Models for Predicting Snow-Removal Costs and Chemical Usage

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One of the objectives of a maintenance cost study by the Ohio Department of Highways is the determination of the major factors that influence maintenance costs. This paper describes several models developed by multiple-regression analysis to predict cost per lane-mile for snow and ice removal on Ohio highways. The models indicate that the 2 most significant independent variables affecting cost per lane-mile for snow and ice removal are inches of snowfall and average daily traffic. The models have been used to budget snow- and ice-removal funds by applying 30-year weather data and current ADT to compute anticipated costs.

This paper explains a method for distributing snow- and ice-control funds to the Ohio state highway system in 88 counties so that differences in route type, road mileage, traffic, and weather are taken into account. Multiple linear regression has been used to obtain mathematical models that give the relationship between cost per lane-mile, ADT, and snowfall for each of 5 route types. The method is the outgrowth of the application of multiple-regression analysis to various maintenance costs in the Ohio Maintenance Cost Study, a federal-aid highway research project now in its ninth year, undertaken in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

The Ohio Department of Highways carries the responsibility for maintaining rural highways on the state highway system and for Interstate highways in both urban and rural areas. Seven of the 8 largest Ohio cities maintain the Interstate highways within their corporate limits and are reimbursed by the state for such maintenance work. The state highway system comprises 18,766 centerline-miles or 38,793 lane-miles. County and township roads and highway and streets within cities are not the responsibility of the Ohio Department of Highways, nor is the Ohio Turnpike.

The state highway system is divided into 5 types of routes: Interstate, divided major highways, 2-lane major highways, auxiliary highways, and local highways. Table 1 gives the lane mileage for these 5 types by county, division, and state.

Today in the various highway departments throughout the United States 2 different approaches seems to be developing for answering the question, How much money is needed for highway maintenance? This question includes, of course, the question, How much money is needed for snow and ice control in the safe operation of highways? One approach is to inventory not only the miles of pavement but also all other elements of the highway, such as guardrail, acres of right-of-way, miles of ditch, miles of fence, and number of signs. With such an inventory, someone at the field level determines what part of the inventory needs maintenance and repair work. Optimum work methods for doing each item of work are established as are standards for the labor, equipment, and material related to each work item. From these elements a division total is generated and the various division totals are combined to reach a total for the state. In our view, the resulting planning and scheduling requirements are difficult to handle. We are using a different approach to the problem in Ohio.

The Ohio Department of Highways is composed of a central office staff and 12 field divisions. The field divisions are responsible for the construction, maintenance, and operation of state highways. In most cases, divisions consist of 6 to 8 counties (Fig. 1). Funds for maintenance are allocated by the central office to the divisions, and a uniform cost reporting system is used by all divisions. The central office processes the cost data on an IBM 360/50 computer system. By means of this system reports are produced

Figure 1. Field divisions of the Ohio Department of Highways.

that permit comparison of labor, equipment, and material costs among counties within the division and among divisions. By such comparisons, inefficient operation is made evident and is then investigated and corrected by the division management.

Table 2 gives the direct costs for the 15 highest individual work activities, listed in decreasing order of magnitude. The application of chemicals for snow and ice control is the single most costly work item in the entire list of maintenance activities. The amount will vary from year to year depending on the weather, but the item heads the list every year. For this reason there is a continuing surveillance of this activity by both central office and division management. Regression models were developed because of the magnitude of the expenditure for snow and ice control and the related effort by management to evaluate the need for such funds.

Table 3 gives by route type the average snow- and ice-control cost per lane-mile in fiscal year 1969 for the state. Figure 2 shows the large variation in mean annual

TABLE 1

HIGHWAY LANE-MILES BY DIVISION AND TYPES OF ROUTES

Division	Type 10	Type 20	Type 30	Type 40	Type 50	Total
1	193.64	224.30	660.70	1,532.14	549.06	3,159.84
2	256.16	345.60	793.66	1,383.50	363.02	3,141.94
3	292.76	600.80	887.88	1,273.14	768.92	3,823.50
4	454.06	428.96	1,028.40	1,150.12	424.58	3,486.12
5	455.36	279.04	649.50	1,295.32	768.04	3,447.26
6	369.48	382.92	882.42	1,026.22	613.10	3,274.14
7	299.60	258.68	533.30	1,720.60	746.64	3,558.82
8	770.24	395.18	975.98	1,009.64	578.54	3,729.58
9	0	466.60	646.62	1,566.90	638.36	3,318.48
10	145.76	205.88	833.74	1,671.80	890.32	3,747.50
11	192.08	132.36	714.08	1,388.46	510.50	2,937.48
12	360.30	112.22	173.42	393.14	130.18	1,169.26
Total	3,789.44	3,832.54	8,779.70	15,410.98	6,981.26	38,793.92

TABLE 2

DIRECT MAINTENANCE COSTS IN FISCAL YEAR 1969

Activity	Cost ($)
Applying chemicals for snow and ice control	5,830,440
Patching surfaces	3,264,767
Controlling vegetation, mowing	2,483,113
Maintaining aggregate shoulders	1,647,951
Maintaining ditches and paved gutters	1,242,480
Sealing and surface-treating pavement	1,063,612
Maintaining rest areas	1,035,541
Maintaining signs	836,190
Marking centerlines	740,919
Sealing cracks and joints	700,312
Picking up litter	665,580
Removing brush, trees, and stumps	643,123
Cleaning and painting bridges	620,777
Repairing bridges	542,190
Marking edge-lines	508,189

TABLE 3

DIRECT COST FOR SNOW AND ICE CONTROL IN FISCAL YEAR 1969

Type of Highway	Cost per Lane-Mile ($)	Cost per Centerline-Mile ($)
Interstate	301	1,205
Divided major	183	734
2-Lane major	128	257
Auxiliary	138	277
Local	118	236

Note: Costs are statewide mean values.

snowfall over the state. In the northeastern part of the state the annual snowfall is 100 in., whereas for most of the other areas it is only 20 or 30 in. The contours are based on U. S. Weather Bureau data for approximately 30 years. Figure 2 also shows the Interstate highways in relation to the annual showfall; the location of the Interstate highways within the counties is shown in Figure 3. The direct cost for snow and ice control on Interstate highways is $1,205 per centerline-mile, a figure much higher than that for other route types (Table 3). Most of the Interstate route mileage is located in areas of moderate snowfall. Only I-90 from Cleveland east and portions of I-71, I-77, and I-80 south of Cleveland are in the high snowfall area.

Because of the large differences in route types, mileage, mean annual snowfall, and average daily traffic, a method for distributing funds for snow and ice control was needed that would account for such differences. Multiple linear regression was used to develop mathematical models to distribute funds for snow and ice control.

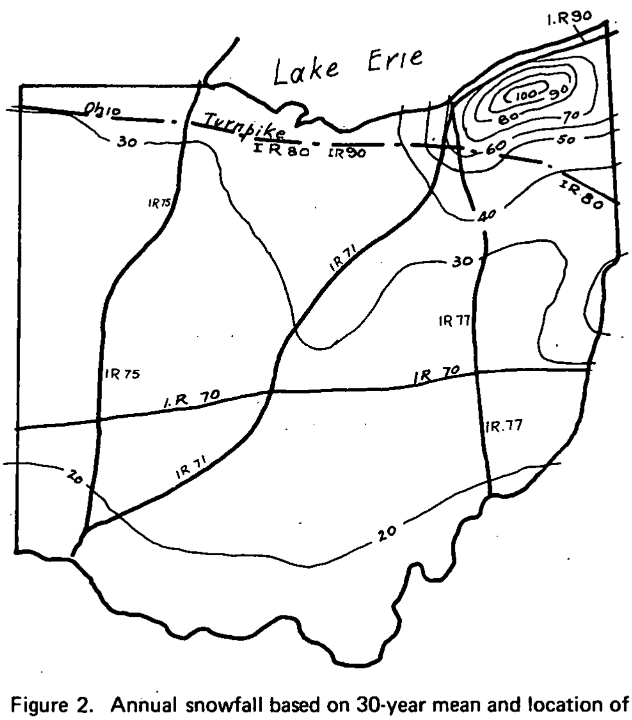

Figure 2. Annual snowfall based on 30-year mean and location of Interstate highways.

Figure 3. Location of Interstate highways within counties.

MULTIPLE REGRESSION

A computer program for multiple linear regression, available from IBM and described in its publication H20-0205-2, has been used. A few changes in input and output were made. The program is written in FORTRAIN IV and permits 99,200 observations with 15 variables and 51,200 observations with 40 variables. It computes mean values, standard deviations, correlation criteria, regression coefficients, and various confidence measures.

The t-test was used to determine whether the regression coefficient obtained for each variable was significantly different from zero. In the present case, the null hypothesis was based on the assumption that the coefficient might be zero.

The computed t-value, which is the ratio of the calculated regression coefficient to the standard error of that coefficient, was compared to a table of t-values having a 0.05 significance level for the appropriate degrees of freedom. If the computed value was larger than the table value, the hypothesis was rejected and the regression coefficient accepted as being significantly different from zero.

Like the t-test, the F-test also includes setting up a hypothesis and then calculating F on the basis that the hypothesis is true. However, where the t-test is a measure of the probability that the regression coefficient is significantly different from zero, the F-test provides a method for determining whether the ratio of the variance is larger than might be expected by chance if it had been drawn from the same population.

The University of California, Los Angeles, has developed a comprehensive battery of statistical programs for biomedical research. In order to make the major programs more readily available to the users of the IBM 360 urban transportation planning battery, the Bureau of Public Roads has included in the battery executable load modules for the 5 most frequently used BIMED programs. One of the programs, Stepwise Multiple Regression, is now on hand in the computer section of the Ohio Department of Highways, and it will be used in our future regression work.

MODELS

The models produced by multiple linear regression give the relation of direct cost (i.e., labor, equipment, and materials) to snowfall and traffic, the independent variables in the models. If

Y = cost per lane-mile (labor, equipment, and materials) for plowing snow, applying chemicals, and cleaning bridges,
X_1 = inches of snowfall, and
X_2 = average daily traffic,

then

$$Y = 7.40\ X_1 + 159.27 \qquad (1)$$

for Interstate highways (route type 10);

$$Y = 4.20\ X_1 + 0.04\ X_2 - 36.75 \qquad (2)$$

for major highways (route types 20 and 30); and

$$Y = 3.54 X_1 + 0.05 X_2 + 9.92 \qquad (3)$$

for auxiliary and local highways (route types 40 and 50).

The model (Eq. 1) indicates that the cost per lane-mile for Interstate highways is independent of traffic. It is believed that this is because there is not a sufficiently large variation in traffic volume on Interstate highways to make it a significant factor in varying the cost of snow and ice control. ADT was used as an independent variable in the regression for Interstate highways, and the resulting regression coefficient was not significantly different from zero.

These models were computed by using input data from the fiscal years 1967 and 1968.

Other independent variables were tried in the regression analysis and the resulting coefficients were found to be not significantly different from zero. The variables tried were as follows:

No.	Variable
1	Average temperature for the winter season
2	Number of days when temperature was 32 F or below
3	Number of days when snow fell
4	Average maximum temperature
5	Average minimum temperature
6	Number of degree days
7	Terrain (Fig. 4)

The input and output data for the 3 equations are given in Tables 4, 5, 6, 7, and 8.

INPUT DATA

The input data used to produce the models were as follows:

1. The cost per lane-mile for each route type for each county was used. Interstate highways are located within 33 counties, so the input consisted of 33 observations or sets of data. The cost used was the 2-year mean value for each county for the fiscal years 1967 and 1968.
2. Data from the U.S. Weather Bureau for 1967 and 1968 were averaged for each county.
3. Average daily traffic values for each county by route type was available from the Bureau of Planning Survey, Ohio Department of Highways.

Figure 4. Terrain of counties.

TABLE 4

REGRESSION ANALYSIS

Item	Interstate Highways (Eq. 1) Variable 2	Interstate Highways (Eq. 1) Variable 4	Major Highways (Eq. 2) Variable 2	Major Highways (Eq. 2) Variable 4	Auxiliary and Local Highways (Eq. 3) Variable 2	Auxiliary and Local Highways (Eq. 3) Variable 3	Auxiliary and Local Highways (Eq. 3) Variable 4
Mean	34.042	411.181	33.054	244.203	33.045	1,444.657	199.641
Standard deviation	11.920	200.155	14.149	125.112	14.050	1,148.510	107.473
Correlation X versus Y	0.441		0.477		0.493	0.564	
Regression coefficient	7.400		4.196		3.541	0.050	
Standard error of regression coefficient	2.707		0.691		0.627	0.008	
Computed t-value	2.733		0.074		5.650	0.565	
Intercept	159.272		-36.748			9.915	
Multiple correlation	0.441		0.761			0.729	
Standard error of estimate	182.547		82.355			74.596	

TABLE 5

ANALYSIS OF VARIANCE FOR THE REGRESSION

Highway	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value
Interstate (Eq. 1)	Attributable to regression	1	248,962.5	248,962.5	7.471
	Deviation from regression	31	1,033,027.4	33,323.5	
	Total	32	1,281,990.0		
Major (Eq. 2)	Attributable to regression	2	643,381.6	321,690.8	47.430
	Deviation from regression	69	467,983.4	6,782.4	
	Total	71	1,111,365.0		
Auxiliary and local (Eq. 3)	Attributable to regression	2	442,123.6	221,061.8	39.727
	Deviation from regression	70	389,515.1	5,564.5	
	Total	72	831,638.8		

TABLE 6

INPUT-OUTPUT DATA FOR INTERSTATE HIGHWAYS

County	Cost per Lane-Mile for Labor, Equipment, and Materials			Snow-fall (in.)	County	Cost per Lane-Mile for Labor, Equipment, and Materials			Snow-fall (in.)
	Value	Estimate	Residual			Value	Estimate	Residual	
1	320.920	444.167	-123.247	38.5	18	610.580	431.587	178.992	36.8
2	307.810	377.568	-69.759	29.5	19	428.330	457.487	-29.157	40.3
3	523.320	479.687	43.633	43.3	20	352.180	373.128	-20.948	28.9
4	395.610	365.729	29.881	27.9	21	389.830	311.709	78.121	20.6
5	430.370	443.427	-13.057	38.4	22	240.190	495.226	-255.036	45.4
6	774.760	487.086	287.673	44.3	23	408.460	399.028	9.432	32.4
7	791.570	491.526	300.043	44.9	24	253.570	320.589	-67.019	21.8
8	829.610	444.167	385.443	38.5	25	442.490	487.826	-45.237	44.4
9	860.550	627.684	232.865	63.3	26	168.760	374.608	-205.848	29.1
10	239.380	295.429	-56.049	18.4	27	383.630	314.669	68.961	21.0
11	600.490	280.630	319.860	16.4	28	338.520	376.088	-37.569	29.3
12	101.950	327.249	-225.299	22.7	29	315.020	331.689	-16.669	23.3
13	363.410	512.246	-148.836	47.7	30	261.060	178.512	82.548	2.6
14	186.710	525.566	-338.856	49.5	31	537.060	406.428	130.632	33.4
15	342.800	441.207	-98.407	38.1	32	169.740	451.567	-281.827	39.5
16	184.560	388.668	-204.108	31.0	33	645.540	494.486	151.053	45.3
17	370.150	432.327	-62.177	36.9					

TABLE 7

INPUT-OUTPUT DATA FOR MAJOR HIGHWAYS

County	Cost per Lane-Mile for Labor, Equipment, and Materials			Snow-fall (in.)	Average Daily Traffic	County	Cost per Lane-Mile for Labor, Equipment, and Materials			Snow-fall (in.)	Average Daily Traffic
	Value	Estimate	Residual				Value	Estimate	Residual		
1	203.750	257.220	-53.470	38.5	3,732.0	37	240.890	253.173	-12.283	36.9	3,819.0
2	171.880	160.161	11.719	29.0	2,120.0	38	186.900	223.723	-36.823	40.3	2,575.0
3	198.860	182.767	16.093	29.5	2,698.0	39	300.730	369.642	-68.912	28.9	8,036.0
4	225.050	103.468	121.581	11.0	2,651.0	40	232.470	202.280	30.190	27.2	3,520.0
5	173.820	212.478	-38.658	31.0	3,358.0	41	191.660	243.168	-51.508	20.6	5,453.0
6	115.170	201.010	-85.840	42.7	1,651.0	42	235.410	184.667	50.743	28.6	2,858.0
7	289.990	268.876	21.114	48.6	2,866.0	43	212.150	284.258	-72.108	45.4	3,678.0
8	260.500	238.540	21.960	35.9	3,513.0	44	150.710	117.140	33.570	16.6	2,374.0
9	195.420	234.933	-39.513	40.9	2,820.0	45	331.080	172.762	158.317	31.8	2,144.0
10	320.060	340.268	-20.209	43.3	5,505.0	46	217.830	276.277	-58.447	50.0	2,909.0
11	399.960	199.931	200.029	22.7	3,986.0	47	141.670	208.217	-66.547	21.8	4,326.0
12	197.610	210.582	-12.972	16.8	4,984.0	48	170.150	177.497	-7.347	11.3	4,702.0
13	177.050	202.321	-25.271	32.9	2,847.0	49	283.860	234.754	49.106	44.4	2,401.0
14	277.020	186.519	90.501	33.7	2,307.0	50	182.920	267.766	-84.846	29.1	5,141.0
15	231.960	249.320	-17.360	27.9	4,763.0	51	176.590	368.637	-192.047	21.0	8,942.0
16	245.910	225.507	-20.403	38.4	2,850.0	52	292.960	367.595	-74.635	29.3	7,931.0
17	248.790	281.357	-32.567	49.9	3,064.0	53	129.340	155.934	-26.594	23.3	2,675.0
18	346.610	234.330	112.280	22.4	4,991.0	54	164.400	156.404	7.995	22.0	2,842.0
19	150.100	233.991	-83.891	33.7	3,645.0	55	137.110	121.709	15.401	22.5	1,805.0
20	271.070	333.438	-62.368	43.6	5,277.0	56	249.930	176.323	73.607	23.5	3,226.0
21	262.930	299.085	-36.156	44.3	4,226.0	57	245.660	271.433	-25.773	20.8	6,226.0
22	249.640	330.023	-80.383	44.9	5,027.0	58	275.160	282.856	-7.696	27.2	3,665.0
23	196.290	249.947	-53.657	38.5	3,527.0	60	158.040	205.076	-47.036	36.0	2,558.0
24	455.500	347.024	108.476	63.3	3,330.0	61	140.050	145.196	-5.146	15.0	3,354.0
25	221.330	220.347	0.983	18.4	5,070.0	62	206.210	169.995	36.215	26.6	2,681.0
26	363.300	220.009	143.291	16.4	5,297.0	63	174.740	156.130	18.610	36.3	1,143.0
27	324.520	262.376	62.144	22.7	5,746.0	64	160.140	119.246	40.894	32.0	612.0
28	393.510	532.478	-138.968	47.7	10,402.0	65	118.880	95.327	23.553	2.6	3,415.0
29	281.640	337.724	-56.084	49.5	4,700.0	66	346.370	249.160	97.210	33.4	4,108.0
30	162.680	223.819	-61.139	37.0	2,968.0	67	230.370	256.778	-26.408	35.3	4,098.0
31	204.730	235.847	-31.117	20.8	5,223.0	68	226.880	189.858	37.022	37.1	1,999.0
32	147.390	229.357	-81.967	38.1	2,994.0	69	379.530	382.289	-2.760	56.4	5,140.0
33	230.580	215.024	15.556	37.5	2,661.0	70	254.020	275.005	-20.985	39.5	4,115.0
34	163.070	258.106	-95.036	31.0	4,644.0	71	993.790	652.513	341.277	45.3	14,069.0
35	164.520	247.597	-83.077	36.9	3,650.0	72	629.640	510.691	118.949	102.1	3,354.0
36	165.520	105.280	60.240	17.9	1,886.0						

TABLE 8

INPUT-OUTPUT DATA FOR AUXILIARY AND LOCAL HIGHWAYS

County	Cost per Lane-Mile for Labor, Equipment, and Materials			Snow-fall (in.)	Average Daily Traffic
	Value	Estimate	Residual		
1	198.950	250.834	-51.884	38.5	2,078.0
2	101.760	183.522	-81.762	29.0	1,409.0
3	104.820	167.022	-62.202	29.5	1,046.0
4	155.090	90.038	65.052	11.0	818.0
5	127.030	156.781	-29.751	31.0	737.0
6	110.830	204.451	-93.621	42.7	861.0
7	85.200	210.998	-125.798	48.6	576.0
8	150.420	173.225	-22.805	35.9	719.0
9	296.390	229.888	66.502	40.9	1,493.0
10	271.860	235.366	36.494	43.3	1,433.0
11	234.160	179.535	54.625	22.7	1,773.0
12	121.930	122.203	-0.273	16.8	1,049.0
13	121.020	192.400	-71.380	32.9	1,311.0
14	240.210	190.551	49.659	33.7	1,218.0
15	200.890	193.419	7.471	27.9	1,683.0
16	195.320	189.125	6.196	38.4	859.0
17	231.150	228.034	3.116	49.9	823.0
18	264.030	185.771	78.258	22.4	1,918.0
19	116.620	179.529	-62.909	33.7	999.0
20	177.550	270.957	-93.407	43.6	2,119.0
21	207.220	239.562	-32.342	44.3	1,446.0
22	278.390	232.375	46.015	44.9	1,261.0
23	230.370	194.411	35.959	38.5	957.0
24	478.360	302.914	175.446	63.3	1,368.0
25	223.470	197.579	25.891	18.4	2,434.0
26	344.850	174.491	170.358	16.4	2,116.0
27	261.430	207.068	54.362	22.7	2,320.0
28	301.090	409.495	-108.405	47.7	4,583.0
29	319.450	278.712	40.738	49.5	1,858.0
30	203.040	171.433	31.607	37.0	606.0
31	167.840	150.913	16.927	20.8	1,338.0
32	126.030	173.214	-47.184	38.1	564.0
33	176.360	189.612	-13.252	37.5	932.0
34	134.230	182.199	-47.969	31.0	1,242.0
35	118.710	205.708	-86.998	36.9	1,294.0
36	171.040	116.786	54.254	17.9	864.0
37	156.770	189.147	-32.377	36.8	972.0
38	183.590	201.288	-17.698	40.3	967.0
39	191.760	231.488	-39.728	28.9	2,369.0
40	239.410	168.038	71.372	27.2	1,228.0
41	164.820	126.447	38.373	20.6	866.0
42	142.830	155.732	-12.902	28.6	885.0
43	206.030	269.680	-63.650	45.4	1,967.0
44	198.380	117.266	81.114	16.6	965.0
45	205.250	158.305	46.945	31.8	711.0
46	156.920	232.918	-75.998	50.0	913.0
47	171.200	176.184	-4.984	32.4	1,024.0
48	158.580	175.644	-17.064	21.8	1,759.0
49	146.260	132.977	13.287	11.3	1,650.0
50	122.040	210.874	-88.834	44.4	869.0
51	239.870	289.273	-49.403	29.1	3,503.0
52	251.980	456.386	-204.406	21.0	7,393.0
53	320.940	323.755	-2.815	29.3	4,174.0
54	133.330	181.056	-47.276	23.3	1,761.0
55	140.820	125.717	15.103	22.0	753.0
56	129.250	123.461	5.789	22.5	673.0
57	150.510	142.857	7.653	23.5	988.0
58	157.170	125.243	31.927	20.8	828.0
59	138.370	144.936	-6.566	27.2	769.0
60	161.270	164.484	-3.214	22.6	1,481.0
61	120.190	168.244	-48.054	36.0	613.0
62	69.130	85.780	-16.650	15.0	452.0
63	79.950	127.862	-47.912	26.6	472.0
64	93.410	158.686	-65.276	36.3	402.0
65	105.320	137.873	-32.553	32.0	291.0
66	109.910	56.016	53.894	2.6	733.0
67	193.860	174.993	18.867	33.4	930.0
68	206.630	197.979	8.651	35.3	1,253.0
69	206.680	180.696	25.984	37.1	783.0
70	257.460	267.207	-9.747	56.4	1,144.0
71	290.920	212.549	78.371	39.5	1,247.0
72	754.510	437.337	317.173	45.3	5,305.0
73	571.440	485.302	86.138	102.1	2,262.0

Generally speaking, greater reliability results from a greater number of observations. At the time this method was first used, data for only 2 years were available. As discussed later, models have now been produced from 3 years of data, and it is planned to use 4 years of data for producing models at the end of the present winter season when the weather data are available.

USE OF MODELS

By using data for the 2 years 1967 and 1968, the models projected the cost for snow and ice control in each county based on average 30-year snowfall and ADT values for each county. The resulting cost per lane-mile for each of the 5 types of routes was then applied to the mileage in each county to compute total funds to be allocated to the individual counties.

The money thus allocated to each county was then budgeted 18 percent for personnel, 19 percent for equipment, and 63 percent for material, as indicated by snow- and ice-control records of 1967 and 1968. By using other regression models for maintenance costs, exclusive of snow and ice control, similar allocations of funds were made to each county. These funds were budgeted 47 percent for personnel, 28 percent for equipment, and 25 percent for material. By combining the money for snow- and ice-control personnel and the money for other maintenance personnel allocated to each county, a labor quota was established. The determination of these quotas was one of the primary objectives of the work utilizing regression models.

TABLE 9

SNOW AND ICE CONTROL COSTS PER LANE-MILE ON INTERSTATE HIGHWAYS PREDICTED BY REGRESSION MODELS USING 30-YEAR MEAN ANNUAL SNOWFALL

County	Snowfall (in.)	Cost per Lane-Mile ($)
Warren	20	307
Wood	30	381
Medina	41	463
Summit	50	529
Cuyahoga	65	640
Ashtabula	75	714

Note: Costs are for plowing, spreading chemicals, and cleaning bridges.

TABLE 10

COMPARISON OF REGRESSION MODELS USING 2 AND 3 YEARS OF DATA

Highway	Years of Data	Model Equations	Multiple Correlation Factor
Interstate	2	$Y = 7.40\ X_1 + 159.27$	0.44
	3	$Y = 9.49\ X_1 + 107.08$	0.60
Major	2	$Y = 4.20\ X_1 + 0.04\ X_2 - 36.75$	0.76
	3	$Y = 4.87\ X_1 + 0.03\ X_2 - 33.19$	0.80
Auxiliary and local	2	$Y = 3.54\ X_1 + 0.05\ X_2 + 9.92$	0.73
	3	$Y = 4.28\ X_1 + 0.04\ X_2 + 4.13$	0.80

An additional application of the models is the calculation of cost per lane-mile by using the actual snowfall experienced in any given year and comparing the cost from the model with the actual cost. Table 9 gives lane-mile values of direct cost of snow and ice control for Interstate highways in several counties with increasing amounts of snowfall.

As previously stated, the regression models referred to up to this time were based on input data for the 2 years 1967 and 1968. When 1969 data became available, models were produced using 3-year data. As would be expected, the models based on more data had higher R-values, multiple correlation coefficients. Table 10 gives a comparison of the models using 2 and 3 years of data and the R-values for each model. The snowfall in inches, X_1, is a factor of greater influence in the 3-year models, and the average daily traffic, X_2, is of lesser influence in the 3-year than in the 2-year models. It is planned to use 4-year data with regression analyses to further improve the models. Updated traffic data will also be used. We anticipate that with the use of 4-year data higher multiple correlation coefficients will be obtained. The R-value when squared and multiplied by 100 gives a percentage figure that indicates how well a regression model explains the relationship among the variables, in this case, the relationship among the cost of snow and ice control, snowfall, and traffic volume.

Although not within the scope of this paper, we are using regression models to budget all maintenance funds to the 88 counties in Ohio. The models used relate cost per lane-mile to average daily traffic by each of five types of routes for work other than snow and ice control. These models include constant terms that represent the basic maintenance costs not associated with the variations in traffic. This is a new method for budgeting maintenance funds in Ohio, and we believe it will be of increasing benefit as time goes on.

We have also used regression models to identify factors affecting maintenance cost in specific areas as follows:

Dependent Variable (cost per lane-mile)	Independent Variables
Cost of applying chemicals	Snowfall, ADT
Concrete pavement and berm maintenance cost	Age of pavement, region of state, number of days 32 F or below, ADT
Rest area maintenance cost	ADT, parking spaces, number of toilet fixtures
Cost of litter pickup	ADT, region of state

The Bureau of Planning Survey in the Department of Highways is using regression analysis in connection with the 14 urban transportation studies under way in Ohio. For this work the California BIMED programs mentioned earlier are being used to obtain the relationship between trips and various land use and socioeconomic variables.

We have found in Ohio that multiple-regression models produced by readily available computer programs are useful in budgeting maintenance and operations funds. These models can also be useful in establishing acceptable cost values that can be used to measure work performance. In addition, the factors that significantly affect maintenance costs can be determined. Regression analysis often indicates that factors assumed to be of major importance in their effect on cost are of only minor importance. We plan to increase our use of regression analysis in its application to highway maintenance management in Ohio, and we recommend the use of this statistical method.

REFERENCES

1. Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index. NCHRP Rept. 42, 1967.
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3. Draper, N. R., and Smith, H. Applied Regression Analysis. John Wiley and Sons, New York, 1967.
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Informal Discussion

Question

You stated that regression models based on data from the 2 years 1967 and 1968 were used to project the cost of snow and ice control for the 1969 winter. What were your expenditures for 1967 and 1968, and what was your predicted value for the 1969 winter?

Miller

The total direct expenditure for snow and ice control in 1967 was $8,350,703. In 1968 this expenditure was $8,676,351, and in 1969 it dropped to $6,195,871. Our projection for use in the 1969 budget was $8,428,795. These values indicate that the 2 winters, 1967 and 1968, were average in intensity, whereas the 1969 winter was less severe than the 30-year average. The 1969-70 winter was very severe, and expenditures exceeded the 30-year projection value by approximately 66 percent.

The projection using 30-year weather values allocates approximately 30 percent of our total direct expenditures for snow and ice control. We believe money should be budgeted for average winter conditions. The models developed with multiple regression provide a means for doing this and allocate the money for snow and ice control to each of 88 counties in accordance with long-term weather in the respective counties.

In addition to using the models for budgeting, we also measure county performance by inserting actual weather values in the models and comparing the results thus calculated with the money used in each county. For example, in the northeastern part of the state, one county used 110 percent of the money allocated to it for material to take care of ice and snow work. In a county just south of the first county, only 87 percent of the material money was used although it was also in the relatively high snowfall area. If it be assumed that the highways were open and safe to travel in both counties, the second county referred to was more efficient in its snow- and ice-control work than the first county.

Owen Sauerlender

Do you use division data or county data?

Miller

Data used are from each county having mileage of the route type being studied. Most of the 88 counties have some mileage of route types 20, 30, 40, and 50; and 49 counties have Interstate mileage.

Sauerlender

How do you combine county data?

Miller

We do not combine county input data for regression analysis. The result of applying the regression model is cost per lane-mile for each county. The projected costs thus obtained for each county within a division are summed to determine the projected cost for the division.

Sauerlender

The point I am making is that each county is a separate observation. You get 2 observations, but you do not take into account the time factor.

Miller

You are suggesting that perhaps we were limited in what we could spend for snow and ice control from year to year. We were not limited.

Sauerlender

It is the identical problem of combining cross-sectional data with time series.

Miller

We just averaged both the weather data and the cost data for those 2 years.

Sauerlender

It seems to me that, in this statistical approach, the longer the period you use, the higher your correlation coefficients should be, and that in any one year, for example 1970-71, the pattern of snowfall might be significantly different from the 30-year pattern and, therefore, your allocations might be affected. The amount might be quite different.

P. A. Schaerer

I have much the same question. How close to the 30-year mean annual snowfall were the snowfalls in the 2-year or 3-year period you used for the analysis?

Miller

To answer your question, I would have to refer to the inches of snowfall in each county for the 2-year period and the 30-year mean. I do not have that information, but I do not believe it is as important as the snowfall pattern within individual years. If in 2 different years the snowfall in a given county is the same, say 30 in., but in one year this amount fell in 30 different storms whereas in the other year it fell in 10 different storms, the required snow-removal effort could be quite different. Although I think it would be well to include the number of storms contributing to the total annual snowfall, we did not do this and I do not believe such data are available for 30-year values.

L. Gary Byrd

Did you use cost per centerline-mile or cost per lane-mile for each class of highway? On the Interstate, did you make any allowance for interchanges? Was interchange mileage a separate part of your mileage?

Miller

We used cost per lane-mile for each class of highway in our study of snow- and ice-removal costs. We did not separate lane-miles at interchanges but included the interchange lane-mileage with the regular Interstate lane-mileage. The cost per centerline-mile for Interstate highways given in Table 3 is 4 times the cost per lane-mile. This is an approximation. The cost per lane-mile is accurate. The true cost per centerline-mile is slightly higher than the value given in the table.