Fuel Consumption in Highway Routine Maintenance Activities

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Abstract

This paper describes the results of a study aimed at the identification of fuel consumption by the equipment fleet used in highway routine maintenance activities in the State of Indiana.

Two basic groups of results are presented: (1) the fuel consumption rates for all possible activity-equipment combinations as well as total fuel consumed per production unit of each activity; and (2) the effect of factors such as location (subdistrict), highway type, and season on fuel consumption.

The first group of results will be of direct use to the Indiana Department of Highways (IDOH) in the planning of the annual maintenance program, while the second group will be useful in evaluating the actual fuel use (in the field) by different management units (subdistricts).

INTRODUCTION

With the 1982 Surface Transportation Act providing additional five cents motor fuel tax, a substantial increase in federal aid has taken place and many of the so far deferred major maintenance activities can now be considered. However, routine maintenance activities do not receive any federal aid and they must be accomplished through the state generated revenues. Increased federal aid also requires increased matching funds from the state sources, and thus if there are no little additional state revenues, less funds for routine maintenance may be available. Consequently, routine maintenance is receiving considerable attention from state and local highway agencies.

A major portion of the materials cost in routine maintenance involves motor fuel. Although in recent years there has been a sharp increase in cost for all petroleum related materials, the price of motor fuel

has risen drastically. Highway agencies have started to consider motor fuel as a special resource that needs to be effectively controlled.

This paper presents the results of a study sponsored by the Federal Highway Administration (FHWA) and Indiana Department of Highways (IDOH) aimed primarily to identify the energy needs in terms of fuel consumed by the equipment fleet for maintaining the state highway system in Indiana. The results of the study will be used to establish improved fuel consumption standards for routine maintenance equipment fleet and to identify possible actions that can achieve both energy and cost savings in routine maintenance operations

FUEL CONSUMPTION IN ROUTINE MAINTENANCE

There are two categories of energy consumption in highway routine maintenance: (1) direct energy consumption by equipment fleet; and (2) indirect energy consumption in manufacturing and transporting the materials used in maintenance. In this study, only the first category, direct energy consumption by equipment fleet, was considered.

Inflation and price increase 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 estimated as 30 million dollars, while in 1981 the estimate of this expenditure increased to about 48 million dollars with an average of about 12% yearly rate of increase. On the other hand, while the cost of motor fuel consumed in field activities related to routine maintenance in 1976 was about 2.5 million dollars, this cost increased to about 6 million dollars in 1981 with an average of 28% yearly rate of increase (Figure 1). In addition, the ratio of fuel cost to total maintenance cost increased from 8% in 1976 to about 13% in 1981 (see Figure 1). Figure 1 also shows that the ratio of fuel cost to total material cost increased from 17% in 1976 to 27% in 1982. It should be noted that the fuel costs reported here involve only the fuel used by the equipment fleet required to do the field work in maintenance and they do not include fuel consumed for transportation of supervisors and in other overhead activities.

Motor fuel should be treated as a special resource that needs to be effectively controlled. A careful management of motor fuel cannot be undertaken, however, without detailed information regarding equipment utilization and associated fuel consumption. Many studies were made in the past in the general area of energy use of maintenance equipment (5,6,7,8,9). However, the available information does not provide either the degree of variability of fuel consumption between different equipment types, or the variability of fuel consumption for the same equipment when used in different maintenance activities. Furthermore, the current information of equipment utilization in the IDOH is presented in terms of number of hours or number of miles an equipment is used.

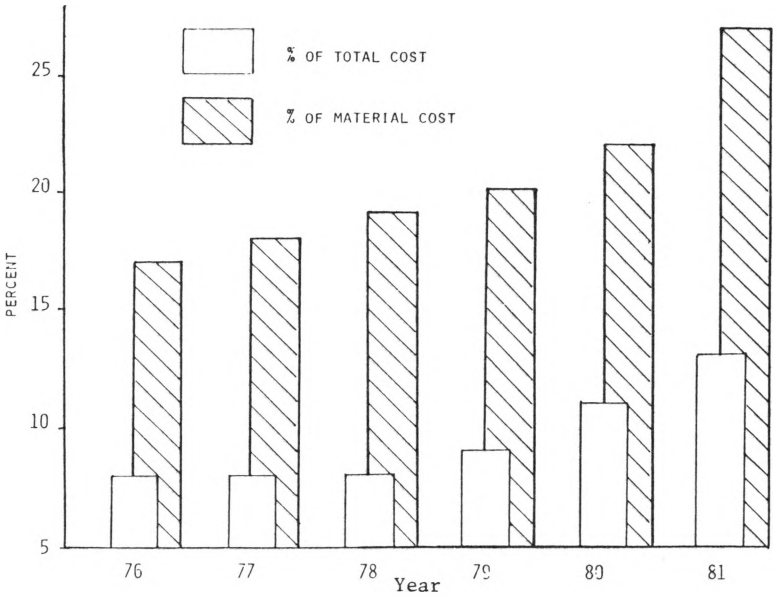

Figure 1. Fuel Cost As Percent of Materials and Total Cost. Source References: 1, 2, 3, 12.

These measures are not detailed enough for maintenance management unless other supporting rates of consumption are developed. Such rates as miles per gallon (mpg) or gallons per hour (gph) are necessary not only to recognize the amount of fuel consumed, but also to identify the degree of use of a particular equipment. This information can then be used in an effort to formulate strategies that can achieve improved equipment utilization and thus can save energy and maintenance costs. The results obtained can also be of use to the IDOH in programming of routine maintenance activities.

STUDY METHODOLOGY AND DATA COLLECTION PROCEDURE

Although the primary objective of this study was to develop new standards for maintenance equipment fuel consumption, it was decided to consider also the calculation of unit costs for the other two resources, material (other than motor fuel) and labor. This was done for two reasons: (1) to update the current material and labor standards, if necessary; and (2) to determine the share of fuel cost in the total cost of undertaking a routine maintenance activity. A discussion of maintenance resource requirements is given in Reference 10.

Field data were collected in the present study using the existing system of data recording with some modifications. The current data recording

system consists of filing work records on a card called crew day card. Each time a crew performs an activity all necessary information is recorded on a crew day card. Information recorded on such cards include: (1) routine maintenance activity type; (2) location where the activity was performed; (3) date; (4) number of crew members and corresponding man-hours; (5) equipment used and corresponding miles or hours; (6) materials used and corresponding quantities; and (7) total accomplishment (production units).

Six subdistricts were chosen within the six districts of the IDOH for field data collection. The location of these subdistricts is shown in Figure 2.

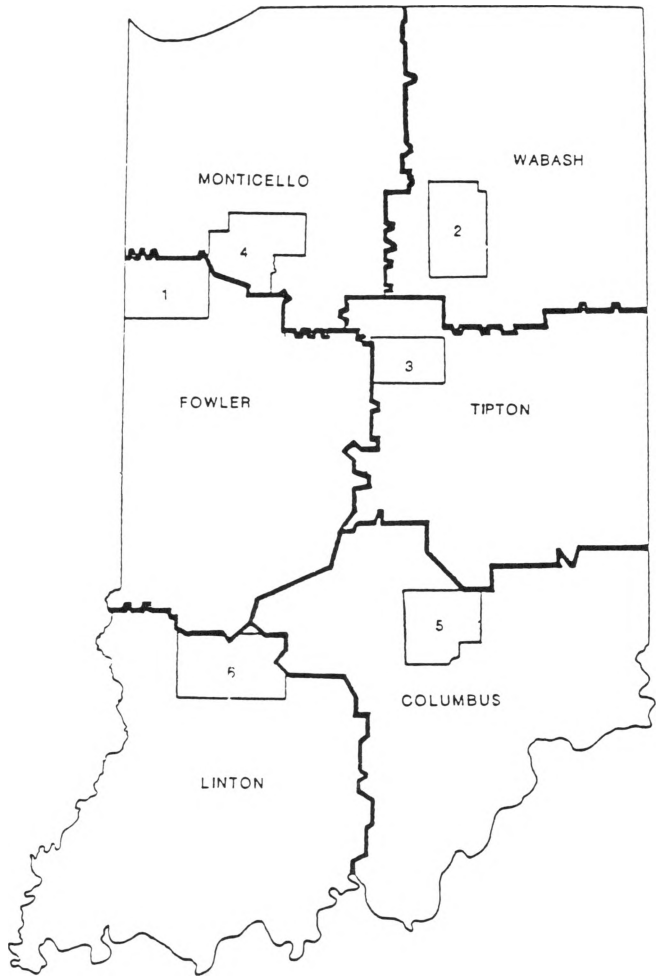

Figure 2. Location of Subdistricts.

The current data recording system of the IDOH does not include any information about the amount of fuel consumed by different equipment types. To provide fuel use data for this study, the subdistrict managers were instructed to fill each equipment with fuel before and after each job. The difference was to be recorded on the same crew day card with other associated data.

To avoid bias toward a specific period of the year, the data collection was spread over the entire fiscal year 1981-1982. The year was divided into four basic work seasons: fall, winter, spring, and summer. During a particular season, the data were collected over an extended period. For example, the fall data were collected for about six weeks during October and November, 1981, the winter data in a period of eight to ten weeks between December, 1981 and April, 1982, the spring data in a period of six weeks between April and May, 1982, and the summer data in a period of six weeks between May and July, 1982. By spreading the sample data over the entire fiscal year, it was ensured that those activities with seasonal peaks would be appropriately represented. For instance, about 50% of the total production units of shallow patching activity is accomplished in the spring season, while machine mowing is concentrated in the summer.

The data were screened and about 15% of the total sample size was excluded for one or more of the following reasons: (1) more than one activity reported on the same crew day card; (2) missing information, such as number of gallons consumed by one or more equipment; or (3) when obvious recording mistakes were detected.

Table 1 shows the different routine maintenance activities included in the maintenance management system of the IDOH, along with their code numbers and units of measure. The list of equipment types used

Table 1. Routine Maintenance Activities Included in the Study

Code No.	Activity Name	Unit of Measure
I. Roadway and Shoulder		
201	Shallow patching	Tons of mix
202	Deep patching	Tons of mix
203	Premix leveling	Tons of mix
204	Full width shoulder seal	Foot miles
205	Seal coating[1]	Lanes miles
206	Sealing longitudinal cracks and joints	Linear miles
207	Sealing cracks	Lane miles
209	Cutting relief joints	Linear feet
210	Spot repair of unpaved shoulders	Tons of aggregate
211	Blading shoulders	Shoulder miles
212	Clipping unpaved shoulders	Shoulder miles
213	Reconditioning unpaved shoulders	Shoulder miles
214	Joint and bump burning	Bumps removed
219	Others	Man-hours

Code No.	Activity Name	Unit of Measure
II. Roadside		
221	Machine mowing	Swath miles
222	Brush cutting	Man-hours
223	Herbicide treatment	Man-hours
224	Seeding and/or fertilizing	Man-hours
225	Topping, trimming or removal of long trees	Trees
226	Stump removal	Stumps
227	Spot mowing and hand trimming	Man-hours
228	Right-of-way fence repair	Linear feet
229	Others	Man-hours
III. Drainage		
231	Clean and reshape ditches	Linear feet
232	Inspect minor drainage structures	Structures
233	Pipe replacement	Location
234	Motor patrol ditching	Ditch mile
235	Cleaning minor drainage structures	Structures
239	Others	Man-hours
IV. Bridges		
241	Hand cleaning bridges	Decks cleaned
243	Bridge repair	Man-hours
244	Flushing bridges	Decks flushed
245	Patching bridge decks	Square feet
249	Others[1]	
V. Traffic Control		
251	Subdistrict sign maintenance	Man-hours
257	Paint pavement messages and special markings	Man-hours
258	Guardrail maintenance	Linear feet
259	Others	Man-hours
VI. Winter and Emergency		
261	Emergency maintenance	Man-hours
263	Snow and ice removal	Man-hours
265	Stockpiling winter materials	Man-hours
269	Others	Man-hours
VII. Public Service		
271	Rest area and lift bridge attendant[1]	Man-hours
272	Roadside park, rest area, and weigh station maintenance	Man-hours
273	Work of Department of Natural Resources[1]	Man-hours
274	Work for state institutions	Man-hours
275	Full width litter pickup	R.O.W. Pass. miles
276	Spot litter pickup	Man-hours
277	Roadway cleaning	Man-hours
279	Others	Man-hours
VIII. Others		
281	Equipment repair and maintenance[1]	Man-hours
283	Buildings and grounds maintenance[1]	Man-hours
284	Materials handling and storage	Man-hours
287	Detour maintenance	Man-hours
289	Other support activities	Man-hours
291	Special maintenance	Man-hours
295	Special maintenance	Man-hours
296	Special maintenance	Man-hours
112	Field maintenance supervision[2]	Man-hours
117	Training[2]	Man-hours
120	Standby time[2]	Man-hours
900	Leave[2]	Man-hours

[1] No data were received for these activities.

[2] No data for these activities (they are not recorded on crew day cards).

in maintenance activities is shown in Table 2 along with the code numbers.

Table 2. List of Equipment Used in Routine Maintenance Activities.

Code No.	Equipment Type	Code No.	Equipment Type	Code No.	Equipment Type
1	Pickup truck	36	Chain saw	71	Ave all
2	Pickup crew cab	37	Concrete saw	72	Sewer jet
3	Aerial Basket truck	38	Pavement Cutter	73	Crane
4	Flatbed truck	39	Hydro-seeder	74	Stake truck
5	Water truck	40	Weed sprayer	75	Generator
6	Bucket truck	41	Paint machine	76	Port Line marker
7	Distributer	42	Tractor truck	77	Van
8	Utility truck	43	Tractor mower	78	Sewer vector
9	Dump truck	44	Compressor	79	Vermeer trailer
10	Do-all truck	45	Mixer		
11	Catch basin cleaner	46	Squeegee Cart		
12	Compactor	47	Flashing arrow board		
13	Tar kettle	48	Porta patcher		
14	Premix storage trailer	49	Jeep		
15	Burner unit	50	Lowboy trailer		
16	Paver	51	Trailer		
17	Widener	52	Pavement Cutter		
18	Jack hammer	53	Chemical spreader		
19	Portable roller	54	Maintainer		
20	Roller	55	Back blade		
21	Street sweeper	56	Berm drag		
22	Broom	57	Undeck body		
23	Backhoe	58	Broom tractor		
24	Excavator	59	Weed eater		
25	Grader	60	Rotor tiller		
26	Loader	61	Rack truck		
27	Snow blow	62	Tilt cab		
28	Chip spreader	63	Pole truck		
29	Salt spreader	64	Gradall		
30	Underbody scrapper	65	Pavement breaker		
31	Brush chipper	66	Semi trailer		
32	Stump cutter	67	Dozzer		
33	Auger/driver	68	W hocker		
34	Lawn Mower	69	Crawler		
35	Hand mower	70	Vermeer cutter		

RESULTS OF THE STUDY

The results of this study can be divided into two major groups. The first group involved fuel consumption rates and costs in various routine maintenance activities. In this group, rates of fuel consumption in terms of number of gallons consumed by the equipment fleet to produce one production unit of each activity, and the proportion of fuel cost to other resource costs were identified. These results can be used directly by the IDOH Maintenance Division in preparing the annual routine maintenance programs.

In the second group, different factors that affect fuel consumption were analyzed to discover possible sources that may cause deviation from the rates developed in the first group. The effect of such factors as highway type and season (i.e., time of the year when the activity is performed) on fuel consumption was analyzed. These results were developed mainly for use by the maintenance division in the process of evaluating actual field work. Although the average rates can be used to make an estimate of total future needs, an analysis of actual performance of various

maintenance activities would require an explicit understanding of the factors that cause variation in fuel use rates.

Calculation of Fuel Consumption Rates and Costs

In this group, fuel consumption rates and costs were computed along with the ratio of fuel cost to total cost or to material cost. Total cost of an activity is defined as the sum of labor, material (other than fuel), and fuel (equipment) costs. Although the IDOH already has very good standard (unit costs) for both labor and material (other than fuel), it was decided to determine these unit costs on the basis of the field sample collected in this study. This way the current rates can be further checked and a uniform and unbiased set of cost data can be developed for the computation of ratios of fuel cost to other resource costs.

Cost Computation Procedure

The general form of cost calculation of an activity is given by:

$$T_k = \sum_i \sum_j f_{ijk} * R_{ijk} * C_{ij} \qquad (1)$$

where,

T_k = total cost in dollars per production unit of the k^{th} activity;
f_{ijk} = usage factor of the j^{th} element of the i^{th} resource when used in accomplishing the k^{th} activity;
R_{ijk} = rate of consumption of the j^{th} element of the i^{th} resource required to produce one unit of the k^{th} activity;
C_{ij} = unit cost of the j^{th} element of the i^{th} resource.

The usuage factor, f_{ijk}, is calculated as

$$f_{ijk} = \frac{n_{ijk}}{N_k} \qquad (2)$$

where,

n_{ijk} = total number of jobs observed using the j^{th} element of i^{th} resource in the k^{th} activity;
N_k = total number of jobs in the k^{th} activity.

Finally, the consumption rate, R_{ijk}, is obtained from

$$R_{ijk} = \frac{U_{ijk}}{P_k} \qquad (3)$$

where,

U_{ijk} = total number of units of the j^{th} element in the i^{th} resource when used in the k^{th} activity;
P_k = total number of units produced of the k^{th} activity.

The computational procedures can best be illustrated by an example. Consider activity number 201 (shallow patching). The computations of labor, material, and fuel costs of this activity are presented in Table 3.

Table 3. Cost Calculation Example (for Shallow Patching Activity).

Resource	i	Element	j	f_{ij}	R_{ij}	C_{ij}	Total Cost
Labor	1	Maintenance Worker IV	1	5.0	2.23 m.hr/Prod. Unit	$5.67 / m.hr.	$77.77 Labor Cost per Production Unit.
	1	" " III	2	1.0	2.23 m.hr/Prod. Unit	$6.52 / m.hr.	
Materials	2	Aggreg. or backfill	1	0.02	1.00 tons/Prod. Unit	4.10 / ton	$27.30 Material Cost per Production Unit.
	2	Seal Cover Aggreg.	2	0.02	0.30 tons/ " "	3.00 / ton	
	2	Bit. Material	3	0.30	7.77 gallons/ " "	0.78 / gallon	
	2	Bit. Mix	4	0.50	1.00 tons/ " "	25.50 / ton	
	2	Salvage Bit. Mix	5	0.50	1.00 tons/ " "	25.50 / ton	
Equipment	3	Pickup Truck	1	0.10	3.66 gallons/ " "	1.05 / gallon	$9.32 Fuel Cost per Production Unit.
	3	Pickup Crew Cab	2	1.10	2.69 " " "	"	
	3	Flatbed Truck	3	0.06	3.27 " " "	"	
	3	Distributer	4	0.02	2.53 " " "	"	
	3	Utility Truck	5	0.01	4.22 " " "	"	
	3	Dump Truck	6	0.91	4.78 " " "	"	
	3	Do-all Truck	7	0.12	3.71 " " "	"	
	3	Compactor	8	0.10	0.19 " " "	"	
	3	Tar Kettle	9	0.06	0.00 " " "	"	
	3	Premix Storage Trailer	10	0.49	0.00 " " "	"	
	3	Roller	11	0.05	0.60 " " "	"	
	3	Loader	12	0.03	1.66 " " "	"	
	3	Air Compressor	13	0.01	2.17 " " "	"	
	3	Flashing Arrow Board	14	0.18	1.14 " " "	"	
	3	Porta Patcher	15	0.09	0.00 " " "	"	
	3	Stake Truck	16	0.01	7.14 " " "	"	
							$114.39 Total Cost per Production Unit.

The usage factor (f_{ijk}, Equation 2) represents the frequency of use of certain resource element. For example, the usage factor of the first element (j = 1) of the first resource (i = 1), namely maintenance worker IV, is 5.0. This means that in the 342 jobs of activity 201 (shallow patching) there was a total of about 1710 maintenance workers of category IV, resulting in an average of 5.0. Similarly, in the 342 jobs where activity 201 was conducted (in the sample), a total of 311 dump trucks was used; the corresponding usage factor is therefore 0.91 for the 6^{th} element (dump truck) in the 3^{rd} resource (equipment).

Rate of consumption is the average number of units of certain resource element required to produce one production unit of activity (R_{ijk}, Equation 3). For example, to calculate the consumption rate of fuel for a dump truck when used in activity 201, the total number of gallons consumed by all dump trucks in the 342 jobs of this activity (U_{ijk}, Equation 3) was calculated and found to be equal to 3640.4 gallons. On the other hand, the total number of activity 201 units produced in the 342 jobs was found to be 1180 tons of mix (P_k, Equation 3). Thus, by applying equation 3, the average fuel consumption rate of a dump truck when used in activity 201 is about 4.78 gallons.

Applications of Equation 1 in this example results in a total cost of $114.39 per production unit of activity 201 (1981-1982 unit costs). The fuel cost per production unit is $9.32 and the total materials cost (including fuel) per production unit is $36.62. Therefore, the motor fuel cost, as a single material item, represents about 25% of the total material costs, and nearly 8% of the total cost for shallow patching activity.

The above calculations were repeated for all other activities considered in this study. A summary of the results is given in Table 4. In addition, Table 4 provides a comparison between different activities in terms of fuel and material (other than fuel) costs per man-hour. Man-hour was chosen as the unit for this comparison because it is common in all activities. On this basis, the high fuel consuming activities could be divided into 3 groups: (1) activities with high degree of equipment involvement in their operations such as activities 203, 204, 205, 212, 213, 226, and 231 (refer to Table 1 for activity names); (2) winter activities such as 263,265, and 266; and activities which involve long distance driving such as 284 and 289.

Table 4. Summary of Resource Costs[1]

Activity Number[2]	Av. Fuel Cost Per Prod. Unit	Av. Material Cost Per Prod. Unit	Av. Labor Cost Per Prod. Unit	Av. Total Cost Per Prod. Unit	Av. Man-Hours Per Prod. Unit	Av. Fuel Cost Per Man-Hour	Av. Material Cost Per Man-Hour
201	9.32	27.30	77.77	114.39	13.39	.70	2.04
202	8.88	25.98	31.77	66.63	5.32	1.67	4.88
203	5.30	26.84	13.93	46.07	2.31	2.30	11.64
204	8.16	77.56	19.65	105.37	3.16	2.58	24.51
205	89.74	1435.41	158.32	1683.47	25.49	3.52	56.30
206	8.25	56.00	49.72	113.97	7.99	1.03	7.01
207	24.41	114.64	166.85	305.90	28.72	.85	3.99
209	.55	2.14	2.67	5.36	.44	1.24	4.87
210	2.26	4.10	7.55	13.91	1.30	1.74	3.16
211	2.80	0	12.49	15.29	2.10	1.34	0
212	55.51	0	147.00	202.51	23.86	2.33	0
213	63.43	305.86	162.45	531.74	26.67	2.38	11.47
214	2.24	1.09	25.15	28.48	4.18	.53	.26
219	.56	3.10	5.85	9.51	1.00	.56	3.10
221	1.95	0	6.65	8.60	1.13	1.73	0
222	.78	0	5.99	6.77	1.00	.78	0
223	.88	15.65	5.95	22.48	1.00	.88	15.65
224	.23	7.03	5.95	13.21	1.00	.23	7.03
225	21.69	0	106.48	128.17	17.37	1.25	0
226	5.30	0	14.08	19.38	2.37	2.24	0
227	.80	0	5.95	6.75	1.00	.80	0
228	.17	1.24	1.13	2.54	.19	.87	6.45
229	1.48	0	5.93	7.41	1.00	1.48	0
231	.24	.03	.58	.85	.10	2.49	.31
232	.27	0	3.72	3.99	.61	.45	0
233	65.20	749.41	365.81	1180.42	61.27	1.06	12.23
234	82.13	0	349.50	431.63	57.20	1.44	0
235	4.06	0	24.05	28.11	4.03	1.01	0
239	.86	3.82	5.88	10.56	1.00	.86	3.82
241	5.69	0	46.60	52.29	7.93	.72	0
243	.62	2.10	6.10	8.82	1.00	.62	2.10
244	2.31	0	20.50	22.81	3.42	.67	0
245	1.01	.49	5.43	6.93	.92	1.10	.53
249	.62	11.09	5.85	17.56	1.00	.62	11.09
251	1.09	5.10	6.20	12.39	1.00	1.09	5.10
257	.79	2.82	6.00	9.61	1.00	.79	2.82

258	.92	6.20	7.13
259	1.21	0	5.92
261	1.83	1.00	6.10
263	5.25	22.46	6.50
265	2.01	0	5.76
266	3.58	0	5.67
269	.81	.23	5.84
271	.98	0	5.40
272	.98	0	5.67
273	.65	4.88	6.00
274	.65	2.17	5.89
275	2.59	0	17.95
276	.98	0	5.67
277	.80	0	6.17
279	1.98	0	5.67
281	0	0	6.00
283	1.64	0	6.00
284	3.73	0	5.95
287	1.08	0	6.10
289	2.86	0	6.10
291	1.86	30.80	6.30
295	.63	9.56	6.30
296	1.64	14.90	6.30
112	0	0	8.00
117	0	0	6.00
120	0	0	6.00
900	0	0	5.50

1 All Costs are based on 1981-1982 prices.

2 Refer to Table 1 for Activity Names.

14.25	1.21	.76	5.11
7.13	1.00	1.21	0
8.93	1.00	1.83	1.00
34.21	1.00	5.25	22.46
7.77	1.00	2.01	0
9.25	1.00	3.58	0
6.88	1.00	.81	.23
6.38	1.00	.98	0
6.65	1.00	.98	0
11.53	1.00	.65	4.88
8.71	1.00	.65	2.17
20.54	3.17	.82	0
6.65	1.00	.98	0
6.97	1.00	.80	0
7.65	1.00	1.98	0
6.00	1.00	0	0
7.64	1.00	1.64	0
9.68	1.00	3.73	0
7.18	1.00	1.08	0
8.96	1.00	2.86	0
38.96	1.00	1.86	30.80
16.49	1.00	.63	9.56
22.84	1.00	1.64	14.90
8.00	1.00	0	0
6.00	1.00	0	0
6.00	1.00	0	0
5.50	1.00	0	0

Factors Affecting Fuel Consumption

In the following, different factors that influence fuel consumption are discussed. This analysis was done in order to provide further insights that may help in evaluating fuel consumption records of different subdistricts or districts in undertaking various maintenance activities. To this end, we considered the following two major factors that affect the fuel consumption rates in maintenance activities: (1) frequency of use of individual equipment; and (2) consumption rate of individual equipment. The effect of highway type and of season on each of these factors were also considered.

Equipment Frequency of Use

The usage factors (f_{ijk}, Equation 1) for all activity-equipment combinations were computed. Several cases were studied to determine whether the frequencies of equipment use on Interstate system (IS) differ from those on Other State Highways (OSH). A close examination of the usage factors developed from the field data indicated that frequency of use of an equipment is independent of highway type.

The next analysis of equipment usage was carried out to examine the variation between subdistricts. It was observed the the frequency of equipment use can be significantly different from one subdistrict to another. In fact, this was noted in more than 50% of the activities. However, for the purpose of illustration we consider here five most frequently undertaken activities. These activities are 201, 221, 231, 251, and 276 (refer to Table 1 for activity names). For each activity we chose the most frequently used equipment (highest usage factor). The results concerning the usage factors for the different cases considered are illustrated in Figures 3 to 7.

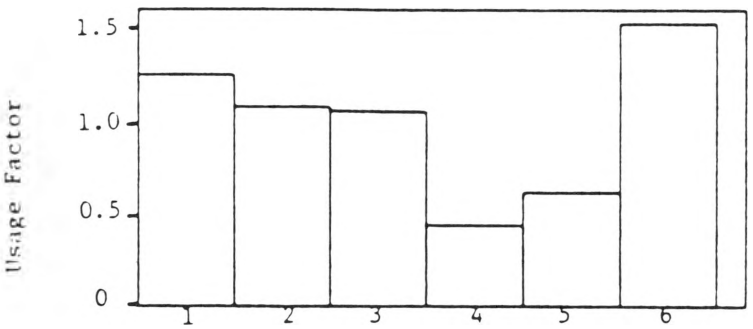

Figure 3. Usage Factors for Dump Truck—Shallow Patching Combination (by Subdistrict).

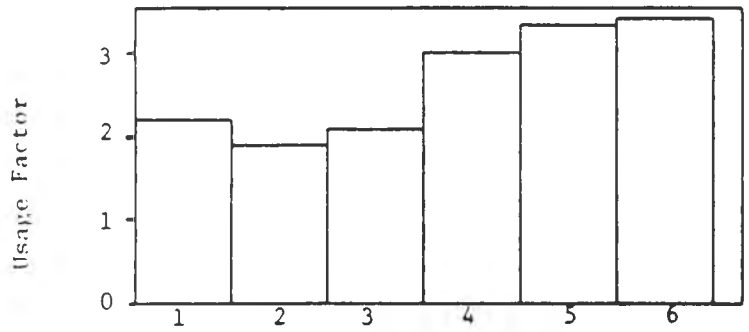

Figure 4. Usage Factors for Tractor Truck—Machine Mowing Combination (by Subdistrict).

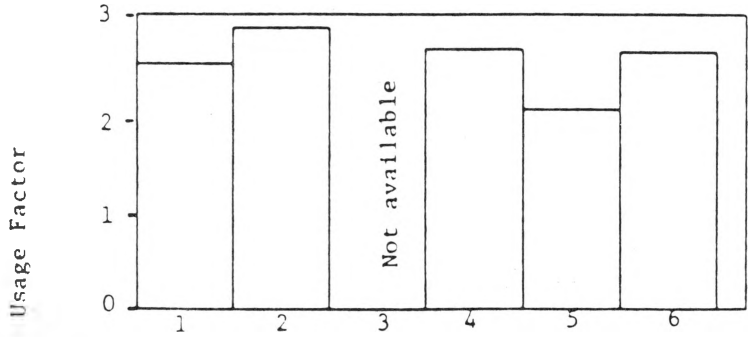

Figure 5. Usage Factors for Dump Truck—Cleaning and Reshaping Ditches Combination (by Subdistricts).

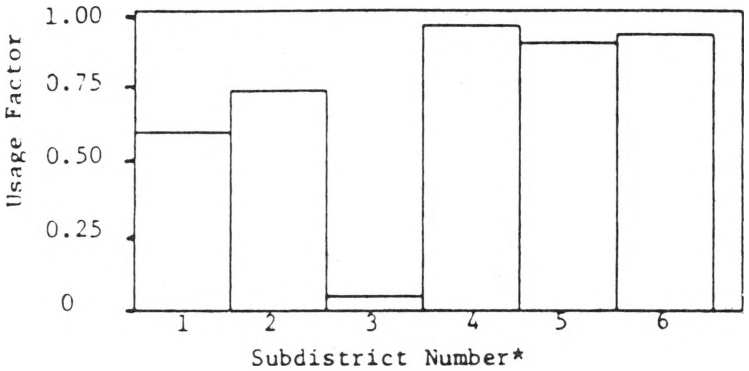

Figure 6. Usage Factors for Utility Truck—Sign Maintenance Combination (by Subdistrict).

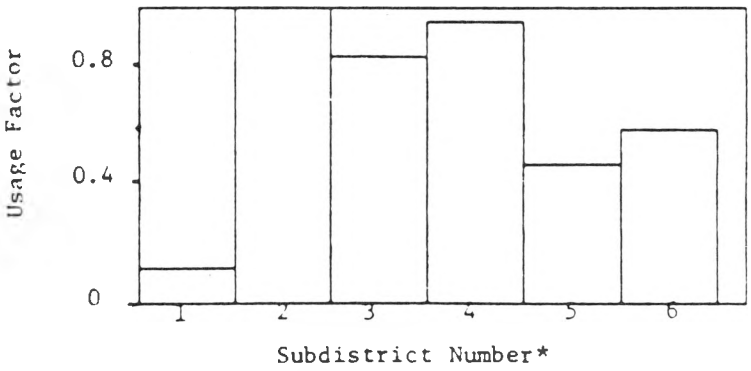

Figure 7. Usage Factors for Pickup Truck—Spot Litter Pickup Combination (by Subdistrict).

* Refer to figure 2 for subdistrict names and locations.

It is obvious from these figures that the frequency of use of an equipment can vary significantly from one subdistrict to another, and consequently, the individual values for each subdistrict can also differ considerably from the total average. To illustrate, consider the case of activity 201, as shown in Figure 3. The usage factor for a dump truck in subdistrict number 1 (refer to Figure 2 for subdistrict locations) is 1.20, whereas it is 0.42 for subdistrict 4 and 1.50 for subdistrict 6. Similar results can be seen for other four cases, as presented in Figures 4 to 7. There are also other numerous cases that indicate a variation between subdistricts in their degree of equipment usage frequency. This fact should be kept in mind in the evaluation process, as this variation can greatly affect the total number of gallons per production unit of an activity.

The last factor that was investigated is the season (time of year when an activity was performed). The same activity-equipment combinations used in the previous analysis (Figures 3 to 7) were utilized in the present analysis.

The main conclusion arrived at in this analysis is that equipment usuage factors vary in many cases from season to season. This is mainly because the availability of an equipment for a given activity is limited by the competition between several activities being undertaken during the same season. For example, considering activity 201 (shallow patching), the usage factor of a dump truck is less in winter than in summer (see Figure 8). This is because during the winter months the use of the available dump trucks for snow removal and ice control is given higher priority over other activities. The variation in other equipment usage factors by season is illustrated in Figures 9 to 12.

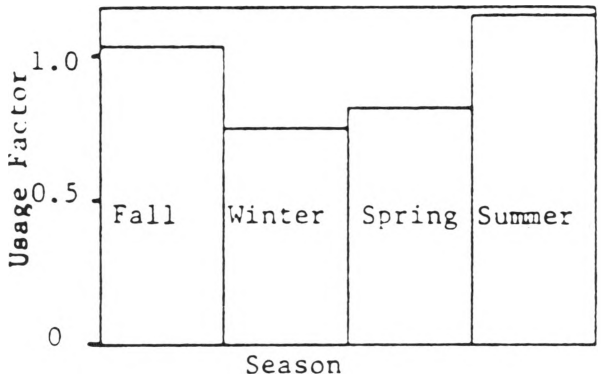

Figure 8. Usage Factor for Dump Truck—Shallow Patching Combination (by Season).

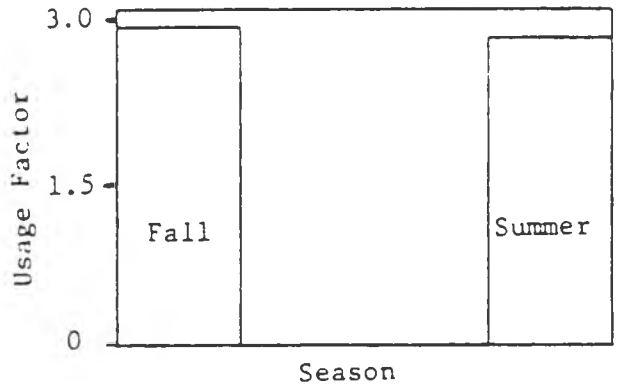

Figure 9. Usuage Factors for Tractor Truck—Machine Mowing Combination (by Season).

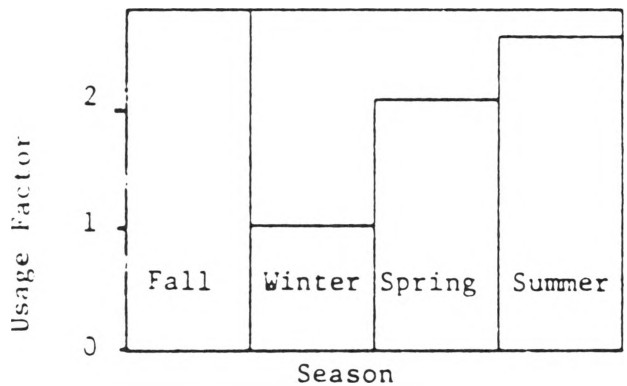

Figure 10. Usage Factors for Dump Truck—Clean and Reshape Ditches Combination (by Season).

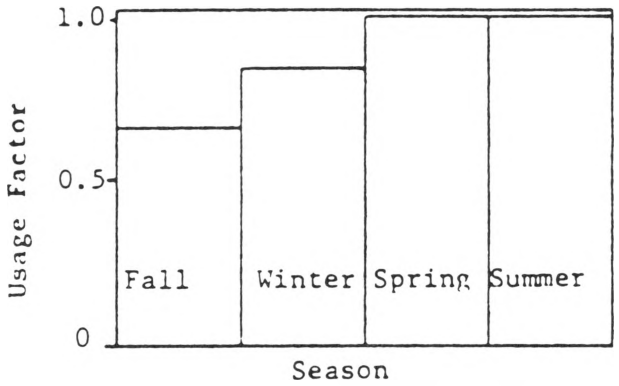

Figure 11. Usage Factors for Utility Truck—Sign Maintenance Combination (by Season).

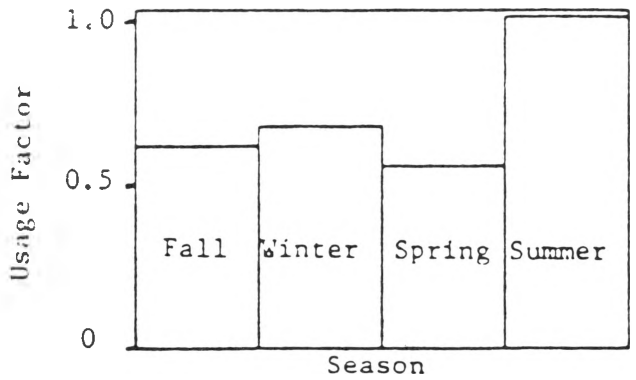

Figure 12. Usage Factors for Pickup Truck—Spot Litter Pickup Combination (by Season).

To summarize, the frequencies of equipment use may vary significantly from one subdistrict to another. This may be due to the availability of certain equipment types in a subdistrict or due to differences in field techniques employed by subdistrict foremen. Also, the difference in equipment usage by season may be significant in many cases. In addition, we observed no difference in equipment usage of an activity performed on Interstate or Other State Highway Systems.

Rates of Equipment Fuel Consumption

Rate of fuel consumption of an equipment when used in an activity is defined as the number of gallons consumed by this equipment to accomplish one production unit of the activity. The summation of these

rates for all equipment used in an activity will result in the overall rate of fuel consumption for the particular activity.

Consumption rates of an equipment usually vary from activity to activity. This is usually so because of the difference in the nature of work conducted by the same equipment in different activities. A good factor to analyze such differences is the equipment operational rates related to fuel consumption, such as miles per gallon (mpg) or gallon per hour (gph). For example, in Figure 13 are shown the operational rates for a dump truck when used in different activities, while Figure 14 shows similar results for a loader The two equipment types, dump truck, and loader, were chosen as examples; however, the available data would allow an analysis of this pattern of variation for any other equipment types. From Figures 13 and 14 and from several other cases it was obvious that an assumption of equal operational rates for a maintenance equipment in different activities can be misleading.

To illustrate, consider Figure 14 where the loader operational rates are shown. In activity 202 (deep patching), 0.94 gph is the operational rate, contrasted to 2.67 and 2.13 gph for activity 212, and 234, respectively. It is clear that the work conducted by a loader in activity 202 is much simpler than that performed in activity 212 or 234, where more gallons per hour are consumed. Same remarks apply to the other example (Figures 13) where more miles per gallon indicate less idling involved in the work.

The first analysis on operational rates of fuel consumption was to examine if these rates differed by type of highway. A relatively small number of data observations was available for jobs done on Interstates. This is because the number of units accomplished in most activities in the Interstate system is much less than that carried out in Other State Highways system. This can be confirmed by the fact that only 10% of the total routine maintenance expenditures in 1981-1982 was for the Interstate system (13).

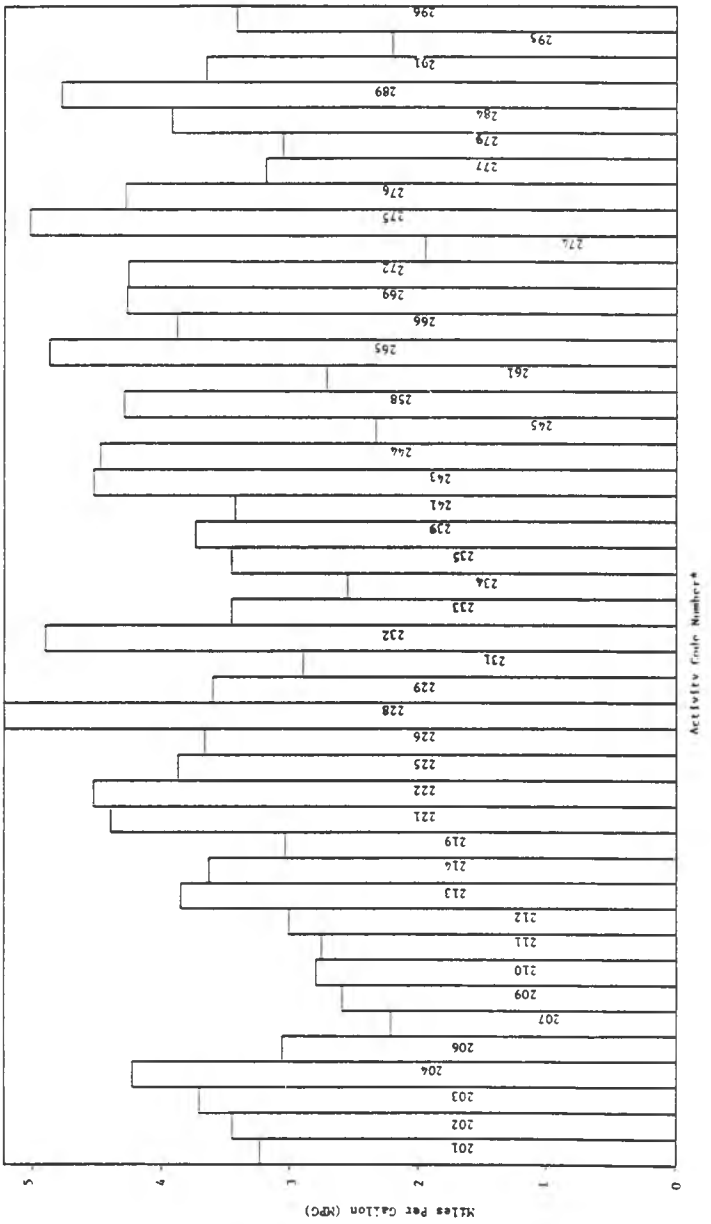

Figure 13. Fuel Consumption Rates (Miles Per Gallon) for a Dump Truck.
*** Refer to Table 1 for Activity Names**

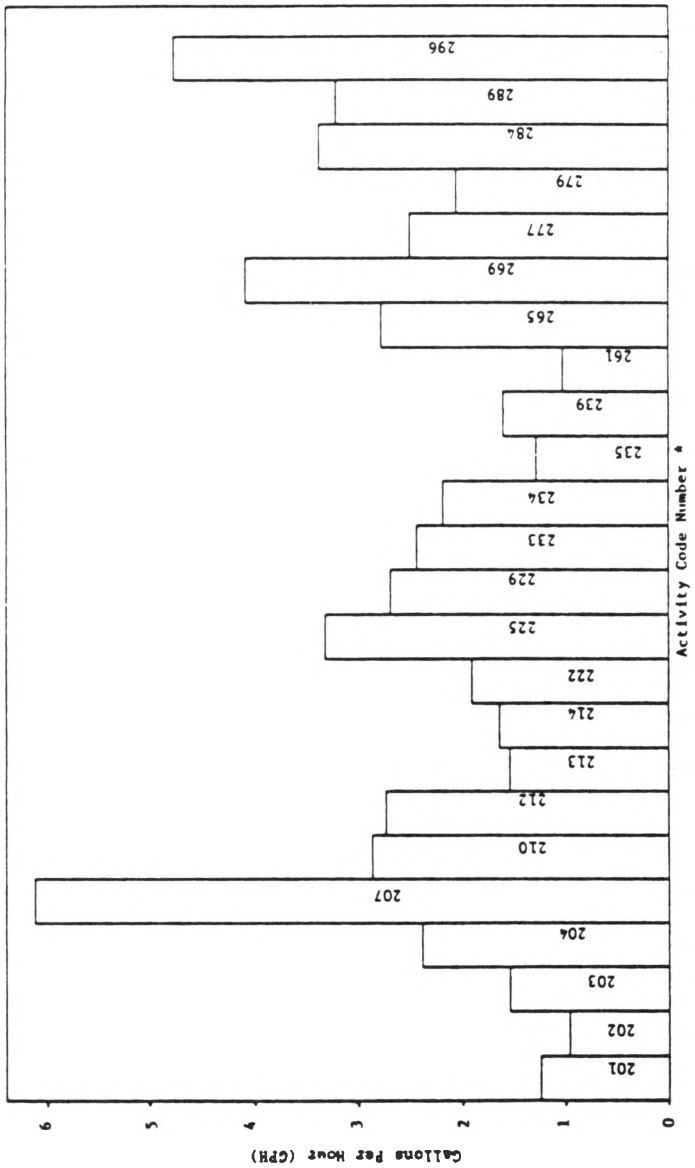

Figure 14. Fuel Consumption Rates (Gallons Per Hour) for a loader.
* Refer to Table 1 for Activity Names

The limited available data for the Interstate system did not cover all activity-equipment-highway type combinations. Only 20 separate statistical tests were therefore applied. Each test is defined by the season, activity number, subdistrict number and equipment number. A list of these tests is shown in Table 5. The reason for considering the above elements in defining each test is to eliminate the effect of factors other than highway type. So, in each test the operational rates of an equipment type in both Interstate and Other State Highways were statistically compared, and the results are reported in the last column in Table 5.

Table 5. Tests to Compare Operational Rates of Fuel Consumption in Interstate and Other State Highway Systems.

Test Number	Season	Activity Number[1]	Subdistrict Number[2]	Equipment Number[3]	Rate	Consumption Rate		Test Significance[6]
						Interstate	Other State Highway	
1	Fall	207	2	1	mpg[4]	3.02	4.49	Yes
2	Fall	207	2	2	mpg	3.59	4.83	Yes
3	Fall	207	2	9	mpg	0.84	1.86	Yes
4	Fall	207	2	44	gph[5]	1.80	1.50	Yes
5	Fall	251	1	8	mpg	7.89	8.80	Yes
6	Fall	276	1	9	mpg	3.49	4.37	Yes
7	Fall	276	2	1	mpg	8.29	7.69	No
8	Fall	276	5	1	mpg	9.50	10.41	Yes
9	Fall	276	5	9	mpg	4.13	5.12	Yes
10	Fall	277	5	1	mpg	11.02	12.22	Yes
11	Fall	277	5	2	mpg	6.33	6.48	No
12	Winter	207	2	2	mpg	3.70	5.58	Yes
13	Winter	207	2	9	mpg	2.30	2.81	Yes
14	Spring	201	1	2	mpg	4.03	5.46	Yes
15	Spring	201	5	9	mpg	2.07	2.91	Yes
16	Spring	222	5	36	gph	0.46	0.50	No
17	Spring	241	5	1	mpg	6.74	5.70	Yes
18	Spring	275	5	9	mpg	2.60	3.65	Yes
19	Spring	277	5	44	gph	2.17	2.88	Yes
20	Spring	279	5	9	mpg	3.05	4.85	Yes

1 Refer to Table 1 for activity names

2 Refer to Figure 5 for subdistrict names and locations

3 Refer to Table 3 for equipment types..

4 Miles per gallon

5 Gallons per hour

6 Yes: The averages are significantly different(at 90% to 95% levels of confidence)

No: The averages are not significantly different (at 90% to 95% levels of confidence)

A "Yes" means that average values of operational rates in the two systems is significantly different at a level of confidence of 90 or 95%. To illustrate, consider test number 15. This text was to compare the output rates (mpg) of a dump truck (equipment number 9) for shallow patching

(activity number 201) on Interstate and Other State Highways within the subdistrict number 5, performed in spring season. It was found that the average operational rates on the two highway systems are significantly different. It is clear that the general trend is a higher rate of fuel consumption on Interstate systems. Out of 20 tests, 17 tests indicated a significant difference between the two highway systems with a higher fuel consumption rate for the Interstate system.

It should be noted that the results are based on relatively small number of Interstate observations and not all activities were covered by the comparison tests. However, the results point out the importance of a careful study of the management units (subdistricts) that have a large portion of Interstate mileage in their highway system. These subdistricts may tend to use more fuel in their operations than those with low amount of Interstate mileage.

The second analysis was carried out to investigate the effect of the time of year (season) on equipment fuel consumption rates. This is the effect of season on the number of miles per gallon or gallons per hour consumed by an equipment when used in an activity. The approach adopted in this analysis was identical to that of the previous analysis. Statistical comparison tests were employed to test if the equipment operational rates were actually affected by the season. Each test is defined by the activity, subdistrict, equipment, and two seasons to be compared. A total of 138 tests were applied in this analysis. A list of these tests is given in Table 6. Tests 1 through 42 were used to compare fall and

Table 6. Comparative Tests for Seasonal Variations

Test No.	Activity No.[1]	Subdistrict No.[2]	Equipment No.[3]	Consumption Rate	Average Fuel Consumption				Test Significance[6]
					Fall	Winter	Spring	Summer	
1	201	2	2	mpg[4]	8.26	7.29			Yes
2	201	2	9	mpg	3.01	2.97			No
3	201	4	2	mpg	8.78	6.23			Yes
4	201	4	9	mpg	3.98	2.84			Yes
5	201	6	2	mpg	8.65	5.89			Yes
6	201	6	9	mpg	3.40	2.57			Yes
7	201	6	47	gph[5]	1.08	0.35			Yes
8	207	2	1	mpg	4.24	2.00			Yes
9	207	2	2	mpg	5.34	4.68			No
10	207	2	9	mpg	2.73	1.67			Yes
11	210	2	1	mpg	8.02	8.31			No
12	211	2	10	mpg	2.40	2.37			No
13	225	2	2	mpg	8.93	7.00			Yes
14	225	2	9	mpg	3.57	3.33			No
15	232	2	1	mpg	7.59	6.94			Yes
16	235	6	1	mpg	11.31	7.94			Yes
17	239	2	1	mpg	8.83	4.44			Yes

Test No.	Activity No.[1]	Subdistrict No.[2]	Equipment No.[3]	Consumption Rate	Average Fuel Consumption				Test Significance[6]
					Fall	Winter	Spring	Summer	
18	251	2	8	mpg	8.24	8.38			No
19	251	4	8	mpg	6.44	6.44			No
20	251	6	8	mpg	8.92	8.00			Yes
21	261	4	1	mpg	8.90	4.91			Yes
22	261	4	9	mpg	4.29	2.42			Yes
23	261	6	1	mpg	13.67	12.05			Yes
24	265	2	26	pgh	1.25	2.04			Yes
25	265	4	26	gph	1.58	4.30			Yes
26	276	2	1	mpg	9.38	7.78			Yes
27	276	2	9	mpg	5.91	4.31			Yes
28	276	4	1	mpg	12.09	11.13			No
29	276	4	2	mpg	9.56	6.47			Yes
30	276	6	1	mpg	15.27	12.94			Yes
31	276	6	2	mpg	15.10	13.41			Yes
32	276	2	1	mpg	7.78	9.38			No
33	276	2	9	mpg	5.91	4.31			Yes
34	284	6	1	mpg	11.60	12.40			No
35	284	6	26	gph	1.42	1.30			Yes
36	289	2	1	mpg[4]	11.67	9.60			Yes
37	289	2	9	mpg	5.20	4.81			No
38	289	2	25	gph	1.67	3.00			Yes
39	289	4	9	mpg	5.00	3.35			Yes
40	289	4	10	mpg	3.76	3.33			Yes
41	289	6	8	mpg	6.62	3.00			Yes
42	289	6	9	mpg	5.36	4.67			Yes
43	201	1	2	mpg	8.18		5.54		Yes
44	201	1	9	mpg	4.01		2.84		Yes
45	201	1	10	mpg	3.93		3.14		Yes
46	201	1	12	gph	0.40		0.40		No
47	201	2	2	mpg	7.50		7.29		No
48	201	2	9	mpg	2.97		2.62		Yes
49	201	2	10	mpg	3.35		2.62		Yes
50	201	4	1	mpg	10.38		9.91		No
51	201	4	2	mpg	8.78		6.27		Yes
52	201	4	4	mpg	7.46		5.27		Yes
53	201	4	9	mpg	3.98		2.95		Yes
54	201	5	2	mpg	8.75		7.98		Yes
55	201	5	9	mpg	4.18		4.74		No
56	201	6	2	mpg	8.65		7.96		Yes
57	201	6	9	mpg	3.40		3.30		No
58	201	6	10	mpg	2.85		2.78		No
59	207	4	2	mpg	8.54		5.44		Yes
60	207	4	7	mpg	3.56		2.43		Yes
61	207	4	9	mpg	2.76		2.65		No
62	207	4	44	gph	2.62		3.19		Yes
63	211	5	1	mpg	7.49		7.39		No
64	211	5	25	gph	1.90		1.99		Yes
65	222	5	2	mpg	9.71		8.06		Yes
66	222	5	9	mpg	4.74		3.37		Yes
67	222	5	36	gph	0.24		0.46		Yes
68	231	5	1	mpg	7.77		7.70		No

Test No.	Activity No.	Subdistrict No.	Equipment No.	Consumption Rate	Average Fuel Consumption				Test Significance
					Fall	Winter	Spring	Summer	
69	231	5	9	mpg	2.42		1.77		Yes
70	233	5	2	mpg	9.17		7.96		Yes
71	233	5	9	mpg	3.66		3.21		No
72	233	5	23	gph	1.50		1.70		Yes
73	251	4	8	mpg	6.44		5.37		Yes
74	251	5	8	mpg	8.84		8.10		Yes
75	261	5	9	mpg	3.28		2.39		Yes
76	269	5	2	mpg	13.16		9.42		Yes
77	269	5	9	mpg	4.60		3.60		Yes
78	269	5	53	mpg	3.33		2.40		Yes
79	272	5	2	mpg	11.45		8.31		Yes
80	272	5	9	mpg	5.31		3.61		Yes
81	275	5	9	mpg	3.91		2.24		Yes
82	276	4	2	mpg	9.60		9.00		Yes
83	276	4	9	mpg	5.00		4.70		No
84	276	5	1	mpg	10.05		9.40		Yes
85	276	5	9	mpg	4.79		3.77		Yes
86	277	4	2	mpg	6.43		5.41		Yes
87	277	4	9	mpg	2.61		1.53		Yes
88	277	4	26	gph	1.67		3.00		Yes
89	277	5	1	mpg	11.54		7.08		Yes
90	277	5	2	mpg	11.85		6.40		Yes
91	284	4	7	mpg	4.21		3.15		Yes
92	284	4	9	mpg	3.63		3.53		No
93	289	4	9	mpg	5.00		4.30		No
94	289	4	10	mpg	3.76		1.19		Yes
95	289	4	74	mpg	10.22		8.11		Yes
96	289	5	42	mpg	3.44		3.66		No
97	201	1	2	mpg	8.18			6.65	Yes
98	201	1	9	mpg	4.01			3.85	No
99	201	1	10	mpg	3.93			3.48	No
100	201	1	12	gph	0.40			0.33	No
101	201	2	2	mpg	7.29			9.07	Yes
102	201	2	9	mpg	2.97			2.93	No
103	201	4	2	mpg	8.78			6.81	Yes
104	201	4	9	mpg	3.98			3.99	No
105	202	1	2	mpg	4.43			2.63	Yes
106	206	1	9	mpg	7.35			3.56	Yes
107	206	4	9	mpg	3.54			2.76	No
108	206	4	44	gph	0.90			1.57	Yes
109	210	1	2	mpg	4.50			7.16	No
110	210	1	9	mpg	2.06			3.75	No
111	210	1	10	mpg	2.99			3.48	No
112	221	1	2	mpg	9.27			7.14	Yes
113	221	1	42	gph	1.28			1.21	No
114	221	1	59	gph	0.20			0.27	No
115	221	6	2	mpg	11.24			9.16	Yes
116	221	6	42	gph	1.15			1.22	No
117	222	4	2	mpg	8.87			7.34	No
118	222	4	36	gph	.13			0.29	Yes
119	227	4	1	mpg	7.80			2.03	Yes

Test No.	Activity No.	Subdistrict No.	Equipment No.	Consumption Rate	Average Fuel Consumption				Test Significance
					Fall	Winter	Spring	Summer	
120	251	4	8	mpg	6.44			6.63	No
121	257	4	8	mpg	9.56			7.45	No
122	276	4	1	mpg	12.09			16.66	Yes
123	277	4	2	mpg	6.43			3.90	Yes
124	277	4	9	mpg	2.61			1.49	Yes
125	284	4	9	mpg	3.63			3.89	No
126	289	4	2	mpg	9.36			12.00	Yes
127	289	4	9	mpg	5.00			5.00	No
128	289	4	10	mpg	3.76			3.66	No
129	289	4	77	mpg	14.2			15.61	No
130	231	4	1	mpg			2.75	7.67	Yes
131	231	4	2	mpg			3.81	7.22	Yes
132	231	4	9	mpg			2.25	3.61	Yes
133	231	4	24	gph			6.40	8.94	Yes
134	239	4	9	mpg			3.44	2.83	Yes
135	251	4	8	mpg			5.37	6.00	Yes
136	277	4	2	mpg			5.41	3.90	Yes
137	277	4	9	mpg			1.53	1.49	No
138	284	4	9	mpg			3.53	3.89	No

1 Refer to Table 1 for activity names

2 Refer to Figure 5 for subdistrict names and locations

3 Refer to Table 3 for equipment types

4 Miles per gallon

5 Gallons per hour

6 Yes: Test is significant at 90% or 95% confidence level.
No: Test is not significant at 90% or 95% confidence level.

winter seasons, tests 43 through 96 to compare fall and spring, tests 97 through 129 to compare fall and summer, and tests 130 through 138 to compare spring and summer. For example, consider test number 10. This test was used to compare the miles per gallon consumed by a dump truck in fall and winter seasons, for activity 207 performed in subdistrict number 2. The test indicated that the average fuel consumption rates of a dump truck during these two seasons for crack sealing are significantly different, with a higher fuel consumption rate in winter.

In comparing the fall versus winter seasons 31 out of 42 tests showed a significant difference between the two seasons (indicated by "Yes" at the last column in Table 6), with higher rates of consumption in winter, at a confidence level of 90 or 95%. Stated differently, less miles per gallon or higher gallons per hour can be expected when an equipment is used to perform a particular activity in winter than in fall.

Fifty-four tests were applied to compare fall and spring. Out of the 54 tests, 40 tests indicated a significantly higher fuel consumption rate in spring than in fall.

For the comparison between fall and summer, 19 out of 33 tests showed no significant difference between the two seasons, nine tests in-

dicating a higher consumption rate in summer, and five tests with a higher rate in fall. Consequently, no clear trend could be established for this group.

The last comparison was between spring and summer. Out of nine, seven tests indicated a higher fuel consumption rate in spring than in summer.

Reviewing the results of the four test groups, it can be concluded that the rate of fuel consumption by an equipment fleet is higher in winter and spring seasons than in fall and summer. However, the degree of that difference may vary between activities. A general conclusion is that for the comparison of the consumption rates a year can be divided into two basic periods, the first including winter and spring seasons, and the second including fall and summer seasons. Jobs executed in winter and spring seasons were observed to consume more fuel than those performed in fall and summer seasons. Furthermore, fuel consumption rates are affected by highway type. More fuel consumption can be expected for jobs carried out on Interstate system than for jobs on Other State Highway system.

SUMMARY AND CONCLUSIONS

This paper has presented the results of a study aimed at the identification of fuel consumption by the equipment fleet used in highway routine maintenance activities in the State of Indiana. Two basic groups of results were considered: (1) the fuel consumption rates for all possible activity equipment combinations as well as total fuel consumed per production unit of each activity; and (2) the effect of factors such as location (subdistrict), highway system type, and season on fuel consumption rates. The first group of results will be of direct use to the IDOH in the planning of the annual maintenance program, while the second group will be useful in evaluating the actual field work of different management units (subdistricts).

Based on the findings from this study, the following conclusions can be made:

1. Motor fuel was the most expensive single material used in routine maintenance activities in 1981-82. It is estimated that about 12 to 13% of the costs for maintenance field activities can be assigned to fuel only. Considering the material costs, 26 to 27% can be attributed to fuel.
2. Routine maintenance activities in winter and emergency group consumed about 43% of the total fuel use. The next highest consumption took place in activities in roadway and shoulder group, where about 19% of total fuel was consumed.
3. A major contributing activity in total fuel consumption in routine

maintenance is snow removal and ice control. In 1981-82 about 38% of the total fuel used in routine maintenance was consumed in this activity.

4. The frequency of equipment was found to be significantly different by location (subdistrict) in at least 50% of the total number of activities. Also, the frequency of use was found to be considerably different from season to season. On the other hand, no significant difference was detected in the frequency of equipment use between Interstate and Other State Highway maintenance activities.
5. The assumption of a standard fuel consumption rate for a given equipment type used in different activities was found to be arbitrary. It was observed that the majority of equipment types have considerably different rates of fuel consumption when used in different activities.
6. Although only a few observations were obtained from the Interstate system, it was found that there is a general trend of a higher fuel consumption rate in jobs done on Interstate system than those done on Other State Highway system.
7. In general, more fuel is consumed in jobs done in winter and spring than in those done in summer and fall.

Based on the findings presented above, it is recommended that equipment information should be incorporated in data recording system. It is further recommended that a disaggregate fuel consumption information for each equipment-activity combination be used in maintenance planning. This procedure will help to prepare an improved annual routine maintenance program.

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