Optimization of Equipment Use in Routine Highway Maintenance

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An optimization procedure was developed for assigning equipment to routine highway maintenance activities so that total fuel consumption would be minimized. The procedure is based on a linear programming technique and determines the optimal assignment of equipment in terms of the number of equipment days of a particular type of equipment to be assigned to a specific maintenance activity. The program is capable of handling a large number of activity-equipment combinations and performs optimization of fuel use as long as some of the types of equipment considered are interchangeable. An application of the procedure using the actual equipment use data from a typical subdistrict in Indiana is presented to demonstrate an equipment assignment problem. The technique was found to be efficient, and it provided feasible results to use in establishing equipment assignment guidelines for fuel conservation.

Highway maintenance consists of a variety of activities that require many different types of equipment. These activities are both labor and fuel intensive. Fuel consumed by maintenance equipment may account for as much as one-third of the total material cost and about one-tenth of the total actual maintenance cost *(1)*. A previous study of fuel use in routine highway maintenance found that some types of equipment were interchangeably used to do the same task and that fuel consumption rates were substantially different for the different types of equipment *(1)*. Consequently, equipment management tools that make possible better control of fuel consumption are important elements of maintenance management. Optimization techniques can be applied to the problem of assigning different equipment to various maintenance activities so that the total fuel consumption can be minimized.

Mathematical modeling techniques have been successfully applied to the problems related to pavement management *(2–4)*. However, the application of mathematical optimization techniques to routine highway maintenance has long been considered infeasible because of the wide variation in the characteristics of routine maintenance activities, because of the many uncertain elements such as the weather, and because of the difficulty of accurately assessing maintenance needs.

Simulation is another operations research technique that can be applied to routine maintenance activities. A project-level simulation model of roadside mowing was developed in the early 1970s *(5)*. Later, a highway maintenance simulation model was developed for the Louisiana Department of Highways *(6)*. Except for these two simulation models, there have not been serious efforts in this area. One reason for this is that simulation models often require a great many assumptions, such as a probability distribution of activity occurrences, that may inversely affect the validity of the models.

Because the specific objective of the present study was to maximize energy conservation, an approach that was focused on the equipment assignment component of the overall maintenance scheduling process was needed. A linear programming technique was applied to develop a mathematical model for determining optimal equipment assignment to minimize total fuel consumption. A sample application is discussed to demonstrate the feasibility of incorporating this equipment assignment technique into the current activity scheduling process.

OPTIMIZATION METHODOLOGY

The concept of the optimization model developed in this study is based on the interchangeability of types of equipment for performing particular tasks of each activity. Equipment that uses less fuel should be assigned as much as possible to minimize total fuel consumption. The field survey data collected in a previous study *(1)* and field observations conducted in the present study showed that different types of equipment are used to perform the same tasks. For example, pickup crew cabs and dump trucks are interchangeably used in rest area maintenance. Similarly, for hauling purposes, pickup trucks, pickup crew cabs, dump trucks, and do-all trucks have been found to be interchangeably used. However, the fuel usage rates of these types of equipment vary considerably. Furthermore, the same type of equipment, when used in different activities, has different fuel usage rates. It is possible, therefore, to optimize the equipment assignment so that the total fuel consumed in performing various activities is minimized.

A trend analysis of fuel use conducted during the study indicated that pickup trucks, pickup crew cabs, dump trucks, and do-all trucks used about 70 percent of the total fuel consumed for all routine maintenance activities excluding snow and ice removal work. Therefore consideration of only these types of equipment can result in a substantial amount of fuel savings.

The optimization model approaches the problem of fuel savings on an aggregated basis. The decision variable used in the model is the number of equipment days of a particular type to be used for an activity. This optimal value can then be taken as the target value of equipment days to be assigned to the activities. The variable of equipment days was used as an aggregate measure because there are daily fluctuations in equipment scheduling due to such factors as the amount of accomplishment, equipment availability, labor availability, and weather conditions. Specific scheduling can be best dealt with by experienced schedulers. Scheduling equipment units while making efforts to conform to targeted values resembles the activity scheduling procedure currently used by subdistricts of the Indiana Department of Highways for preparing the biweekly activity plan *(7)*.

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Development of the Model

The optimization model developed in the present study has two types of constraints: *(a)* planned accomplishments of activities included in the model and *(b)* equipment availability. Both constraints are expressed in equipment days. A flow chart showing the process of model development is shown in Figure 1. A data base that contains equipment usage, fuel usage, productivity, and equipment breakdown data is frequently used during model development.

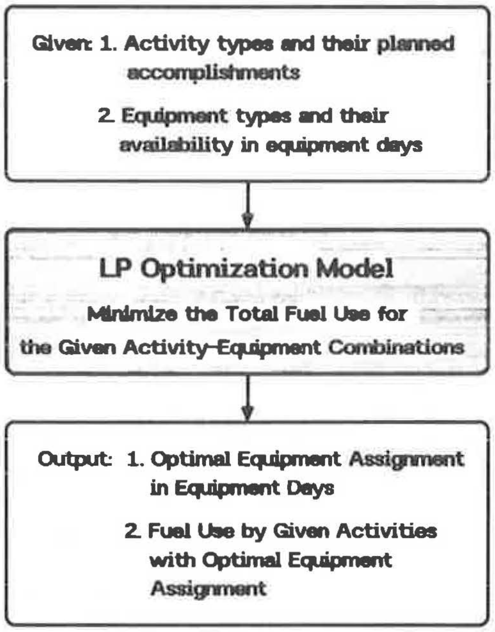

FIGURE 1 Maintenance equipment assignment technique.

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

After the equipment-activity combinations are identified, interchangeable types of equipment are grouped within each activity. Only types of equipment that are interchanageable for a specific task are grouped. If only a particular type of equipment must be used to perform a task, then constraints are appropriately formulated to indicate this requirement. The equipment usage factor of each type of equipment within an interchangeable equipment group is provided as input and the resulting sum of equipment usage rates is considered a combined equipment usage factor. The 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 within 1 working day. The combined equipment usage factor reflects the actual need of equipment for an activity. For example, if a pickup truck and a pickup crew cab are used interchangeably in shallow patching, and if the pickup truck's usage factor is 0.5 and the pickup crew cab's usage factor is 0.7, the combined usage factor of this interchangeable equipment group will be 1.2. This means that for every 100 working days of shallow patching, 120 units of either pickup trucks or pickup crew cabs, or a combination of these two types, will be needed. Combined equipment usage factors are used to compute conversion factors called K-values, which translate the amount of accomplishment for an activity to the number of equipment days necessary to complete the activity using particular equipment within an analysis period. The resulting equipment days form equipment requirement constraints.

After these constraints are determined, the objective function can be formulated. Each coefficient of the decision variable in the model is computed by multiplying a combined usage factor, the fuel usage rate of equipment used for an activity, and a conversion factor (K-value).

Model Formulation

The formulation of the maintenance equipment assignment technique using linear programming is discussed next. The objective function is to minimize the total number of gallons of fuel consumed in performing all scheduled maintenance activities considered.

$$\text{Minimize} \sum_{i} \sum_{j} R_{i,j} \times U_{i,j(l)} \times K_{i,j(l)} \times Y_{i,j}$$

subject to the following constraints:

- Demand constraints—The demand for all scheduled activities must be met:

$$\sum_{j} Y_{i,j} \geq D_{i(l)} \quad \text{for all } i$$

- Capacity constraints—The total number of equipment days assigned to any type of equipment must not exceed the number of equipment days available:

$$\sum_{i} Y_{i,j} \leq C_j \quad \text{for all } j$$

- Nonnegativity constraints—All variables must be greater than or equal to zero:

$$Y_{i,j} \geq 0 \quad \text{for all } i,j$$

where

$Y_{i,j}$ = number of equipment days of equipment j assigned to activity i,

$R_{i,j}$ = fuel consumed by one unit of equipment j in accomplishing one production unit of activity i,

$U_{i,j(l)}$ = combined usage factor of equipment j in interchangeable equipment group l when used in activity i,

N_i = scheduled level of accomplishment of activity i,

$D_{i(l)}$ = number of equipment days required to perform the scheduled accomplishment (N_i) of an activity i by equipment j that belongs to an interchangeable equipment group l,

C_j = number of available equipment days of equipment j,

$K_{i,j(l)}$ = units of accomplishment of activity i by equipment j of equipment group l.

$D_{i(l)}$ is computed as follows:

$$D_{i(l)} = N_i/K_{i,j(l)}$$

It should be noted that the types of equipment that are interchangeable must have the same K-value.

Procedure for Estimating K-Values

The K-value can be interpreted as the capacity of one unit of equipment of a particular type to perform a particular task in 1 workday called a crew day. This value is stated in terms of the production unit of the activity in which the equipment is used. Thus K-value is expressed in units of accomplishment per equipment per crew day.

For example, a K-value of 1.1 for dump trucks used in crack sealing indicates that 1.1 lane miles of sealing can be accomplished on the average by one dump truck per crew day. The use of K-values allows different units of measurement to be converted to a common measure—equipment days—for the decision variables employed. K-values are used for translating the information on scheduled production units of different activities into the equipment days necessary to complete the scheduled levels. The resulting equipment days are then used as work demand constraints in the optimization model. K-values are also used to transform the optimal solutions given in equipment days back into original units of production of each activity so that fuel consumption can be computed by using available fuel usage rates given in gallons per production unit. K-values are computed by the following formula:

$$K_{ij(l)} = P_i \Big/ \sum_{j \varepsilon l} F_{ij}$$

where

$K_{ij(l)}$ = K-value for equipment type j in an interchangeable equipment group l for activity i,

P_i = production per crew day for activity i,

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

$\sum_{j \varepsilon l} F_{ij}$ = combined usage factor for equipment type j in an interchangeable equipment group l when used in activity i.

The combined usage factor indicates how many equipment units would be required to perform a certain amount of accomplishments per crew day if only one type of equipment were used.

Model Output

The unit of decision variables is given in equipment days. For example, $Y_{207,1}$ is the number of equipment days allowed for equipment number 1, a pickup truck, to be used for activity 207, crack sealing. The model tries to minimize the total amount of fuel consumed by the activity-equipment combinations considered. Therefore the optimization model may indicate that some activities would receive more than or less than the amount of equipment days for certain types of equipment than normally are used for those activities. As long as the equipment can be interchanged, such recommendations should be followed because the overall fuel use would eventually be minimized by letting other activities use equipment that is less fuel consuming. If the results appear to be grossly misrepresented or far from reality, equipment grouping needs to be reconsidered and constraints adjusted to reflect any corresponding changes.

In actual scheduling, when an equipment unit has been assigned to an activity, it is not available for other activities for the entire day. The average number of equipment units to be assigned to do one activity during one crew day can be computed by dividing the values for decision variables by proper crew days scheduled. Therefore, if one decision variable has 200 equipment days for a particular type of equipment and 100 crew days are scheduled, the new usage factor will be 2.0.

APPLICATION OF THE MODEL

A sample problem applied to the subdistrict level was used to compare the fuel use expected on the basis of the current equipment assignment practice observed in the field survey with that of the optimal equipment assignment determined by the model. The problem was developed by using routine maintenance accomplishment data *(8)*, equipment use data *(1)*, and equipment availability data compiled during the study. The purpose of the application problem was to demonstrate the possible use of the methodology.

Description of the Sample Subdistrict

The Fowler subdistrict chosen for the analysis is a typical subdistrict in Indiana, where most of the highways are non-Interstate routes. This sample subdistrict was one of the six subdistricts in which a field survey of equipment and fuel use was previously conducted *(1)*.

TABLE 1 ACTUAL ACCOMPLISHMENTS OF 12 MAJOR ACTIVITIES AND ESTIMATED FUEL CONSUMPTION DURING FY 1984 FOR THE FOWLER SUBDISTRICT

				Interstates		OSH		All	
Activity Code	Activity Name	Unit of Measurement	Fuel Use (gal/unit) *(1)*	Actual Accomplishment (units) *(8)*	Estimated Fuel Use (gal)	Actual Accomplishment (units) *(8)*	Estimated Fuel Use (gal)	Actual Accomplishment (units) *(8)*	Estimated Fuel Use (gal)
201	Shallow patching	Tons of mix	8.78	113	990	814	7,150	928	8,150
205	Seal coating	Lane miles	85.14	–	–	95	8,090	95	8,090
207	Sealing cracks	Lane miles	23.27	–	–	186	4,330	186	4,330
210	Spot repair of unpaved shoulders	Tons of aggregate	2.15	36	80	655	1,410	691	1,490
212	Clipping unpaved shoulders	Shoulder miles	52.86	–	–	75	3,960	75	3,960
221	Machine mowing	Swath miles	1.35	–	–	2,177	2,940	2,177	2,940
231	Clean and reshape drainage structures	Linear feet	0.22	140	30	41,426	9,110	41,566	9,140
235	Clean minor drainage structures	No. of structures	3.81	32	120	361	1,380	393	1,500
251	Subdistrict sign maintenance	Man-hours	1.02	638	650	2,306	2,350	2,944	3,000
283	Buildings and grounds maintenance	Man-hours	1.52	–	–	4,170	6,340	4,170	6,340
284	Material handling and storage	Man-hours	3.52	–	–	2,153	7,580	2,153	7,580
289	Other support activities	Man-hours	2.69	–	–	3,742	10,070	3,743	10,070

Note: Dashes = activity not carried out or information unavailable.

Description of Maintenance Demand

Table 1 gives the 1984 maintenance accomplishments of the subdistrict for the 12 major fuel-consuming activities. It provides the overall maintenance need for this subdistrict including the work done both on Interstate and on other state highways (OSH). It can be seen that activity 271 on the Interstate system is a major fuel-consuming activity and that other activities on the Interstate system require much less fuel. On the other hand, most of the activities on the OSH consume a considerable amount of fuel. Therefore the sample problem considered only the 12 activities on the OSH for modeling purposes.

Availability of Equipment

The data in Table 2 indicate how equipment availability constraints were derived. In this sample problem, five types of hauling equipment were considered. First, four major types of equipment were selected: pickup truck, pickup crew cab, dump truck, and do-all truck. Utility trucks were then added because pickup trucks and pickup crew cabs can often be used for the same sign maintenance work as utility trucks. During FY 1984 the sample subdistrict had 11 pickup trucks, 6 pickup crew cabs, 1 utility truck, 20 dump trucks, and 7 do-all trucks. To compute the number of available equipment days of each type of equipment, 250 working days or crew days per year were used. The value for annual available equipment days was adjusted for possible mechanical breakdowns. The statewide average breakdown rates were used here because the existing equipment management system does not provide equipment breakdown rates for each type of equipment by subdistrict.

The equipment days used for activities not included in the optimization model were subtracted from the adjusted equipment days. It was also necessary to subtract equipment days used for supervision of field activities by the superintendent and three unit foremen because this activity (Activity 112) is no recorded on crew-day cards. It was assumed that personnel in supervisory positions use one pickup each working day. The remaining equipment days then become constraints to the optimization model.

Computation of K-Values

The computation of K-values is a key element of the maintenance equipment assignment technique. In a previous report *(1)* equipment usage factors were computed for all equipment and activity combinations. The usage factor indicates how often a particular type of equipment is used for an activity. For example, a usage factor of 1.10 indicates that 110 units of this type of equipment are used in 100 crew days of this activity, or 110 equipment days are assigned for 100 crew days of this activity. This means that more than one unit is used on some of the crew days.

A comparison of computed usage factors, field survey data (crew-day cards), and the field operations handbook *(7)* shows which types of equipment can be interchanged. For example, for Activity 207, crack sealing, the equipment usage factors for dump trucks and do-all trucks are 1.77 and 0.57, respectively, as the data given in Table 3 indicate. Dump trucks are used in

TABLE 2 ESTIMATED AVAILABLE EQUIPMENT DAYS OF FIVE TYPES OF EQUIPMENT FOR THE 12 ACTIVITIES INCLUDED IN THE MODEL: FY 1984, FOWLER SUBDISTRICT DATA

	Pickup Truck	Pickup Crew Cab	Utility Truck	Dump Truck	Do-All Truck
Availability					
No. of pieces of equipment	11	6	1	20	7
Total No. of equipment days available[a]	2,750	1,500	250	5,000	1,750
Breakdown rate[b] (%)	12	4	2	18	12
Remaining equipment days available	2,420	1,440	245	4,100	1,540
Equipment days used for activities other than the 12 included in the model					
Interstate (INT)	76	637	37	1,021	10
Other state highways (OSH)	404	224	69	2,014	57
INT + OSH	480	861	106	3,035	67
Supervision[c]	1,000	–	–	–	–
Total excluded	1,480	861	106	3,035	67
Equipment days available for 12 activities included in the model	940	579	139	1,165	1,473

[a] 250 working days per year.

[b] Statewide average equipment breakdown rates were used.

[c] One superintendent and three unit foremen are assumed to each use one pickup truck each day to supervise field maintenance activities.

crack sealing to spread cover aggregate (usually sand) over the bituminous material applied to cracks. Do-all trucks can be used to do the same work. Because these two types are used for the same purpose, they form an interchangeable group for this particular activity (207), and the usage factor of this group is the summation of the usage factors of dump trucks and do-all trucks. For the sample analysis, the combined usage factor then becomes 2.34. This value is reasonable; the handbook for foremen *(7)* estimates two dump trucks for each crack-sealing activity.

The basic idea of a trade-off between types of equipment was used to estimate other combined usage factors. Table 3 gives the 12 activities and equipment usage factors for the five major types of hauling equipment. Pickup trucks and pickup crew cabs were treated as interchangeable, and dump trucks and do-all trucks were assumed to be interchangeable. When equipment types were not interchangeable, constraints were constructed accordingly. In the case of sign maintenance, pickup trucks, pickup crew cabs, and utility trucks can be interchanged.

After the combined usage factors for the types of equipment needed for different activities were determined, K-values were computed. Table 4 gives the annual average accomplishments per crew day for the 12 activities in the Fowler subdistrict

TABLE 3 INDIVIDUAL EQUIPMENT USAGE FACTORS AND COMBINED USAGE FACTORS

	Usage Factors *(1)* for Equipment Type					Combined Usage Factors for Interchangeable Equipment Types				
Activity Code	1	2	8	9	10	1 + 2	9 + 10	1 + 2 + 9 + 10	1 + 2 + 8	9
201	0.10	1.10	–	0.91	0.12	1.20	1.03	–	–	–
205	1.00	1.00	–	9.00	–	2.00	–	–	–	9.00
207	0.53	1.13	–	1.77	0.57	1.66	2.34	–	–	–
210	0.75	0.36	–	0.50	1.33	1.11	1.83	–	–	–
212	0.85	0.60	–	3.35	–	1.45	–	–	–	3.35
221	0.12	0.81	–	0.07	0.01	–	–	1.01	–	–
231	0.51	0.86	–	2.56	–	1.37	–	–	–	2.56
235	0.74	0.35	–	0.17	0.04	–	–	1.30	–	–
251	0.18	0.03	0.79	–	–	–	–	–	1.00	–
283	0.37	0.37	–	1.05	–	0.74	–	–	–	1.05
284	0.09	0.02	–	1.23	0.14	0.11	1.37	–	–	–
289	0.19	0.14	–	0.70	0.14	0.33	0.84	–	–	–

Note: 1 = pickup truck, 2 = pickup crew cab, 8 = utility truck, 9 = dump truck, and 10 = do-all truck. Dashes = this equipment not used for this activity.

TABLE 4 ESTIMATED CAPACITY OF TYPES OF EQUIPMENT, K-VALUE

			Combined Usage Factors (equipment/crew day)					K-Values (production/equipment/crew day)				
Activity Code	Accomplishment per Day[a]	Unit of Measure	Pickup Truck	Pickup Crew Cab	Utility Truck	Dump Truck	Do-All Truck	Pickup Truck	Pickup Crew Cab	Utility Truck	Dump Truck	Do-All Truck
201	3.79	Tons of aggregate	1.20	1.20	–	1.03	1.03	3.16	3.16	–	3.68	3.68
205	8.64	Lane miles	2.00	2.00	–	9.00	–	4.32	4.32	–	0.96	–
207	2.51	Lane miles	1.66	1.66	–	2.34	2.34	1.51	1.51	–	1.07	1.07
210	26.20	Tons of aggregate	1.11	1.11	–	1.83	1.83	23.60	23.60	–	14.32	14.32
212	3.13	Shoulder miles	1.45	1.45	–	3.35	–	2.16	2.16	–	0.93	–
221	22.21	Swath miles	1.01	1.01	–	1.01	1.01	21.99	21.99	–	21.99	21.99
231	881.40	Linear feet	1.37	1.37	–	2.56	–	643.36	643.36	–	344.3	–
235	20.06	Structures	1.30	1.30	–	1.30	1.30	15.43	15.43	–	15.43	15.43
251	15.07	Man-hours	1.00	1.00	1.00	–	–	15.07	15.07	15.07	–	–
283	32.00	Man-hours	0.74	0.74	–	1.05	–	43.24	43.24	–	30.48	–
284	16.19	Man-hours	–	–	–	1.37	1.37	–	–	–	11.81	11.81
289	12.23	Man-hours	0.33	0.33	–	0.84	0.84	37.06	37.06	–	14.56	14.56

Note: Dashes = this equipment not used for this activity.

[a] Estimated from crew-day cards and IDOH's accomplishment records (MM–113) *(8)*.

during FY 1984. The K-value is obtained by dividing the average accomplishment per day by the combined usage factor as is done in Table 4. The measurement unit of the K-value is therefore the accomplished production units per equipment unit per crew day. Figure 2 shows which types of equipment were considered interchangeable for various activities.

Estimated Fuel Consumption

The objective function of the optimization model is to minimize total fuel consumed by types of equipment in accomplishing needed maintenance work. The model is run for cases of unconstrained and constrained equipment availability. The unconstrained case refers to the situation in which optimal equipment assignment was derived without considering availability of the equipment at the subdistrict level, and the constrained case considers actual availability of equipment. The fuel consumption calculated under both cases was compared with actual fuel consumption, as estimated. Table 5 gives fuel consumption rates of types of equipment for different activities included as input to the optimization model. The values for estimated fuel consumed by various types of equipment under current assignment practices were computed using these rates. Table 6 gives fuel consumption for the activities included in the model for the sample subdistrict in FY 1984.

Summary of Results

The Linear, Interactive and Discrete Optimization (LINDO) computer program developed at the University of Chicago *(9)* was used to solve the problem. Results of the optimization efforts are summarized in tables and are discussed next.

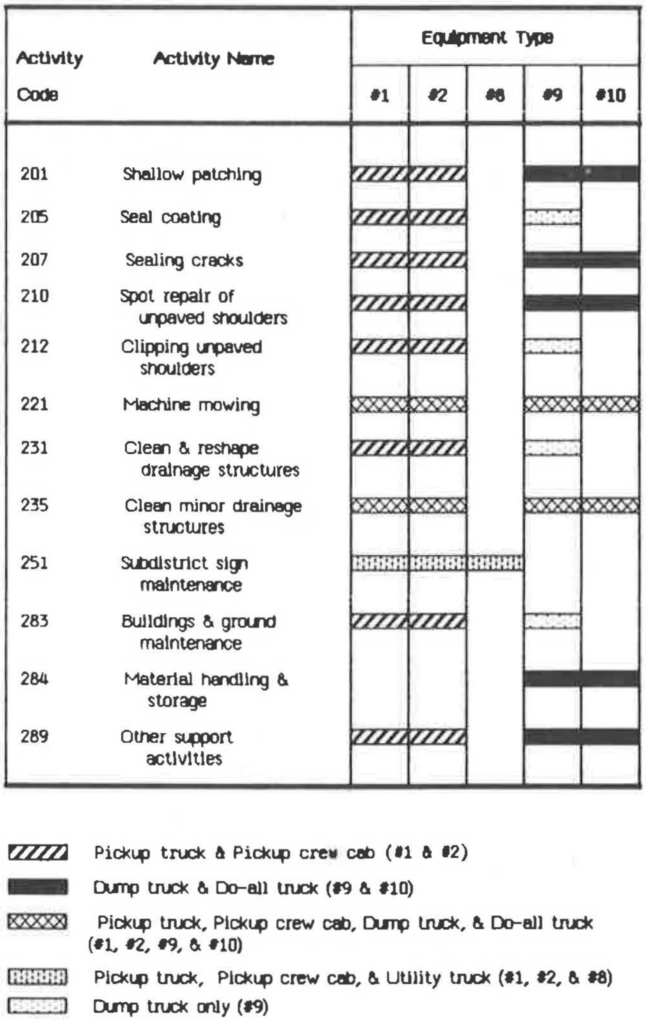

FIGURE 2 Combinations of types of equipment considered interchangeable for the example subdistrict.

TABLE 5 FUEL CONSUMPTION RATES FOR FIVE TYPES OF EQUIPMENT FOR DIFFERENT ACTIVITIES INCLUDED IN THE OPTIMIZATION MODEL (gal per production unit/mpg) *(1)*

Activity Code	Activity Name	Unit of Measurement	Pickup Truck	Pickup Crew Cab	Utility Truck	Dump Truck	Do-All Truck
201	Shallow patching	Tons of mix	3.66/7.35	2.69/6.67	–	4.78/3.17	3.71/3.08
205	Seal coating	Lane miles	1.10/9.00	2.42/4.40	–	8.03/4.14	–
207	Sealing cracks	Lane miles	2.89/4.33	3.07/5.75	–	6.15/2.17	6.55/2.36
210	Spot repair of unpaved shoulders	Tons of aggregate	0.21/8.24	0.54/5.27	–	0.93/2.74	0.76/6.20
212	Clipping unpaved shoulders	Shoulder miles	4.32/7.31	4.11/8.05	–	10.25/2.95	–
221	Machine mowing	Swath miles	0.36/7.10	0.48/7.92	–	1.60/4.30	0.80/2.88
231	Clean and reshape drainage structures	Linear feet	0.01/6.68	0.02/6.82	–	0.05/2.84	–
235	Cleaning minor drainage structures	No. of structures	1.28/7.88	0.92/7.50	–	7.20/3.39	1.92/6.83
251	Subdistrict sign maintenance	Man-hours	1.04/10.69	0.69/9.03	1.03/7.62	–	–
283	Buildings and ground maintenance	Man-hours	0.27/10.45	0.16/7.45	–	0.43/3.35	–
284	Material handling and storage	Man-hours	–	–	–	1.35/3.84	1.54/3.80
289	Other support activities	Man-hours	0.68/11.53	0.62/8.69	–	1.37/4.68	2.00/3.52

Note: Dashes = this equipment not used for this activity.

Constrained Problem

Table 7 gives a comparison of optimal equipment assignment resulting from the model and the actual equipment use derived from the field survey data *(1)*. For the constrained case the disposable equipment days given in Table 2 formed the equipment availability constraints. It can be seen that there is a difference between estimated field equipment use and optimal equipment use. For example, in the case of crack-sealing activity, the optimal assignment was to use only pickup trucks and dump trucks instead of pickup trucks, pickup crew cabs, dump trucks, and do-all trucks as was done in the estimated field assignment.

Estimated fuel consumption by the equipment-activity combinations included in the model under the field assignment practice was 44,442 gal (Table 6), whereas fuel consumption for the optimal equipment assignment was 40,612 gal (Table 8), an 8.6 percent reduction from estimated equipment use. This

TABLE 6 FUEL CONSUMED BY FIVE MAJOR TYPES OF HAULING EQUIPMENT FOR THE 12 MAJOR ACTIVITIES IN THE FOWLER SUBDISTRICT

Activity Code	Fuel Use by Type of Equipment per Activity[a] (%)						Total Fuel Used by All Types of Equipment[b] (gal) on OSH	Fuel Used by the Five Types of Equipment (gal) on OSH
	1	2	8	9	10	Total		
201	4.17	33.70	–	49.54	5.07	92.5	7,150	6,614
205	1.29	2.84	–	84.88	–	89.0	8,090	7,200
207	6.58	14.91	–	46.78	16.04	84.3	4,330	3,650
210	7.33	9.04	–	21.63	47.01	85.0	1,410	1,199
212	6.95	4.67	–	64.96	–	76.6	3,960	3,033
221	3.20	28.80	–	8.30	0.59	40.9	2,940	1,202
231	2.32	7.82	–	58.18	–	68.3	9,110	6,225
235	24.86	8.45	–	32.13	2.02	67.5	1,380	932
251	18.35	2.03	79.77	–	–	100.0	2,350	2,350
283	6.57	3.89	–	29.70	–	40.2	6,340	2,549
284	–	–	–	47.17	6.13	53.3	7,580	4,040
289	4.80	3.23	–	35.65	10.41	54.1	10,070	5,448
Total								44,442

Note: 1 = pickup truck, 2 = pickup crew cab, 8 = utility truck, 9 = dump truck, and 10 = do-all truck. Dashes = this equipment not used for this activity.

[a] Computed using data found in Sharaf et al. *(1)*.

[b] From Table 1.

TABLE 7 ESTIMATED FIELD EQUIPMENT ASSIGNMENT VERSUS OPTIMAL EQUIPMENT ASSIGNMENT (in equipment days)

	Estimated Field Assignment[a] for Equipment Type					Optimal—Constrained—for Equipment Types					Optimal—Unconstrained—for Equipment Types				
Activity	1	2	8	9	10	1	2	8	9	10	1	2	8	9	10
201	22	237	–	196	26	0	258	–	0	221	0	258	–	0	221
205	11	11	–	99	–	22	0	–	99	–	22	0	–	99	–
207	39	84	–	131	42	123	0	–	174	0	123	0	–	174	0
210	19	9	–	13	33	28	0	–	0	46	28	0	–	0	46
212	20	14	–	80	–	35	0	–	81	–	0	35	–	81	–
221	12	79	–	7	1	99	0	–	0	0	99	0	–	0	0
231	24	40	–	120	–	64	0	–	120	–	64	0	–	120	–
235	13	6	–	3	1	0	23	–	0	0	0	23	–	0	0
251	28	5	121	–	–	0	154	0	–	–	0	154	0	–	–
283	48	48	–	137	–	0	96	–	137	–	0	96	–	137	–
284	12	3	–	164	19	–	–	–	182	0	–	–	–	182	0
289	58	43	–	214	43	53	48	–	257	0	0	101	–	257	0
Total	306	579	121	1,165	165	424	579	0	1,050	267	336	667	0	1,050	266

Note: 1 = pickup truck, 2 = pickup crew cab, 8 = utility truck, 9 = dump truck, and 10 = do-all truck. Dashes = this equipment not used for this activity.
[a]Estimated using data found in Sharaf et al. *(1)* and Report MM–113 *(8)*.

reduction is substantial because the fuel consumed by the activities considered in the model accounts for only about 60 percent of the total fuel consumed in routine maintenance at the state level. Therefore, if other activities were included in the model, the estimation of the amount of fuel saved would increase even if the percentage reduction remained the same. A simple multiplication of the number of subdistricts (37 subdistricts in Indiana) by the reduction of this example can mean a savings of approximately 141,710 gal of fuel every year. This could amount to about $106,283 in cost savings every year if fuel cost is assumed to be $0.75/gal. Table 8 also gives the activities that would use less or more fuel in the optimal case than in field assignment.

Table 9 gives the available equipment days and the consumed equipment days for each type of equipment for both the estimated field equipment assignment and the optimal equipment assignment. It is evident that the model can determine critical types of equipment as well as redundant types of equipment. This information can help determine which types of equipment need to be added to or removed from the current fleet. For example, the most critical type of equipment for this subdistrict is pickup crew cab. The other four types considered in the model are sufficient to meet the needs of this subdistrict for carrying out regular maintenance activities. Equipment days available for do-all trucks greatly exceed actual demand. The reason for this is that most do-all trucks are kept for snow and ice removal work in winter, and the model did not include this emergency activity.

Unconstrained Problem

To check how much fuel could be saved if all needed equipment were available, an unconstrained case was analyzed.

TABLE 8 FUEL CONSUMED BY EACH ACTIVITY UNDER THREE EQUIPMENT ASSIGNMENT SCENARIOS

Activity Code	Estimated Field Assignment (gal)	Optimal Assignment for Constrained Case (gal)	Optimal Assignment for Unconstrained Case (gal)
201	6,614	5,738 (–876)	5,738 (–876)
205	7,200	7,078 (–122)	7,078 (–122)
207	3,650	3,568 (–82)	3,568 (–82)
210	1,199	1,063 (–136)	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	432 (–500)	432 (–500)
251	2,350	1,602 (–748)	1,602 (–748)
283	2,549	2,376 (–173)	2,376 (–173)
284	4,040	3,981 (–59)	3,981 (–59)
289	5,448	5,112 (–336)	5,073 (–375)
Total	44,442	40,612 (–3,830)	40,550 (–3,892)

Note: Values in parentheses are the difference between estimated fuel consumption and fuel consumption under optimal equipment assignment.

TABLE 9 EQUIPMENT DAYS USED BY EACH TYPE OF EQUIPMENT UNDER THREE EQUIPMENT ASSIGNMENT SCENARIOS

Equipment No.	Type of Equipment	Available Equipment Days	Equipment Days Used: Estimated Field Assignment	Optimal Assignment: Constrained	Optimal Assignment: Unconstrained
1	Pickup truck	940	306	424	336
2	Pickup crew cab	579	579	579	667
3	Utility truck	139	121	0	0
9	Dump truck	1,165	1,165	1,050	1,050
10	Do-all truck	1,473	165	267	267

Table 7 gives the equipment assignment obtained by the unconstrained version of the optimization model. The unconstrained equipment assignment is somewhat different from both the field assignment and the constrained assignment. Fuel consumption for the unconstrained optimal assignment resulted in 40,550 gal, as given in Table 8. There could be as much as an 8.8 percent reduction from estimated current fuel consumption. However, because there was only one critical type of equipment, pickup crew cab, the difference in total fuel consumption between the constrained and the unconstrained assignments was only about 0.2 percent for this subdistrict.

Sensitivity Analysis

A sensitivity analysis is recommended when any type of equipment is found to be critical for equipment assignment. Critical types of equipment can be identified by examining the results of the constrained and unconstrained versions of the optimization program. The objective of the sensitivity analysis is to determine explicitly the impact of each type of equipment on overall fuel consumption. In the sample problem, only the pickup crew cab was found to be critical. Adding an extra pickup crew cab to the current fleet of the subdistrict would help conserve fuel; however, the marginal fuel savings is only 0.2 percent. In other subdistricts, the marginal fuel savings might be substantial if one or two types of equipment were available. In such situations, it may be beneficial to borrow the necessary units from other subdistricts as needed.

Importance of Input Data

The validity of the results of the optimization technique developed in this study is largely dependent on the accuracy of the input data. Three types of information are critical: *(a)* equipment usage factors, *(b)* fuel consumption rates, and *(c)* interchangeability of types of equipment.

Currently, usage factors obtained from the field survey *(1)* are average usage factors of six subdistricts selected for the survey. Therefore they may not necessarily reflect exactly the equipment usage pattern of a particular subdistrict. There is also a problem of time lapse between the period (FY 1982) when the field data were taken for computing equipment usage factors and the study period (FY 1984).

Fuel consumption rates are probably the input that most affect the accuracy of the results. Fuel consumption rates for all equipment types are given in gallons per production unit. These rates are greatly affected by the condition of job sites, even within each activity. Hauling distance and the manner in which equipment units are used can also substantially affect the fuel requirement for one unit of production. Fuel consumption rates now available are average values for the six subdistricts used for the field survey *(1)*. To increase the accuracy of the results for a particular subdistrict, it is recommended that each subdistrict monitor fuel consumption rates for its own fleet.

Interchangeability of equipment can be found by observing crew-day cards and by field observation. In the example, it was assumed that the interchangeability observed in the period when the field survey was done had remained the same for the study period. However, equipment interchangeability may alter over the years. Such alterations need to be taken into account before the optimization program is run.

The problems of usage factors, fuel consumption rates, and interchangeability of equipment types can be resolved by regularly updating the equipment use and fuel consumption data. Any changes in equipment interchangeability can be evaluated by examining updated equipment usage factors. The only data that are not currently recorded on crew-day cards are fuel consumption data. If the fuel consumption data were kept current, IDOH would be in a better position to maintain close control of its fuel conservation programs.

CONCLUSIONS

The example discussed in this paper demonstrated the usefulness and efficiency of the maintenance equipment assignment technique developed in the study. The technique allocates equipment to various maintenance activities within given constraints on resources and maintenance requirements.

Because this technique treats the equipment assignment problem from a macroscopic view, it will not be affected by fluctuations in equipment use due to various conditions pertinent to equipment scheduling, such as weather and equipment breakdowns. The technique is capable of dealing with a large number of activities and a variety of types of equipment. Fuel reduction will not, of course, be attained unless interchangeable equipment types or units exist, because minimized fuel consumption is basically the result of substituting one type of equipment for another. Use of such an optimization technique in highway maintenance equipment management is considered potentially feasible.

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