Routine maintenance of highways is highly fuel-intensive work. Approximately 4.0 million to 5.5 million gallons of fuel are required each year for routine maintenance of state highways in Indiana. In the first phase of a study to identify potential cost and energy savings in routine maintenance of state highways in Indiana (*1*), a detailed field investigation was conducted to estimate fuel consumption rates by type of activity and by activity-equipment combination. It was found that a single type of equipment had different fuel consumption rates for different maintenance activities. Also, some types of equipment were more frequently used than others. Several maintenance activities dominate the use of fuel. The same was true for maintenance equipment. Although there were various types of equipment used in performing different maintenance activities, it was found that only a few types of equipment use the majority of fuel consumed for maintenance. In planning for energy conservation in maintenance, it is necessary to concentrate on those activities and types of equipment that consume most of the fuel. The objectives of this part of the study were to determine if there existed definite trends in the consumption of fuel by type of activity and by type of equipment, to identify the elements of routine maintenance that should be the prime targets for fuel conservation efforts, and to develop energy conservation guidelines and strategies.

DATA BASE

The unit equipment usage factors and fuel consumption rates developed in the first phase of the study (*1*) were used as input to the present analysis. Also used were annual maintenance accomplishment records (*2*) kept by the Indiana Department of

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Highways (IDOH). The IDOH develops maintenance accomplishment plans based on actual accomplishments of the past 3 consecutive years. The data from 3 consecutive fiscal years, 1982, 1983, and 1984, were used in this trend analysis.

DATA ANALYSIS

Three fuel use–related variables were computed for each activity: equipment usage factor (F_{ij}), fuel consumption rate by type of equipment (R_{ij}), and fuel consumption by type of activity (T_i). Subscript i denotes the ith type of activity and subscript j denotes the jth type of equipment. Fuel consumption by an activity is therefore

$$T_i = \sum_j R_{ij} * F_{ij}.$$

Using these three variables, three types of fuel share values were computed. These fuel share values are (*a*) fuel share by type of equipment within an individual activity (S_{ij}), (*b*) fuel share by type of activity in total fuel consumption (A_i), and (*c*) fuel share by type of equipment in total fuel consumption (E_j).

$$S_{ij} = F_{ij} * (R_{ij}/T_i) * 100 \tag{1}$$

$$A_i = 100 * P_i * T_i \bigg/ \sum_{i=1}^{n} P_i * T_i \tag{2}$$

$$E_j = \sum_{i=1}^{n} S_{ij} * A_i/100 \tag{3}$$

where

S_{ij} = share of equipment type j in the total fuel consumption of activity i (percent),

A_i = share of activity type i in total fuel consumption for all activities (percent),

E_j = share of equipment type j in the total fuel consumption for all activities (percent),

F_{ij} = usage factor of equipment type j when used in activity i,

R_{ij} = consumption rate (gallons per production unit) of equipment type j when used in activity i,

T_i = consumption rate (gallons per production unit) of activity i,

P_i = total units of production of activity i, and

n = total number of activity types.

RESULTS OF TREND ANALYSIS

Despite the differences in the amounts of accomplishment of individual activities each year, a similar fuel consumption trend was found among equipment during fiscal years 1982, 1983, and 1984. Approximately 4.0 million to 5.5 million gallons of fuel were consumed annually by maintenance equipment units used for field activities only. This value does not account for the fuel used by field maintenance supervision. Currently, maintenance supervision is not recorded on daily report cards called crew-day cards. About 3.5 million gallons of the total annual fuel consumption are used for regular maintenance activities, and the rest is spent for snow and ice removal. A reduction of a mere 1 percent of the fuel used for regular activities, therefore, would save about 35,000 gal of fuel each year. The results presented in this section refer to fuel consumption in regular activities and do not include snow and ice removal.

Fuel Consumption by Maintenance Activity

The trends in fuel consumption by activity group and by activity type were analyzed to find what specific activities or groups must be targeted to achieve the highest return on energy conservation efforts. The three activity groups used for maintenance management purposes in Indiana are (a) highway class (Interstates and other state highways), (b) maintenance work category, and (c) major activity area.

Highway Class

The split of fuel consumption between the two highway classes remained stable during the 3 years studied. On average, Interstate highways required 340 to 350 gal/mi/year of fuel for maintenance, and other state highways required 250 to 260 gal/mi/year. Approximately 15 percent of the estimated total fuel consumed was for maintenance activities on Interstate highways, and the remaining 85 percent was used on other state highways. Efforts for energy conservation, therefore, should focus particularly on maintenance work on other state highways.

Work Category

Routine maintenance work consists of four categories (3): (a) limited, (b) unlimited, (c) overhead, and (d) variable. These categories represent the importance and ranking of routine maintenance activities. Limited activities include activities for which quantites can be established. Unlimited activities include activities that are to be performed when needed and in the amount required to correct the deficiency. Overhead activities include work items such as rest area attendant, standby time, and maintenance field supervision. Variable activities include activities for which a given amount of work is not urgently needed each year. The planned work for variable activities is desirable, but it is not critical if all of the planned work is not completed during any one year.

Of the 63 activities considered in the study, 14 are in the limited category, 22 are in the unlimited category, 14 are in the variable category, and the remaining 13 are in the overhead category. Approximately two-thirds of estimated total annual fuel consumption is attributable to activities in the limited and unlimited categories. Because the amount of work done in these two categories greatly affects fuel consumption, an improvement in the procedures used to assess the needs of specific maintenance activities within these categories is desirable if energy conservation programs are directed to these activities. Activities in the overhead category mostly fall into public service and "other" maintenance areas. These activities are not directly related to the performance of the highway. Activities in the variable category are minor maintenance work that is left out of the limited or unlimited categories. Therefore fuel consumption by this category can be reduced if the activities in the limited and unlimited categories are better managed.

Major Activity Area

Types of maintenance activities were grouped into the eight major maintenance areas given in Table 1. A substantial portion of total maintenance cost can be attributed to the roadway and shoulder area (Area 1), followed by the others area (Area 8) as shown in Figure 1a. Total cost was broken down into fuel, material, and labor costs. All costs were computed using 1982 unit cost data. Areas 1, 3, and 8 consumed most of the fuel used in maintenance work (Figure 1b). Indeed, Area 8 uses more fuel than is shown here because the fuel used for field maintenance supervision is not currently recorded on crew-day cards.

TABLE 1 ROUTINE MAINTENANCE AREAS INCLUDED IN THE STUDY

Area No.	Activity Area
1	Road and shoulder
2	Roadside
3	Drainage
4	Bridges
5	Traffic control
6	Winter and emergency
7	Public service[a]
8	Others[b]

[a] Includes activities such as rest area maintenance and litter pickup.
[b] Includes activities such as material handling and storage and other support activities.

The roadway and shoulder area accounts for most of the materials cost (Figure 1c). Although this paper deals only with direct energy use, petroleum products are a substantial part of the materials used in highway routine maintenance. Therefore improvement in the quality of materials and maintenance work should provide opportunities to reduce overall energy use including indirect energy. Good management of the first three areas—roadway and shoulder, roadside, and drainage—can contribute greatly to energy conservation.
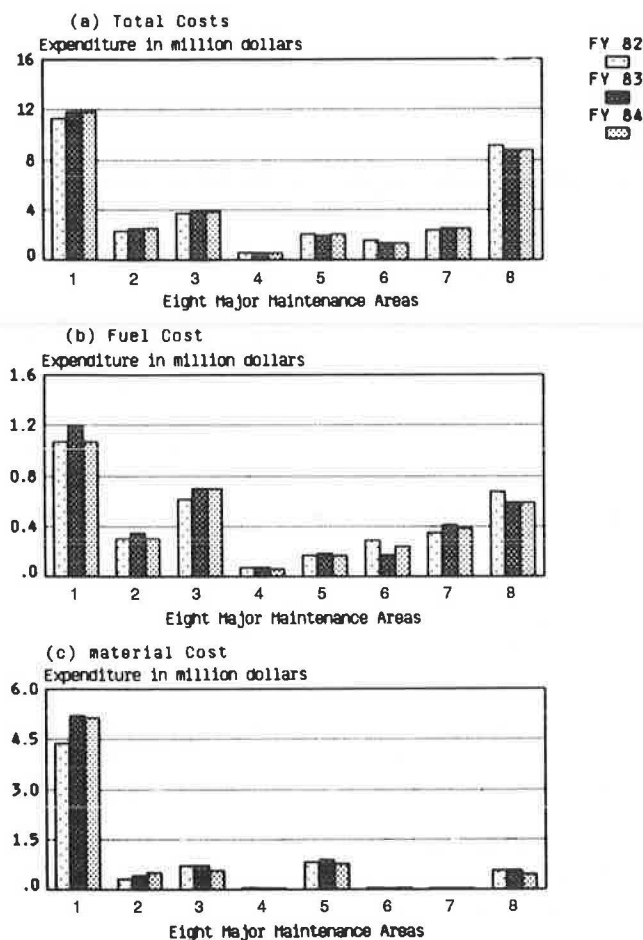
(a) Total Costs

Expenditure in million dollars

FY 82
FY 83
FY 84

Eight Major Maintenance Areas

(b) Fuel Cost

Expenditure in million dollars

Eight Major Maintenance Areas

(c) material Cost

Expenditure in million dollars

Eight Major Maintenance Areas

FIGURE 1 Maintenance cost splits among eight major activity groups.

Fuel Consumption by Activity

Fuel consumption by activity tends to be concentrated in a few activities each year. Most of the activities considered in the study used less than 2 percent of the total fuel consumed. Activities that used more than 3 percent of the total fuel consumed were identified as dominant activities, and they are given in Table 2. These activities, excluding snow and ice removal and supervision, account for approximately 65 percent of total fuel consumed.

As the data in Table 2 indicate, the major fuel-consuming activities are included in a small number of maintenance areas. Roadway and shoulder maintenance area (Area 1) and cleaning and reshaping of ditches (Area 3) alone accounted for approximately 39 percent of the total fuel consumed in FY 1984. Similar trends were found in fiscal years 1982 and 1983. Energy-saving efforts therefore should be first directed to these areas. According to an optimization procedure developed in this study (see paper by Sinha et al. in this Record), it was found that the rest area work would contribute most substantially to fuel savings if assignment of equipment to this task were properly done.

Fuel Consumption by Equipment Type

A variety of types of equipment is used for routine maintenance activities. First, the demand level for a particular type of equipment by various activities was identified. Then, dominant equipment types were singled out and their fuel consumption was examined.

A majority of the types of equipment are used for fewer than 10 different types of activity. Some types of equipment, such as water truck or catch basin cleaner, can be used only in specific activities and their low shares of fuel consumption reflect their limited use. Only five types of equipment were used by more than 20 activities: pickup truck, pickup crew cab, dump truck, do-all truck, and loader. Equipment used mostly for hauling consumed most of the fuel used in maintenance in each of the 3 years considered in the study.

Table 3 gives the dominant types of equipment that use more than 1 percent of the total fuel consumed annually. Altogether

TABLE 2   MAJOR FUEL-CONSUMING ACTIVITIES (FY 1984 state-level total)

Maintenance Area	Activity Code	Description	Fuel Consumed (1,000 gal)	Share (%)
1	201	Shallow patching	233.1	7.00
	205	Seal coating	119.3	3.58
	207	Sealing cracks	170.4	5.11
	210	Spot repair of unpaved shoulders	102.2	3.07
	212	Clipping unpaved shoulders	117.9	3.54
2	221	Machine mowing	126.9	3.81
3	231	Clean and reshape ditches	451.7	13.56
	235	Cleaning minor drainage structures	90.2	2.71
5	251	Subdistrict sign maintenance	103.9	3.12
7	271	Rest area and lift bridge attendant	161.8	4.86
8	283	Buildings and grounds maintenance	200.3	6.01
	284	Materials handling and storage	134.0	4.02
	289	Other support activities	160.7	4.82
Total			2,172.4	65.21

Note: Activity 263, snow and ice removal, was excluded from the share computation.

TABLE 3   MAJOR TYPES OF FUEL-CONSUMING EQUIPMENT (FY 1984 state-level total)

Equipment Code	Equipment Type	Fuel Consumed (1,000 gallons)	Share in Percent	Demand Level
1	Pickup truck	326.5	9.8%	A
2	Pickup crewcab	370.4	11.1%	A
4	Flatbed truck	33.8	1.0%	E
7	Distributer	80.7	2.4%	E
8	Utility truck	127.7	3.8%	E
9	Dump truck	1,480.8	44.4%	A
10	Do-all truck	164.9	5.0%	D
24	Excavator	139.7	4.2%	F
25	Grader	68.8	2.1%	E
26	Loader	135.1	4.1%	D
42	Tractor truck	145.5	4.4%	E
44	Compressor	35.0	1.1%	E
64	Gradall	47.9	1.4%	F
	Total	3,156.8	94.9%	

* Demand level:
A = Used by equal to or more than 50 activity types
B = Used by equal to or more than 40 but less than 50 activity types
C = Used by equal to or more than 30 but less than 40 activity types
D = Used by equal to or more than 20 but less than 30 activity types
E = Used by equal to or more than 10 but less than 20 activity types
F = Used by less than 10 activity types

Note: Activity 263, snow and ice removal, was excluded from share computation.

they accounted for about 95 percent of the total fuel consumed. Dump trucks alone accounted for approximately 45 percent of the total fuel used every year for all routine maintenance activities. Their fuel use shares remained stable during the 3 years despite the variation in annual accomplishment of activities. Therefore, if better management of the equipment fleet is considered as a means of conserving energy, these 13 types are the ones that should be included first. Some equipment, such as dump trucks and pickup trucks, can be interchanged for some activities.

ENERGY CONSERVATION STRATEGIES

The analysis indicated that there exist definite trends in fuel consumption by type of activity and equipment. The findings of the trend analysis made it possible to identify a set of strategies for conserving fuel and reducing the cost of routine highway maintenance.

Fuel Savings by Managing Activities

About one-third of the routine maintenance activities considered in the study consumed most of the fuel. The following two broad approaches can be considered for these major fuel-consuming activities.

The first approach is to improve the current procedure for assessing routine maintenance needs of major fuel-consuming activities so that actual accomplishments can be close to planned accomplishments and the fuel consumption of a particular year can be reasonably estimated. If a substantial amount of fuel reduction becomes necessary for that year, low-priority works, such as those in the variable category, can be postponed to the following year, provided that the limited and unlimited activities are well controlled.

The second approach is to evaluate the effectiveness of maintenance activities. This approach is particularly applicable to those activities that have a cause-and-effect relation. A good example of this approach is discussed in the paper by Sharaf and Sinha in this Record. They report that after pavement maintenance costs were analyzed, it was found that highway segments that received more crack sealing in the fall require smaller amounts of shallow patching the following spring. Crack sealing is a preventive maintenance activity, whereas shallow patching is remedial work. It was estimated that Indiana could save nearly 10,000 gal of fuel every year simply by completing crack sealing as scheduled. One-third of the 37 subdistricts in Indiana fall sort of their planned production units of crack sealing by more than 10 percent every year.

Fuel Savings by Managing Equipment Use

Of the 79 types of equipment used in routine maintenance, only 13 consumed more than 1 percent of the total fuel. Altogether they used about 95 percent of the total fuel. Four kinds of hauling equipment (pickup truck, pickup crew cab, dump truck, and do-all truck) consumed most of it (about 70 percent). For some activities, these types of equipment are interchangeable. Other types of equipment, such as grader, excavator, and tractor truck, are intended for specific tasks and usually cannot be interchanged.

Because different equipment types can be used interchangeably to perform some of the same tasks, careful equipment assignment can save a considerable amount of fuel because of the wide variation in fuel usage rates of different types of equipment. A mathematical optimization model has been developed in the study for the purpose of determining the optimal mix of types of equipment for performing various activities (see paper by Sinha et al. in this Record). Furthermore, an effort is needed to control the amount of time equipment idles. Reduction of hauling distance of excavated materials can also contribute to reduction of fuel consumption.

Dieselization of Equipment

Maintenance equipment is either gasoline or diesel powered. Diesel is now widely viewed as the desirable power source for many types of maintenance equipment. Dieselization of maintenance equipment units has just recently been started at IDOH and diesel fuel consumed is still a small portion of the total fuel consumed. The percentage of diesel fuel consumed was well below 10 percent of total fuel consumption in the past 3 years. Dieselization of dominant fuel-consuming equipment, such as dump trucks and tractor trucks, would eventually contribute to overall energy savings.

CONCLUSIONS

The trend analysis conducted in this study formed a basis for identifying components of routine highway maintenance to which energy conservation efforts should be directed. Thirteen dominant activities, which were mostly in the road and shoulder, roadside, and drainage maintenance groups, were identified.

The analysis also identified critical types of equipment. Thirteen of the 79 types of equipment included in the study were found to be critical with respect to energy conservation. These types account for about 95 percent of total fuel consumed. Furthermore, the four major fuel-consuming types of equipment—pickup truck, pickup crew cab, dump truck, and do-all truck—use about 70 percent of total fuel consumed every year.

By carefully managing the dominant activities and critical types of equipment, highway agencies should be able to better control fuel consumption in routine highway maintenance. To implement such a program, however, it is desirable that equipment use and fuel consumption data be regularly recorded and monitored.

ACKNOWLEDGMENT

REFERENCES

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