SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-85/18

Executive Summary

ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE

Mitsuru Saito
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Kumares C. Sinha

PURDUE UNIVERSITY

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Final Report

Executive Summary

ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE: FINAL REPORT

TO: Harold L. Michael, Director
Joint Highway Research Project

October 9, 1985
Revised July 10, 1986
Project: C-36-67L

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

File: 9-11-12

Attached is the Final Report on the HPR Part II Study entitled, "Energy Conservation and Cost Savings Related to Highway Routine Maintenance". This final report covers the entire study with particular emphasis on Tasks 2, 3 and 4 dealing with optimization procedure and development of energy conservation guidelines. The research in the final phase of the study was conducted by Mitsuru Saito under my direction.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as fulfillment of the objectives of the research.

Respectfully Submitted,

K C Sinha

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Final Report

Executive Summary

ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE

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16. Abstract

This research was conducted in three phases. The first two phases were presented in two interim reports. This report includes a summary of the first two phases and a detailed discussion of the final phase. The final phase of the study focused on a trend analysis of energy use in routine maintenance and development of an optimization approach that can be used to determine the optimal assignment of various equipment types to different activities. The use of the approach was illustrated through an example application. A set of energy conservation guidelines was then outlined for possible implementation.

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Introduction

Highway routine maintenance involves a sizable expenditure for a state highway agency. In Indiana, total annual maintenance expenditure in recent years has been about $50 million. Maintenance expenditure involves labor, materials and equipment. Motor fuel constitutes the largest single expensive item in materials cost. In recent years the total cost for direct fuel use in field activities excluding supervision has been about $6 million.

Motor fuel is a special resource that needs to be effectively controlled. The present study was directed to develop appropriate strategies that can be used to control fuel use in maintenance field activities. To that end the study was divided into three phases. In the first phase a field survey was conducted in six subdistricts in Indiana in FY 1982 to collect information on fuel consumption by various equipment types when used in different maintenance activities. The second phase of the study concentrated on pavement maintenance, and the third phase involved a trend analysis of fuel use and formulation of an optimization model. The final phase also included the development of a set of guidelines that can be used to implement a program directed at energy conservation and cost savings in highway routine maintenance.

Field Data Collection and Fuel Consumption Rates

Field data were collected using the current data recording system that consists of filing work records on a card called crew day card. Each time a crew performs an activity in a day all necessary information on material, labor and equipment is recorded on a crew day card. For the purpose of this study fuel use information was added in the crew card records. Six subdistricts were chosen within the six districts of the IDOH for field data collection. The data were collected during the fiscal year 1982. The year was divided into four basic work seasons: fall, winter, spring and summer. The routine maintenance activities included in the study are shown in Table 1.

The data were analyzed to provide two primary sets of information. In the first set fuel consumption rates and costs of various activities were calculated. Rates of fuel consumption in terms of number of gallons consumed by various equipment types to accomplish one production unit of each activity were estimated along with the proportion of fuel cost to other resource costs. In the second set, different factors that affect fuel consumption were analyzed, including highway type, subdistrict location and season.

A summary of the results involving various resource costs for different activities is given in Table 2. Costs were also analyzed by maintenance group and by work control category. In addition, fuel consumption rates of various equipment-activity combinations were identified. An example is presented in Figure 1 for a loader when used in different activities.

Based on the analysis of the data the following conclusions were made:

1. Motor fuel is the most expensive single material used in routine maintenance.

2. Snow and ice removal is the single major fuel consuming activity. However, this activity is entirely weather dependent and it cannot be controlled in the same manner as other activities.

3. For various reasons, frequency of equipment use is significantly different from subdistrict to subdistrict for most activities.

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
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]	

Table 1. Routine Maintenance Activities Included in the Study (Continued)

Code No.	Activity Name	Unit of Measure
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).

Table 2. Summary of Resource Costs[1]

Activity Number	Av. Fuel Cost Per Prod. Unit	Av. Material Cost Per Prod. Unit	Av. Labor Cost Per Prod. Unit	Ave. 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	27.3	77.77	114.39	13.39	0.70	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	0.85	3.99
209	0.55	2.14	2.67	5.36	0.44	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	531.45	26.67	2.38	11.47
214	2.24	1.09	25.15	28.48	4.18	0.53	0.26
219	0.56	3.10	5.85	9.51	1.00	0.56	3.10
221	1.95	0	6.65	8.60	1.13	1.73	0
222	0.78	0	5.99	6.77	1.00	0.78	0
223	0.88	15.65	5.95	22.48	1.00	0.88	15.65
224	0.23	7.03	5.95	13.21	1.00	0.23	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	0.80	0	5.95	6.75	1.00	0.80	0
228	0.17	1.24	1.13	2.54	0.19	0.87	6.45
229	1.48	0	5.93	7.41	1.00	1.48	0
231	0.24	0.03	0.58	0.85	0.10	2.49	0.31
232	0.27	0	3.72	3.99	0.61	0.45	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	0.86	3.82	5.88	10.56	1.00	0.86	3.82
241	5.69	0	46.60	52.29	7.93	0.72	0
243	0.62	2.10	6.10	8.82	1.00	0.62	2.10
244	2.31	0	20.50	22.81	3.42	0.67	0
245	1.01	0.49	5.43	6.93	0.92	1.10	0.53
249	0.62	11.09	5.85	17.56	1.00	0.62	11.09
251	1.09	5.10	6.20	12.39	1.00	1.09	5.10
257	0.79	2.82	6.00	9.61	1.00	0.79	2.82
258	0.92	6.20	7.13	14.25	1.21	0.76	5.11
259	1.21	0	5.92	7.13	1.00	1.21	0
261	1.83	1.00	6.10	8.93	1.00	1.83	1.00
263	5.25	22.46	6.50	34.21	1.00	5.25	22.46
265	2.01	0	5.76	7.77	1.00	2.01	0
266	3.58	0	5.67	9.25	1.00	3.58	0
269	0.81	0.23	5.84	6.88	1.00	0.81	0.23
271	0.98	0	5.40	6.38	1.00	0.98	0
272	0.98	0	5.67	6.65	1.00	0.98	0
273	0.65	4.88	6.00	11.53	1.00	0.65	4.88
274	0.65	2.17	5.89	8.71	1.00	0.65	2.17
275	2.59	0	17.95	20.54	3.17	0.82	0
276	0.98	0	5.67	6.65	1.00	0.98	0
277	0.80	0	6.17	6.97	1.00	0.80	0
279	1.98	0	5.67	7.65	1.00	1.98	0
281	0	0	6.00	6.00	1.00	0	0
283	1.64	0	6.00	7.64	1.00	1.64	0
284	3.73	0	5.95	9.68	1.00	3.73	0
287	1.08	0	6.10	7.18	1.00	1.08	0
289	2.86	0	6.10	8.96	1.00	2.86	0
291	1.86	30.80	6.30	38.96	1.00	1.86	30.80
295	0.63	9.56	6.30	16.49	1.00	0.63	9.56
296	1.64	14.90	6.30	22.84	1.00	1.64	14.90
112	0	0	8.00	8.00	1.00	0	0
117	0	0	6.00	6.00	1.00	0	0
120	0	0	6.00	6.00	1.00	0	0
900	0	0	5.50	5.50	1.00	0	0

1. All costs are based on 1981-1982 prices.
2. Refer to Table 1 for activity names.

Figure 1. Fuel Consumption Rates (Gallons Per Hour) for a Loader.

*Refer to Table 1 for activity names.

4. Frequency of equipment use is considerably different from season to season.

5. The assumption of a standard fuel consumption rate for equipment types can be grossly erroneous.

Pavement Maintenance

A detailed examination was made of the pavement maintenance costs. This phase of the study included: i) development of a comprehensive data base that combines pavement maintenance information, climatic zone, traffic information, and pavement characteristics; ii) development of pavement maintenance rates by highway system, by pavement type, and by climatic zone; iii) analysis of labor, material, and total expenditure trends over four fiscal years; iv) correlation analysis between yearly total expenditures and that between shares of different activities of total expenditures; and v) analysis of the relationship between the level of pavement routine maintenance and pavement characteristics. Multiple regression was used to develop prediction models for total maintenance expenditure as well as for level of expenditure in maintenance groups of sealing and patching activities. Possible applications of the study results were illustrated through examples involving tradeoff between patching and sealing as well as between routine maintenance and resurfacing.

In order to develop a common data base the state highway system was divided into 820 highway sections. A highway section represents the portion of a specific highway that lies between county limits. The data included geographic location (climatic zone), pavement type (flexible, rigid and resurfaced), traffic (AADT, percent of trucks and EAL), pavement characteristics (age and layer thickness), and pavement maintenance records for fiscal years 1980 through 1983 (total production units, total man-hours, and types and quantities of materials). An important feature of the study was that it used only those data that are routinely collected by the state.

The analysis indicated that the accuracy of pavement maintenance cost estimation depends largely on the accuracy of predicting the cost of patching (shallow and deep) and sealing activities. These two activities constitute more than 85% of the total IS pavement maintenance costs and more than 65% of the total OSH pavement maintenance costs. The single activity which contributed most of the total pavement maintenance costs is the shallow patching activity, where about 30% to 40% of the total pavement maintenance expenditures is spent.

There is a significant difference in the use of labor and materials for the same pavement maintenance activities applied to IS and OSH. This is because maintenance practices are different for these two systems. In addition, maintenance needs of these two systems are also very different. The consumption rates and frequencies of use of material in patching and sealing activities changed significantly over the four years 1980-1983, particularly for bituminous materials and mixtures. On the other hand, labor consumption rates remained generally stable over the same period.

Maintenance expenditures were consistently higher on OSH miles than on IS miles. Also, it was found that maintenance expenditure was higher in the northern zone than in the southern zone. Furthermore, there was a noticeable difference in pavement maintenance expenditure on various pavement type-highway class combinations. The analysis also indicated the trend that the portion of total expenditure allocated to patching activities in the north is higher than that in the south. On the other hand, this trend was reversed in the case of sealing activities. A high negative correlation was observed between sealing expenditure in the fall season (before winter) and patching expenditure after winter. This indicated the importance of sealing as preventive maintenance that may result in a reduction in the amount of repair or emergency patching activities.

In developing prediction models, it was found that traffic level (accumulated EAL) and location (north or south) were the major factors affecting total pavement maintenance expenditure. Regression models to predict sealing and patching expenditures for different highway class-pavement type combinations were also developed. Sealing expenditure was found to be a function of traffic level and location. However, for the regression model to predict patching expenditure, sealing expenditure before winter during the same year was found to be a significant factor in addition to traffic and location. This result is reasonable, because pre-winter sealing work would reduce the extent of spring thaw damage resulting in less potholes.

Two examples of possible applications of the study results in the area of energy and cost savings in pavement routine maintenance were considered. The first application addressed probable savings resulting from increasing the level of sealing activities. A definite tradeoff relation was observed between the amount of sealing (preventive maintenance) and that of patching (corrective maintenance). By increasing the sealing activities, the consequent increase in fuel consumption in sealing activities would be less than the fuel saved due to the resulting reduction in the level of patching activities. For example, the effect of increased levels of sealing on IS rigid pavement is presented in Figure 2. It was estimated that increasing the sealing level by 5 percent statewide, about 6,000 gallons of fuel per year could be saved and an increase of 25 percent would save about 29,000 gallons per year. In addition to these savings, an increased sealing program can also improve the level of service due to an expected reduction in pavement breakups (patching required).

The second example considered an analysis of pavement routine maintenance versus resurfacing. A simple aggregate analysis was performed which presented a methodology to use the results of this study in the area of tradeoff between maintenance and rehabilitation.

Trends in Fuel Use

In planning for energy conservation in maintenance, it is necessary to concentrate on those activities and equipment types that consume the most fuel. The trend analysis conducted on the basis of routine maintenance accomplishment records of three consecutive years, 1982, 1983, and 1984, showed the existence of a reasonably stable trend in the consumption of fuel by activity type and by equipment type. It also identified the elements of routine maintenance that should be the prime targets for fuel conservation efforts.

On the average, about 3.5 million gallons of the total annual fuel consumption are used for activities other than snow and ice removal. A mere reduction of one percent of the fuel used for regular activities, therefore, would save about 35,000 gallons of fuel or approximately 36,750 dollars each year with a fuel price of $1.05 per gallon. This saving would range from $26,250 to $70,000 with fuel price ranges of $0.75 to $2.00 per gallon,

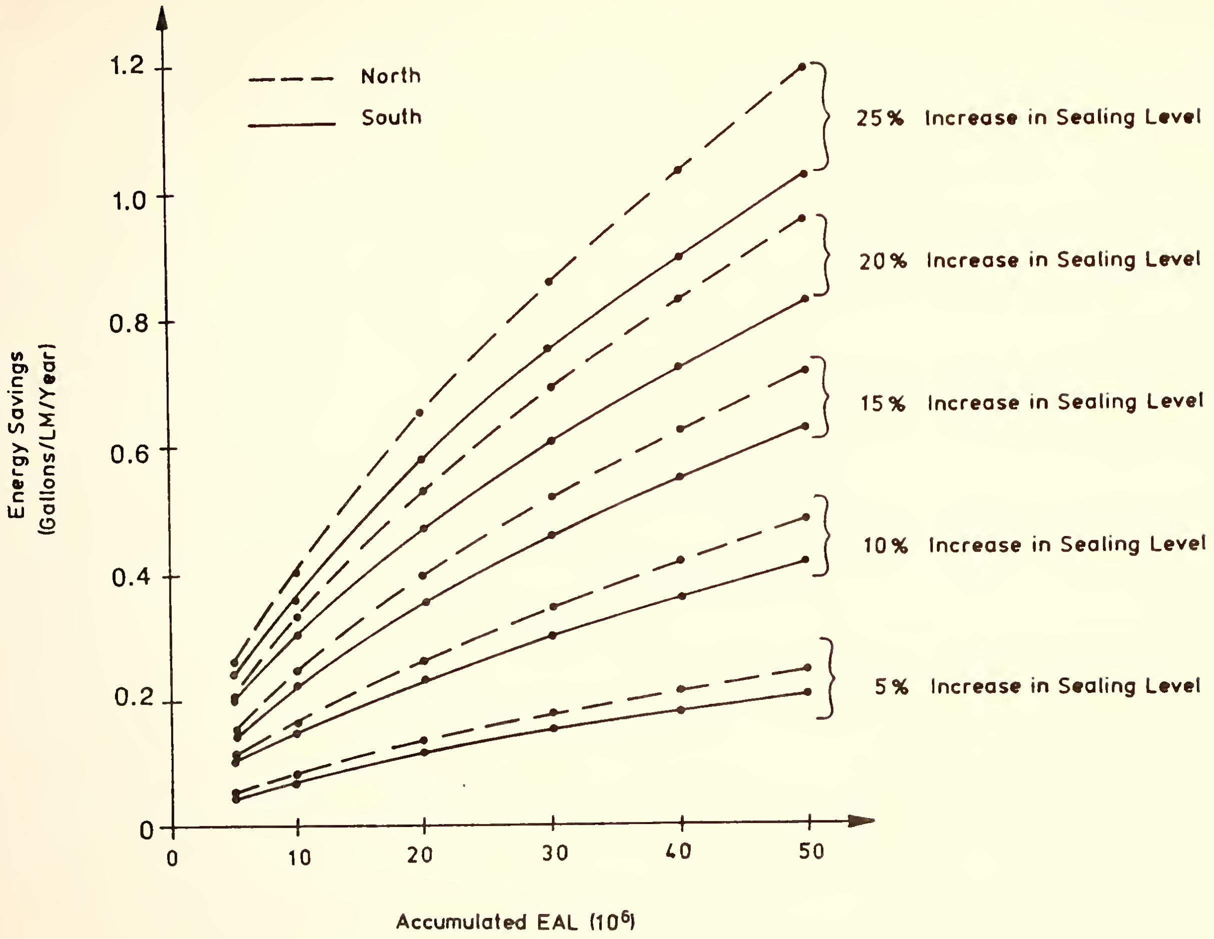

Figure 2. Energy Savings Due to Increase in Sealing Level for Interstate Rigid Pavement.

respectively. In fiscal year 1984, interstate highways required, on the average, 340 to 350 gallons/mile/year of fuel for maintenance, whereas other state highways required 250 to 260 gallons/mile/year. However, only approximately 0.40 million gallons of fuel were used in total for interstates. On the other hand, 2.94 million gallons of fuel were spent for the maintenance of other state highways. Therefore, the reduction of fuel use by managing maintenance activities on other state highways is much more substantial than the fuel savings in maintenance of interstates.

Routine maintenance activities are grouped by the IDOH into four major categories which deflect the importance and ranking of the activities. They are in descending order of importance: 1) limited activities, 2) unlimited activities, 3) overhead activities, and 4) variable activities. Maintenance activities in the limited and unlimited categories used approximately 2.31 million gallons of fuel in 1984. This accounted for 69% of the total fuel consumption in maintenance excluding snow and ice removal.

In order for energy saving measures to be effective, maintenance activities should closely follow the planned program. Actual accomplishments of the limited activities were, however, found to be significantly different from the planned accomplishments at some subdistricts. Variations between the actual and planned accomplishments were more frequent among the activities in the unlimited category. These variations may create a difficulty in actually setting goals in fuel reduction. Since about two-thirds of the estimated total annual fuel consumption is due to these categories, an improvement in the procedure to assess needs of specific maintenance activities is strongly desired if energy conservation programs are directed to these activity categories.

Fuel consumption by activity shows a tendency of being concentrated on a few activities every year. Thirteen activities were identified as dominant in fuel consumption in fiscal year 1984, as shown in Figure 3. These thirteen activities accounted for approximately 65% of the total fuel consumption excluding snow and ice removal and supervision. About one-fourth of the total fuel consumption was due to roadway and shoulder related maintenance activities. The single most fuel consuming activity was found to be the cleaning and reshaping of ditches (Activity 231) and it accounted for 13.6% of total fuel consumption.

The majority of equipment types are used for less than ten different activities. Thirteen equipment types were found to be dominant and accounted for about 95% of total fuel consumption, as shown in Figure 4. The most fuel consuming type was the dump truck, followed by pickup crew cabs and pickup trucks.

Formulation and Application of Optimization Model

An optimization model was developed for assigning various equipment types to different activities in such a way that total fuel consumption would be minimized. The concept of the optimization model was based on the interchangeability of equipment types for particular tasks of each activity. The decision variable used in the model is the number of equipment days of a particular type to be used for an activity. The optimal value can than be taken as the target value of equipment days to be assigned to the activities. Two types of constraints are used in this optimization model: 1) planned accomplishments of activities and 2) equipment availability.

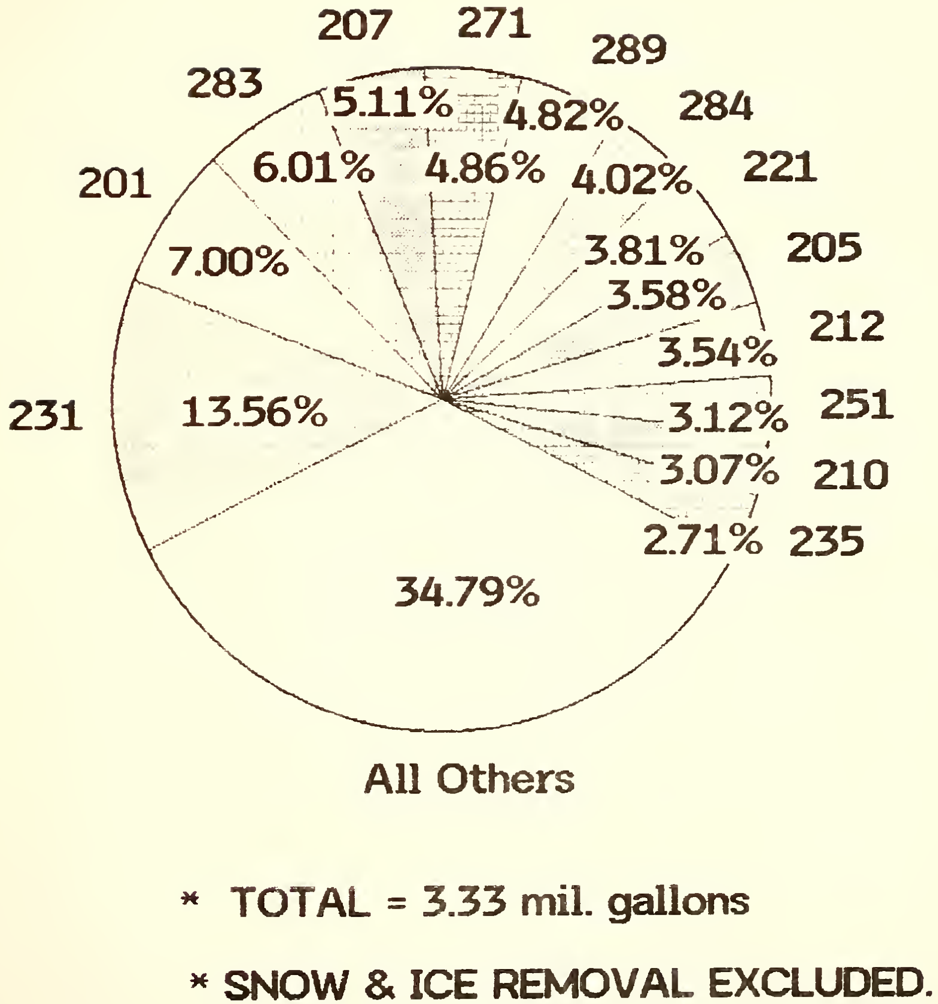

Figure 3. Fuel Consumption by Activity Type in Percent during Fiscal Year 1984

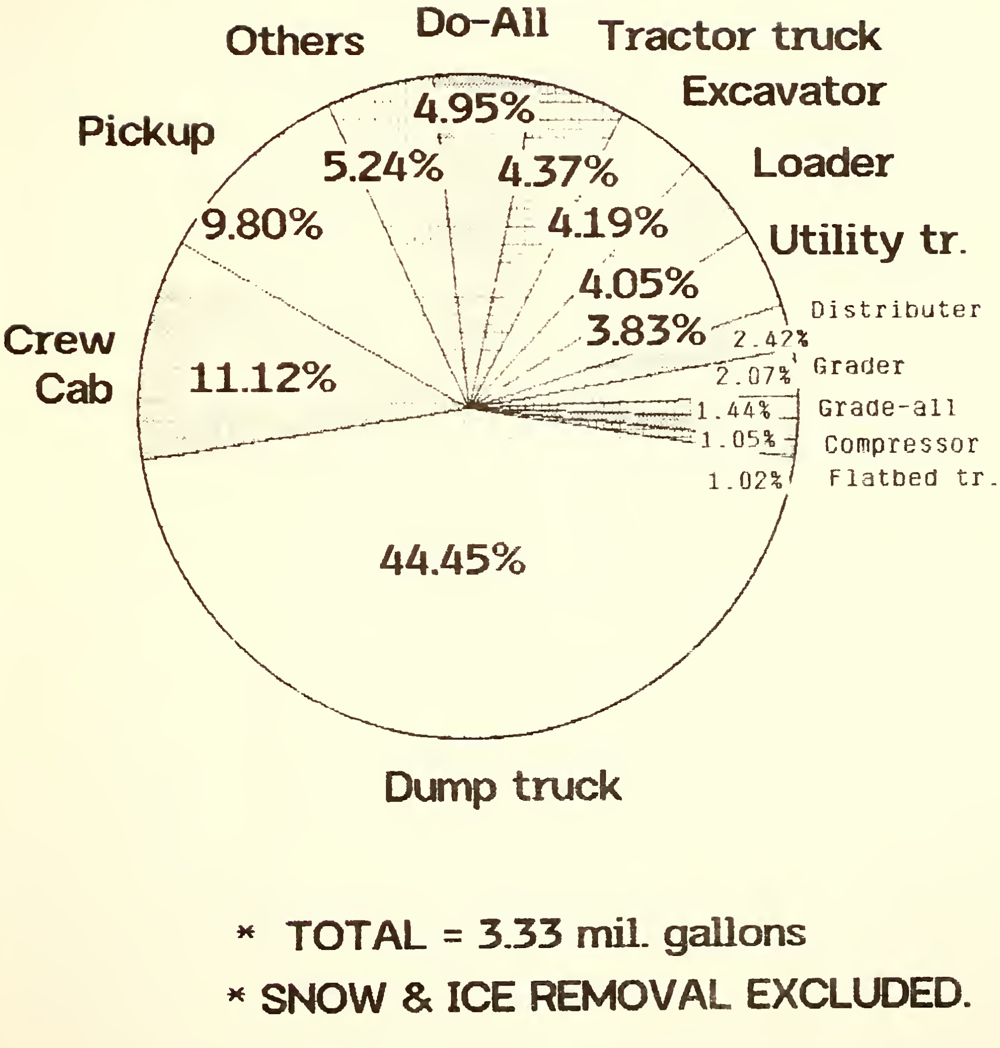

Figure 4. Fuel Consumption by Equipment Type in Percent during Fiscal Year 1984

First, planned accomplishments of all maintenance activities are set and activities which are considered in the model are selected from the activity list. A set of equipment types is then selected. The availability of selected equipment types is expressed in equipment days. Total available equipment days of a particular equipment type are computed by simply multiplying the number of units of the equipment type by the number of working days available during the analysis period. From the total available equipment days, the number of equipment days that are expected to be lost due to mechanical breakdowns and the number of equipment days necessary to perform other activities which are not considered in the model must be subtracted. The remaining equipment days for each selected equipment type, then, form equipment availability constraints.

After the equipment-activity combinations are identified, interchangeable equipment types are grouped within each activity. If a particular equipment must be used to perform a task, then constraints are appropriately formulated to indicate this requirement. Equipment usage factor of each equipment within an interchangeable equipment group is provided as input and the resulting sum of equipment usage rates is considered as a combined equipment usage factor. Equipment usage factor is defined as the average number of equipment units of a particular type used to complete a scheduled amount of an activity in one working day.

The model can be used at any level of management, state, district, subdistrict or even at the unit level for a given period. An example problem applied to the Fowler subdistrict was used. The actual accomplishment records of fiscal year 1984 were used to show the usefulness of the model. The fuel use resulting from the optimal equipment assignment was compared with the actual fuel use estimated for the subdistrict.

The optimization model was run for both constrained and unconstrained cases. The constrained case represented the actual equipment availability constraints, whereas the unconstrained case allowed as many equipment days as required. Table 3 shows a comparison of fuel consumption by activity type between the estimated actual assignment and optimal assignments. Table 4, on the other hand, shows a comparison of equipment days required by the actual assignment and optimal assignments.

The estimated actual fuel consumption by the equipment-activity combinations included in the model was 52,981 gallons, whereas the fuel consumption for the optimal assignment with actual equipment constraints was 46,411 gallons, indicating a 12.4% reduction in fuel use. This reduction is substantial because the fuel consumed by the activities considered in the model accounted for only about 65% of the total fuel consumed in routine maintenance at the state level. A simple multiplication of the number of subdistricts (37 subdistricts in Indiana) by the reduction of fuel use in the Fowler subdistrict could mean a savings of approximately 243,000 gallons of fuel every year. This could amount to about $280,000 of cost savings every year as well as a large savings in fuel consumption. If other activities were included in the model, the estimation of the amount of fuel saved would increase even if the percentage reduction might remain the same.

The information provided by the model can help identify which equipment types need to be added or be eliminated from the current fleet. For example, for the Fowler subdistrict, the pickup crew cab was found to be the most critical equipment type. The remaining equipment types were abundant for the

Table 3. Fuel Consumed by Each Activity Under Three Equipment Assignment Scenarios

Activity Number	Actual Equipment Assignment	Optimal Assignment for Constrained Case		Optimal Assignment for Unconstrained Case	
	gallons	gallons		gallons	
201	6,614	6,686	(+72)	5,738	(-876)
205	7,200	7,078	(-122)	7,078	(-122)
207	3,650	3,568	(-82)	3,564	(-86)
210	1,199	1,062	(-137)	1,063	(-136)
212	3,033	3,043	(+10)	3,020	(-13)
221	1,020	792	(-410)	792	(-410)
231	6,225	5,827	(-398)	5,827	(-398)
235	932	437	(-495)	432	(-500)
251	2,350	2,377	(+27)	1,591	(-759)
271	8,539	3,697	(-4,842)	3,697	(-4,842)
283	2,549	2,715	(+166)	2,376	(-173)
284	4,040	3,981	(-59)	3,981	(-59)
289	5,448	5,148	(-300)	5,073	(-375)
Total	52,981	46,411		44,236	

Table 4. Equipment Days Used by Each Equipment Type Under Three Equipment Assignment Scenarios

Equip. No.	Equipment Type	Available Equipment Days	Equipment Days Used		
			Actual Assignment	Optimal Assignment	
				Constrained	Unconstrained
1	Pickup truck	940	306	841	336
2	Pickup crew cab	1,123	634	1,123	1,767
3	Utility truck	139	121	139	0
9	Dump truck	1,715	1,715	1,050	1,050
10	Do-all truck	1,473	166	267	266

Fowler subdistrict for carrying out regular maintenance activities.

The optimization routine considers the equipment assignment problem on a macroscopic scale. Therefore, the results are not affected by fluctuations in equipment use due to various conditions pertinent to equipment scheduling, such as weather and breakdowns. The technique is capable of dealing with a large number of activities and a variety of equipment types provided that there is an interchangeability of certain equipment types.

Guidelines for Fuel Conservation

A set of guidelines were developed for energy conservation and cost savings in highway routine maintenance. The guidelines are broad and can be applied to any element of the routine maintenance system. However, they should be first applied to the dominant activity and equipment types. Two major approaches can be taken to achieve the goal of fuel savings, as shown in Figure 5. Equipment management is a direct approach where fuel use can be specifically considered, whereas in maintenance management fuel savings can be considered indirectly through other objectives. A summary of possible strategies is given below.

A. Equipment Management

1. Equipment types should be identified in terms of their fuel consumption rates. Equipment types with lesser fuel consumption rate should be assigned first as long as they are available and compatible to do the required task. The optimization model developed in the study should be a useful tool in implementing this guideline.

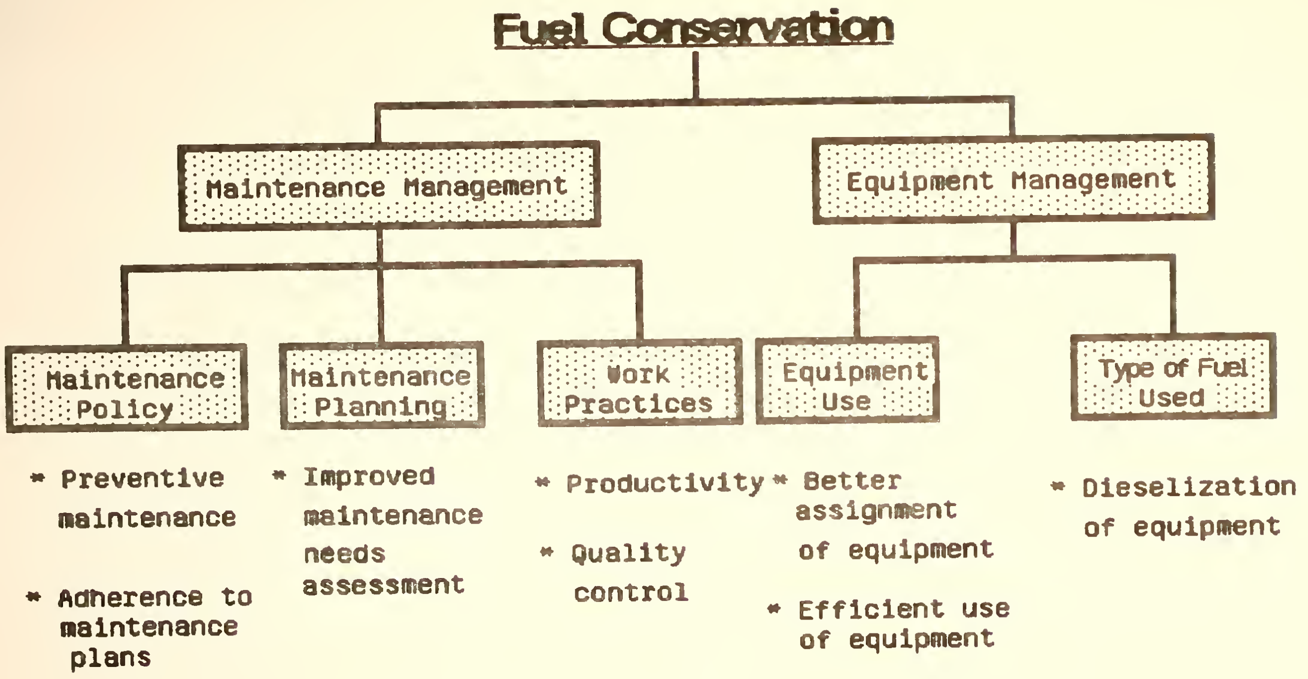

Figure 5. Approaches to Energy Conservation Related to Routine Maintenance

2. Equipment units should be used efficiently by making efforts to reduce hauling distance, loading time and idling time.

3. Majority of the total fuel consumption is due to several dominant equipment types, which are mostly used for hauling purposes. Some of these equipment types have been dieselized. However, dieselization of equipment types has just begun recently in Indiana and diesel fuel consists of less than 10% of total fuel consumption in routine maintenance. When reduction in fuel use is considered to be the prime target, a diesel powered fleet is more energy efficient than a gasoline powered fleet.

B. Maintenance Management

1. An increase in the amount of preventive maintenance activities will result in the reduction of corrective maintenance activities. A pavement maintenance cost analysis conducted in the study showed that highway sections which received more crack sealing in fall required less shallow patching the following spring.

2. In order to implement an effective fuel conservation program, it is essential that planned accomplishments be completed within a reasonable level of variation.

3. The adherence to planned accomplishments becomes meaningful only when the planned accomplishments truly reflect actual needs of maintenance. Where true needs are assessed and deficiencies are corrected in due time, an estimate of fuel use can be accurately made and the implementation of appropriate measures for fuel conser-

vation can be effective. Furthermore, priorities of various maintenance work may be taken into account and the amount of low priority activities can be reduced when an emergency fuel reduction program has to be implemented.

4. Improvements in maintenance productivity and quality control can help reduce cost and fuel consumption in routine maintenance. It was found that a subdistrict with a high production/crewday does not always have a high production/worker/crewday. This implies that there is an optimal number of workers and additional workers would not increase overall productivity. Moreover, repairs of better quality should eventually reduce overall maintenance needs in the future and help contribute to cost reduction and fuel savings.

Suggestions for Implementation

The following suggestions are offered for implementing the findings of the study.

1. Energy conservation efforts should be first directed to major fuel consuming equipment and activity types. Major equipment types include pickup truck, pickup crew cab, dump truck, and do-all truck. Major activities are those included in the road and shoulder, roadside, and drainage maintenance groups.

2. The road and shoulder group incurs the largest amount of material cost. In this group, shallow patching (Activity 201), seal coating (Activity 205), and crack sealing (Activity 207) are the three major material consuming activities. Since these

three activities require a substantial amount of bituminous materials, careful management of these activities would not only reduce direct energy consumption, but would also result in an overall conservation of petroleum products.

3. Adherence to planned accomplishments should be monitored, especially for activities in the limited category, such as preventive maintenance. The completion of such activities would reduce the amount of corrective maintenance, and thus contribute to energy and cost savings.

4. The procedure for assessing maintenance needs should be improved and strengthened to enable more accurate estimates of maintenance work. Without a fairly accurate estimation of annual accomplishments and compliance with the planned accomplishments, it is difficult to prepare plans for energy savings. It should be mentioned here that a study is currently underway at Purdue University to develop improved procedures to assess maintenance needs.

5. Efficient use of equipment units and selection of proper equipment types should be emphasized. Efficient equipment use in routine maintenance may involve the reduction of idling time. In addition, use of equipment units which are commensurable with the task requirement should reduce excess travel distance by reducing unnecessarily repeated runs.

6. Dieselization of major fuel consuming equipment units should be considered, because diesel-powered engines have been found to

be economical in terms of fuel use.

7. Equipment usage guidelines based on the results of the optimization model should be incorporated into the daily scheduling routine. A procedure similar to the current activity scheduling process can be used. Such guidelines would help minimize fuel use, if closely followed. Also, if incorporated, the program would be able to indicate when and what additional units would be necessary at a subdistrict.

Benefits of Implementing Suggested Energy Conservation Measures

The expected benefits of the implementation of the suggested energy conservation measures can be substantial. Cost savings accrued from the suggested conservation efforts would pay back the costs for conducting and implementing the study in a short period. The total study cost was $79,000 for three years and some additional cost can be expected for implementation. However, the implementation does not call for any radical change in the existing maintenance management process. Thus, the additional cost for implementation will not be substantial. Furthermore, the actual additional cost for implementation will depend on the specific measures undertaken. Assuming the implementation would require the equivalent of one half man-year, the range of implementation cost can be expected to be $15-20,000 per year. However, the expected benefits of the proposed measures would far exceed the additional cost.

Fuel savings that can be derived from optimizing the use of five major equipment types (pickup truck, pickup crew cab, utility truck, dump truck and do-all truck) was estimated to be about 6,570 gallons in one year for the example subdistrict used in the study. Although there are variations among subdistricts, a simple multiplication of the number of subdistricts (37 subdistricts in Indiana) would result in a savings of about 243,000 gallons of fuel every year. In addition to this reduction, fuel savings can be achieved by various actions within maintenance management. For example, a 10% increase of sealing activities could save about 11,000 gallons of fuel every year.

Fuel savings from other maintenance management efforts are difficult to estimate at present because of various factors that are involved. However, if it is assumed that a saving of merely 1% of total amount of fuel consumed for routine maintenance can be achieved by maintenance management, approximately 35,000 gallons of fuel can be saved. When these fuel savings are added up, up to approximately 289,000 gallons of fuel can be saved each year. This can amount to $217,000 to $578,000 of cost savings every year if the fuel price ranged from $0.75 to $2.00 per gallon, respectively. At the minimum, if one assumes only 1% of fuel use in specific routine maintenance activities considered in the study can be saved, cost saving would reach $26,250 to $70,000 every year with the fuel price ranging from $0.75 to $2.00 per gallon, respectively. It is obvious, therefore, the cost of the study and possible subsequent implementation would be paid back in a few years once energy conservation programs were put into practice.

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